# RESPONSE OF ONION( *Allium Cepa* L, )TO DIFFERENT IRRIGATION LEVELS UNDER DRIP AND CONVETIONAL FURROW IRRIGATION WITH AND WITH OUT MULCH AT MELKASSA , CENTRAL RIFT VALLEY OF ETHIOPIA

**M.SC. THESIS**

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**OCROBER, 2020**

**HAWASA UNIVERSITY, HAWASA**

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**Thesis Submitted to the School of Biosystem and Water Resources Engineering, School of Graduate Studies**

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**IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN WATER RESOURCE ENGINEERING AND MANAGEMENT**

**GEBEYEHU ASHEMI**

**OCTOBER, 2020**

**HAWASA UNIVERSITY, HAWASA**

# HAWASA UNIVERSITY
# SCHOOL OF GRADUATE STUDIES
# EXAMINER’S APPROVAL SHEET

We, the undersigned, members of the Board of examination of the final open defense by Gebeyehu Ashemi have read and evaluated his thesis entitled **“ Response of Onion (*Allium Cepa* L,) to Different irrigation levels under Drip and Convetional Furrow Irrigation with and without Mulch at Melkassa , Central Rift Valley Of Ethiopia”,** and examined the candidate. This is , therefore,for certify that the thesis has been accepted in partial fulfillment of the requirements for the degree.

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Final approval and acceptance of the thesis is contingent upon the submission of the final copy of the thesis to the School of Graduate Council (SGC) of the candidate's major department.

# DEDICATION

I dedicate this thesis manuscript to my mother Keneni Gutema and my sister, Kuli Ashemi who aspires to see me obtaining an education at the highest level.

# 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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## ABBREVIATIONS AND ACRONYMS

| | |
|---|---|
| ANOVA | Analysis of variance |
| ASMDL | Allowable Soil Moisture Depeletion Level |
| Aw | Area Wetted |
| BD | Bulk Density |
| CWUE | Crop Water Use Efficiency |
| CV | Coefficient of Variation |
| DI | Drip Irrigation |
| DP | Deep Percolation Ratio |
| Dz | Effective Root Depth |
| DU | Distribution Uniformity |
| Ea | Field Application Efficiency |
| *ea* | Air Vapor Pressure |
| ECe | Electrical Conductivity |
| *es* | Saturation Vapor Pressure |
| ET | Evapotranspiration |
| ETc | CropEvapotranspiration |
| ETo | Reference Evapotranspiration |
| FC | Field Capacity |
| FI | Furrow irrigation |
| FWUE | Field Water Use Efficiency |
| ha | hectares |
| Ig | Gross Irrigation Depth |
| In | Net Irrigation Depth |
| IRn | Net Irrigation Requirements |
| IRg | Gross Irrigation Requirements |
| Kc | Crop Coefficient |
| Kd | discharge Coefficient |
| kPa | Kilo Pascal |
| Kr | Ground Cover Reduction Factor |
| Ky | Yield Response Factor |

| | |
|---|---|
| LSD | Least Significant Difference |
| LR | Amount of Water Required for the Leaching of Salts |
| MAD | Management Allowed Deficiency |
| MADPM | Management Allowed Deficiency with plastic mulch |
| MADNM | Management Allowed Deficiency with no plastic mulch |
| MARC | Melkassa Agricultural research center |
| MC | Volumetric Moisture Content |
| MoE | Ministry of Education |
| MoWR | Ministry of Water Resources |
| Msl | Meters Above Sea Level |
| Ms | Weight of Oven Dry Soil |
| $n_e$ | Number of Emitters |
| NM | No Mulch |
| Pe | Effective Rainfall |
| PVC | Polyvinyl Chloride |
| Pw | Percentage Wetted Area |
| PWP | Permanent Wilting Point |
| qlq | Mean Lowest Quarter Drippers Discharge |
| qa | Average Emitter Flow Rate |
| $qv$ | Emitter Flow Variation |
| RAW | Readily Available Water |
| Re | Reynold’s Number |
| Rn | Net Radiation at the Crop Surface |
| RR | Runoff Ratio |
| $S$ | Standard Deviation |
| SAR | Sodium Adsorption Ratio |
| $S_e$ | Emitter Spacing |
| SM | Straw Mulch |
| SMC | Soil Moisture Content |
| SMD | Soil Moisture Depletion |
| TAW | Total Available Water |
| U2 | Wind speed at 2 m Height |
| UC | Uniformity Coefficients |
| US$ | United States Dollar |

| | |
|---|---|
| Vs | Volume of the Same Soil |
| W.a | Wetted Area |
| Wds | Weight of Dry Soil |
| Wws | Weight of Wet Soil |
| WV | World Vision |
| WUE | Water Use Efficiency |
| Y | Yield |
| Ya | Actual Harvested Yield |
| Ym | Maximum Harvested Yield |
| $Z_{Av}$ | Mean of Depths Infiltrated over the Furrow Length |
| Zmin | Minimum Infiltrated Dep |

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# ABSTRACT

*Water is a scarce resource in Central Rift Valley of Ethiopia and is a major limiting factor for crop production. Onion is one of the major economically important vegetable crops grown under irrigation in central rift valley. The field experiment was conducted at Melkasa agricultural research center during the dry season to identify irrigation method and irrigation application level with and whithout mulch that maximizes productivity of onion per unit of water consumed and enhanced onion crop production. The experiment was carried out using split plot design inRCBD having twelve treatments with three replications.The FAO's recommended allowable Manageable depletion level of onion is 25%. In this study 75%, 100% recommended and 125% were tested. The experiment consisted of two irrigation methods viz.,furrow irrigation and drip irrigation as main plot and three levels of Manageable allowable depletion viz., 125%, 100% and 75% with and whith out mulch as sub-plot.The analysis of variance revealed that irrigation methods and management allowed depletion levels had a significant ($p<0.01$ and $p<0.05$) effect on onion vegetative parameters like plant height, leaf height and yield parameters like bulb diameter, bulb height, total bulb yield, marketable bulb yield, and water productivity. The highest and lowest onion vegetative and yield parameters were obtained from drip irrigation and furrow irrigation method, respectively. Moreover, the highest and lowest onion vegetative and yield parameters were obtained from drip irrigation under 75% MAD with mulch and furrow irrigation under125% MAD without mulch, respectively. Further, their interaction had a significant effect on total bulb yield and water productivity. Nonetheless, they had no significant effect on number of leaves per plant, plant height, leaf height, bulb diameter, marketable bulb yield and bulb height.The maximum total bulb yield (37.1 ton/ha), marketable bulb yield (33.1 ton/ha), bulb diameter (5.6 cm), crop water use efficiency (0.78 kg/m$^3$)and irrigation water use efficiency, (0.60 kg/m$^3$) were observed from drip irrigation method at 75% MAD with mulch application, while significantly lower as (30.5 ton/ha), (26.7 ton/ha), (5.0 cm), (0.53 kg/m$^3$)and (0.40 kg/m$^3$) respectively were recorded from furrow irrigation method at 125% MAD with out mulch application. Generally, drip irrigation was working efficiently according to its design and economically acceptable. Among all tested treatments drip irrigation method under 75% MAD with mulch was the best practice because of its high yield and water productivity .*

**Key words:** Drip irrigation, Furrow irrigation, MAD, Onion, Water productivity

# 1. INTRODUCTION

## 1.1. Backgruond

Water is man kind's most vital and versatile natural resource. It is also considered as an essential resource for irrigation. Irrigation can be defined as an artificial application of water to soil for the purpose of supplying the moisture essential in the plant root-zone to prevent stress that may cause reduced yield and/or poor quality of harvest of crops (Reddy, 2010).

Irrigated agriculture is the largest water-consuming sector and it faces competing demands from other sectors, such as the industrial and the domestic sectors. The sector is also facing increasing challenges in the face of rapid population growth, decreasing availability of land and competition for scarce water resources. With an increasing population and less water available for agricultural production, the food security for future generations is at stake. Hence the key challenge for future is growing more food with less water by way of increasing crop water productivity (CWP). A higher CWP results in either the same production from fewer water resources, or a higher production from the same water resources, so this is of direct benefit for other water users (Kijne *et al.*, 2003).

The competition for existing freshwater supplies will require a paradigmatic shift from maximizing productivity per unit of land area to maximizing productivity per unit of water consumed. This shift will, in turn, demand broad systems approaches that physically and biologically optimize irrigation water relative to water delivery and application schemes, rainfall, critical growth stages, soil fertility, location, and weather (Evans and Sadler, 2008).

Irrigation development is increasingly implemented in Ethiopia more than ever. Expansion of irrigated area combined with the efficient management of water will enhance the attainment of food security and poverty alleviation goals of the country. Although the country is well known for its vast water resources potential its erratic distribution both in space and time coupled with limited capacity is the most challenging problem that limited the contribution of the resources to the socio-economic development of the country (Mekonen, 2011).

Agricultural production particularly vegetable crops are intensively cultivated under irrigation in Central Rift valley (CRV) Ethiopia. The region is a semi-arid with limited water resources. Considering increasing demand for water combined with high evapotranspiration rates in the region, effective and efficient use of existing water resources need to be discovered.

Onion is one of the most important vegetable crops widely grown and economically important vegetable crops throughout the world (Brewster, 1997). It is also widely cultivated as source of income by many farmers in many places of Ethiopia. The country has a great potential to produce the crop throughout the year both for local consumption and export. The majority of onion production is found in the CRV of Ethiopia. The climate and soil condition of the region favors the production of the crop.

Traditionally, farmers in the central rift valley of Ethiopia have been using the most conventional surface irrigation system, most commonly the furrow irrigation system, for growing the crops. Furrow irrigation is characterized by low irrigation efficiency. Under common furrow irrigation, over irrigation is inevitable, particularly in the upper part of a field near the water source. Over-irrigation leads to greater water losses and leaches the pesticides and chemicals into the groundwater causing lower water application efficiency and pollution problems as well (Sharkawy *et al.,* 2006). The crop productivity under furrow irrigation can be achieved by applying the required amount at the right time. The crop is shallow rooted and sensitive to water stress. As a result it is commonly given light and frequent irrigation to avoid water stress (Doorenbos and Kassam, 1996). Maximum yield could be achieved with the achievement of the entire crop water requirement.

Drip irrigation is one of the most efficient forms of irrigation technology currently available. It is a technology by which water can be conserved and yield increase for farmers, especially those who are cultivating in semi-arid conditions of the world or in areas where competition over water resources is escalating. Drip irrigation offers many advantage over furrow irrigation including water saving, reducing labor required for irrigation, reducing soil erosion and increasing crop productivity. Therefore, the efforts are now warranted to harness the available quantities of water and put them to efficient use to realize higher productivity per drop (Solaimalai *et al.,* 2005).

On-farm water use efficiency and hence water productivity can be improved by moving to a more efficient irrigation system. Sprinkler and drip irrigation can save non-effective water loss (Ali and Talukder, 2008). Modernization and optimization of irrigation systems can contribute to increasing water productivity (Playán and Mateos, 2006).

Management allowed depletion (MAD), sometimes called the readily available water (RAM) is the fraction of the total available soil water which is most easily extracted by the plant roots without creating stress. The water content approaching permanent wilting point (PWP) cannot be easily extracted by the plant roots. As ET occurs, the soil water reservoir begins to be depleted. As the soil dries, the remaining water is held more tightly by capillary forces in the soil, making it more difficult for the plant to extract it. For this reason, ET will start to decrease long before the PWP is reached. Since the lowest ET will generally reduce yields, growers should irrigate before the root zone water content reaches the level that restricts ET (Palanisami, 2002).

Hence, this study was initiated to identify appropriate irrigation method and optimal irrigation application level with and with out mulch that will improve yield and water productivity of onion at Awash Melkassa.

