EVALUATION OF DEFICIT IRRIGATION AND MULCHING ON WATER PRODUCTIVITY OF TOMATO (*Lycopersicon esculentum Mill*) UNDER DRIP IRRIGATION SYSTEM AT KALLU WOREDA, SOUTH WOLLO, ETHIOPIA

MSc. THESIS

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Evaluation of Deficit Irrigation and Mulching on Water Productivity of Tomato (*Lycopersicon esculentum Mill*) Under Drip Irrigation System at Kallu Woreda, South Wollo, Ethiopia

A Thesis Submitted to the Postgraduate Program Directorate through The School of Water Resource and Environmental Engineering, HARAMAYA UNIVERSITY

In Partial Fulfillment of the Requirements for the Degree of MASTER OF SCIENCE IN IRRIGATION ENGINEERING

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POSTGRADUATE PROGRAM DIRECTORATE

I hereby certify that I have read and evaluated this thesis entitled **Evaluation of Deficit Irrigation and Mulching on Water Productivity of Tomato (*Lycopersicon esculentum Mill*) Under Drip Irrigation System at Kallu Woreda, South Wollo** prepared under my guidance by Mr. Kassahun Alebachew Ahmed. I recommend that it be submitted as fulfilling the thesis requirement.

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DEDICATION

I dedicate this thesis manuscript to all my families for their love and dedicated partnership in the success of my life and to my father Alebachew Ahmed and my mother Deberi Endeshaw who passed away when I was Degree and Diploma student respectively.

STATEMENT OF THE AUTHOR

By my signature below, I declare and affirm that this thesis is my own work. I have 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 in September 1979 in Kallu Woreda Harbu 01 Kebele. He followed his elementary education at Harbu Elementary School and Kombolcha Junior and Senior Secondary School in Kombolcha. He completed his high school education in 1996 and then in 2003 joined Kombolcha Industrial Technology Collage and graduated Diploma in small scale irrigation and drainage in 2005. In 2011 graduated with B.Sc. degree in Natural Resource Management from Wollo University.

He was working in office of Agriculture, South wollo zone, Kallu Woreda as soil and water conservation expert. In July 2014, he was enrolled to the Postgraduate Program Directorate of Haramaya University to pursue for his MSc. study under Soil and Water Engineering program, Irrigation Engineering stream

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ABBREVIATIONS AND ACRONYMS

AF	After Irrigation
BM	Bulrush Mulch
BF	Before irrigation
CC	Cubic centimeter
CFD	Computational Fluid Dynamic
COE	Characteristics of Emitters
CO – SERAR	Commission for Sustainable Agriculture and Environmental Rehabilitation of Amara Region
CV	Coefficient of Variation
DAT	Days after Transplanting
DU	Distribution Uniformity
EU	Emission uniformity
FAO	Food and Agricultural Organization
FC	Field Capacity
FDRE	Federal Democratic Republic of Ethiopia
FTC	Farmer Training Center
GTP II	Growth and Transformation Plan II
GIWR	Gross Irrigation Water Requirement
IWUE	Irrigation Water Use Efficiency
LSD	Least Significance Difference
NIWR	Net Irrigation Water Requirement
PWP	Permanent Wilting Point
QV	Emitter flow variation
RCBD	Randomized Complete Block Design
RDI	Regulated Deficit Irrigation
SM	Sugarcane Mulch
TAW	Total Available Water
UA	Uniformity Application
WAE	Water Application Efficiency
WL	Water Level
WUE	Water Use Efficiency
WM	Without Mulch

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Kassahun Alebachew

ABSTRACT

This study investigated the combined effects of deficit irrigation under drip irrigation system and mulches on yield and water-use efficiency on tomato production at Miawa Farmer Training center, south Wollo, and Kallu worda during 2016 irrigation season. A factorial combination of three levels of water (namely 70%, 80% and 90% ETc) combined with three mulch treatments (namely, without mulch (WM), sugarcane mulch (SM) and bulrush mulch (BM)) with three replications. The yield and yield-contributing all parameter in the mulched treatments for all levels of irrigation there is significantly difference compared to those in the un-mulched treatments. The yield of tomato increased with the increasing amount of irrigation water in un-mulched treatment. The trend was reversed when drip irrigation was coupled with mulches. The highest yield for each mulch (44.04 t/ha for sugarcane and 30.19 t/ha for bulrush) was obtained when 80% and 90% of water requirement was applied respectively. With 90% water application, sugarcane-mulched treatment produced lower yield than the bulrush-mulched treatment. The highest head volume and plant height recorded on 80% ETc with sugarcane mulch (54.67 cc and 84.33 cm, respectively). The highest water use efficiency was obtained 142.96 kg/ha/mm with 80% water application under sugarcane mulch. The study thus reveals that drip irrigation with mulch has an explicit role in increasing the yield and water productivity of tomato.

Key words: deficit irrigation, mulch material, water productivity and yield.

1. INTRODUCTION

1.1. Background

Irrigation is one of the most important inputs for agricultural production. Limited water resources and increasing water demand for industrial and urban settlements have caused decreases in the quantity and quality of agricultural water use (Osman *et al*, 2001). On the other hand, the use of irrigation methods or systems that require low labor and energy inputs has become more popular in recent years. These conditions are readily satisfied by means of drip (micro) irrigation systems.

Ethiopia is facing a tremendous challenge in meeting the food needs of rapidly growing population. There are small, medium and large scale irrigation systems in Ethiopia (FAO, 1995). To this end, both irrigated and dry land cropping areas will have to be developed or improved in the future. However, these tasks will not be easy; the cost of developing large scale and medium scale level irrigation is high. Therefore, efficient utilization of water resources and development of small scale irrigation schemes at family level is crucial for countries like Ethiopia, which has a huge water resource: yet their population is chronically food insecure. Drip irrigation system reduced the water requirement of the crop by 47 to 62% as compared to furrow irrigation (Baye Berihun, 2011). As Fekadu and Teshome (1997) cited Pruitt, drip irrigation increased the yield of tomato and water use efficiency (WUE) by 19 and 20%, respectively as compared to furrow irrigation. Similarly, Raina *et al*. (1998) reported that drip irrigation besides giving a saving of 32% water resulted in 49.5% higher yield as compared to surface irrigation. It is prudent to make efficient use of water and bring more area under irrigation through available water resources. This can be achieved by introducing advanced methods of irrigation and improved water management practices (Zaman *et al*., 2001). Drip irrigation in combination with mulch is one of the best irrigation methods, which can improve the water management practice significantly (Kay, 1978; Jalota and Prihar, 1998). Water applied by a drip system enters into the soil through small holes placed directly on the soil surface. The possibility of applying water at very slow rates offers the drip irrigation system the means to deliver water to the soil in small and frequent quantities at a relatively low cost compared to other pressurized systems. Therefore, water stress in the root zone does not generally occur, and plants use irrigation water more efficiently than in other irrigation methods (Keller and Bliesner, 1990; Hargreaves and Merkley, 1998).

Farmers in dry lands of Ethiopia depend on erratic, unrealistic and low rainfall to produce staple food crops for their livelihoods. Shortage of water represents one of the most limiting factors in crop production worldwide (Mohamed, 2000). Irrigation can be important for vegetable crops because many are shallow rooted and therefore sensitive to water shortage. Vegetable production is a high-cost enterprise with a high value end product and many growers feel the need to have irrigation available as an insurance against drought. There are several potential benefits from irrigating vegetables, e.g. yield increase, improvement in plant establishment, continuity of supply to market or processor, and increased quality (Bailey, 1990). As water supplies become scarcer and the cost of water for irrigation increases, irrigation-scheduling methodologies need to be more precise (Gonzalez-Altozano and Castel, 2000). One of the options proposed for that purpose is the use of regulated deficit irrigation (RDI). The RDI is an irrigation strategy designed to save water with a minimum impact on yield and quality (Ruiz-Sanchez *et al*., 2000).

Reducing non-productive loss of irrigation water is best achieved through the integrated use of regulated deficit irrigation along with mulching material and drip irrigation for maximum water use efficiency (WUE) in arid and semi-arid lands (Hanson, 1994; Hacham, 2001).

Tomato is one of the most widely grown vegetables in the world. Tomato plants are sensitive to water stress and show high correlation between evapotranspiration and crop yield (Nuruddin *et al*, 2003). However, no work has been done to study the effect of drip irrigation in combination with mulch in the study area. The present study was planned to evaluate the effect of mulch and amount of water on the yield of tomato under drip irrigation system and to assess the water productivity in relation to mulch used in tomato production.

1.2. Statement of the Problem

In the woreda farmers use surface, underground, spring and rain water resource for irrigation practice to harvest income generating vegetables and fruits as well as staple food production. Farmers are practicing traditional furrow irrigation system. Even though some farmers are trying to use modern furrow irrigation, this is not effective due to lack of knowledge and skills. This inefficient utilization of water usually posed problem in increasing salinity of the land, water logging, low crop productivity and water loss. Therefore, application of deficit amount of water through drip irrigation system with different mulch materials may be suitable approach to increase the maximum productivity of water for tomato production system in the woreda irrigation practice.

1.3. Objective of the Study

The general objective of this study is to evaluate different deficit irrigation level and mulching material for the better net of tomato production/ productivity.

- Specific objective
  - ✓ To evaluate the effect of deficit irrigation on water productivity of tomato.
  - ✓ To evaluate the interaction effect of mulching and deficit irrigation on water productivity of tomato.

2. LITERATURE REVIEW

2.1. Irrigation: perspectives and status in Ethiopia

Irrigation is the supply of water to agricultural crops by artificial means, designed to permit farming in arid regions and to offset the effect of drought in semi-arid regions. Even in areas where total seasonal rainfall is adequate on average, it may be poorly distributed during the year and variable from year to year. Where traditional rain-fed farming is a high-risk enterprise, irrigation can help to ensure stable agricultural production (FAO, 1997).

Irrigation plays the key role in the performance of agriculture, which increases income growth. A reliable and suitable irrigation water supply can result in vast improvements in agricultural production and assure the economic vitality of the region. Income growth is essential for economic growth (Hussain and Biltonen, 2001). They also improve the quality of natural environment and even reduce their incidence of crime and violence (Loayza and Soto, 2002). Some has estimated that as little as 15-20 percent of the worldwide total cultivated area is irrigated. Judging from irrigated and non-irrigated yields in some areas, this relatively small fraction of agriculture may be contributing as much as 30-40 percent of gross agricultural output (FAO, 1989).

Many countries depend on surface irrigation to grow crops for food and fiber. Without surface irrigation their agricultural production would be drastically lower and problems of unreliable food supply, insufficient rural income and unemployment would be widespread. Although precise data are lacking, estimation of surface irrigation accounts for some 80 to 90 percent of the total 260 million hectares of irrigated land worldwide, mainly in developing countries in the tropics and sub-tropics, where hundreds of millions of farmers depend on surface irrigation to grow their crops (Jurriens *et al.*, 2001).

The method, frequency and duration of irrigations have significant effects on crop yield and farm productivity. For instance, annual crops may not germinate when the surface is inundated causing a crust over the seed bed. After emergence, inadequate soil moisture can often reduce yields, particularly if the stress occurs during critical periods. Even though the most important objective of irrigation is to maintain the soil moisture reservoir, how this is accomplished is an important consideration. The technology of irrigation is more complex than many appreciate. It is important that the scope of irrigation science is not limited to diversion and conveyance systems, or solely to the irrigated field, or only to the drainage pathways. Irrigation is a system extending across many technical and non-technical disciplines. It only works efficiently and continually when all the components are integrated smoothly (FAO, 1989).

2.1.1. Water resources and irrigation development of Ethiopia

It is believed that Ethiopia has a total volume of 123 billion cubic meters of surface water and about 40 billion cubic meters of groundwater (Abiti, 2011). The distribution is not, however, uniform. The western half of the country receives sustainable amounts of precipitation and has many perennial rivers and streams while the precipitation is marginal in the eastern half of the country. The Ethiopian plateau is the source of the Abay, Tekeze, Mereb, Baro- Akobo and Omo rivers that flow to the west and southwest- crossing the border. (Abiti, 2011).

Ethiopia has a long history of traditional irrigation systems and yet. Simple river diversion still is the dominant irrigation system in Ethiopia. Awulachew *et al*., (2010), estimates of the irrigation potential of Ethiopia has estimated that 5.3 million hectares. Of the potential 3.7 million ha is from surface water (small, medium and large scale), while the remaining 1.6 million ha is from rain water harvesting technologies and ground water. In terms of utilization, only about 12% (about 857,933 ha) has been irrigated by 2015 (FDRE, GTP II, 2016).

2.2. Mulching Practice

Mulch is a protective layer of either organic or inorganic material that is spread on the top soil to: 1) reduce the moisture loss from the soil by preventing evaporation from sunshine and desiccating winds, 2) prevent weed growth, 3) improve soil condition, 4) provide home for earthworms and natural enemies found in the soil, 5) reduce soil compaction from the impact of heavy rains (Lamont, 1999; Ramakrishna *et al*., 2006; Anonymous, 2008). Mulch helps regulate soil temperature by shading it in the summer thus keeping it cooler and helps insulate it in the winter from chilling winds. This temperature regulating effect helps encourage the root growth of plants, and prevent soil erosion. Agriculture with mulch in the tropics promotes plant health and vigor. Mulching improves nutrient and water retention in the soil, encourages favorable soil microbial activity and worms, and suppresses weed growth. When properly executed, mulching can significantly improve the well-being of plants and reduce maintenance as compared to bare soil culture (Ramakrishna *et al*., 2006; Anonymous, 2008).