## 1.2. General Objective

As the general objective, this study was designed to see the response of onion to different irrigation levels using drip and furrow irrigation with and with out mulch that maximizes productivity of onion per unit of water consumed and enhanced onion crop production at Awash Melkasa.

## 1.3. Specific objectives

The study was undertaken with the following specific objectives

- To evaluate the effect of furrow and drip irrigation methods on yield, yield components and water use efficiency of Onion.
- To identify optimal irrigation level for onion production under drip and furrow irrigation.
- To see the effect of mulching on yield of onion under drip and furrow irrigation method.

# 2. LITERATURE REVIEW

## 2.1. Water Resources Potential of Ethiopia

Ethiopia is endowed with abundant water resources. A large number of rivers flowing on either side of the rift valley form a drainage network that covers most of the country. Most of the rivers that carry the water resources, however, end up in neighboring countries hence making them international or Transboundary Rivers. The total surface water resources of Ethiopia, coming from the country's twelve river basins, are estimated to be in the order of 122 billion cubic meters per year. With regard to groundwater resources, the true potential of the Country is not yet known, however, it is widely reported that Ethiopia possesses a groundwater potential of approximately 2.6 billion cubic meters of groundwater(Awulachew *et al.,* 2006).

Ethiopia comprises 112 million hectares (Mha) of land. Cultivable land area estimates vary between 30 to 70 Mha. Currently, high estimates show that only 15 Mha of land is under cultivation. For the existing cultivated area, it is estimated that only about 4 to 5 percent is irrigated, with existing equipped irrigation schemes covering about 640,000 hectares. This means that a significant portion of cultivated land in Ethiopia is currently not irrigated. However, it is estimated that total irrigable land potential in Ethiopia is 5.3 Mha assuming use of existing technologies, including 1.6 Mha through RWH and ground water. This means that there are potential opportunities to vastly increase the amount of irrigated land (Awulachew *et al.,* 2010).

The main sources of water for irrigation, livestock consumption and domestic use in Ethiopia are mainly from rivers/streams, groundwater, lakes and artificial ponds and surface water (seasonal). The distribution of these sources is uneven, in some areas abundant and in others scarce. This variability is mainly due to the diversified landscape and agro-climatic condition the country owns (Goshu, 2007)

"Green water" i.e., rainfall as reported by (Awulachew *et al.,*(2005), is the major source of agricultural water in Ethiopia. They also further stated that the major problem associated with rainfall-dependent agriculture in the country is the high degree of variability and unreliability. As a result, production capacity varies from region to region each year. Due to climate-induced rainfall variability, dry spells, and drought, agricultural production often fails and is doing so more frequently over time.

## 2.2. Irrigation Development in Ethiopia

Gebremedhin and Asfaw (2015) reviewed the Ethiopian irrigation development systems and found that irrigation was practiced during ancient times in Ethiopia even if its exact date of emergence is unknown. Ancient use of irrigation water was through theuse of surface irrigation methods and spate irrigation types. Modern irrigation was started at the Awash River basin with the bilateral cooperation of Ethiopia and Dutch company. This was started during the 1950s for the productions of commercial crops such as sugar cane and cotton. Irrigation of these crops was applied by surface irrigation methods and less efficient pressurized irrigation systems.

Traditional small-scale irrigation schemes (SSIs) have existed for perhaps several hundred years, mostly developed by feudal landlords, notably in Hararge, Shewa,and Gojam. These developments were usually no more than a few hectares in area and diverted water from streams, often only to provide supplementary irrigation. Over the past few decades, many of these schemes have expanded as skills developed, irrigating areas of fifty or more hectares (Awulachew *et al.*, 2006).

Ethiopia's experience in large-scale irrigation development and management is in state enterprises, mainly growing industrial crops like cotton and sugar cane. The experience in modern small-scale irrigation (SSI) development and management started in the 1970s by the Ministry of Agriculture (MoA), in response to major droughts, which caused widespread crop failures and consequent starvation. The sector could be used to reduce family risks that are associated with crop failures resulting from droughts (Awulachew *et al.*, 2006).

## 2.3. Importance of Irrigation

Irrigation is one means by which agricultural production can be increased to meet the growing food demands in Ethiopia. Increasing food demand can be met in one or a combination of three ways: increasing agricultural yield, increasing the area of arable land, and increasing cropping intensity (number of crops per year). Expansion of the area under cultivation is a finite option, especially in view of the marginal and vulnerable characteristic of large parts of the country’s land. Increasing yields in both rainfed and irrigated agriculture and cropping intensity in irrigated areas through various methods and technologies are the most viable options for achieving food security in Ethiopia. If the problem is afailure of production as a result of natural causes, such as dry-spells and droughts, agricultural production can be stabilized and increased by providing irrigation and retaining more rainwater for in-situ utilization by plants (Awulachew *et al.*, 2005).

Heavy reliance on rain-fed agriculture, during conditions of very variable rainfall and recurrent droughts, affects agriculture and, hence, has adverse effects on the economy of the country. Enhancing public and private investment in irrigation development has been identified as one of the core strategies to delink economic performance from rainfall and to enable sustainable growth and development (World Bank, 2006; MoWR, 2002; MoFED, 2006).

Irrigation contributes to the national economy in several ways. At the micro level, irrigation leads to an increase in yield per hectare and subsequent increases in income, consumption and food security (Lipton *et al.,* 2003; Hussain and Hanjra, 2004). Irrigation enables smallholders to diversify cropping patterns and to switch from low-value subsistence production to high-value market-oriented production (Hagos *et al.,* 2009). Irrigation can benefit the poor specifically through higher production, higher yields, lower risks of crop failure, and higher and all year round farm and non-farm employment (Hussain and Hanjra, 2004).

Irrigation has shaped the economies of many semiarid and arid areas, permanently coloring the social fabric of numerous regions around the world. It has stabilized rural communities, increasing income and providing many new opportunities for economic advancement (Qadir *et al.,* 2007).

Irrigation in Ethiopia is considered as a basic strategy to alleviate poverty and hence food security. It is useful to transform the rain-fed agricultural system which depends on rainfall into the combined rain-fed and irrigation agricultural system. This is believed to be the most prominent way of sustainable development in the country (Gebremedhin and Asfaw, 2015).

The impact of drought on the overall macro-economy of Ethiopia is very significant. There is very strong correlation between hydrology and Ethiopia’s GDP performance. It is widely accepted that the Ethiopian economy is taken hostage to hydrology due to the so far insignificant infrastructural development in the water sector. Oftentimes, Ethiopia is ravaged by droughts, leading to dramatic slowdowns in economic growth. The development of water storage facilities which could be used, among other things, to develop irrigation is seen as a way of reducing Ethiopia’s dependence on the annual availability of rainfall (World Bank, 2006).

## 2.4. Water Resource Scarcity and Irrigated agriculture

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

Agricultural production is the major user of the Earth’s water resources and the water demand for this sector is increasing steadily with its root on population growth. These days about 70% of the available water we have on Earth is used for agriculture and by 2020 additional 17% more water is needed than is available now if we are to feed the world (Lascano and Sojka, 2007). In Ethiopia total water withdrawals in 2002 were estimated to be 5.6 $km^3$ of which 5.2 $km^3$ (93.6%) was used for agricultural (World Bank, 2006). Irrigated agriculture is the main user of the available water resources. About 70% of the total water withdrawals and 60-80% of total consumptive water use are consumed in irrigation (Hoffman and Evans, 2007).

Irrigated agriculture is the primary user of fresh water resources (FAO, 2002; Fereres and Soriano, 2007). Irrigation uses take almost 60% of all the world’s freshwater withdrawals. It is therefore not surprising that irrigated agriculture, especially in arid and semi-arid areas, is facing pressures to reduce its water use in order to also cater for other water users like power and water needs for growing urban and industrial areas, and the ample water that is needed to provide in-stream flows to preserve native fish populations in various regions.

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

Consequently, many countries in Sub-Saharan Africa are planning to increase irrigated agriculture as a contribution to attaining the Millennium Development Goals. In particular in developing countries, the area equipped for irrigation is expected to have expanded by 20 percent (40 million ha) by 2030. This means that 20 percent of total land with irrigation potential but not yet equipped will be brought under irrigation, and that 60 percent of all land with irrigation potential (402 million ha) will be in use by 2030 (FAO, 2003).

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

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

Under these circumstances it is crucial that the role of water in securing food supply is understood and the potential for improving overall agricultural productivity with respect to water is fully realized. As a result irrigated agriculture has to cut down the amount of water use for crop production and at the same time to produce more crops with less water. Serious water shortages are developing in the arid and semi-arid regions as existing water resources reach full exploitation. The situation is exacerbated by the declining quality of water and soil resources. The dependency on water has become a critical constraint on further progress and threatens to slow down development, endangering food supplies and aggravating rural poverty. The need to minimize the amount of water used in irrigation is, thus, now a common concession among stakeholders in water resource management.

## 2.5. Irrigation Method

### 2.5.1. Furrow Irrigation

Furrow irrigation method is one of surface irrigation methods in which small regular channels direct water across the field. Furrow irrigation method is best suited to deep, moderately permeable soils with uniform relatively flat slopes and for crops that are cultivated in rows (vegetables, beans, cotton and potatoes, etc). Furrows are particularly well adapted for irrigating crops, which are susceptible to fungal root rot since water ponding and contact with plant parts can be avoided (Michael, 1997).

Furrow irrigation may be adapted on a wide range of natural slopes without causing erosion by designing the furrows across the slope rather than down the slope. The method reduces labour requirements in the land preparation and irrigation. Compared to check basin method, there is no wastage of land in field ditches. Most crops can be irrigated by furrow method except those grown in ponded water such as rice. The furrow method is particularly suitable for irrigating crops subject to injury if water covers the crown or stem of the plants, as the crops may be planted on beds between furrows (Michael, 1997). Moderate to high application efficiency can be obtained if good water management practices are followed and the land is properly prepared. Many different kinds of crops can be grown in sequence without major changes in design layout or operating procedures. The initial capital investment is relatively low on lands not requiring extensive land forming as the furrow are constructed by common farm implements. Soils, which form surface crusts when flooded, can readily be irrigated, because water moves laterally under the surface. This irrigation method is best suited to medium and moderately fine textured soils with relatively high available water holding capacity and hydraulic conductivity, which allow significant water movement in both the horizontal and vertical directions. Using furrows for irrigation necessitates, the wetting of only part of the surface (20 % to 50%), thus reducing evaporation losses, lessening the puddling of heavy soils, and making it possible to cultivate the soil sooner after irrigation. Nearly all row crops are irrigated using furrow method rather than flooding. Furrow irrigation is advantageous when the available irrigation streams are small, and for land of uneven topography (Michael,1997).

Furrow irrigation avoids flooding the entire field surface by channeling the flow along the primary direction of the field using furrows, creases, or corrugations. Water infiltrates through the wetted perimeter and spreads vertically and horizontally to refill the soil reservoir. Furrows are often employed in basins and borders to reduce the effects of topographical variation and crusting. The distinctive feature of furrow irrigation is that, the flow into each furrow is independently set and controlled as opposed to furrowed borders and basins where the flow is set and controlled on a border-by-border or basin-by-basin basis (Walker, 1989).

Furrows provide better on-farm water management flexibility under many surface irrigation conditions. The discharge per unit width of the field is substantially reduced and topographical variations can be more severe. The smaller wetted surface area the lower evaporation losses would be. Furrows provide the irrigator more opportunity to manage irrigations towards higher efficiencies as field conditions change during each irrigation time throughout the growing season (Walker, 1989).