2.3. Types of Mulches

Lal (1987) defined mulching as the application of a layer of dissimilar material, separating the soil surface from the atmosphere. According to Wild (1988), mulches are organic or inorganic materials spread on the surface of the soil to protect it from the full force of the sun, raindrops and wind which may otherwise induce surface crusting, freezing and evaporation of the bare soil. Mulching is the application of covering layer of material to the soil surface (Norman, 1992). Traditional farmers use organic mulch materials such as cereal straw and stalk, crop debris, sawdust, leaves, grass, maize Stover, weeds, manure, Spanish moss, and various water plants. In modern or commercial agriculture, inorganic mulches used include aluminum foil, asphalt, paper, glass wool, petroleum mulch and various polythene mulches such as black or transparent polythene sheets (Thurston, 1997). The main types of mulches are organic materials obtained from plant and animal residues and inorganic materials which are usually synthetic in nature.

2.4. Effect of Organic Mulches on Soil Moisture

According to Koni (1983), reported of better soil moisture conservation with the application of sorghum stubbles, cotton stubbles and maize stubbles as mulch in pepper than the bare soil. Mulch protects the soil from direct rays of the sun which would cause evaporation of moisture from the soil surface and cause drying of the soil profile. This leads to improved and higher soil moisture. According to Dilipkumar *et al*., (1990), mulching reduces soil water evaporation. Thus, it enhances more retention of soil moisture. Moisture retention of soil has been shown to be improved by the application of organic mulches. Moisture contents of soils under organic mulches - grass straw, rice straw, rice husk and sawdust were higher than those in the control

(Nkansah *et. al*., 2003). Organic mulches helped to maintain soil moisture content longer than bare soil. Mulching conserves water by reducing evaporation and mitigates negative effects of water stress on plant growth and yield under semi-arid conditions.

2.4.1. Effect of organic mulches on soil temperature

Mulching aids in the control of temperature fluctuations (Dilipkumar *et al*., 1990). Agele *et al*., (2000) studied the effect of tillage and mulching on the performance of post-rainy season tomato in the humid, south of Nigeria. He reported that mulching resulted in reduced soil temperature that led to increased yield. Several studies conducted by (Ashworth and Harrison, 1983; and Agele *et al*., 2000) have also shown that mulching with organic materials regulates soil temperatures and consequently increase crop production. Organic mulches - grass straw, rice straw, rice husk and sawdust were more effective in reducing soil temperature compared to the control (Nkansah *et al*., 2003). Gandhi and Bains (2006) reported that mulches moderate hydrothermal regime of the soil and modify the microclimate by modifying soil temperature.

2.4.2. Effect of organic mulches on plant growth

2.4.2.1. Plant height

According to Nkansah *et al*. (2003), organic mulches increased tomato plant height than the control. According to Awodoyin *et al*., (2007), the highest plant height of tomato was recorded under wood chips and grass mulches over the control (un-mulched). Liasu and Abdul (2007) observed higher plant height of tomato plants in pots mulched with wild sunflower leaves compared to those in un-mulched pots. According to Ojeniyi *et al*., (2007), cocoa husk increased tomato plant height compared to the control.

According to Iftikhar *et al*., (2011), mulch material had significant effect on plant height. The highest chilli plant height was noted in rice straw mulch followed by sugarcane bagasse mulch and wheat straw mulch. The lowest plant height was recorded in control plants.

2.4.2.2. Number of branches

In his experiment to study the effect of Lantana leaves and grass mulches on growth and yield of capsicum, Thakur *et al*., (2000), reported that Lantana leaves and grass mulches maintained higher number of branches as compared to un-mulched treatments. Gandhi and Bains (2006) reported of higher number of tomato plants branches under straw mulch as compared to no mulch. Cocoa husk increased number of branches of tomato plant compared to the control (Ojeniyi *et al*., 2007).

2.4.3. Effect of organic mulches on plant yield

2.4.3.1. Mean fruit weight

According to Gandhi and Bains (2006), tomato plants under straw mulch recorded higher fruit weight as compared to no mulch. Iftikhar *et al*., (2011), observed that Sugarcane bagasse, rice straw, and wheat straw mulches significantly influenced chilli fruit weight. Sugarcane bagasse mulch recorded the highest fruit weight followed by rice straw, wheat straw and control in that order.

2.4.3.2. Fruits weight per plant

According to Norman *et al*. (2002), there were increased fresh ear weights of sweet corn from plants under grass mulch compared to those from control plants. Cocoa husk increased tomato fruits weight per plant compared to the control (Ojeniyi *et al*., 2007).

2.4.3.3. Number of fruit per plant

Organic mulches had the highest tomato fruit number per plant than the control. Rice husk mulch recorded the highest fruit number per plant over rice straw, grass straw and sawdust mulches (Nkansah *et al*., 2003). Grass mulch recorded the highest number of fruits per tomato plant followed by wood chip mulch in comparison to control (Awodoyin *et al*., 2007). The number of fruits produced during the first week of fruit production was highest in tomato plants in pots mulched with wild sunflower leaves while plants in un-mulched pots had the lowest number of fruits per plant (Liasu and Abdul, 2007).

According to Ojeniyi *et al*., (2007), Cocoa husk increased number of tomato fruits compared to the control. The use of mulch material influenced the number of chilli fruits per plant. The highest fruit number per plant was recorded in sugarcane bagasse mulch followed by rice straw mulch and wheat straw mulch. Control recorded the lowest fruit number per plant (Iftikhar *et al*., 2011).

2.4.3.4. Yield per hectare

The application of straw mulch increased tomato and okra yields over control (Gupta and Gupta, 1987). According to Dilipkumar *et al*., (1990), under rain fed situations mulching increased the yield over no mulching. Tomato yields were higher in organic mulched plots than the control. Significant higher yield of tomato was reported under hairy vetch mulch than bare soil (Aref *et al*., 1996).

Gandhi and Bains (2006) found out that tomato plant under straw mulch recorded higher fruit yield as compared to no mulch. According to Awodoyin *et al*., (2007), wood-chips mulch recorded the highest fruit yield of tomato followed by grass mulch compared to the control (un-mulched) plots.

Cover crops and the application of organic mulches increased tomato yield more than control (Qingren *et al*., 2008). Bare soil plots resulted in lowest yield of tomato but this was not significantly different from yields obtained from mulched plots (Osei-Bonsu and Asibuo, 2013).

2.5. Localized Irrigation Systems

Localized irrigation systems apply water directly where the plant is growing thus minimizing water loss through evaporation from the soil. Such localized irrigation systems include drip irrigation, porous clay pots, porous pipes, and perforated plastic sleeves. Drip irrigation with drip or trickle irrigation the water is applied into the soil through a small-sized opening directly on the soil surface or buried in the soil. By applying water at a very slow rate, drip irrigation is capable of delivering water to the roots of individual plants as often as desired and at a relatively low cost. Because drip irrigation makes it possible to place water precisely where and when needed with a high degree of uniformity and efficiency (90% or more) the method is useful under many field and water situations. Losses to runoff, deep percolation and evaporation are minimal; this means that most of the irrigation water is taken up by the plant. Drip irrigation is often the favoured method of irrigation, for example on steep and undulating slopes, for porous soils, for shallow soils, fields having widely varying soils, where water is scarce, where water is expensive, and where water is of poor quality (Isaya v., 2001).

2.6. Irrigation Efficiency

Irrigation efficiency is the ratio between the volume used by plants throughout the evapotranspiration process and the volume that reaches the irrigation plots and indicates how efficiently the available water supply is being used, based on different methods of evaluation (Michael, 1997). The designs of the irrigation system, the degree of land preparation, and the skill and care of the irrigator are the principal factors influencing irrigation efficiency. Efficiency in the use of water for irrigation consists of various components and takes into account losses during storage, conveyance and application to irrigation plots. Identifying the various components and knowing what improvements can be made is essential for making the most effective use of vital but scarce resource.

2.6.1. Application efficiency

After the water reaches the field supply channel, it is important to apply the water as efficiently as possible. A measure of how efficiently this is done is the application efficiency. One very common measure of on farm irrigation efficiency is application efficiency. That asks how much of the water applied to the crop is actually used for crop growth or other beneficial uses? The definition of application efficiency, Ea, has been fairly well standardized as:

$$Ea = \frac{depth\ of\ water\ added\ to\ the\ rootzone}{Depth\ of\ water\ applied\ to\ the\ field} \tag{2.1}$$

According to Jurriens *et al*., (2001), application efficiency is a common yardstick of relative irrigation losses and this definition is valid for all situations and all irrigation methods. Losses from the field occur as deep percolation and as field tail water or runoff and reduce the application efficiency. 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 (FAO, 1989).

2.6.2. Water storage efficiency

The water requirement efficiency, Er, which is also commonly referred to as the storage efficiency is defined as:

$$\mathrm{Er} = \frac{volume\ of\ water\ added\ to\ root\ zone\ storage}{potential\ soil\ moisture\ storage\ volume} \qquad (2.2)$$

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 when either 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.

2.6.3. Distribution efficiency

A variety of terms have been developed to describe irrigation uniformity. Four widely used parameters for measuring emitter discharge uniformity in the case if field evaluations are: Distribution uniformity (DU), emitter flow variation (qv), uniformity application (UA) and coefficient of variation (CV) (Mizyed and Kruse, 2008).

One measure which emphasizes the under-watered area and looks at the critical regions is the Distribution uniformity (DU). It gives an indication of the magnitude of the uneven distribution and can be defined as the percent of average application amount in the lowest quarter of the field (Rogers *et al*., 1997). The lowest quarter fraction, dlq [mm], has been used by the United

States Department of Agriculture (USDA) since the 1940s' and has proved to be useful in irrigated agriculture and is defined by the following (Burt *et al.*, 1997):

$$\text{DU} = \frac{Q_{lq}}{Q_a} \times 100 \qquad (2.3)$$

where: Qlq = average discharge rate of lowest 1/4 of emitter discharge observations (l/hr): Qa = average discharge rate of all observations (l/hr).

The emitter flow variation, Qv (%) is calculated using equations the following

$$Q_v = \frac{(Q_{max} - Q_{min})}{Q_{max}} \times 100 \qquad (2.4)$$

where: Q_{max} = the maximum emitter flow rate (l/hr); Q_{min} = minimum emitter flow rate (lit/hr) Q_v = the emitter flow variation (%).

Coefficient of variation, (**CV**) is calculated using the following equation

$$CV = \frac{S}{Q_a} \times 100 \qquad (2.5)$$

where; S is the standard deviation of emitter flow rate: Qa is the mean emitter flow rate (lit/hr): CV is coefficient of variation(%).

2.7. Water Uniformity in Drip Irrigation System

According to Solomon, (1998), the term 'irrigation uniformity' refers to the variation or non-uniformity in spatial distribution of the amounts of water applied to locations within the wetted area. Uniformity influences crop yields through the agronomic effects of under and over-watering. Insufficient water leads to high soil moisture tension, plant stress and reduced crop yields. Excess water may reduce crop yields as a result of leaching of plant nutrients, results in an anaerobic rooting environment as well as increased disease or failure to stimulate growth of economically valuable parts of the plant (Griffiths and Lecler, 2001). Heerman *et al.*, (1990) note that irrigation uniformities for overhead sprinkler irrigation systems can be evaluated by measuring the spatial distribution of application depths with catch cans. For drip systems, the emitter discharge is measured and for surface systems the intake opportunity time is typically used for evaluating irrigation uniformities.

According to Pereira (1999), several parameters are used as indicators of the uniformity of water application to a field. The most commonly used, which are dependent on the irrigation system, are the Coefficient of Uniformity (CU), Distribution Uniformity (DU), and the Statistical Uniformity coefficient (SU). According to James (1988), the performance of a farm irrigation system is determined by the efficiency with which water is diverted, conveyed, and applied, and by the adequacy and uniformity of application in each field on the farm. Mishra and Ahmed (1990) also said that irrigation efficiency indicates how efficiently the available water supply is being used, based on different methods of evaluation. The objective of these efficiency concepts is to show where improvements can be made, which will result in more efficient irrigation.

2.7.1. Coefficient of uniformity

One of the first and most common quantitative measures of uniformity is the Christiansen Uniformity coefficient (CU). This was developed for evaluating sprinkler systems in 1942, and is still the most widely used and accepted measure for uniformity (Ascough and Kiker, 2002). The CU provides a quantitative measure of the average deviation from the mean application depth (King *et al*., 2000).

The CU can be expressed by (ASAE S436.1, 1998):

$$CU = 100 * \left[1 - \frac{\sum_{i=1}^{n}|D_i - D_m|}{D_i * n}\right] \tag{2.6}$$

Where:

D_i is the catch-can depth of application [mm],

D_m is the mean catch-can depth [mm], and

n is the number of catch cans.

2.7.2. Statistical uniformity

Ascough and Kiker (2002) state that Statistical Uniformity (SU) is usually used to represent the uniformity of micro-irrigation systems, such as drip irrigation. The main reason being that water is not applied to the whole field area (Koegelenburg and Breedt, 2003). The SU can be expressed as shown in Equation 2.7 (Pereira, 1999):

$$SU = 100 *(1- Vq) = 100*(1 - \frac{S_d}{Q_a}) \tag{2.7}$$

where; Vq is the coefficient of variation of emitter flow, Sd is the standard deviation of emitter flow [l/h] and Q a is the average emitter flow rate [l/h].

2.8. Irrigation Scheduling

Scientific irrigation scheduling is a combined management and technical approach to ensure that crop water needs are met. This technique facilitates timely and accurate provision of water to crops, conserves water and energy, and improves irrigation performance, crop yield and quality (Tacker *et al*., 1996) and sustainability of irrigated agriculture (Smith *et al*., 1996). It is aimed at achieving an optimum water status for productivity by keeping soil moisture close to field capacity (Jones, 2004). Achieving optimum benefit from irrigation in a variable climate is dependent on regulating timing and quantity of water applied to provide continuously changing crop water requirements (Bailey and Spackman, 1996).

Among the benefits of proper irrigation scheduling is: improved crop yield and/or quality, water and energy conservation, and lower production costs (James, 1988). Normally farmers will use their own experience and indicators (wilting characteristics, soil dryness) to determine when to irrigate (Smith and Munoz, 2002). According to them this has proved not very accurate and a “scientific” advice to farmers on when to irrigate can lead to considerable water savings and to a more rational planning of water distribution. Of several methods to determine when to irrigate, “Water indicator” and “Soil budget” are the two widely used techniques (James, 1988). The water budget technique is based on the equation:

$$I = ET - P_e + RO_i + DP_i + L + D_{rz}(q_f - q_i) \qquad (2.8)$$

where:

I= Irrigation requirement; ET= evapotranspiration; Pe= effective precipitation (cm);
ROi,= runoff due to irrigation (cm); DPi= deep percolation due to irrigation (cm);
Drz= depth of root zone (cm); Q_f & Q_i *= final and initial soil moisture contents.*

Water budget method is more commonly applied these days. The large amount of studies and research on water crop requirements has lead more accurate ET crop estimation from weather data and has made the ETo based on water balance method the most convenient and reliable way to predict when to irrigate (Smith and Munoz, 2002).

Soil based irrigation scheduling involves determining the current water contents of the soil, comparing it to a predetermined minimum water content and irrigation to maintain soil water contents above the minimum level. Soil indicators of when to irrigate also provide data for estimating the amount of water to apply per irrigation.

According to Mishra and Ahmed (1990), irrigation interval is calculated by the formula:

$$Irrigation\ Interval = \frac{AMD}{ETc} \qquad (2.9)$$

where: *AMD* = allowable soil moisture depletion, cm
ETC = daily water use, cm/day

Depth of irrigation application is the depth of water that can be stored within the root zone between field capacity and the allowable level the soil water can be depleted for a given crop, soil and climate. It is equal to the readily available soil water over the root zone (James, 1988).

According to FAO (1989), the total available water (TAW), for plant use in the root zone is commonly defined as the range of soil moisture held at a negative apparent pressure of 0.1 to

0.33 bar (a soil moisture level called 'field capacity') and 15 bars (called the 'permanent wilting point'). The TAW will vary from 25 cm/m for silt loams to as low as 6 cm/m for sandy soils.

The moisture deficit (*d*) in the effective root zone is found out by determining the field capacity moisture contents and bulk densities of each layers of the soil (Mishra and Ahmed, 1990).

$$d = \sum_{i=1}^{n} (\mathrm{FCi} - \mathrm{PWi})/100 \times ASi \times Di \qquad (2.10)$$

where: *FCi = field capacity of the* i^{th} *layer on oven dry weight basis*

PWi = actual moisture contents of the i^{th} *layer on oven dry weight basis*

Asi= apparent specific gravity of the i^{th} *layer*

Di = depth of i^{th} *layer and, n=number of layers in the root zone*

2.9. Deficit Irrigation Effects

Deficit (or regulated deficit) irrigation scheduling is one way of maximizing water use efficiency for higher yields per unit of irrigation water used in agriculture (Nagaz *et al*., 2012, Geerts and Races, 2009). In deficit irrigation application, the crop is exposed to a certain level of water stress either during a particular growth period or throughout the whole growing season, without significant reductions in yields (FAO, 2000). The expectation is that the yield reduction by inducing controlled water stress will be insignificant compared with the benefits gained through diverting the saved water to irrigate additional cropped area (Kirda *et al*., 1999; Gijón *et al*., 2007). In Ethiopia conditions, results on deficit irrigation level, irrigation level have positively influenced marketable yield of tomato, with tomato yield decreasing as the water deficit level increased (Birhanu and Tilahun, 2012); onion in South-northern Ethiopia by Bekele and Ketema (2007) and Mulu and Alamirew (2012). However, previous findings showed that the amount of water applied and method of application varied across the reports by crop and study site.

2.10. Soil Water Availability

Soil water availability refers to the capacity of a soil to retain water available to plants. After heavy rainfall or irrigation, the soil will drain until field capacity is reached. Field capacity is the amount of water that a well-drained soil should hold against gravitational forces, or the amount of water remaining when downward drainage has markedly decreased. The total available water in the root zone is the difference between the water content at field capacity and wilting point (Allen *et al*., 1998):

$$TAW = 1000\ (FC - WP)\ Zr \tag{2.11}$$

where: TAW = the total available soil water in the root zone [mm],

FC= the water content at field capacity [$m^3\ m^{-3}$],

WP = the water content at wilting point [$m^3\ m^{-3}$],

Zr is the rooting depth [m].

The fraction of TAW that a crop can extract from the root zone without suffering water stress is the readily available soil water:

$$RAW = TAW * MAD \tag{2.12}$$

where:

RAW the readily available soil water in the root zone [mm],

MAD average fraction of total available soil water (TAW) that can be depleted from the root zone before moisture stress (reduction in ET) occurs [0-1].

If there are plants growing on the soil, the moisture level continues to drop until it reaches the "permanent wilting point" (PWP). Soil moisture content near the wilting point is not readily available to the plant. Hence the term "readily available moisture" has been used to refer to that portion of the available moisture that is most easily extracted by the plants, approximately 75% of the available moisture. After that, the plants cannot absorb water from the soil quickly enough to replace water lost by transpiration (ICE, 1983).

2.10.1. Measurement of soil moisture

Soil water content in the soil is expressed in to different units , as volumetric (V) and gravimetric water content (m). The volumetric water content is the volume of liquid per volume of soil and the gravimetric water content (m) is the mass of liquid per mass of dry soil (Jury *et al*., 1991). A variety of methods and device can be used to measure soil water. The gravimetric soil moisture content θw is typically determined directly. The disturbed 50g soil samples are taken from the field with spiral hand augers, the moist weight was determined by weighing the sample at the time of sampling, and the dry weight was obtained after drying the sample to a constant weight in an oven. The standard method of drying is to place the sample in an oven at 105^{o}C for 24 hours (Evans *et al*., 1996). The gravimetric water content will be calculated using the following equation (FAO, 1989., Jury *et al*., 1991; Evans *et al*., 1996).

$$\text{è}w = \frac{(Ww - Wd)}{Wd} * 100 \qquad (2.13)$$

where; è$_{w}$ is soil water content (in %); W_w is weight of moist soil in gram; Wd is weight of oven dry soil in gram.

The volumetric water content was calculated from the gravimetric water content using the following expression (FAO, 1989).

$$\text{è}v = \text{è}w\ (\%) * \text{ñ}b \qquad (2.14)$$

where; èv is volumetric water content (cm^3); ñb is bulk density (g/cm^3)

2.11. Soil Texture Analyze

Soil scientists have long recognized the importance of soil texture to plant growth, cultivation, hydraulic conductivity and soil strength. However, managers preparing to determine soil texture are sometimes confused by conflicting procedural recommendations. Textural classes can be determined either in the field or by a laboratory particle size distribution analysis. The laboratory analysis most often available to land managers is some version of the hydrometer method first introduced by Bouyoucos (1927). Day (1965) and the American Society for Testing and Materials (A.S.T.M.) (1972) have detailed the procedure generally accepted by land management agencies and an updated edition was recently released (Gee and Bauder, 1986). In this method, a measured amount of soil is suspended in water and the suspension density is determined with a specialized hydrometer. As soil particles settle, the suspension density decreases. Because larger particles settle faster, the particle size and summation percent remaining for that size can be calculated for each measurement time using the observed hydrometer level, and these results are graphed. From the relationship on the graph, the percent of a particular particle size class can be estimated (Day, 1965).

2.12. Crop Water Requirement

The first step in the proper design of an irrigation scheme, it is necessary to know the crop water requirement. The crop water requirements defined as the rate of evaporation of a disease free crop growing in a field of not less than one hectare under optimal soil conditions. The crop water requirement is designed as ETcrop and is expressed in millimeter per day (FAO, 1998). Direct measurement procedures are laborers and time consuming. So now a day CROPWAT model developed is used widely (Allen *et al*., 1998).

CROPWAT model is a computer program for irrigation planning and management, developed based on the FAO Penman-Moneith (Smith, 1992). Calculation of water and requirements utilize inputs of climatic, crop and soil data, as well as irrigation and rainfall data. Its basic function includes the calculation of reference evapotranspiration, crop water requirement and crop and scheme requirement. Reference evapotranspiration can be calculated from the actual temperature, humidity, sunshine/radiation and wind speed data, according to FAO penman-Monteith method (Allen *et al*., 1998).

$$ETo = \frac{0.408\Delta(Rn - G) + Y\frac{900}{T+273}U_2\,(es - ea)}{\Delta + Y(1 + 0.34U_2)} \qquad (2.15\ )$$

where : Eto is reference evapotranspiration in mm/day, Rn net radiation at the top surface (MJm^{-2}/day), G is soil heat flux density (MJm^{-2}/day), T mean daily air temperature (^{o}C), U_2 is wind speed at 2 m height (m/s), $e_s - e_a$ is saturation vapor pressure deficit (Kpa), Δ is the slope vapor pressure curve (Kpa/^{o}C), Y is psychrometric constant (Kpa/^{0}C) (Allen *et al*., 1998).

Crop water requirement (ETc) over the growing season are determined from ETo and estimates of crop evaporation rates, expressed as crop coefficient (Kc), based on a well-established procedures. The updated values of crop coefficients are determined from Allen *et al*. (1998).

$$ETc = Kc \times ETo \qquad (2.16)$$

where: ETc is crop evapotranspiration, Kc is crop coefficient, and ETo is reference evapotranspiration in mm/day.

2.13. Net and Gross Irrigation Water Requirement

Net-irrigation water requirement

NIWR is the amount of irrigation water required to meet the evapotranspiration need of a crop during its full growth and computed as the difference between crop water requirement (CWR) and effective precipitation (Pe).

$$NIWR = CWR - Pe \qquad (2.17)$$

where: NIWR is Net-Irrigation Water Requirement; Pe effective precipitation is calculated based on FAO CROWAT computer model (Smith, 1992) as a daily soil water balance which is determined from empirical formula.

$$Pe = P - (C^*P) \quad \text{or} \quad Pe = f^*\, P \qquad (2.18)$$

where: P = daily rainfall (mm), f and C is constants and their values are 0.2 and 0.8, respectively.

Gross Irrigation Water Requirement

The gross depth of irrigation equals the net irrigation depth divided by the application efficiency (FAO, 1998).

$$\mathrm{GIWR} = \frac{\mathrm{NIWR}}{\mathrm{Ea}} \tag{2.19}$$

where: GIWR is gross irrigation water requirement in mm; NIWR Net irrigation Water Requirement in mm and Ea is application efficiency in %.

2.14. Hydraulics of Drip Irrigation

A successful uniform application through drip irrigation system depends on the physical and hydraulic characteristics of the drip tubing (Al – Amoud, 1995). In surface drip irrigation systems, uniformity can be evaluated by direct measurement of emitter flow rates. The emission uniformity (EU) criterion is used largely to design micro irrigation laterals. The EU is affected by the variation of pressure head due to elevation changes and head losses along the lines, as well as by water temperature, manufacture’s variation, grouping of emitters, clogging, variability in soil hydraulic characteristics, and emitter spacing (Wu, 1997). Introduction of emitters along a drip irrigation line modifies flow stream lines; inducing local turbulence that results in additional head losses friction losses and local losses due to the presence of emitters in the pipe are must be considered (Bagarello *et al*., 1992; Al-Amoud, 1995; Provenzano *et al*., 2004).