### 2.5.2. Drip Irrigation

Drip irrigation involves supplying water to the soil very close to the plants at very low flow rates (0.5 – 10 lt/hr) from a plastic pipe fitted with outlets (drip emitters). The basic concept underlying the drip irrigation method is to maintain a wet bulb of soil in which plant roots suck water. Only the part of the soil immediately surrounding the plant is wetted. The volume and shape of the wet bulb irrigated by each drip emitter are a function of the characteristics of the soil (texture and hydraulic conductivity) and the discharge rate of the drip emitter. Applications are usually frequent (every 1-3 days) to maintain soil water content in the bulb close to field capacity (Sileshi and Taffa, 2006). Compared to the sprinkler and furrow irrigation methods (with efficiencies of 60 – 70 % in high management systems), drip irrigation can achieve 90 –95% efficiency (Isaya, 2001).

Drip irrigation has the potential to be the most efficient irrigation technology when evaluated in terms of either crop production per unit of water consumed by ET or per unit of water applied. This is because the water can be uniformly delivered to each plant through a closed pipe system. Thus, converting from traditional surface irrigation to drip irrigation can significantly increase the area of land that can be fully irrigated with a given volume of water (Keller, 2002). Results from various research stations in India indicated that in most cases the production of different crops per unit of water supplied is increased by 100 to 200%. But of even greater importance, the production per unit land area is increased by 20 to 50%. This increase in production per unit of land results from the more precise timing, higher uniformity and accurate amount of water applied made possible by using drip irrigation. Thus, more favorable soil moisture conditions can be maintained throughout the cropping season (Keller, 2002).

Different studies (examples: Hanson and May,2004), Safontas and di Paola (1985), (Aujla *et al*., 2004.. etc) showed that drip irrigation boosted yield more than other methods of irrigation. In 1999, an aid agency, Swiss Development Cooperation, conducted a study in Maharashtra on small farmers growing a variety of crops, including beans, papaya, vegetables and flowers. The size of the farms ranged from100m$^2$ to 2000 m$^2$ hectare and included a mix of drip systems. Compared with flood irrigation methods, the study found average water savings of 55 per cent, labour savings of 58 per cent and reduction in expenditure on pesticides and fertilizers averaging 16 per cent (Pandey, 2001). Gincoglan *et al*., (2005) have studied the effect of different irrigation methods on yield of red hot pepper and plant mortality caused by Phytophthora capsici Leon. They found that the highest mean potential dry yield of pepper with 1.58 t $ha^{-1}$ using drip irrigation method as compared to basin, furrow and sprinkler irrigation methods.

## 2.6. Measurement of Soil Moisture

According to Hansen, *et al*. (1979) in irrigated regions the capacity of the soil to store available water for use of growing crops is of special importance and interest, because the depth of water to apply in each irrigation and the interval between irrigation are both influenced by storage capacity of the soil. Many tried and proven methods of estimating or measuring soil moisture are available, for example, gravimetric method, electrical porous blocks, neutron probe and TDR.

Among these methods, gravimetric soil analysis is the most trusted one. In this method soil samples are taken with soil auger and weighed and dried in an oven at 105°C for about 24 hours, until all the moisture is driven off. After removing from oven they are cooled slowly at room temperature and weighed again. The difference in weight is the amount of moisture in the soil (Michael, 1978). According to Jensen (1983), the weight basis water content ($\Theta_w$) of a soil in % can be calculated from the expression:

$$\theta_w = \frac{\theta_w - \theta_d}{\theta_d - \theta_c} \times 100 \tag{2.1}$$

Where $\theta_w$ is mass of wet soil sample in gm, $\theta_d$ is mass of dry soil sample in gm and $\theta_c$ is weight of crucible in gm.

This method is chiefly limited in its usefulness by the time required to collect samples and dry them in an oven. Its accuracy depends on the number of samples taken and on the skill used in obtaining and handling the samples. It requires using facilities not ordinarily owned by growers and requires much time and labor. The method is used principally in experimental work and is a standard against which other methods of soil water determination can be compared (Hansen, *et al*., 1979).

## 2.7. Crop Water Requirement

The term crop water requirement is defined as the amount of water required to compensate the evapotranspiration loss from the cropped field. Crop water requirement refers to the amount of water that needs to be supplied, while crop evapotranspiration refers to the amount of water that is lost through evapotranspiration (Allen *et al*., 1998). For the determination of crop water requirement, the effect of climate on crop water requirement, which is the reference crop evapotranspiration (ETo) and the effect of crop characteristics (Kc) are important (Doorenbos and pruitt, 1977).

The growth and yield of any crop is related to the amount of water used. The variable amount of water contained in a soil and its energy state are important factors affecting growth of plants (Hillel, 2004). The accuracy of determination of crop water requirements will be largely dependent on the type of the climatic data available and the accuracy of the method chosen to estimate the evapotranspiration (Nuha and Henery, 2000). Based on the comparative studies of the reference evapotranspiration methods and recommendations of a panel of experts and researchers organized in FAO, Rome, in 1990, the Penman Monteith equation has been adopted as the globally best performing method of estimating evapotranspiration (Smith *et al*., 1991). The calculation can be done using CROPWAT model. Reference evapotranspiration ($ET_o$) is calculated based on the FAO Penman-Monteith method (Allen *et al*., 1998) as:

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T + 273} U_{2(e_s - e_a)}}{\Delta + \gamma(1 + 0.34U_2)} \qquad (2.2)$$

Where, $ET_o$ is reference evapotranspiration (mm/day), Rn is net radiation at the crop surface (MJ/m2/day), G is soil heat flux density (MJ/m2/day), T is mean daily air temperature at 2 m height (°C), $U_2$ is wind speed at 2 m height (m/s), $e_s$ is saturation vapor pressure (kPa), $e_a$ is actual vapor pressure (kPa), es - ea is saturation vapor pressure deficit (kPa), $\Delta$ is slope of vapor pressure curve (kPa/°C), $\Upsilon$ is psychrometric constant (kPa/ °C).

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

$ETc = ET_o \text{ X } Kc \qquad (2.4)$

Where, ETc = crop evapotranspiration; Kc = crop coefficient; $ET_o$ = reference evapotranspiration

A procedure for calculation of crop evapotranspiration for well-watered conditions using the reference crop approach is recommended by Allen *et al*. (1998). Reference evapotranspiration ($ET_o$) can be estimated using the Penman-Monteith equation. Various crop growth stages and their respective lengths are identified for the locations of interest, and then Kc for the various stages of the crop is determined. Kc values are then adjusted for frequency of wetting condition for rain or irrigation. Then crop coefficient curves are developed to determine Kc values for periods of any length, e.g. monthly or daily periods. Crop ET is then calculated for well-watered conditions for each period of interest as the product of $ET_o$ and Kc. Having ETc and all necessary meteorological data, crop water requirement can compete with the aid of CROPWAT program. The gross water requirement will be then computed assuming 60% of application efficiency as suggested by FAO (1989).

## 2.8. Irrigation Scheduling

Irrigation schedules are set times and intervals for irrigation. The irrigation time is determined by the water requirement for a given irrigation interval, water holding capacity of the soil and uniformity of irrigation systems. Irrigation interval depends on the daily water consumption, soil moisture storage capacity and readily available soil moisture to maintain the ideal soil moisture content for crop use (Barragan and Wu, 2001).

Applications are normally timed to replace water before yield-reducing water stress occurs. Water losses occur mainly through crop evapotranspiration (ETc) and exact estimates of ETc are needed to accurately determine soil water depletion. Crop evapotranspiration depends on the weather and on plant and management factors. Assuming there is no plant stress, the actual evapotranspiration is at a maximum value. If properly irrigated, most crops will have the maximum evapotranspiration (Snyder, 2014).

One of the more widely promoted procedures for irrigation scheduling is the water balance technique. The method involves maintaining a favorable soil water balance by monitoring all additions and losses of a field’s water. Often referred to as evapotranspiration or ET scheduling, the most important component of the water balance is an accurate estimate of crop water use. The ET-based water balance irrigation scheduling methods are increasingly being used throughout the world because they are easy to apply (Jones, 2004). The general approach to these methods is to maintain a running balance of current soil moisture available to the plant by tracking the ET losses and the additions from irrigation and precipitation. Because many of the components are estimated, a good field-check program is recommended to test that the calculations are correct (Snyder, 2014).

## 2.9. Mulches

Mulch is any material placed on the soil surface to conserve moisture, lower or increase soil temperature around plant roots, prevent erosion and reduce weed growth. Mulch insulates and protects soil from drying and hard-baking effects caused by evaporation of water from soil exposed to hot sun and winds. Straw mulch soils are cooler than non mulched soil and have less fluctuation in soil temperature. Optimum soil temperature and less moisture evaporation from the soil surface enable plants to grow evenly. Plant roots find a more favorable environment near the soil surface where air content and nutrient levels are conducive to good plant growth (Wayne, 1996).

Mulch breaks the impact force of rain and irrigation water thereby preventing erosions, soil compaction and crusting. One proven technique for increasing water infiltration is also the use of mulch. Mulched soils absorb water faster. Organic surface mulching has been effective in soil and water conservation, maintaining favorable temperature conditions (reduce the maximum soil temperature at 5 cm depth by as much as 20 ºC) and improving soil structure through enhancing biological activities (Lal, 1979). At the same time, it has distinct advantage of excluding light, which prevents germination of many weed seeds. Fewer weeds provide less competition for available moisture and nutrients.

The development of the polyethylene polymer in the 1930’s, and its release onto the market in the early 1950’s in the form of plastic films, allowed for profitable production of certain vegetables within plastic covered structures (Lamont, 1996). Benefits of plastic mulch include: increased and earlier harvests, higher quality produce, better weed control and insect management, and more efficient use of irrigation water and fertigation nutrients (Lamont, 1993).

To extend the growing season of a certain crop, it is necessary to grow the crop in sub-optimal conditions such as cold weather. Cool soil temperatures can have number of adverse effects on plant root growth such as: slower cell division and cell maturation rates, reduced water uptake, and reduced nutrient uptake (Nielsen, 1974). Black and clear mulches have shown the greatest soil warming potential among the various mulch colors (Ham et al., 1993). Black mulch reflects less short-wave radiation (10%) and absorbs more radiation (90%) than any other colored mulch (Teasdale, 1995). Dark colored mulches (black or red) typically have higher surface temperatures than clear or white mulch (Decoteau et al., 1989). The heat absorbed by dark -colored mulches is conducted to the soil surface, which raises the soil temperature. Therefore, it is very important to apply dark plastics tightly over the bed to maintain good soil- to -mulch contact. An air gap between the mulch and the soil creates a greater distance for the heat to travel before entering the soil and, consequently, much of the heat created at the mulch surface is lost to the atmosphere (Tarara, 2000).

Clear mulch absorbs only 5% of short-wave radiation, reflects 11%, but transmits 84% of it (Tarara, 2000). Clear mulch surface temperatures do not reach the levels found on black plastic due to their low absorption rates of short-wave radiation. Clear plastics actually heat the soil by transmitting light to the soil surface, rather than conducting heat like dark plastics (Ham and Kluitenberg, 1993). Consequently, laying clear mulch loosely across the soil creates an insulating air gap between the mulch and soil that results in higher daytime temperatures under clear plastic than black plastic mulch (Liakatas et al., 1986). If clear plastic is laid tightly across the bed its effects will be minimized and in this situation black plastic laid tightly across the bed would bemore effective at heating the soil (Liakatas et al., 1986). Research with clear plastic surface mulch in combination with supported row covers, has shown that clear plastic mulch is more effective than black plastic in increasing early yield and total yield of spring transplanted tomatoes (Ricketson and Thorpe, 1983).