The relationship between the emitter flow rate and the static pressure of the pipe, which is called characteristic of emitters (COE), is very important to a drip irrigation system. This relationship is used. The most important properties in drip tubing irrigation systems are uniformity; anti-clogging unregulated dripper varies with inlet water pressure rather than friction losses along the laterals, both in designing the desired emitter flow path. Computational Fluid Dynamics (CFD) numerical technique was applied to investigate the flow, heat and mass transfer for many years. CFD technique has many advantages compared with other numerical calculation methods. The simulation can maintain a stable boundary condition while CFD modeling can be easily simulated with the change of the structure specification. The numerical calculation results can help researcher analyze the hydraulic performance of the emitters and modify the geometries of the flow path, thus reducing time and cost for producing new emitter designs (Provenzano *et al*., 2004).

2.15. Water Productivity

The main challenge confronting both rain fed and irrigated agriculture is to improve water productivity of WUE for sustainable irrigated agriculture. To apply relatively ideal furrow irrigation system was effective in increasing fruit yield and water use efficiency. The amount of water (transpiration, plant growth, evaporation from the soil, drainage loss) required to produce a unit of dry weight material is a measure of water use efficiency (Ascough and Kiker, 2002; Baye, 2011).

Increasing water productivity can be important pathway for poverty reduction, especially in the developing countries, where the variability of water productivity of within and between fields is very high, according to specific condition under which the crop are grown (Haileslassie *et al*., 2009a; Haileslassie *et al*., 2009b). The crop water productivity is a vital parameter to assess the performance of irrigated and rain fed agriculture.

The physical crop water productivity (kg/m^3) is the ratio of crop yield (tone/ha) to the amount of water used (m^3/ha). The economic water productivity (\$/m^3) relates the economic benefits per units of water used. In an effort to measure productivity, four performance indicators are calculated; output per crop area (\$/ha), output per command area (\$/ha), output per unit of irrigation supply (\$/m^3), and output per unit of water consumed (\$/m^3) (Barker *et al*., 2003).

2.16. Agronomy of Tomato (*lycopersicon esculentum* Mill)

Tomato is the most important warm seasonal fruit vegetable grown throughout the world. Tomato that grows well drained fairly fertile soil rich in organic matter is preferred. It can be grown at elevation of greater than 1500 m.a.s.l. the increasing demand for vegetable has contributed to the growing popularity of this crop, particularly in the urban areas. For the grower keen or maximizing tomato production, knowledge of major tomato pests and disease and their control is essential. Mulch improves soil moisture retention there by increase crop yield (Hune, 2009; Oiganji *et al*., 2010).

Growing requirement and harvesting of tomato are as follows:

Soils: Tomato has given good results when grown in well-managed sandy loam sand heavy clay loams free of hardpan but best results are obtained in deep, well-drained loams. The soil should be rich in organic matter and plant nutrients, with a pH value of 6 to 7.

Climate: the crop does well in a range of temperature between 21^{o}C to 27^{o}C day and 10^{o}C to 20^{o}C night is favorable for plant development and fruit in the country.

Weeding: the crop should be kept free of weeds especially in its flowering stages to avoid losses due to competition from weeds; which can also be a source of pests and should be controlled at all time.

Fertilizer application: the following is a guide for fertilizer application: Nitrogen (NO3, NH4)- 250 kg/ha, phosphate (P_2O_5) – 40 – 60 kg/ha and potash (K_2O) - 50 – 60 kg/ha.

Water management: Sufficient soil moisture is necessary throughout the growing season to produce good tomato. Irrigation is especially important when planting during the dry spell; this helps the young plants withstand the intense sunlight and heat and supplies good sized fruit with sufficient water to develop quickly.

Harvesting: Tomato can be harvested at different ripening stages with creates or plastic boxes: Mature green: When the fruits are fully green, the seed cavity filled with jelly substance, and the seeds are well developed

Turning/breaker: When the surface of the fruit, at the blossom end, turns to pink

Pink; when most of the surface of the fruit is turned to pink
Red/hard ripe: When the fruit is fully colored, but firm flesh
Over ripe: When the fruits are fully colored, but soft

Fresh market tomatoes could better be harvested at turning stage,

3. MATERIALS AND METHODS

3.1. Description of the Study Area

3.1.1. Location, topography and soil

The experiment was conducted in the year of 2016 irrigation season at Miawa farmer training center / FTC / farm land, located at kallu woreda, Amhara Regional State. It is geographically located at the latitude of 8°40'00" to 13°45' N and longitude 35° to 41° E covering a total land area of 155,640 km^2. The specific study site is located at 10°54'00" to 10°54'30"N latitude and 39°45'15" to 39°45'45" E longitudes and at the altitude of 1600 meters above sea level. The study area is situated South of Kombolcha town and North of Addis Ababa at about 29 km and 350 km distance, from the two population centers respectively. The soil types of the area are clay loam (Dessie zonal soil laboratory). Irrigation water was delivered to this experimental site by water pump from the *Aledali* River to night storage and water tank of gravity drip irrigation on filed conditions.

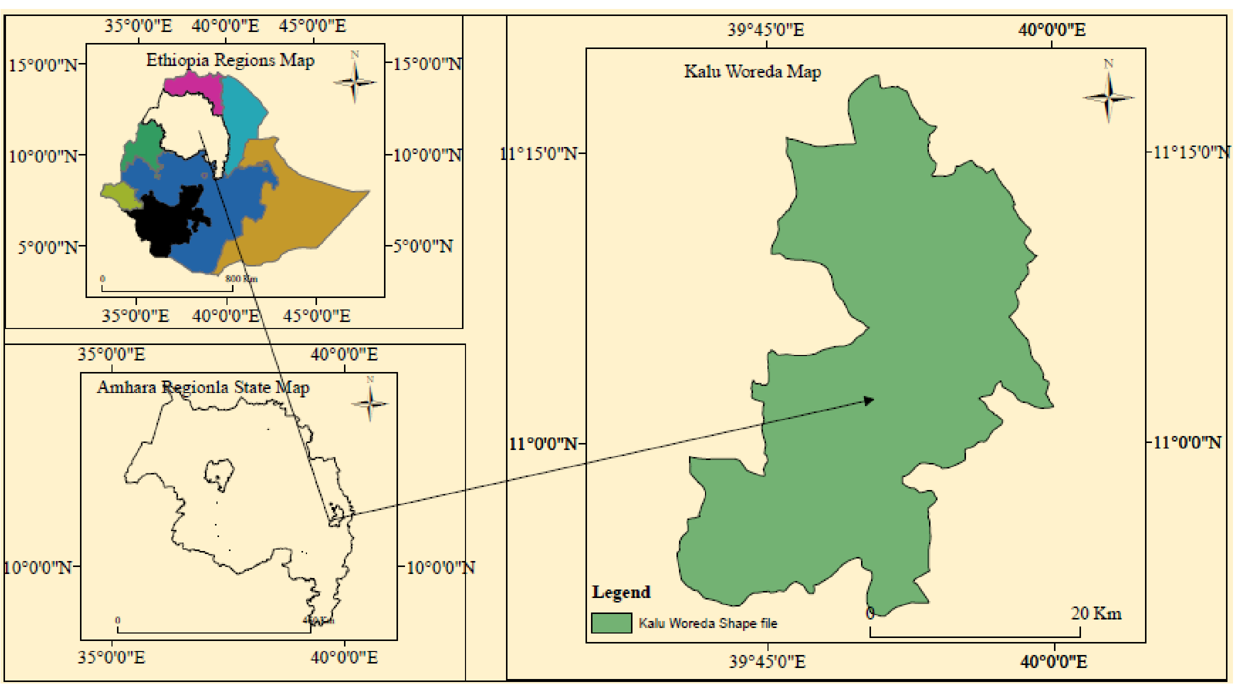

Figure 1 Location map of study area

3.1.2. Climate

The climate is characterized as semiarid with a mono-modal rainfall pattern. The long–term average annual rainfall in the area varies from 800 mm up to 1100 mm, which is erratic and uneven in distribution (Kombolcha metrological station). The rain season occurs from May to October and the maximum rain is received in the months of July and August. The site has a minimum and maximum temperature of 15^{o}C and 27^{o}C, respectively. The climatic conditions during the experimental period are presented in Table 1.

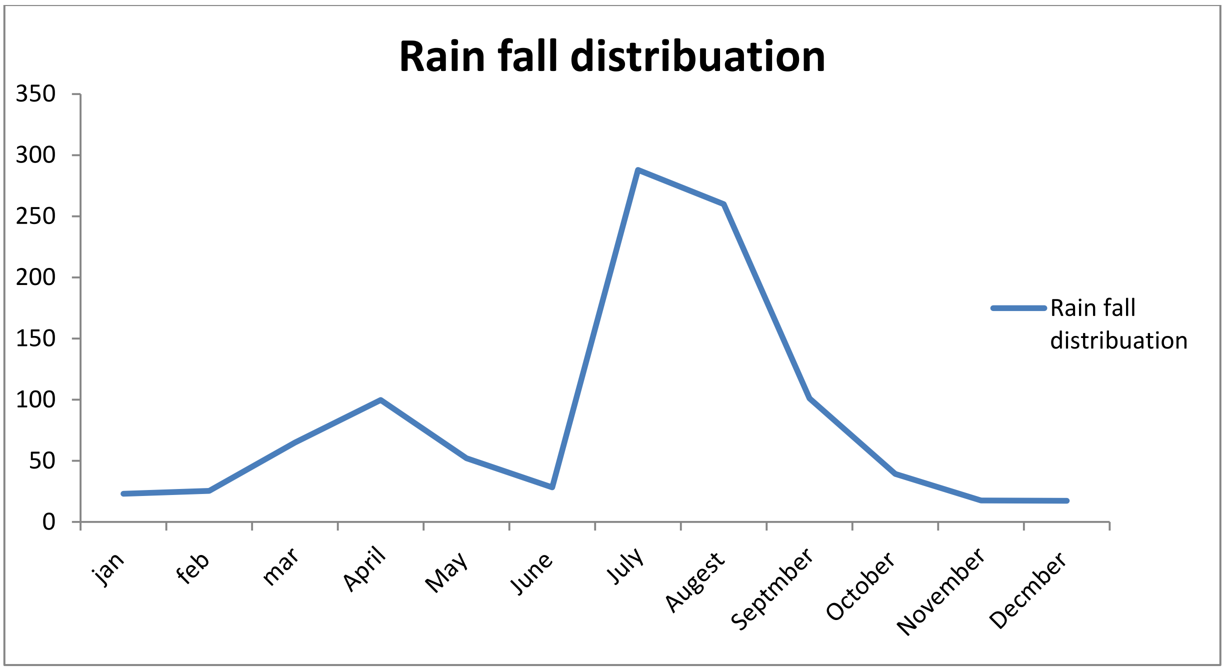

Figure 2 Average rain full distribution in the area

Table 1. Climatic data during experiment

Month	March	April	May	June	July
Rainfall (mm)	22.0	150.0	69.0	20.0	10.0
Maximum temp. (^{o}C)	30.0	28.0	37.5	30.7	28.0
Minimum temp. (^{o}C)	14.6	16.0	15.0	15.1	16.0

Source= Rainfall data direct measurement at site, Temperature from Kombolcha meteorology station, monthly report.

3.1.3. Cropping practices and crop production

Farmers cultivate subsistence and cash crops with rainfed agriculture and supplementary irrigation. The major field crops grown in the study area are Sorghum, Maize and *Teff*. Horticulture crops included onion, tomato and pepper. The main perennial and cash crop are sugar cane, papaya and banana. Mixed farming system is generally practiced in the study area.

3.2. Experimental Method

3.2.1. Experimental design

The experimental design was two factor experiment arranged in Split-Plot Design (SPD). The factor was, in the main plot different irrigation level (90% ETc, 80% ETc and 70% ETc) the sub plot with different mulch type (sugar cane leaf mulch, bulrush mulch and no mulch). The experiment was conducted in a total area of 1287 m^2 (33 m * 39 m). The main plot size have been 11 m * 11 m (121 m^2) with 27 number of lateral and the space between main plots and lateral was 1.5 m and 1 m respectively. There were 9 treatments and 3 replications in the experiment. The treatments was randomly applied to each of the main plot irrigation level and in lateral mulching type with irrigation level and each treatment was assigned in the lateral as given in Figure 2.