In controlled environments plant root growth increases with increased temperature from a minimum to an optimum temperature (Diaz-Perez and Batal, 2002) and increases past optimum temperatures are accompanied by decreased root and shoot growth (Miller, 1986). Although no data are available for optimum root zone temperature for field tomatoes (Diaz-Perez and Batal, 2002), research has shown that nutrient uptake from nutrient solutions are optimal at 25°C (Tindall et al., 1990). Research using black mulch for production of field tomatoes has shown temperatures that steadily hovered 10-25 degrees above optimum temperature throughout the season, and in these conditions straw mulch actually outperforms black plastic (Tindall et al., 1991).

White mulch absorbs 51% of short-wave radiation, reflects 48% into the atmosphere, and transmits only 1% of it to the soil (Tarara, 2000). This low rate of radiation absorption (clay loam soils have an absorption rate of 70-86% depending on moisture levels (Tarara, 2000)), and high rate of reflection leads to soil temperatures that are at or below temperatures found on bare ground (Ham *et al*., 1993, Decoteau et al., 1989). Although, increased foliage found over white plastic does not necessarily lead to higher photosynthate produced (Decoteau *et al*., 1989).

Weed control is another important benefit of using mulch. In open- field tomato production, a “critical weed free period” of 28-55 days exists, during which time a single thorough hand hoeing will prevent yield loss (Weaver and Tan, 1983). Weeds growing before this timeframe will not compete significantly with the crop, whereas weeds growing beyond this point will reduce yields primarily by shading the crop (Jensen et al., 1989). Black mulch effectively stops weed growth by intercepting nearly all-incoming radiation and, in combination with its soil warming effects, promotes early season weed growth. Early season weed growth is confined and suppressed by clear plastic mulch as the season progresses, making removal of the plastic and cultivation unnecessary (Ricketson and Thorpe, 1983). Because weeds growing beneath clear plastic will push up and against the mulch, care must be taken to firmly secure down the mulches edges to prevent weeds from growing out from under the plastic and interfering with crop.

## 2.10. Soil-plant -water relationship

### 2.10.1. Water holding capacity of soils

Water content is one of the most variable characteristics of soil. The soil acts as areservoir for water, making it available for plants as it is needed. Soil water is very important to the entire soil system, not only because it is necessary for plant growth, but because the nutrients required for plant growth are also present in the soil solution. Most of the important soil reactions (weathering, cation exchange, organic matter decomposition, fertilization) take place in the context of the soil solution. Thus, it is evident that the moisture status of a soil is a key property.

Numerous other soil properties depend very strongly upon water content. For instance, mechanical properties such as consistency, plasticity, strength, compactibility, penetrability, stickiness and trafficability depend on soil water content.

Water holding capacity of soil is one of the dominant factors influencing irrigation. The water holding capacity of a soil mainly depends on its porosity. The porosity of a soil is defined as the ratio of the volume of pores in the soil mass to its total volume, and it is expressed as percentage. In general there are two types of soil pores viz. capillary or small pores and non-capillary or large pores.

The capillary pores hold tightly by capillarity a large amount of water at saturation and prevent it from being drained off under gravity. On the other hand the non-capillary pores do not hold water tightly and hence a large amount of water held by the soil at saturation is drained off under gravity. Thus capillary pores induce greater water holding capacity while non-capillary pores induce drainage and aeration.

The relative magnitude of these types of pores in a soil depends on its texture and structure. Thus a sandy soil has more non-capillary pores which result in better drainage and aeration but lower water holding capacity. On the other hand a clayey soil has more capillary pores which result in better water holding capacity but poor drainage and aeration. The water held by the soil is extracted by the roots of the plants for being used by the plants. In general the extraction of water from the soil by roots of the plants is resisted by some forces, but the resisting forces are more in clayey soils than in sandy soil. Thus water cannot be easily extracted by the roots of the plants in clayey soils although large amount of water is held by these soils. On the other hand relatively less amount of water is held by sandy soils, but water can be easily extracted from these soils by the roots of the plants.

Thus an ideal soil for irrigation is that which has its pore space almost equally divided between capillary and non-capillary pores. Such a soil has enough small pores to provide adequate water holding capacity and also enough large pores to permit adequate drainage and aeration, and easy extraction of water by the roots of the plants. The loams are therefore ideal soils as they possess good water holding capacity, have good drainage and aeration, and allow extraction of water by roots of the plants without much resistance.

### 2.10.2. Classification of soil water

The water added to a soil mass during irrigation or otherwise is held in the pores of the soil which is termed as soil water or soil moisture. The soil water may exist in the soil in various forms, on the bases of which it may be classified in the following three categories

**Hygroscopic Water:** is the water which is absorbed by the particles of dry soil from the atmosphere and is held as a very thin on the surface of the soil particles due to adhesion or attraction between surface of particles and water molecules. Below then permanent wilting point the soil contains only hygroscopic water. Since hygroscopic water is held with considerable fore, it cannot be removed easily from the soil particles.

**Permanent welting point (PWP)** is the moisture content level at which plants are water stressed and irreversibly wilt. If water is continually taken-up by plants and no additional water is added to the soil in the form of precipitation or irrigation water, the medium and small soil pores will be emptied of water. With time, the plant will eventually wilt when it cannot extract more water. The soil is said to be at the permanent wilting point when plants can no longer exert enough force to extract the remaining soil water. At the permanent wilting point, water is held in the soil at about 1.5 MPa (15 bars).

**Field capacity (FC)** is the amount of water remaining in the soil after the large pores have drained. Medium and small pores are still filled with water held against the force of gravity. Soil water at field capacity is readily available to plants and sufficient air is available in the soil for root and microbial respiration. The optimum water content for plant growth is considered to be close to field capacity. Soils at field capacity are generally considered to be holding water at a tension of about 0.01-0.03 MPa (0.1-0.3 bars).

**Capillary water**: the water con tent retained in the soil after the gravitational water has drained off from the soil is called capillary water. It is held in the soil by surface tensionasa continuous film around the soil particles and in the capillary pores between the soil particles. The capillary water is thus held in the soil against the force of gravity. The plant roots gradually absorb the capillary water which thus constitutes the principal source of water for plant growth. The capillary water supplies the water needed by plants. Hence, it is also designate as plant available water. Main factors that influence the amount of capillary water in the soil are the structure, texture and organic matter content of the soil. A greater amount of water is held by a fine textured soil than by a coarse textured one.

**Gravitational water** : it is that water wich is not held by the soil but drains out freely under the influence of gravity. Within the adhesion of water to the soil during irrigation or otherwise, the water content of the soil is raised to a state of saturation. At this point the soil pores are completely filled with water and the soil contains the maximum possible water content, which thus constitutes the upper limit of the gravitational water.

## 2.11. Soil Water Depletion

Soil water depletion (SWD) is the fraction of the available soil water that will be used to meet evapotranspiration (ET) demands. As ET occurs, the soil water reservoir begins to be depleted. As the soil dries, the remaining water is held more tightly by capillary forces in the soil, making it more difficult for the plant to extract it. For this reason, ET will start to decrease long before the PWP is reached. Since the lowest ET will generally reduce yields, growers should irrigate before the root zone water content reaches the level that restricts ET.The smaller allowable depletions are required for sensitive crops at critical stages of growth and the vice versa (Palanisami, 2002).

Irrigation is timed using a management allowable depletion (MAD), which is the maximum or critical soil water depletion (SWD) that is acceptable between irrigation applications. Irrigation events are usually timed so that applications are made the day before or after the SWD exceeds the MAD (Snyder, 2014).

The management decision concerning the level of MAD is the one that must be done by every irrigation manager before irrigations are scheduled. Decreasing the MAD increases the frequency of irrigation (but decreases the amount per irrigation) to provide a more favorable crop root environment and reduce water stress during requirements because the soil will be maintained wetter (Kandiah, 2002).

## 2.12. Agronomy of Onion

Onion is a cool season biennial monocot with a prominent bulb, hollow cylindrical leaves and a strong odor when bruised. The crop is said to be tolerant to frost. The optimum temperature for plant development varies between 13$^0$C and 24 $^0$C, while, for raising seedlings, it requires up to 20-25 $^0$C and generally require high temperatures for bulbing and curing (Kalb and Shanmugasundaram, 2001).

Onions grow on a variety of soils ranging from sand to clay loams. However, they prefer loamy soil that is fertile, well drained and high in organic matter, with a preferable pH range of between 6.0 and 8.0 (Olani and Fikre, 2010). Onions do not thrive in soils below pH 6.0 because of trace element deficiency, or occasionally, aluminum or manganese toxicity. Onions could be produced on slightly alkaline soils, but are sensitive to soil salinity. According to the FAO (2002), a soil salinity level of 4.3 dS/m or more could decrease the yield of onion by up to 50%.

Onion plants usually require substantial amount of nutrients. According to the study by Kalb and Shanmugasundaram (2001), onions with a bulb yield of 18 t/ha require an average of 66, 11 and 70 kg/ha of N, P and K nutrients, respectively. Some pre-plant nitrogen is needed as a starter fertilizer to avoid losses through either leaching or volatilization while the plant roots are not developed enough to absorb the bulk application (Shock *et al.,* 2000). After plant establishment, one or two side dressings of nitrogen fertilizers are required during the season. Insufficient nitrogen will induce early maturity and reduce bulb size, while high nitrogen may increase bulb size, but cause large nicks and soft bulbs with poor storage quality.

Onions require frequent irrigation throughout the growing season for several reasons. The root system is shallow, therefore, very little water is extracted from a soil depth deeper than 0.6 m, and most is from the top 0.3 m. Onion roots are mostly non-branching and all roots originate at the stem, or basal plate of the plant. This indicates that upper soil areas must be kept moist to stimulate root growth. Rates of transpiration, photosynthesis and growth are lowered by even mild water stress (Voss and Mayberry, 1997).

Onions show little capacity for reducing leaf water potential by osmotic adjustment to compensate for reduced water availability at the root. Onion crop fields that frequently experience water stress would suffer growth retardation and produce excessive numbers of doubles or splits, reducing the grade of bulbs. For optimum yield, onions require 350-550 mm of water, but may use more than that in areas where ET is appreciably higher (Kalb and Shanmugasundaram, 2001).

Onions are harvested when 80% of the bulbs become completely mature, which is evident by the collapse of 20 to 50% of the neck tissue and falling of the tops. That is usually 100 to 140 days after transplanting (Brewster, 1990). After harvesting, the roots are trimmed and the tops cut away. Bulbs are usually put into an appropriate case and allowed to cure outdoors. After bulbs are properly cured, onions are graded according to the local standards of the country. According to the USDA standard, onions are graded for size and shape, proper maturity and firmness. Onions must also be free of splits, seed stems, dry sunken areas, roots, tops, translucent or watery scales, moisture, disease and insects (Shock *et al.,* 2000).

# 3. MATERIALS AND METHODS

## 3.1. Description of the Study Area

### 3.1.1. Location

The study was conducted at Melkassa Agricultural Research Center experimental site during 2017/18 dry season. The area is Located in the Central Rift Valley of Ethiopia. It is geographically located between latitude of 8024' to 8026' N, longitude of 39019' to 39019' E and the mean altitude of the area is 1550 m.a.s.l (Figure 1). It is located about 107 km to the East of Addis Ababa, capital city of Ethiopia and 17 km Southeast of Adama. Loam and clay loam soil textures are the dominant soils of the area, which is classified as Lithosols with pH of 7.