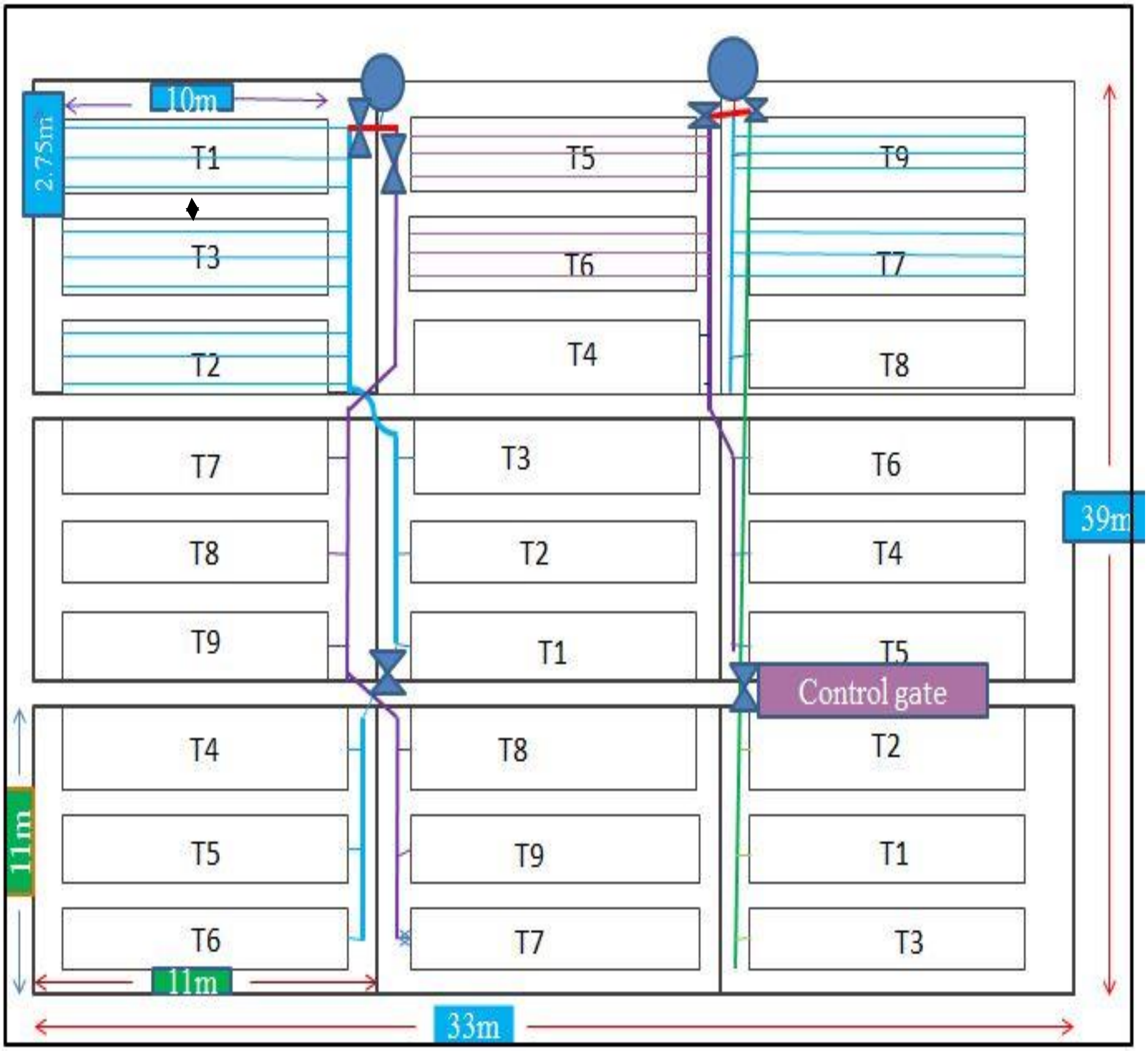

Figure 3 Field layout of the experiment

Treatment;

T1 = 90% ETc without mulch

T2 = 90% ETc with sugarcane mulch

T3 = 90% ETc with bulrush mulch

T4 = 80 % ETc without mulch

T5 = 80% ETc with sugarcane mulch

T6 = 80% ETc with bulrush mulch

T7 = 70% ETc without mulch

T8 = 70% ETc with sugarcane mulch

T9 = 70% ETc with bulrush mulch

3.2.2. Seedling preparation and transplanting

Seedling of tomato were prepared at suitable site by preparing bed on which seeds was raised at Kallu woreda Miawa farmer training center (FTC) and at its nursery stage (30 - 40 days) after germination tomato plant was transplanted to experimental plots. The seed space on the bed of each plot was 75 cm by 30 cm. The numbers of seedling on each lateral plot (bed) were 99. The number of seedling in each row was 33 spaced at 30 cm and the number of row of seedling on each of lateral bed was 3 spaced at 75 cm.

3.2.3. Land preparation and mulch application

The experimental plot was plowed by oxen and the design lay out was done and different types of mulch materials was applied to cover each of the designated plots (beds). The experimental plots were covered with sugarcane leaf and bulrush straw mulch four days before transplanting in the experiment field.

3.3. Design and Installation of Drip Irrigation System

3.3.1. Design of drip irrigation system

The main line

The main pipe line was made of Polyvinyl chloride (PVC) and installed on the surface of ground, running for 39 m length and 40 mm diameter.

The lateral lines

Lateral lines were made of black low density polyethylene (L.D.P.E) built in at 20 mm diameter. There were 27 lateral lines in each main pipe line, which line were connected by grommets. At the end of each lateral, there was an end stop to block the lateral line, thereby preserving water supply.

Emitters (drippers)

One pressure compensating drippers per plant were used (the discharge of one emitter 0.5 l/h).

3.3.2. Installation of drip irrigation system

The type of drip irrigation system to be used in the study area was family drip irrigation. The experimental field was prepared to create suitable condition for crop growth and installation of on-line surface drip system. The 5000 liter water tank was mounted to the stand at height of 1 m above the ground based on the recommendation of FAO (2000). The drip system consists of PVC main line, lateral and dripper. The main line receives water directly from the water tank the laterals were connected with main line and all drippers are on line with laterals. The drip lateral line tubing has an emitter spacing of 30 cm so that each emitter supplies water to a single plant. Water was filled to a small scale drip irrigation tank with water pump and amount of water was released to the field depending on the crop water requirement, which was calculated with CROPWAT software (Smith, 1992a). All the emitter is the same diameter so the released amounts of water were managed with manually operating the gate valve with time.

3.4. Data Collection Techniques

Primary and secondary data were collected during the experiment. The primary data collected were include soil data (texture, field capacity, permanent wilting point and moisture content), emitters discharge rate and supplies water, growth and yield component of tomato. Secondary data collected from Kombolcha metrological station include rainfall, minimum and maximum air temperature, sunshine hours, wind speed and relative humidity.

3.4.1. Soil sampling and analysis

The soil was characterized in terms of its physical properties. The soil properties analyzed include: moisture content, texture, bulk density, water retention at filed capacity and permanent wilting point.

3.4.1.1. Soil moisture content determination

Soil moisture status of the experimental field was determined at four crop growth stages to study the effect of level of mulching on soil moisture conservation and water productivity. The soil water content was determined by collecting soil sample from the center of each plot at depth of 0 – 20 cm, 20 – 40 cm and 40 – 60 cm. This provides one sample from surface depth and one sample from subsurface depth making a total of 3 samples from each lateral, 9 from a block and a total of 81 samples from the entire experimental field during a single period (growth stage). A total of 324 samples were taken at four growth stage. Soil samples were taken before and after irrigation in each block at 20 days after transplanting (DAT) of seedlings, 50 days after transplanting (DAT), 90 days after transplanting (DAT) and 100 days after transplanting (DAT) of seedling of harvesting stage. The soil moisture content was calculated by equation (2.13).

3.4.1.2. Texture analysis

The particle size distribution in the soil profile was done using the hydrometric method following the procedures. For this disturbed soil samples from the 6 locations on the experimental field (X- direction system) were collected from a depth of 0 – 30 cm and 30 – 60 cm with the help of soil auger and prepare composite sample. From the percentage of sand, silt and clay calculated on the data sheet, the textural triangle diagram was used to determine the texture class of the soil.

3.4.1.3. Determination of FC, PWP and bulk density

Field capacity (FC), permanent wilting point (PWP) moisture content and bulk density (p_b) of the study area were determined using 3 undisturbed soil samples collected by using core samples from the soil pit at the depth interval of 0 – 30 cm and 30 – 60 cm from the surface. Soil samples were saturated for one day and a pressure of 1/3 bar (filed capacity) and 15 bars (for permanent wilting point) were exerted until no more change in weight of sample was observed. After getting moisture values available, water availability to crops from this soil were calculated. The total available water (TAW) for the plant use in root zone was computed as the difference in moisture content between field capacity (FC) and permanent wilting point (PWP) as following equation (2.11) (Allen *et al.*, 1998).

Soil bulk density was determined from undisturbed soil sample by core sampling method in the field at two depths 0 – 30 cm and 30 – 60 cm, oven dried for 24 hours at 105^{o}C and weighed for dry density using the following formula (Jury *et al.*, 1991).

$$pb = \frac{Wd}{Vc} \tag{3.1}$$

where: p_b is soil bulk density (g/cm^3), W_d is weight of dry soils (g) and V_c is volume of core sampler (cm^3).

3.4.2. Crop water and irrigation water requirements

Crop coefficient (Kc) for initial, development, mid and late season stages, root depth, allowable depletion level was determined from CROPWAT data base and FAO tables (Allen *et al*., 1998). According to Nuruddin *et al.*, (2003) tomato plants are sensitive to water stress at flowering and fruit sizing stage.

Reference crop evapotranspiration

Monthly reference crop evapotranspiration (ETo) for each year of climatic record was calculated based on the modified FAO Penman menthieth equation (Allen *et al*., 1998) using FAO CROPWAT software (equation 2.15). The input data include location, altitude, latitude and longitude of meteorological station; it used 20 years metrological data, monthly average daily value of maximum and minimum air temperature (^{o}C), air humidity, sunshine hours and wind speed at 2 m height. This input data were collected from Kombolcha meteorological station (Appendix Table 1 - 6).

Crop water requirement

The crop water requirement (ETc) can be determined for tomato crop of the study area over the growing season for the average year based on the established procedure given by (Allen *et al*., 1998) equation (2.16).

Net irrigation water requirement

Tomato (*Lycopersicon esculentum Mill*) can flourish under irrigation in the lower altitudes. Irrigation is a standard practice in vegetable crop like tomato. Water needed per irrigation is determined as net depth of irrigation water that is required consumptively for crop production. It is the amount of irrigation water required to bring the soil moisture level in the effective root zone to field capacity. Thus it is the difference between the field capacity and the soil moisture content available in the root zone before starting irrigation. This is obtained by the relation given below.

$$\text{Water needed (d)} = \frac{(\theta fc - \theta i) * pb * Dr}{100} \qquad (3.2)$$

where: d is the net amount of water to be applied during irrigation (cm), θ_{fc} is field capacity moisture content in the root zone (in %), θ_i is field moisture content before irrigation in the root zone (in %), Dr is the depth of the root zone (cm) and p_b is bulk density of the soil in the root zone (g/cm^3).

3.5. Water Productivity

Physical water productivity or water use efficiency (WUE) and irrigation water use efficiency (IWUE) was determined by dividing the yield to seasonal evapotranspiration and total seasonal irrigation water applied, and calculated by the following equation.

$$WUE = \frac{Ya}{ETc} \tag{3.3}$$

where: WUE is water use efficiency (Kg/m^3), Ya is actual yield (Kg/m^2), and ETc is seasonal crop evapotranspiration (m^3/m^2).

3.6. Uniformity of Drip Emitters

Both the application of the right amount of water and its uniformity of the distribution of irrigation water over the field is important for crop production. In many cases, yield may be directly related the uniformity at which water is applied (Clemmens, 1986). Uniform application of water along a row crop with drip irrigation depend on; emitters must not clog due to residual materials, soils particles or chemical deposited in water: emitters manufactured from the same design must achieve initially uniform discharge; drip irrigation should be designed to compensate for pressure variations along the laterals. A variety of terms have been developed to describe irrigation uniformity. Four widely used parameters for measuring emitter discharge uniformity in the case of field evaluation are: Distribution uniformity (DU), emitter flow variation (qv), coefficient of variation (CV) and uniformity application.

Distribution Uniformity (Du) is calculated as the ratio of its average discharge rate of low quarter of emitter discharge observations to average discharge rate of all observations (Kruse, 1978) and equation (2.3).

The emitter flow variation Qv (%) was calculated using equations (2.4) (Burt *et -al*., 1997).

Coefficient of variation, CV (%) was calculated using the equation (2.5); (Burt *et al*., 1997).

The uniformity of application is evaluated using the Christianson Uniformity coefficient (Jensen, 1983; Michael, 1997; Jurriens *et al*., 2001). This is given as:

$$CU = 100 * \left[1 - \frac{d}{nX}\right] \tag{3.4}$$

where: Cu = Christianson Uniformity Coefficient;

d =deviation of observation from the mean;

n = number of observations;

X = Average depth infiltrated;

Xi = Depth infiltrated at observation point i

3.7. Agronomic Parameters of Tomato

In the experiment the agronomic parameters were collected in the study site to know the effect of mulch type and irrigation level combination on different stage of crop growth in days (initial stage 25, development stage 30, mid-season stage 35 and late season stage 45). Hence the different parameters were measured and collected are as follows.

3.7.1. Growth components and physiological parameters

Plant height (cm): the height of the randomly selected tagged plants was recorded at 20 DAT, 50 DAT and 100 DAT, in centimeter by measuring the height from ground level to the terminal growing point of the shoot, then mean height was worked out.

Number of branch per plant: the total number of branch was counted at, 50 and 90 DAT and the average number of outer branch per plant was calculated from tagged plant.

3.7.2. Yield and yield related parameters

Fruit head volume (cc): the volume of head was done by water displacements method. The randomly selected twenty heads has been immersed individually in a container contain water and the amount of water displaced by each head were measured using measuring cylinder and then the average volume of head was expressed in cubic centimeter (cc).