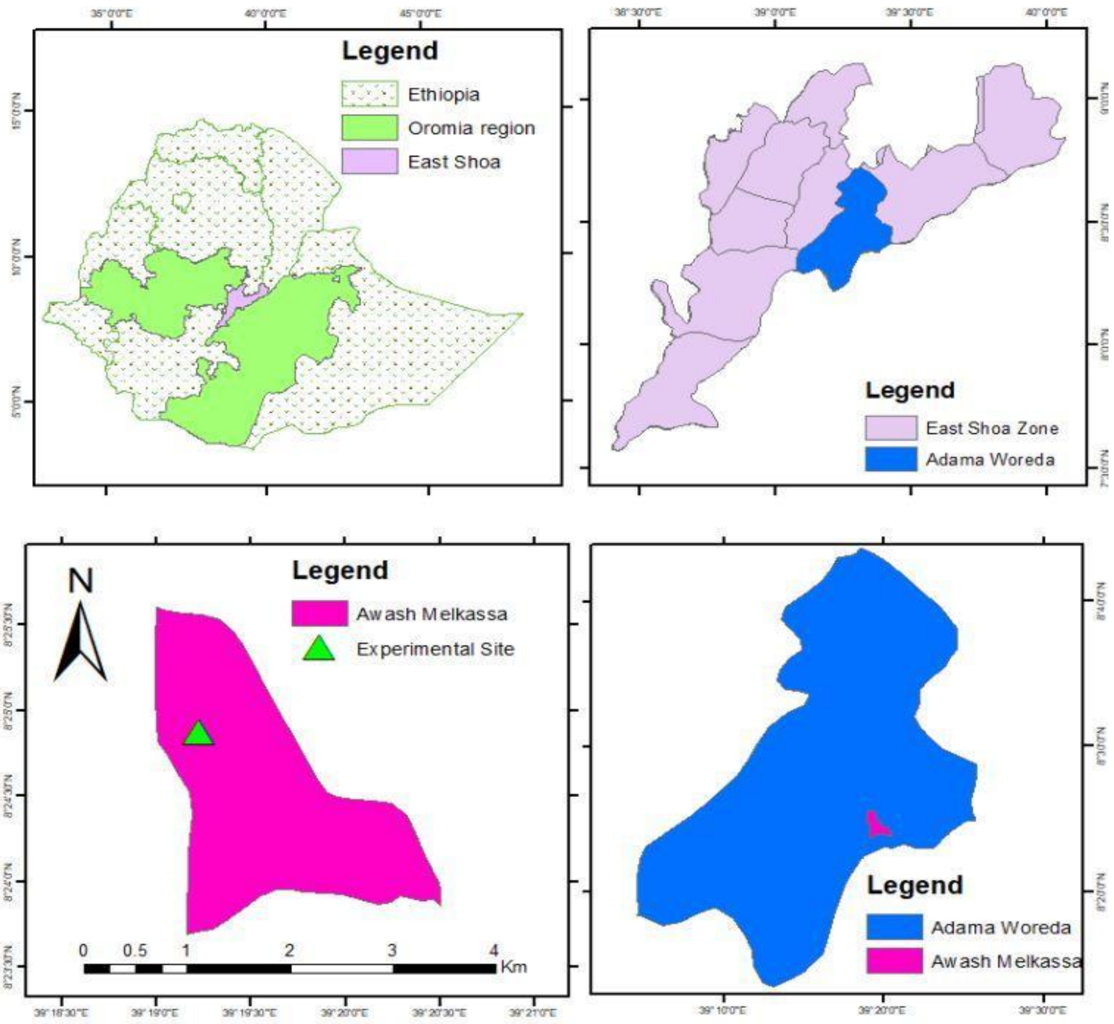

Figure 1. Location of the study area

### 3.1.2. Climate

Long-term (1977 – 2017) climatic record from station, average annual rainfall in the area is 824.9 mm. The climate of the area is characterized as semi-arid with uni-modal low and erratic rainfall pattern. Kiremt season have got more rainfall about 67.4% of the total rainfall of the area occurs from June to September, with peak month of July and August. The mean maximum and minimum monthly rainfall is 204.2 and 9.6 mm occurs in the month of August and November, respectively. The mean maximum temperature varies from 26.3 to 31.0$^0$C while the mean minimum temperature varies from 10.4to 16.4$^0$C, with the average of 21.3$^0$C (Figure 2 and Appendix table 1).

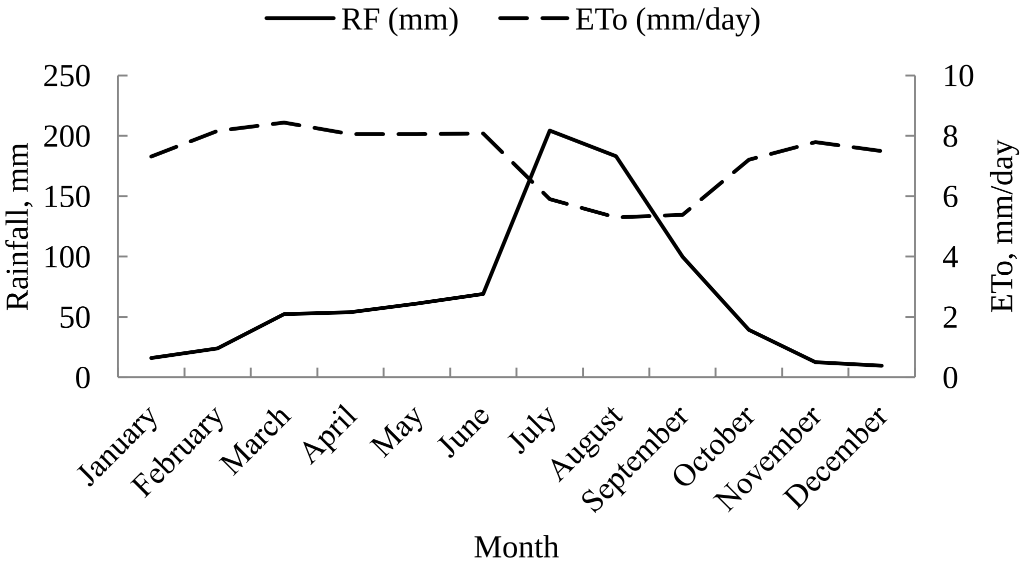

Figure 2. Long-term monthly climatic water balance of the study area

### 3.1.3. Agronomic practice

Farmers in the area grow crops three times a year of which two using traditional furrow irrigation during cool (September to January) and warm (February to May) seasons and the other during the rainy season (June–September) using rainfall and irrigation as a supplementary. The crops grown include pepper, tomato, onion, potato, shallot, haricot beans, sweet potato, papaya, wheat, maize and teff. Most of the time, vegetable crops grow during dry season and cereal crops during rainy season (Scholten, 2007). The source of irrigation water in the study area is Awash River.

## 3.2. Experimental procedures

### 3.2.1. Experimental design and treatments

Treatments include two methods of irrigation: furrow irrigation (FI) and drip irrigation (DI), two levels of soil water depletion, 25% below and above FAO's recommended allowable Manageable depelation level of onion (75% of and 125% of ASMDL) and a control irrigation application, FAO's recommended allowable Manageable depelation level of onion (100%ASMDL*) and two mulching techniques : no mulch [NM], and white plastic mulch [PM] having twelve treatment combinations arranged in a split plot design in RCBD with three replications, in which the irrigation methods were used as main plot and the three irrigation applications together with the two mulching technique were used as sub-plot. The treatment combination is given in Tables 1 and 2, and layout in Figure 3

| *Sub-plot* | *Main-plot - Irrigation method* | |
|---|---|---|
| Irrigation Level | *Drip Irrigation* | *Furrow Irrigation* |
| *75% MADPM* | *T1* | *T7* |
| *75% MADNM* | *T2* | *T8* |
| *100% MADPM* | *T3* | *T9* |
| *100% MADNM* | *T4* | *T10* |
| *125% MADPM* | *T5* | *T11* |
| *125% MADNM* | *T6* | *T12* |

Table 1. The exprimental treatments combinations

| Treatment | Description |
|---|---|
| T1 | Drip irrigation method with 75% of MAD level with plastic mulch |
| T2 | Drip irrigation method with 75% of MAD level without plastic mulch |
| T3 | Drip irrigation method with 100% of MAD level with plastic mulch |
| T4 | Drip irrigation method with 100% of MAD level without plastic mulch |
| T5 | Drip irrigation method with 125% of MAD level with plastic mulch |
| T6 | Drip irrigation method with 125% of MAD level without plastic mulch |
| T7 | Furrow irrigation method with 75% of MAD level with plastic mulch |
| T8 | Furrow irrigation method with 75% of MAD level without plastic mulch |
| T9 | Furrow irrigation method with 100% of MAD level with plastic mulch |
| T10 | Furrow irrigation method with 100% of MAD level without plastic mulch |
| T11 | Furrow irrigation method with 125% of MAD level with plastic mulch |
| T12 | Furrow irrigation method with 125% of MAD level without plastic mulch |

Table 2. Treatment description

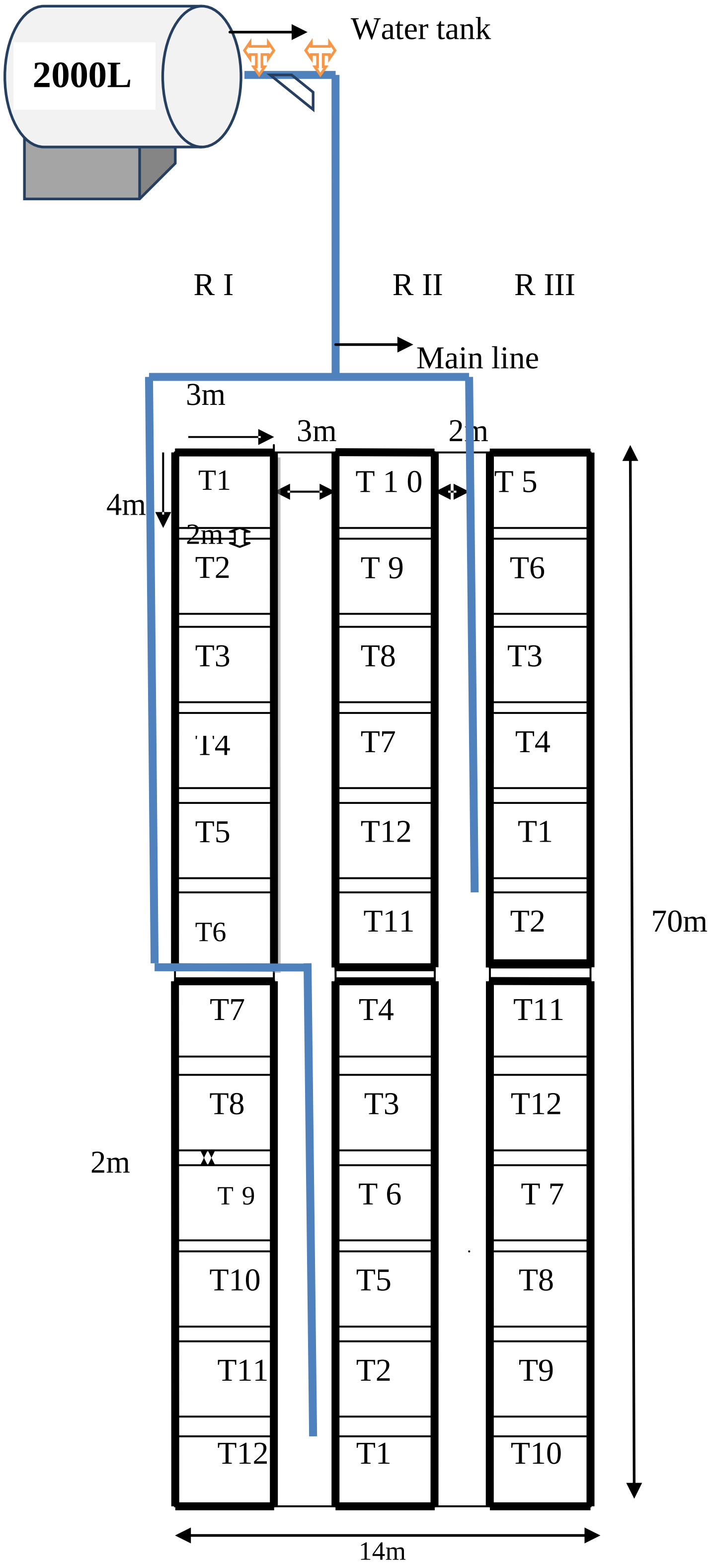

Figure 3. Expremental layout

### 3.2.2. Preparation of the Experimental area

Field experiment was carried out during dry cropping season (October – February) 2017/18 and the field was ploughed using tractor, leveled and made ready for plot layout. The experimental field plot layout was made by dividing the field in to 36 plots and each experiment plot has plot sizes of 3m by 4m to accommodate five furrows with spacing of 60cm between ridges and 4m furrow length. The plots and replications plot had a buffer zone of 2m and 3m between plots on none supplying and supplying canal sides, respectively to eliminate influence of lateral sub-surface water movement.