Fruit head weight (Kg/plant): tomato fruits were harvested when they have firm, compact and attained physiological maturity. The fresh weights of heads (kg) were recorded and the average weight of head had been calculated.

Marketable head yield (t/ha): the marketable head yield of ten sample plants were randomly selected from lateral plots and the weight was determined at harvesting stage and have been recorded and converted to t/ha.

Unmarketable head yield (t/ha): the yield which have been obtained by sorting the diseased, discolored, small size, totally unwanted by consumers from the marketable fresh heads were recorded at each harvests and convert to t/ha.

Total head yields (tons/ha): the weight of total (marketable and unmarketable) head yields per plot at harvesting from the sample plants was recorded and summed up to estimate yield per hectare.

3.8. Statistical Analysis

For each measured response data variables of analysis of variance (ANOVA) were computed. Data were analyzed for variability using the statistical package SAS version 9. Mean separation were done using the Least Significance Difference (LSD) method at 1% and 5% level of probability.

4. RESULTS AND DISCUSSION

4.1. Soil Physical Property

Soil samples were taken during the experiment period, the experimental site had textural classes of upper and lower fields are the same but middle part of the command area showed slight difference. The experimental area is dominated by clay loam (45% sand, 39% clay and 16% silt).

Table 2. Physical property, bulk density and permanent wilting point

Sample location	Soil depth (cm)	Bulk density (gm/cm^3)	FC (%)		PWP (%)		Soil textural class
			w/w	v/v	w/w	v/v	
Blok 1	0 - 20	1.35	34.25	46.24	17.77	23.99	CL
	20 - 40	1.23	37.33	45.92	19.72	26.62	CL
	40 - 60	1.45	39.04	56.61	20.97	30.41	CL
Blok 2	0 - 20	1.35	34.70	46.85	18.82	25.40	CL
	20 - 40	1.19	37.89	45.09	19.94	23.73	SC
	40 - 60	1.45	39.67	57.52	20.91	30.32	SC
Blok 3	0 - 20	1.37	32.95	45.14	17.66	24.20	CL
	20 - 40	1.24	36.26	44.96	18.94	23.49	CL
	40 - 60	1.46	37.72	55.07	20.04	29.26	SC

4.2. Average Moisture Content Before Irrigation and After Irrigation

The result presented in Table 3 is the average moisture contents of the experimental sites before and two days after irrigation. The average moisture contents within the three soil layers of the experiment fields were in the increasing trend down to the profile which happened to be typical of the moisture characteristics after irrigation. The bulk density of the area shows variation with depth. From this it can be concluded that the water holding capacities of the soil based on bulk densities is characterized as moderate (George *et al*., 2013).

Table 3. Moisture content before irrigation and after irrigation

Farm location	Soil depth (cm)	Ave. bulk density (gm/cm^3)	Average moisture content by mass (%)		Ave. moisture content within the root zone by volume basis (%)	
			BI	AI	BI	AI
Blok 1	0-20	1.35	24.38	43.14	32.91	58.24
	20-40	1.23	24.46	43.22	30.08	53.16
	40-60	1.45	24.74	42.61	35.87	61.78
	Average				**32.95**	**57.73**
Blok 2	0-20	1.35	25	45.5	33.75	61.43
	20-40	1.19	26.33	44.43	31.33	52.87
	40-60	1.45	25.95	42.44	37.63	61.54
	Average				**34.24**	**58.61**
Blok 3	0-20	1.37	22.27	42.17	30.51	57.77
	20-40	1.24	23.05	40.82	28.58	50.62
	40-60	1.46	24.16	39.89	35.27	58.24
	Average				**31.45**	**55.54**

*BI = before irrigation, AI = after irrigation

4.3. Total available water (TAW) within the root zone

Results of field capacity and permanent wilting point on volume basis are presented in Table 4 as a volume basis. Total available water (TAW) which is the amount of water that the crop can extract from its root zone is directly related to variation in field capacity and permanent wilting point. As a result, high values of TAW were found in subsurface soil; whereas lower values were found in the top soil. The TAW within the root zone of the upper, middle and lower end fields were 140.22, 140.33 and 136.64 mm respectively. As it has been seen from Table 4, the TAW was almost in decreasing order from the upper to lower end of the field.

Table 4. Total available of water in the root zone

Field location	Soil depth(cm)	Bulk density (gm/cm^3)	FC (%)		WP (%)		TAW (mm/m)	TAW (mm)
			w/w	v/v	w/w	v/v		
Blok 1	0 - 20	1.35	34.25	46.24	17.77	23.99	222.50	44.50
	20 - 40	1.23	37.33	45.92	19.72	26.62	216.60	43.32
	40 - 60	1.45	39.04	56.61	20.97	30.41	262.00	52.40
	Average						**233.70**	**140.22**
Blok 2	0 - 20	1.35	34.70	46.85	18.82	25.4	213.99	42.80
	20 - 40	1.19	37.89	45.09	19.94	23.73	215.28	43.06
	40 - 60	1.45	39.67	57.52	20.91	30.32	272.40	54.48
	Average						**233.89**	**140.33**
Blok 3	0 - 20	1.37	32.95	45.14	17.66	24.20	209.94	42
	20 - 40	1.24	36.26	44.96	18.94	23.49	214.6	43
	40 - 60	1.46	37.72	55.07	20.04	29.26	258.2	51.64
	Average						**227.58**	**136.64**

4.4. Uniformity of the Drip Irrigation System

Uniformity of drip irrigation system is the measure of how evenly water is applied during an irrigation event. If irrigation application is not uniform, some part of the irrigated area will receive too much and some will get little water, because of this uneven distribution of water, growth of plants are affected.

Accordingly, the average emission uniformity, emitter flow variation and coefficient of variation obtained in the experimental site were 94.8%, 12.57% and 4.26%, respectively (Table 5). Based on the recommendation of Bralts (1986), the emission uniformity was excellent, emission uniformity minimum, mean and maximum are 90%, 95% and 100% respectively. (Appendix Table 14), emitter flow variation was acceptable (Appendix Table 15) and according to ASAE (1985) emitter coefficient variation was good (Appendix Table 15).

Table 5. Value of uniformity characteristics of drip irrigation

Parameter	Block 1	Block 2	Block 3	Average
Maximum rate of discharge (l/hr)	0.46	0.41	0.41	0.43
Minimum rate of discharge (l/hr)	0.41	0.35	0.36	0.37
Average	0.44	0.38	0.39	0.4
q_{lq}	0.42	0.36	0.37	0.38
Standard deviation	0.017	0.017	0.017	0.017
Emitter flow variation	10.87	14.63	12.2	12.57
Coefficient of variation	3.84	4.59	4.34	4.26
DU (%)	95.5	94.0	95.0	94.8

4.5. Irrigation Water Requirement

The water requirement of tomato was computed for the growing season using the CROPWAT 8 computer program with climate, soil and crop input data from the study area. The average reference evapotranspiration (ET_o) of the site was found to be 3.95 mm/day (Appendix Table 7). The total available water of the soil was 139.07 mm (Table 4). The net irrigation requirement was calculated using the CROPWAT 8 Computer program is presented in Table 6.

Table 6. Crop water requirement and deficit irrigation level of tomato

	March	April	May	June	July
Calculated Eto (mm/day)	4.21	4.44	4.63	4.67	4.03
Kc per Month	0.71	1.03	1.18	0.97	0.69
Monthly ETc (mm/day)	2.99	4.57	5.46	4.53	2.78
90% ETc (mm/day)	2.69	4.11	4.91	4.08	2.5
80% ETc (mm/day)	2.39	3.66	4.37	3.62	2.22
70% ETc (mm/day)	2.09	3.2	3.82	3.17	1.95

4.6. Effect of irrigation levels and mulch yield and yield component

4.6.1. Effect of irrigation levels and mulch on plant height

The result of irrigation level and mulch effects on plant height is provided on table 7 below. There is highly significance difference in Plant height among experimental treatment at 90 DAT and 50 DAT at 1% level (Appendix Table 10, 11 and Table 7). In the case of 20 DAT, there was significance difference at 5% level among experimental treatments (Appendix Table 9). At 90 DAT, the minimum plants height (61 cm) was observed at T1 (90% ETc without mulch). This is may be due to insufficient water availability in the soil profile. The maximum plant height (84.3cm) was observed at T5 (80% ETc sugarcane mulch), this result was in line with the findings of J.C Paul, *et al.*, (2013) and S.K Biswas *et al*, (2014). The highest increase in vegetative growth in treatment T5 might be due to the availability of soil moisture as well as temperature from mulching at optimum level (Tiwari *et al*, 1998a; Tiwari *et al.*, 1998b; Pattanaik *et al*., 2003). Aklilu (2009) also reported that such effects are mainly attributed to the capacity of the mulch to conserve soil moisture. There is no difference between irrigation level with bulrush mulch treatment and 90% ETc and 70% ETc with sugarcane mulch. This is due to the effect of mulch type with the irrigation level.

Table 7. Mean value of tomato plant height

Irrigation water level	plant height (PH) (cm)								
	Mulch treatment								
	20 DAT			50 DAT			90 DAT		
	WM	SM	BM	WM	SM	BM	WM	SM	BM
90% ETc	21.5^{ab}	19.8^{abcd}	20.9^{abc}	42.7^{b}	45.3^{b}	44.3^{b}	61.0^{c}	67.3^{cb}	67.3^{cb}
80% ETc	18.3^{cd}	22.0^{a}	17.3^{d}	42.0^{b}	58.3^{a}	41.7^{b}	63.3^{cb}	84.3^{a}	66.7^{cb}
70% ETc	19.0^{bcd}	17.7^{d}	18.0^{cd}	41.3^{b}	44.3^{b}	43.7^{b}	72.0^{b}	68.0^{cb}	69.0^{cb}
Mean	19.6^{a}	19.8^{a}	18.7^{b}	42.0^{b}	49.3^{a}	43.2^{b}	65.4^{b}	73.2^{a}	67.7^{b}
CV		8.7			7.8			7.4	
LSD 0.05		2.97			6			8.8	

*WM = without mulch, SM = sugarcane mulch, BM = bulrush mulch

4.6.2. Effect of irrigation levels and mulch on fruit head volume.

As the result show in the Table 8 There is significance difference in fruit head volume among experimental treatment. The maximum fruit head volume size was observed at 80% ETc with sugarcane mulch and the minimum fruit head volume size are at 70% ETc with bulrush mulch .This result is antithesis with that of Topcu *et al*, (2007), found that the full irrigated treatment and conventional deficit irrigation with 50% less irrigation water did not have significant difference in average head volume and Rami, A. *et al.*, (2012) also investigated in 3 deficit irrigation water level; 100% ETc, 80% ETc and 60% ETc, for his result shows that there is no significant difference in fruit head volume. In sugarcane mulch there is a difference in fruit head volume between different irrigation levels (80% ETc with 90% ETc 70% ETc). There is no significance difference between without mulch(WM) and bulrush (BM) mulch with different irrigation level and between 90% ETc and 70% ETc with different mulch treatment respectively.

Table 8 Mean value of head volume of tomato fruit

Irrigation water level	HEAD VOLUME (cc) Mulch treatment			Mean
	WM	SM	BM	
90% ETc	33^{b}	37.33^{b}	35^{b}	35.11^{b}
80% ETc	35^{b}	54.67^{a}	34.33^{b}	41.33^{a}
70% ETc	31^{b}	33.67^{b}	26^{b}	30.22^{b}
Mean	33^{b}	42^{a}	32^{b}	
SE±	5.75			
CV		19.94		
LSD 0.05		12.2		

4.6.3. Effect of irrigation levels and mulch on marketable and total yield

All the drip treatments with mulch resulted highly significant difference in marketable and total yield among experimental treatments (Appendix table 14 and 15). The yield of tomato increased with the increase in water supply without mulch. The effect was reverse when drip irrigation coupled with either sugarcane or bulrush mulch; there was a decrease in tomato yield with the increase in irrigation regime. This result complies with that of Shrivastava *et al*. (1994).

The maximum marketable and total yield of tomato observed at T5 (80% ETc with sugarcane mulch) and the minimum yield recorded at T7 (70% without mulch). Experimental treatment T5 (80% ETc with SM) and T7 (70% ETc with SM) produced slightly higher yield than the same irrigation regime with BM. The increased yield under sugarcane mulch with lower water regime might have resulte from better water utilization, higher uptake of nutrient and excellent soil-water-plant relationship. The next higher yield recorded with 90% ETc with bulrush straw mulch this result comes from creating favorable moisture for plant growth. Irrigation of the same level without mulch produced the lowest yield and there is yield difference among them. This result showed that the deficit irrigation level alone cannot effective in yield production and WUE without mulching. However, 90% ETc irrigation supply produced lower yield when no mulched than mulched with bulrush (21.48 and 30.19 ton/ha, respectively). The marketable and total yield under all levels of drip irrigation with BM was at par while with SM. There is marketable and total yield difference between 90%, 80% ETc and 70% ETc irrigation levels and without mulch, sugarcane leaf mulch and bulrush mulch.

Table 9. Mean value of marketable and total yield of tomato

Irrigation waterlevel	Marketable fruit yield (ton/ha)				Total yield (ton/ha)			
	Mulch treatment				Mulch treatment			Mean
	WM	SM	BM	Mean	WM	SM	BM	
90% ETc	20.6^{cbd}	26.6^{b}	28.4^{b}	25.19^{b}	21.48^{ed}	28.45^{cd}	30.19^{b}	26.7^{b}
80% ETc	23.9^{cb}	41.2^{a}	20.9^{cbd}	28.67^{a}	25.6^{cbd}	44.04^{a}	22.0^{cebd}	30.5^{a}
70% ETc	15.5^{d}	24.8^{cb}	17.5^{cd}	19.27^{c}	16.5^{e}	27.0^{c}	18.9^{d}	20.8^{c}
Mean	20.0^{b}	30.88^{a}	22.3^{b}		21.2^{c}	33.2^{a}	23.7^{b}	
SE±		3.71				3.95		
CV		18.66				18.62		
LSD0.05	-	7.87	-	-		8.4		

4.7. Water Use Efficiency

The average seasonal water use for all the drip treatments at 70, 80 and 90% irrigation levels was 398, 454 and 511 mm, respectively. There is highly significant difference in crop water use efficiency among experimental treatment (Appendix 16). At the same irrigation level (70% ETc) are recorded better WUE in sugarcane mulch (100.2 kg/ha/mm) than bulrush mulch and without mulch treatment (70.3 kg/ha/mm and 61.5 kg/ha/mm). However, the maximum crop water use efficiency observed at T5 (80% ETc with Sugarcane mulch) (143 kg/ha/mm); the un-mulched treatment remaining always behind the mulched treatment. At high irrigation level of 90% ETc, there is no difference between sugarcane mulched and bulrush straw mulched treatment (Table 10). In sugarcane mulch there is difference in crop water use efficiency between different irrigation level (90% ETc, 80% ETc and 70%ETc). Also there is a difference in CWUE between different type of mulch (WM, SM and BM) and irrigation level 80% ETc with 90% ETc and 70% ETc. Mulch reduced the rate of water loss through evaporation from soil surface. So, the soil-water-plant relationship was better in low irrigation regime than high irrigation regime that might help produce higher yield and thereby higher WUE. In drip alone treatment, the highest WUE was also recorded in low irrigation regime treatment. In general, the trends for the WUE related to the total water use for various drip treatments showed that the lower the amount of water use, the higher was the WUE. Besides, low irrigation regime reduced deep percolation and increased water use from root zone soil (Ayars *et al*. 1999).

Table 10. Crop water use efficiency

Irrigation water level	CWUe (kg/ha/mm) Mulch treatment			Mean
	WM	SM	BM	
90% ETc	61.9^{c}	82.0^{cb}	86.0^{cb}	76.6^{b}
80% ETc	83.1^{cb}	143.0^{a}	71.3^{c}	99.1^{a}
70% ETc	61.5^{c}	100.2^{b}	70.3^{c}	77.3^{b}
Mean	68.8^{c}	108.4^{a}	75.9^{b}	
SE$\pm$	13.2			
CV	19.18			
LSD 0.05	28			

5. SUMMARY, CONCULUSION AND RECOMMENDATION

5.1. Summary

Due to high temperature and associated evaporation and low rainfall, the soil moisture level in the dry season is comparatively low and sometimes the moisture condition is lower than the permanent wilting point where plants cannot survive. Mulching is essential to overcome moisture stress and to stabilize crop production in arid, semi-arid and sub humid area in warm season. Mulch is used to cover soil surface around the plants to create suitable condition for the growth. This may include temperature moderation, salinity and weed control (Aklilu, 2009).

This research was conducted to investigate the impact of deficit irrigation with mulches on yield and water productivity of tomato in irrigation season under drip irrigation system. The research was conducted, at Miawa FTC, to study the effect of deficit irrigation with different type of mulches on yield and water productivity and to select the most effective type of mulch with irrigation level for maximum yield and water productivity in tomato production. Treatments consists the combination of mulch and irrigation level; control, sugarcane leaf and bulrush straw with different irrigation level (70% ETc, 80%ETc and 90% ETc) three replications arranged in split – plot design.

During the experiment data such as volumetric moisture content at different growth stage (initial, development, mid stage and late stage of crop growth), at two soil depths (0-30 cm and 30-60 cm) and agronomic parameters were taken and analyzed.

The result indicated that the yield of tomato from 80% ETc with sugarcane mulch was higher (44.04 ton/ha) than 90% ETc with bulrush mulch (30.19 ton/ha) in the same high irrigation level (90% ETc) high amount of yield recorded in bulrush mulch (30.19 ton/ha) than that of without mulch and sugarcane leaf mulch, 21.48 ton/ha and 28.45 ton/ha respectively.

Water use efficiency at irrigation level of 70% ETc with sugarcane leaf mulch (T8) observed better WUE (100.2 kg/ha/mm) than that of un-mulched plot treatment (T7) (61.51 kg/ha/mm).

However, 80% ETc level of irrigation with sugarcane leaf mulch (T5) performed better water use efficiency than any other treatment (143 kg/ ha /mm).

This result indicates that the mulch types with irrigation level are highly related in the yield production and water use efficiency. With increasing irrigation level without mulch yield has increased, while under combined mulch the reverse was observed.

5.2. Conclusion

In view of the objectives of this research and results and discussions presented in earlier sections the following points can be concluded. Generally, mulching showed significant effect on water use efficiency and agronomic parameters. According to the findings of this experiment, the highest yield production and crop water use efficiency was obtained using 80% ETc with sugarcane mulch (44.04 ton/ha and 142.96 kg/ha/mm) respectively and followed by 90% ETc with bulrush straw mulch (30.19 ton/ha and 86kg/ha/mm). In this experiment application of mulch played a greater role in minimizing evapotranspiration, due to that available water to plants root varied appreciably. Variation between the two mulching material indicates that different materials have different moisture retention capacity and thus selection of mulching material need to be an important component of water application.

5.3. Recommendation

From the result of the experiment, the following recommendations are developed:-

- The result showed that mulching and drip irrigation can saves water while increasing yield compared to un-mulched practices. I this regards farmers need to be capacitated to practice this particularly in arid and semi-arid areas where water shortage is major problem and conflict between upstream and downstream irrigators is major concern.

- To validate the results of this finding and practically use the result by farmer, the experiment has to be repeated at different places and seasons so that concrete findings could be developed.

- The experimental crop considered here was tomato. But other vegetable crop especially long duration and crop sensitive to draught stress should be checked in this agro ecology with different types of mulch.

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7. APPENDICES

7.1. Appendix Tables

Appendix Table 1. Mean monthly rainfall (mm) of kombolcha metrology station (1995 - 2014)

Year	Jun	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
1995	0	29.5	48	212.8	87.4	30	284	254.5	73.3	30.3	0	44.6
1996	49	3.4	139.7	133.4	121	61.8	163.5	347.1	37.3	2.3	57.2	1.9
1997	33.6	0	64	69	13.6	110.2	233.5	192.9	52	155	87	0
1998	92.5	94.2	36.4	124.6	49.2	2.9	522.6	248.2	114.5	76.5	0	0
1999	54.4	3.8	22.7	19	5.4	10.8	374.3	318.4	109.1	122	0	2
2000	0	0	6.2	132.8	70.8	42.3	323.6	349.3	119.3	57.4	58.5	38.3
2001	4.4	2.7	134.9	39.2	42.9	46.8	350.4	235.4	115.3	7.1	0.8	8.9
2002	18.1	5.8	58.9	82.1	20.7	10.6	278.5	254.8	86.8	7.1	0	62.2
2003	64.7	26	75	80.9	5.8	48.1	214.9	269.3	149.3	14.6	12.9	60.2
2004	12.6	11.7	39.7	142.3	14.8	28	220.3	239.4	82.5	66.8	40.1	5.5
2005	17.4	4.5	75.8	67	86.4	20.5	356.9	320.6	40.8	25.7	6.7	0
2006	8.8	0	122	87	44.3	14.7	333	277	140.3	62	1.2	6.4
2007	40.5	34	52.3	115	15	37	320.7	175.5	92.3	21.6	6.6	0
2008	25.5	0	0	18.1	52.7	29.4	295	209.1	68.7	47.3	75.6	0
2009	23.6	11.4	17	13.4	17	34.6	370.1	320.4	58.1	63.2	11.5	31.6
2010	0	31.6	70.7	102.7	107.6	15.9	363.9	107.6	57.9	11.7	15.2	11.6
2011	15	0	50.4	25.5	130.9	20.4	278	338.6	90.5	16.6		
2012	0.3	0	109	177.1	34	50.1	284	261.6	52.9	0.5	41.4	0
2013	36.8	0.3	54.2	55.2	40	1.8	336.3	284.9	67.2	132.7	0.6	0
2014	1.8	21.7	52.7	55.1	0	0	307.5	319.5	0	0	11.4	6

Appendix Table 2. Monthly sun shine hour

Year	Jun	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
1995	9.7	7.9	7.8	7.4	8.9	8.9	6.5	6.9	7	8	9.4	8.2
1996	7	9.5	7.3	8.6	7.7	7.6	6.3	6.6	6.8	9.2	8.2	9.1
1997	6.4	10.3	7.2	7.7	9.4	7.2	7.4	6.8	7.2	7.2	7.3	9.8
1998	5.9	6.6	7	8.6	8.5	8.9	6.2	5.3	6.6	6.5	9.6	10.2
1999	7.6	xx	8.1	10.2	9.2	7.8	5.9	7.2	7.1	6.1	9.8	9.2
2000	10.1	10.6	9.6	7.5	9.1	8.7	7	5.8	6.6	7.2	8.4	8.3
2001	7	9.3	5.5	9.7	8.9	xx	xx	5.3	7.4	7.5	8.8	9.5
2002	6.9	9.4	7.4	9.2	8.9	7.6	7.1	7.3	6.2	8.7	12.6	6
2003	7.8	8.7	8.1	7.6	10.3	7.2	5.7	5.7	6.5	9.2	9.2	9
2004	7.9	8.4	8.6	6.8	10	6.3	6.7	7.2	6.7	8.1	9.6	8.1
2005	7	10	8.3	8.1	8.2	8.4	6.7	7.5	7.2	8.2	9.5	10
2006	9.2	8.1	7.7	7.7	9.5	7.9	6.3	6.2	6.8	7.9	8.5	6.9
2007	6.1	7.4	8.7	8.5	8.7	6.3	5.3	7.1	6.8	8.9	8.8	10.2
2008	8.9	10	10.7	9.2	8.7	8.6	6.5	6.7	7	7.6	7.9	9.4
2009	8.2	8.4	8.7	9.3	9.8	9.1	5.9	6.5	7.6	7.4	10	6.6
2010	8.4	6.3	5.9	6.7	7	7.1	6.8	5.7	7.3	8.6	9.2	7.7
2011	7.7	9.5	7.9	8.9	7.7	8.5	6.8	6.8	7.5	9.3	6.8	10
2012	9.2	10.7	9.2	7.7	8.7	7.2	5.3	5.4	6.7	9.4	9.7	9.4

Appendix Table 3. Average maximum temperature ^{o}C

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sep	Oct	Nov	De
1996	2	26.7	25.8	26.5	26.7	28.8	28.1	26.6	26.7	26.4	24.3	24.1
1997	23.8	25.9	27.1	26.8	29	29	28	27	27.4	25.9	24.8	24.7
1998	23.7	24.5	26.1	28.5	28.4	31.7	27.4	26.4	26.6	25.8	25.2	25.1
1999	24.4	27.6	26.7	29.3	30.6	31.4	26.9	26.6	26	24.2	24.3	23.8
2000	25.5	26.9	28.1	28	28.5	31	28.2	26.6	26	25.1	24.3	23.8
2001	23.2	26.1	25.4	27.8	29.3	30.3	27.6	26.5	26.2	26.2	25	25.4
2002	24	26.5	27.2	27.8	30.5	31.3	30	27.8	26	26.7	26.1	24.2
2003	24.1	27.1	27.5	27.7	30.2	30.7	28.1	26.4	26.3	26.1	25.8	24.5
2004	26.1	25.5	27.2	26.5	30.1	29.9	28.7	27.5	26.4	25.2	25.5	24.9
2005	25	28.1	28.1	28.1	27.8	30.7	27.8	27.3	26.9	26	25.8	-
2006	25	28.1	28.1	28.1	27.8	30.7	27.8	27.3	26.9	26	25.8	
2007	25.6	27.2	27.1	26.3	29	31.4	28	27.2	26.5	26.7	25.4	24.7
2008	23.6	26.3	28.2	27.6	30.4	30.4	27.1	27.3	27.3	26.2	25.3	25.5
2009	26.3	26.5	29.3	29	30.2	31	29.2	27.3	27.2	26.3	24.8	25.1
2010	25.2	27.1	28.6	29.3	28.4	32	28.2	27.5	28	26.2	26.7	24.8
2011	25.6	26.5	26.6	28.5	29.2	31.5	28.6	29.2	27	27	25.9	24.3
2012	24.8	27.1	26.4	29.5	28.4	30.1	28	26.7	27.1	26.3	24.7	25.7
2013	26.4	27.6	28.3	26.9	28.6	30.2	28.2	27.5	27.6	26.7	26.9	26.1
2014	26.3	27.5	28.5	29.2	29.7	30.8	28.2	26.4	27.4	26.1	25.8	24.8