### 3.2.3. Installation of drip irrigation sets

In case of drip irrigation, the plots were leveled manually to create uniform plots within the given treatment. There were 18 plots laid out 4m length, five laterals per plot, 60cm spacing between laterals and 20cm interval between emitters. Wooden platform to carry the water container was constructed. The height of the plat form was 1.5m above the ground. The water container was drilled and 1 inch socket welded 10cm above the bottom to provide the water pressure required to operate the system. The container on the platform was mounted in such a way that the water out let was at a height of 1.1m. A 1 inch male elbow, on the container water out let, was attached to female elbow, and flow regulator fittings were mounted at main line of each Tee connector. The water distribution system components (32mm, main line) were laid and connected the water container to the (25mm, sub main line) and sub main line connected to individual drip lines. The drip lines (laterals) of 16mm diameter were unrolled and laid along the crop rows and each lateral served one row of crop. Emitter was inserted in the punched hole. The end of the laterals and the main lines were closed with end cup to avoid direct soil contact and thus prevent clogging.

## 3.3. Crop Management Practices

The experimental plots were pre-irrigated before three days to planting. Onion variety Nafis was planted on well prepared experimental field plots in third week of October 2017. This varitey was selected because of it’s widely acceptance by local farmers and for its higher yield performance and disease resistance. The recommended rate of 200 kg/ha DAP and 200 kg/ha urea waas uniformly applied to the plots. DAP was applied at planting time only whilst urea was applied in split application, half at planting and another half twenty days after planting.

Light irrigations was applied prior to start of treatments applications for ten days. The treatments applications was started on 28 October, 2017. Water applications for control irrigation treatments (ASMDL*) were based on the predetermined amount of irrigation water allowable soil moisture depletion for Onion (p = 0.25) and those two levels of soil water depletion treatments (75% of ASMDL, and 125% of ASMDL) were imposed as planned.

In furrow irrigation, each plot was irrigated using Parshall flume. In drip irrigation, each plot was irrigated through drip lines (laterals) of 16 mm diameter that was laid along the full length of each furrow bed. Depending on soil type, emitter was placed at 20cm interval along the lateral lines. Water tanker of 2000 liters capacity was placed at 1.5m above ground to supply the required irrigation water to a block of experimental field through main line that was connected with sub-main line and manifold of drip irrigation system. All cultural practices were done in accordance to the recommendation made for the area.

## 3.4. Irrigation Water Source and Management

### 3.4.1. Irrigation water source and quality

The source of water for this experiment was used from Awash River . Water quality analysis prior to installation and use of drip irrigation has been made. The electrical conductivity of (EC ) of the irrigation water was 1.12 dS/m, which is between 700 µmhos/cm and 3000 µmhos/cm. Thus there is moderate limitation to use this water for irrigation.

### 3.4.2. Irrigation management

The amount of water that can be extracted by plant roots is held in the soil in an ‘available’ form. The actual volume of water that can be obtained from the soil profile depends on the depth of the root system. Not all of the water found in the root zone was actually be taken up by roots. The total available water (TAW), stored in a unit volume of soil, is approximated by taking the difference between the water content at field capacity (FC) and at permanent wilting point (PWP). The TAW is expresses as:

$$TAW = (FC - PWP) * BD * Dz)/100 \qquad (3.1)$$

where; FC and PWP in % on weight basis, BD is the bulk density of the soil in gm cm$^{-3}$, and Dz is the maximum effective root zone depth in mm. The bulk density, BD, is the mass of a soil in a unit volume for undisturbed soil condition and is expressed on dry weight basis of the soil as:

$$BD = Ms/ Vt \qquad (3.2)$$

where Ms is the weight of oven dry soil (gm), and Vs is the volume of the same soil (cm$^3$).

For maximum crop production, the irrigation schedule will be fixed based on readily available soil water (RAW). The RAW is the amount of water that crops can extract from the root zone without experiencing any water stress. The RAW was computed from the expression:

$$RAW = p*TAW \qquad (3.3)$$

where; RAW in mm, p is in fraction for allowable/permissible soil moisture depletion for no stress and TAW is total available water in mm**.**

Soil moisture will be monitored gravimetrically at 15cm and soil depth increments up to 60cm soil depth ( 15-30,30-45 and 45 – 60cm) with neutron probe in a single replication. Permissible soil moisture depletion will be taken as ASMDL* requirement and all other treatments will be adjusted accordingly to irrigate the plots. The depth of irrigation supplied at any time will be obtained from a simplified water balance equation which is expressed as:

$$In = ETc - Pe \qquad (3.4)$$

where In is the net irrigation depth (mm), ETc is the crop water requirement (mm) and Pe is the effective rainfall (mm) which is a part of rainfall that enters in to the soil and makes available for crop production. The effective rainfall we estimated using dependable rain (FAO/AGLW formula) method as given by (Allen *et al*., 1998) as.

$$Pe = 0.6 *P -10 \text{ for month} \leq 70 \text{ mm} \qquad (3.5)$$

$$Pe = 0.8 *P - 24 \text{ for month} \geq 70 \text{ mm} \qquad (3.6)$$

where Pe is the effective rainfall (mm ) and P is total rainfall (mm).

The gross irrigation requirement will be obtained from the expression:

$$Ig = \frac{In}{Ea} \quad \text{Furrow irrigation} \qquad (3.7)$$

$$Ig = \frac{In \times w.a}{Ea} \quad \text{Drip irrigation} \qquad (3.8)$$

where; Ig is the gross irrigation depth (mm); Ea is the field application efficiency (%) and w.a. is the wetted area (%).

In the case of furrow irrigation, knowing the application efficiency of the furrows (60%), the time required to deliver the desired depth of water into each furrow will be calculated using the equation:

$$T = (dxWxL)/ (6xQ) \qquad (3.9)$$

where; d = gross depth of water applied (cm), W and L = width and length (m) of the experimental plot, T= application time (min) and Q is flow rate (discharge) (l/s). Soil moisture depletion at any soil moisture level will be observed with the following expression as:

$$SMD = (FC - MC) \times Dzr \qquad (3.10)$$

where, SMD = soil moisture depletion (mm), FC = volumetric soil moisture content at field capacity (mm), MC = volumetric moisture content at time of irrigation (mm), and Dzr = Depth of effective root zone (mm).

In the case of drip irrigation, knowing drip/emitter size, length of lateral and the number of laterals per plot, the time required to deliver the desired depth of water will be calculated as follows:

- Number of Emitters per lateral = $\frac{\text{Lateral length (m)}}{\text{Emitter spacing (m)}}$ (3.11)
- Flow rate required per plot = number of emitters per lateral x number of laterals per plot x emitter discharge (lt/sec) (3.12)
- Time required to irrigate a plot (sec) = gross irrigation (ltr)/Flow rate required per plot (lt/sec). (3.13)

## 3.5. Data Collection

### 3.5.1. Climatic data

Data on daily climate of the site was collected from the Melkassa Agro-meteorological observatory. The reference evapotranspiration (ETo) was computed using Penman-Monteith method, CROPWAT ver. 8.0 window based computer model from the climatic data gathered from Melkasa Agricultural Research Center. The Onion crop evapotranspiration (ETc) for each day was computed by multiplying the ETo by the crop coefficient (Kc) values obtained from FAO (1977) for each of the four stages of Onion , initial, development, mid and late season. The Kc values represented the ratio of crop evapotranspiration (ETc) and reference evaporation (ETo) rate each day. The effective rainfall was computed by the CROPWAT program from the monthly total rainfalls. The net daily crop water requirement was computed by reducing the ETc by the daily effective rainfall. The gross water requirement was computed by applying field application efficiency.

### 3.5.2 Crop Data

Data on plant height, leaf height and leaf number per plant was recorded from five randomly selected plants in three middle rows of each experimental plot and the same plant was used for subsequent measurement. Data on total yield and yield components such as the Total bulb yield, Merkable bulb yield , bulb diameter, bulb height from each experimental plot were collected.

### 3.5.3. Soil sampling and analysis

To study and characterize the soil at the study site representative samples were taken and determination of organic matter content, pH, texture, bulk density, moisture content at field capacity (FC) and permanent welting point (PWP) were made. Moisture content of the experimental plots before irrigation was estimated.

Prior to land preparation for the experiment, soil samples were collected from the experimental field using core sampler from the soil depths of 0 – 15 cm, 15 – 30 cm, 30 –45 cm and 45-60 cm before the field was ploughed for determining physical and chemical properties of soil. Soil physical properties like textural class, bulk density, and infiltration rate, FC, PWP and TAW were determined. Soil chemical properties like pH, Organic carbon content, Organic matter content(OM) and electrical conductivity (EC) were analyzed.

#### 3.5.3.1 Bulk density

To determine bulk density, undisturbed soil sample of known volume were taken using core sampler from three representative places in the trial plot at four different depths (0-15 cm, 15-30 cm, 30-45 cm and 45-60 cm). The sample were dried in an oven to determine the dry weight fraction. Then bulk density was calculated as the ratio of dry weight of the soil to known cylindrical core sampler volume (Hillel, 2004).

$$BD = Ms/Vt \tag{3.14}$$

where BD = bulk density (g/cm$^3$), Ms = dry weight of the soil (g) and Vt = total volume of the soil (cm$^3$)

#### 3.5.3.2. Field capacity and permanent wilting point

The soil moisture content at field capacity (FC) and permanent wilting point (PWP) were determined after soil samples were saturated for one day (24hrs) using the pressure plate apparatus. Field capacity was determined by exerting a pressure of 0.33 bars and permanent wilting point was determined by exerting a pressure of 15 bars until no change in moisture was observed. The FC and permanent wilting point PWP values were further used to determine total available water (TAW).

$$TAW = 10(\theta_{FC} - \theta_{PWP}) \tag{3.15}$$

where TAW = total available water in the root zone (mm/m), FC = moisture content (vol.%) at field capacity and PWP = moisture content (vol.%) at permanent wilting point.

#### 3.5.3.3. Soil texture

Soil texture was determined by hydrometer method and the soil textural class was determined using the textural triangle of USDA system as described by (Sahlemedin and Tesfaye, 2000).

#### 3.5.3.4. Organic matter and pH measurements

Titration method, which is oxidation under standardized condition with potassium dichromate in sulpheric acid, was followed for organic carbon determination. Finally, conversation of organic carbon to organic matter is therefore obtained by multiplying percentage organic carbon by 1.724 described as by Walkley and Black (1974). The degree of acidity or basicity or alkalinity is expressed by pH. Hence, the pH of the soil was measured by means of pH meter in the supernatant suspension of 1:2.5, soil: liquid mixture as described by (Jackson, 1958).