Appendix Table 4. Average minimum temperature of Kombolcha metrology station

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sep	Oct	Nov	De
1996	12.4	10.9	13.5	13.7	13.9	14.8	15.2	14.9	14.3	9.5	8.8	8.3
1997	11.1	8.6	13.4	13.5	13.3	14.6	14.9	14.1	13	11.5	11	8.4
1998	13.1	13.8	14.1	14.5	14	15.1	15.1	15.1	13.6	11.7	7.1	5.9
1999	9.1	8.2	12.8	12.2	14.3	15	15	14.6	14.1	12	6.8	8
2000	8.5	8.1	11.3	13.5	14.4	14.6	14.5	14	13.3	11.8	8.9	8.5
2001	8.6	9	13.1	12.8	14.3	15.7	14.4	15	12.7	11.4	8.2	8.1
2002	11.4	10.8	13.2	13.5	14.3	15.3	15.9	15.2	14.4	10.4	8.2	12.6
2003	10.7	11.9	13.3	14.1	14.2	15	15	15.4	14.6	9.4	8.5	8.1
2004	14.5	10.5	11.2	14.4	13	13.5	14.8	14.6	17.9	9.5	8.6	10.3
2005	13.6	10	13.3	13.8	15.1	15.1	15.2	15.2	14.4	9.7	8.1	5.7
2006	9.6	12.5	12.8	13.9	13.9	14.8	15.3	15.2	14	11.8	10.1	12.1
2007	11.4	12.5	12	14	14.5	16.5	15.4	15.1	14.4	9.8	8.6	6.5
2008	9.2	9	8.9	12.9	15.4	15.7	15.8	15.1	14.3	11.3	9.4	8
2009	10	11	12.2	13.5	12.5	16.2	15.4	15.4	14	11.5	8.6	12.1
2010	10.4	13.6	13.2	15.1	15.5	16	15.7	15.5	14.5	11.6	9.3	9.5
2011	11	9.8	11.7	13.8	15.1	15.4	15.7	15.3	13.7	10.9	11.9	8.4
2012	8.8	7.6	10.5	13.8	13.9	15.2	15.4	15.2	14.5	9.8	9.6	9.4
2013	10.1	10	14.2	15.3	15.3	16.8	16	15.4	14.1	12	10.7	7.5

Appendix Table 5. Average wind speed

Year	Jan	Feb	mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
1995	1.43	1.57	1.56	1.37	1.16	1.46	1.37	1.16	0.89	0.77	1	1.08
1996	1.31	1.44	1.32	1.12	1.03	1.51	1.66	1.49	1.02	0.93	0.94	1.11
1997	1.2	1.38	1.39	1.26	1.41	1.46	1.39	1.06	0.81	0.68	0.77	0.98
1998	1	1.03	1.02	1.02	xx	1.53	1.35	1.07	0.81	0.64	0.8	0.97
1999	1.04	1.19	1.25	1.33	1.57	1.56	1.48	1.18	0.85	0.64	0.79	0.92
2000	1.08	1.15	1.33	1.25	1.2	1.41	1.32	1.2	0.81	0.58	0.71	0.79
2001	0.98	1.06	0.87	0.98	1.15	1.21	1.25	1.04	0.83	0.75	0.81	0.76
2002	0.82	0.97	0.88	0.96	1.02	1.24	1.27	1.07	0.68	0.59	0.66	0.78
2003	0.78	0.85	0.88	0.76	1	1.04	1.03	1.01	0.7	0.56	0.64	0.67
2004	0.88	0.89	0.87	0.77	0.9	0.91	1.19	0.74	0.49	0.4	0.49	0.63
2005	0.71	0.81	0.76	0.68	0.7	0.86	0.85	0.78	0.57	0.43	0.5	0.56
2006	0.73	0.84	0.78	0.71	0.77	0.9	0.78	0.7	0.56	0.49	0.55	0.71
2007	0.68	0.64	0.65	0.59	0.65	0.76	0.66	0.62	0.46	0.39	0.48	0.6
2008	0.9	0.85	0.85	0.94	0.93	0.88	0.94	0.74	0.52	0.37	0.44	0.55
2009	0.68	0.69	0.77	0.71	0.81	0.71	0.39	0.35	0.33	0.27	0.41	0.32
2010	0.51	0.49	0.44	0.43	0.44	0.67	0.62	0.5	0.3	0.31	0.27	0.3
2011	0.39	0.54	0.44	0.56	0.46	0.52	0.49	0.39	0.26	0.36	0.33	0.42
2012	0.52	0.54	0.57	0.38	0.41	0.77	0.52	0.42	0.35	0.37	0.37	0.45

Appendix Table 6. Relative humidity

Year	Jun	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
1996	70	55	67	60	54	37	47	60	56	48	55	48
1997	65	44	58	56	41	47	55	60	56	62	66	56
1998	74	70	66	54	48	28	61	67	64	63	50	43
1999	55	38	57	37	34	31	58	63	63	67	52	55
2000	47	38	39	46	44	33	56	64	62	65	63	62
2001	64	51	65	46	45	32	58	65	60	56	49	50
2002	66	50	57	52	37	33	47	56	62	48	47	67
2003	64	54	56	57	35	35	56	65	64	50	53	57
2004	62	53	44	62	33	37	51	59	60	59	56	63
2005	63	46	57	52	55	39	60	61	60	55	52	52
2006	61	63	62	66	54	42	64	68	66	58	60	68
2007	74	66	57	62	46	46	67	65	64	59	59	55
2008	61	54	36	48	46	42	56	64	63	60	66	58
2009	63	57	54	50	39	39	62	66	60	61	52	70
2010	60	62	63	64	59	41	59	71	65	56	58	61
2011	65	51	57	51	57	45	59	69	62	57	70	59
2012	59	50	51	67	54	44	62	65	60	53	54	57
2013	59	52	58	57	49	40	62	72	63	64	63	57
2014	52	63	59	55	59	42	55	68	66	66	52	64

Appendix Table 7. Monthly Reference evapotranspiration of the crop

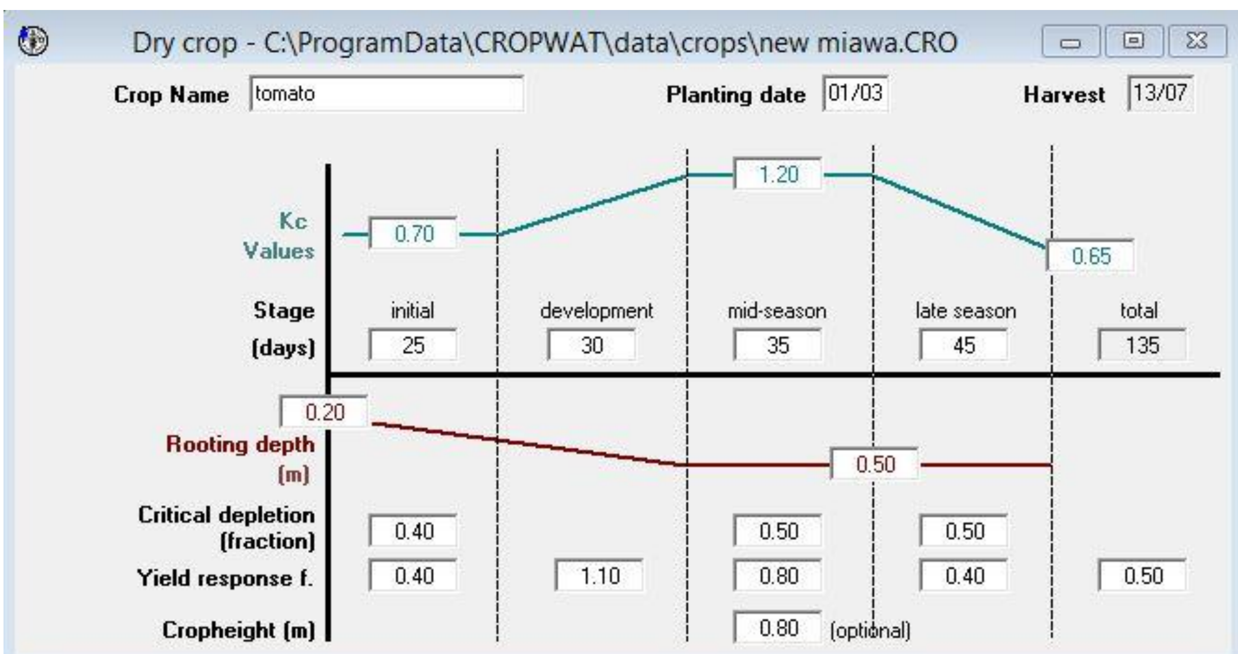
Monthly ETo Penman-Monteith - C:\ProgramData\CROPWAT\data\climate...

Country: ethiopia | Station: kombolcha

Altitude: 1857 m. | Latitude: 11.08 °N | Longitude: 39.72 °E

Month	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	ETo
	°C	°C	%	m/s	hours	MJ/m²/day	mm/day
January	10.8	24.9	62	0.9	7.9	18.8	3.36
February	10.4	26.0	54	0.9	8.3	20.7	3.88
March	12.5	27.4	56	0.9	8.0	21.4	4.21
April	13.8	28.0	56	0.9	8.2	22.2	4.44
May	14.3	29.1	47	0.9	8.9	22.9	4.63
June	15.3	30.7	39	1.1	7.4	20.2	4.67
July	15.3	27.3	58	1.0	6.1	18.4	4.03
August	15.0	27.1	65	0.9	6.1	18.7	3.89
September	14.2	26.8	62	0.6	7.0	19.9	3.94
October	10.9	26.0	58	0.2	8.1	20.6	3.61
November	9.0	24.6	57	0.6	9.1	20.6	3.52
December	8.7	23.5	58	0.7	8.9	19.6	3.23
Average	**12.5**	**26.8**	**56**	**0.8**	**7.8**	**20.3**	**3.95**

Appendix Table 8. Tomato crop Parameters used for CROPWAT model



Appendix Table 9. ANOVA for plant height at 20 DAT

Source of variation	DF	SS	MS	F-VALUE	Probability
Replication	2	9.2	4.6		
Treatment	8	72.47	9	3.07	0.0269
Experimental error	16	47.24	2.95		
Total	26	128.92			

*, significant

Appendix Table 10. ANOVA for plant height at 50 DAT

Source of variation	DF	SS	MS	F - Value	probability
Replication	2	39	19.5		
Treatment	8	507	63.38	5.28	0.0023
Experimental error	16	192	12		
Total	26	738			

**, highly significant

Appendix Table 11. ANOVA for plant height at 90 DAT

Source of variation	DF	SS	MS	F - Value	probability
Replication	2	91.56	45.78		
Treatment	8	1055.34	131.92	5.1	0.0028
Experimental error	16	413.77	25.86		
Total	26	1560.67			

**, highly significant

Appendix Table 12. ANOVA for plant fruit head volume

Source of variation	DF	SS	MS	F - Value	probability
Replication	2	4.22	2.11		
Treatment	8	1495.33	186.92	3.76	0.0115
Experimental error	16	794.45	49.65		
Total	26	2294			

*, significant

Appendix Table 13. ANOVA for number of branch

Source of variation	DF	SS	MS	F - Value	probability
Replication	2	1.407	0.704	0.71	0.5079
Treatment	8	5.85	0.731	0.73	0.6607
Experimental error	16	15.93	0.995		
Total	26	23.19			

ns = no significant

Appendix Table 14. ANOVA for marketable fruit yield

Source of variation	DF	SS	MS	F - Value	probability
Replication	2	124.49	62.24	3.01	0.077
Treatment	8	1372.19	171.52	8.29	0.0002
Experimental error	16	331.01	20.69		
Total	26	1827.69			

**, highly significant

Appendix Table 15. ANOVA for yield production

Source of variation	DF	SS	MS	F - Value	probability
Replication	2	143.59	71.8		
Treatment	8	1649.36	206.17	8.42	0.0002
Experimental error	16	375.28	23.46		
Total	26	2168.22			

**, highly significant

Appendix Table 16. ANOVA for crop water use efficiency

Source of variation	DF	SS	MS	F - Value	probability
Replication	2	1545.2	772.6	2.95	0.081
Treatment	8	15273	1909	7.3	0.0004
Experimental error	16	4187.2	2617		
Total	26	21055.3			

**, highly significant

Appendix Table 17. General criteria for field emission uniformity

Emission Range	Classification
90 - 100%	Excellent
80 - 90%	Good
70 - 80%	Fair
Less than 70%	Poor

Source: adapted from ASAE standards EP 405, 1985

Appendix Table 18. General criteria for emitter flow variation

Emitter flow variation	Recommendation
<=10%	Desirable
10-20%	Acceptable
>20%	Unacceptable

Source: Bralts, 1986.

7.2. Appendix Figures

Appendix Figure 1. Drip installation and mulching

Appendix Figure 2. Tomato Plant transplanting

Appendix Figure 3. Soil Sample and head volume measurement