### 3.5.3.5. Soil moisture depelation and infiltraton capacity

Soil samples were also collected from each experimental plots for determining moisture depletion by using gravimetric method. The gravimetric soil moisture was determined using the expression:

$$SMC\ (\%) = \frac{(Wws - Wds)}{Wds} * 100 \tag{3.16}$$

where SMC is the soil moisture content at time of sampling (%), Wws is weight of wet soil (gm) and Wds is weight of dry soil (gm).

The soil moisture depletion at any time was computed from the expression:

$$SMD = (FC - SMC) * BD * Drz \tag{3.17}$$

where SMD is the soil moisture depleted in mm, FC = field capacity (%), SMC is the soil moisture content(%) BD = bulk density (g/cm$^3$) and Drz = root depth (m).

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

$$\theta_v = \frac{\rho_b}{\rho_w} \times \theta_m \tag{3.18}$$

Where: $\theta_v$ is volumetric moisture content in (%); $\rho_b$ is soil bulk density (g cm$^{-3}$), and $\rho_w$ is water density g cm$^{-3}$.

The soil infiltration capacity was made using the double ring infiltrometer. Infiltration measurement was made at four random spots and the average value was made to represent the infiltration rate of the experimental site before land preparation for the experiment Infiltration characteristics of the soil was determined by ponding water in the metallic double cylinders installed in the field and observing the rate at which the water level in the cylinder was lowering. Stopwatch was used to record time and all measurements replicated three times to come on conclusion.

## 3.6. Distribution Uniformity

### 3.6.1. Distribution uniformity of furrow irrigation

To fully express the efficiency of an irrigation system, the uniformity of water applied needs to be evaluated. Distribution uniformity (DU) is a term that describes how uniformly water is applied in the field. It is the ratio of the average depth infiltrated in the low one-quarter of the field divided by the average depth infiltrated over the entire field. It is expressed as:

$$DU = \frac{D_{lq}}{D_{av}} \times 100 \tag{3.19}$$

Where, DU = distribution uniformity (%),

Dlq= average depth of water infiltrated in the low one-quarter of the field (mm)

Dav = average depth of water infiltrated over the field (mm)

### 3.6.2. Distribution uniformity of drip emitters

The uniformity of water application will be calculated in terms of coefficient of variation (CV), emitter flow variation ($q_{var}$), distribution uniformity (DU), and uniformity coefficients (UC) . The coefficient of variation and emitter flow variation was calculated using equation (3.19) and (3.20) respectively, following the procedure recommended by Wu (1983).

**Coefficient of variation (CV) expressed as:**

$$CV = S/q_a \quad (3.20)$$

where: $S$ = standard deviation of emitter flow rates (l/h) and $q_a$ = average emitter flow rate (l/h).

**Emitter flow variation ($q_{var}$) expresses as:**

$$q_{var} = q_v = (q_{max} - q_{min})/q_{max} \quad (3.21)$$

where: $q_{max}$ = maximum emitter flow rate (l/h) and

qmin = minimum emitter flow rate (l/h).

The uniformity coefficients (UC) which is often described in terms of the coefficient of variation defined as the ratio of the standard deviation to the mean was calculated using equation (3.21) expressed as:

$$CU = (1-s/qa) \times 100 \quad (3.22)$$

where: $S$ = deviation of emitter flow rates (l/h) and

$qa$ = average emitter flow rate (l/h).

Distribution uniformity will be calculated using equation (3.22) Kruse,1978) as follows;

$$DU = (q_{1q}/ qa) \times 100 \quad (3.23)$$

where: $qa$ = average emitter flow rate (l/h); and

q = The average lowest quarter emitter flow rate (l/h).

## 3.7. Wetting Pattern of Drip System

Wetting diameter was measured at 0-15, 15-30, 30-45 and 45-60 cm soil depth by excavating and exposing a vertical plane passing through plan of application after full irrigation. The average wetted is used to determine the wetted area.

## 3.8. Water Use Efficiency

The water use efficiency associated with the different irrigation treatments was calculated by dividing harvested yield in kg per unit of water in mm.

### 3.8.1. Crop Water Use Efficiency

The crop water use efficiency was determined using the expression:

$$\mathrm{CWUE} = \frac{\mathrm{Y}}{\mathrm{ET_c}} \tag{3.24}$$

Where: CWUE = crop water use efficiency (kg $ha^{-1}mm^{-1}$)

Y = yield ($kgha^{-1}$) and

$ET_C$ = crop evapotranspiration (mm)

### 3.8.2. Irrigation Water Use Efficiency

The field water use efficiency was calculated from the expression:

$$\mathrm{IWUE} = \frac{\mathrm{Y}}{\mathrm{I_g}} \tag{3.25}$$

Where: IWUE = Irrigation water use efficiency (kg $ha^{-1}mm^{-1}$)

Y= yield ($kgha^{-1}$)

$I_g$= gross irrigation (mm)

### 3.9. Economic Analysis

Benefit-cost analysis was carried out to determine the economic feasibility of drip and furrow irrigation.The useful life of drip system was considered to be 5 years (Tiwari *et al.,* 2003) and the discount factor is chosen as 15%. The cost of onion production includes expenses incurred in field preparation, cost of seeds, sowing, fertilizer, weeding, crop protection measures, irrigation water, and cost of drip set and harvesting. The income from produce was estimated using prevailing average market prices at the time the crop was harvested (11 Birr/kg). The pricing level practiced in Awash River Basin (0.00015 US$/m$^3$) which is low compared to in other countries (Mekonen *et al.*, 2015). Therefore field price of water 1 Birr/238 m$^3$ was considered. All costs and benefits were calculated on hectare basis in Ethiopian Birr (Birr/ha). The total cost of production, benefit-cost ratio, irrigable land by using saved water, net return from saved water and net return from cultivation of onion over 1 ha were then estimated.

### 3.10. DataAnalysis

The effect of furrow and drip irrigation under different irrigation levels and mulching practices on the growth and yield of Onion were analyzed by using SAS statistical software and if there is a significant difference among the treatments mean separation was made using Least Significant Difference (LSD) or Duncan's Multiple Range Test (DMRT) method. To quantify the relation among irrigation levels, crop water use efficiency, Irrigation water use efficiency, and yield and yield components, correlation and regression analyses was carried out.

# 4. RESULTS AND DISCUSSION

## 4.1. Soil Properties

Some of the physical and chemical properties of the soil at the experimental site ( texture, bulk density, field capacity and permanent wilting point, organic matter content and pH), were analyzed and the summarized results are presented and discussed as follows.

### 4.1.1. Soil physical properties

The results of the particle size distribution is given in Table 3. The result of the soil analysis from the experimental site showed that the composition of sand, silt and clay percentages were in the range of 36.0 – 28.5%,45.0 – 35.0% and 29.0 – 24.0%, respectively. Thus, according to the USDA soil textural classification, the percent particle size distribution for experimental site was classified as loam.

Table 3. Summarized soil particle size distribution

| Soil depth (cm) | Sand | Silt | Clay | Textural classes |
|---|---|---|---|---|
| 0-15 | 28.50 | 45.00 | 26.50 | Loam |
| 15-30 | 33.50 | 42.50 | 24.00 | Loam |
| 30-45 | 36.00 | 35.00 | 29.00 | Clay loam |
| 30-60 | 36.00 | 37.50 | 26.50 | Loam |
| Mean | 33.50 | 39.80 | 26.50 | Loam |

### 4.1.2. Bulk density, field capacity and permanent wilting point

The bulk density of the soil of the experimental site showed a variation with depth (Table 4). It varied between 1.057 and 1.247 ($gm/cm^3$). The top soil surface has slightly lower bulk density than the subsurface and this may be due to compaction of soil in greater depth of soil layer. In general, the weighted average bulk density of the soil was found to be 1.162($gm/cm^3$).

The observed average soil moisture content at FC was varied within a narrow range of 33.8 – 39.3% on volume basis. The top 0-15 cm light soil surface was having lower field capacity (FC) while 15-30, 30-45, and 45-60 cm soil layers were having larger FC values on volume basis. The observed soil moisture content at PWP was also showed a variation with depth in a narrow range of 20.8 – 23.5% on volume basis.

The total available water (TAW) that is the amount of water that a crop can extract from its root zone was directly related to variation in FC and PWP. As a result, high value of TAW was found in the soil depth of 30-45 cm; whereas the lower values were observed at 0-15 cm soil depth.

Table 4.Soil moisture constants and bulk density of experimental site

| Sampling depth (cm) | Bulk density (gmcm3 | FC % | PWP % | TAW |
|---|---|---|---|---|
| | | w/w | w/w | mm/m |
| 0-15 | 1.057 | 33.8 | 18.8 | 170.1 |
| 15-30 | 1.152 | 36.5 | 21.1 | 170.7 |
| 30-45 | 1.191 | 39.3 | 23.5 | 180.8 |
| 45-60 | 1.247 | 37.7 | 22.9 | 180.4 |
| Mean | 1.166 | 36.82 | 21.58 | 175.5 |

## 4.2. Soil chemical properties

As indicated in Table 5. the pH of the experimental area varies from 6.74 for the depth 0 -15 cm to 7.2 for the depth 45-60 cm indicating that soil is slightly alkaline and hence, suitable for crops. The soil has an electrical conductivity of 0.2 to 0.30 dS/m through the 60cm soil profile. The saturated extract electrical conductivity of the soil was varied from 0.30 to 0.2 dS/m for soil depths considered (Table 5). This indicates that the soil is none saline and suitable for crop production (FAO 1985). The organic matter content of the soil varied from as low as 3.4 % to as high as 7.4%. The average organic matter content of the soil was about 7.0%. The OM content of this experimental field had highest 7.4% in the surface soil (0-15 cm depth) where as lowest 3.4% OM found in the bottom 45- 60 cm soil depth. The average value of organic matter content was found to be 7.0% indicating that all the values of OM were with range of 3.36–7.40% and could be rated as moderate, that the field had an average structural condition with average structural stability.

Table 5. Selected soil chemical properties of the surface of the experimental field.

| soil chemical properties | soil depth (cm) | | | |
|---|---|---|---|---|
| | 0-15 | 15-30 | 30-45 | 45-60 |
| pH | 6.74 | 7.07 | 7.08 | 7.18 |
| Organic Matter content (%) | 7.40 | 6.72 | 5.24 | 3.36 |
| Available Nitrogen (%) | 0.37 | 0.34 | 0.26 | 0.17 |
| Organic carbon conent (%) | 4.29 | 3.90 | 3.04 | 1.95 |
| Electrical conductivty (ds/m) | 0.21 | 0.23 | 0.30 | 0.31 |

### 4.3. Soil infiltration rate

The generated information on soil infiltration rate and cumulative infiltration from the field test data were presented in figure 3. The basic infiltration rate was about 16 mm/hr, this means that a water layer of 16 mm on the soil surface will take one hour to infiltrate (Appendix table 8). At the beginning, water infiltrated rapidly. As more water replaces the air in the pores, the water infiltrates more slowly and eventually reaches a steady rate which is called the basic infiltration rate. This rate of infiltration is in the range of infiltration characteristics of loam soils(Brouwer and Heibloem, 1990; Andreas and Karen, 2002).

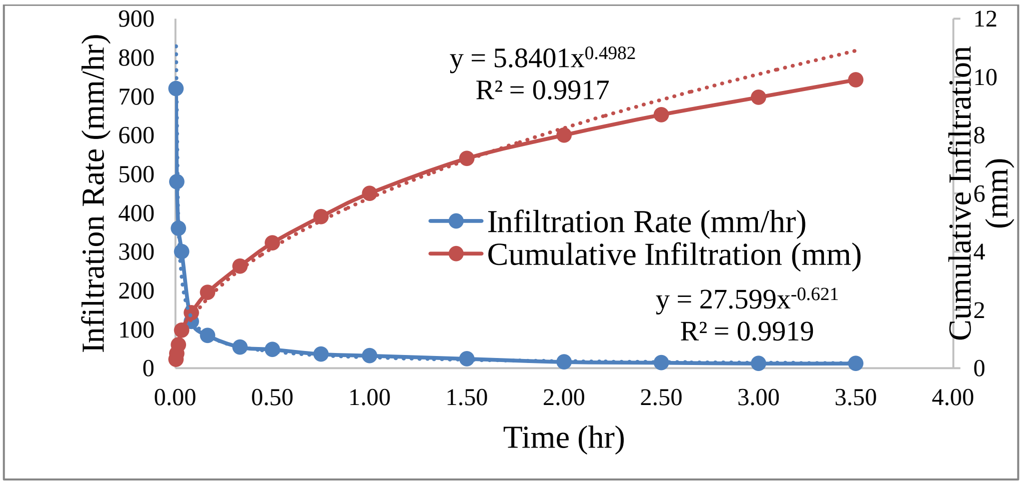

Figure 3. Infiltration rate of the soil

### 4.4. Distribution Uniformity of Furrow irrigation

Distribution uniformity calculated for furrow irrigation were 87%, 82.6% and 78.8% at 100 % MAD, 75% MAD and 125% MAD irrigation levels respectively (Appendix Table 23). This result seems closely related to that of Ismail *et al.* (2004) who observed that distribution uniformity of surface irrigation greater than 80% are homogenous, greater than 70% slightly homogenous and less than 70% non homogenous. FAO (1992) also suggested that the average distribution efficiency DU of 65% as sufficient and DU of 30% as poor.

### 4.5. Distribution Uniformity of Drip Emitters

The measured values of emitter discharge uniformity parameters were presented in table 6 . Analysis of data on emitter discharge observation under all parameters has shown better performance.The values of distribution uniformities (Du) and uniformity coefficient (Cu) were 96.23% and 97.84%, respectively. The field distribution uniformity was excellent, emitter coefficient of variation was good and according to Bralts (1986) emitter flow variation was acceptable.

Table 6. Uniformity of drip irrigation

| Parameters | Units | Average |
|---|---|---|
| Distribution uniformities (Du) | % | 96.23 |
| Emitter flow variation ($q_V$ ) | % | 6.77 |
| Coefficient of variation (Cv) | % | 2.10 |
| Uniformity coefficient (Cu) | % | 97.84 |

## 4.6. Wetting Pattern of Drip System

The result on wetting diameter for the drip system measured at 0, 20,40 and 60 cm depths is shown in figure 4. The wetted diameter was found to be widest at the surface and got narrower and narrower as the depth increased and with axially symmetrical pattern in a vertical direction (Appendix table 10).At the surface the total wetted area of the plot was 9.10 m$^2$ which is around 60% of the total area of a plot. This is in agreement to the findings of Segal *et al.* (2000) who stated that only a fraction of the soil surface generally between 15 to 60 percent is wetted in drip irrigation system. Naglič (2014) reported that the wetted radius of wetting pattern for a given volume of water applied was larger for fine-textured soils, such as silt loam, silty clay, clay loam, sandy silt loam and clay and smaller for coarse-textured ones, such as sand, loamy sand, sandy clay loam and sandy loam. The wetted depth tends to be larger for coarse-textured soils, as sand, loamy sand and sandy clay. At the stage of surface drip irrigation system installation, the placement of the emitters above the soil surface causes water infiltration within a very small area compared to the total soil surface area. According to Gardenas *et al.* (2005) and Skaggs *et al.* (2010), the shape of the wetted soil volume under single drip emitter is influenced by soil hydraulic properties, soil texture, soil structure, impermeable layers in the soil profile and anisotropy such as horizontal and vertical permeability.

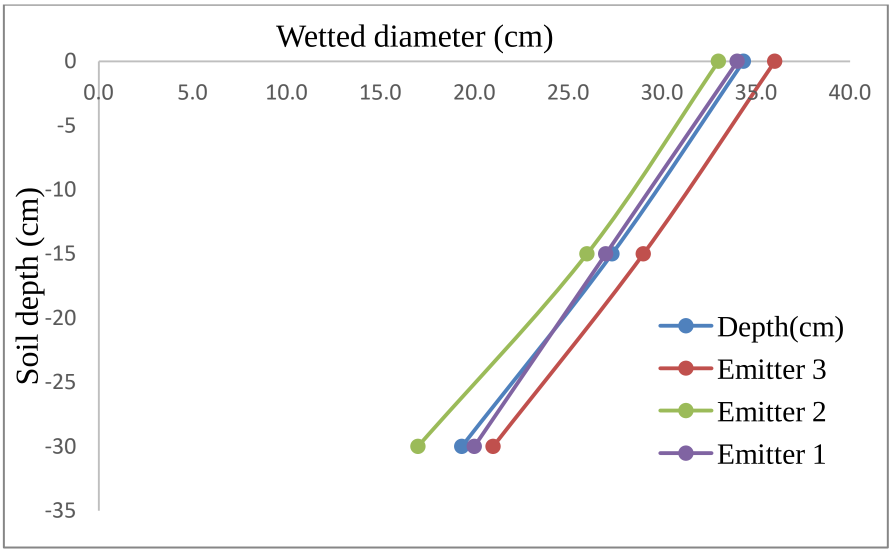

Figure 4. wetted diameter of drip irrigation

## 4.7. Irrigation Water Application in the Experimental Area.

Seasonal crop water requirement of onion determined based on the seasonal water application depth from transplanting to harvest and vary based on the irrigation level of treatments. Common irrigation depth of 26.5 mm was applied for all treatments from transplanting for well establishment of the onion before treatment start. During the experiment there were rainfall and the total rainfall recorded was 21.5 mm then effective precipitation was calculated. The highest effective rainfall recorded on February 27, 2018, and rainfall records on Nov. 11, 2017, Jan 9, 2018 and Feb. 19, 2018 were not effective. The total result of calculated effective rainfall was 12.25 mm that reduced from net irrigation depth during the next irrigation treatment application (Appendix Table 7).

The total net of irrigation water determined in mm for no mulch treatment (from 75%MAD to 125%MAD) were 595.5, 581.6 and 569.5 through both irrigation methods at the entire growing of the crop as it was determined from multiplication of total available water (TAW) and depletion fraction (75%MAD,100%MAD and 125%MAD). The total gross of irrigation water applied in mm for no mulch treatment (from 75%MAD to 125%MAD) were 992.4, 969.4 and 949.1 through furrow irrigation method and 661.7, 646.3 and 632.8 mm of total gross irrigation applied to each treatment (from 75%MAD to 125%MAD) through drip irrigation method. In otherways the total net of irrigation water determined in mm for mulch treatment (from 75%MAD to 125%MAD) were 476.4, 465.3 and 455.6 through both irrigation methods at the entire growing of the crop as it was determined from multiplication of total available water (TAW) and depletion fraction (75%MAD, 100%MAD and 125%MAD). The total gross of irrigation water applied in mm for mulch treatment (from 75%MAD to 125%MAD) were 794.0, 777.5 and 759.3 through furrow irrigation method and 529.3, 517.0 and 506.2 mm , total gross of irrigation water applied to each treatment (from 75%MAD to 125%MAD) through drip irrigation method. The total gross depths of irrigation water applied in mm through both irrigation methods were varied (Table 7) . The variation of application depth occurred between these irrigation methods were due to high and low application efficiency of drip (90%) and furrow irrigation (60%), respectively. Only a fraction of the soil surface between 15 to 60 percent is wetted in drip irrigation system (Segal *et al.*, 2000). The total net and gross depths of irrigation water applied in mm for mulch and no mulch treatments were varied (Table 7) . The variation of application depth occurred between these treatments were due to the effectiveness of plastic mulches to conserve moisture.

Table 7.Seasonal Crop and irrigation water requirement of onion crop

| Treatments | IRn (mm) | $P_{ef}$ (mm) | CWR (mm) | IRg (mm) | CWUE (kg/ha.mm) | IWUE (kg/ha.mm) |
|---|---|---|---|---|---|---|
| T1 | 476.4 | 12.25 | 488.65 | 529.3 | 0.86 | 0.77 |
| T2 | 595.5 | 12.25 | 607.75 | 661.7 | 0.62 | 0.56 |
| T3 | 465.3 | 12.25 | 477.55 | 517.0 | 0.80 | 0.72 |
| T4 | 581.6 | 12.25 | 593.85 | 646.3 | 0.58 | 0.53 |
| T5 | 455.6 | 12.25 | 467.85 | 506.2 | 0.75 | 0.67 |
| T6 | 569.5 | 12.25 | 581.75 | 661.7 | 0.56 | 0.48 |
| T7 | 476.4 | 12.25 | 488.65 | 794.0 | 0.64 | 0.39 |
| T8 | 595.5 | 12.25 | 607.75 | 992.2 | 0.50 | 0.30 |
| T9 | 465.3 | 12.25 | 477.55 | 777.5 | 0.64 | 0.39 |
| T10 | 581.6 | 12.25 | 593.85 | 969.4 | 0.49 | 0.30 |
| T11 | 455.5 | 12.25 | 467.75 | 759.3 | 0.59 | 0.35 |
| T12 | 569.5 | 12.25 | 581.75 | 949.1 | 0.46 | 0.27 |

IRn = net irrigation requirement, IRg = gross irrigation requirement, CWR = crop water requirement ,CWUE Crop water use efficiency,IWUE Irrigation water use efficiency and $P_{ef}$ = effective rainfall .

## 4.8. Effects of Irrigation Methods and MAD Levels on Crop Physiology

The response of onion physiology like number of leaves per plant, plant height and leaf height to irrigation methods and MAD level with and whith out mulch is presented in table 8.

Table 8 .Effect of irrigation methods and water application under mulching on crop physiology

| Treatment | Plant height (cm) | Leave height(cm) | Leave number |
|---|---|---|---|
| DI | 67.4a | 54.9 $^{a}$ | 13.2 $^{a}$ |
| FI | 58.6 $^{b}$ | 47.7 $^{b}$ | 11.6 $^{b}$ |
| LSD (0.05) | 1.3 | 1.1 | 0.9 |
| CV (%) | 4.3 | 4.3 | 4.3 |
| 75% MADPM | 66.0 $^{a}$ | 53.8 $^{a}$ | 13.0 $^{a}$ |
| 75% MADNM | 64.8$^{a\ b}$ | 52.8$^{ab}$ | 12.8 $^{ab}$ |
| 100% MADPM | 64.7 $^{ab}$ | 52.7 $^{ab}$ | 12.5 $^{abc}$ |
| 100% MADNM | 62.2 $^{abc}$ | 50.7 $^{abc}$ | 12.3 $^{bc}$ |
| 125% MADPM | 61.2 $^{bc}$ | 49.8 $^{bc}$ | 12 $^{c}$ |
| 125% MADNM | 58.9 $^{c}$ | 48.0 $^{c}$ | 12 $^{c}$ |
| LSD (0.05) | 3.9 | 3.3 | 0.6 |
| Cv (%) | 6.1 | 4.1 | 3.1 |

### 4.8.1. Number of green leaves per plant

The analysis of variance (Appendix Table 11) for green leaves per plant revealed that there was significant effect at ($p < 0.05$) due to irrigation methods. The mean values of leaves per plant were 11.6 and 13.2cm for irrigation methods of furrow and drip irrigation respectively (Table 8). The mean value of drip irrigation method was higher than that of furrow irrigation method and the means were highly significantly ($p<0.01$) difference.

The effects of MAD level under mulching on green leaves per plant were significant at ($p <0.05$). Table 9, shows that, as the application of irrigation level increased from 75%MAD under plastic mulch and no mulch to125% MAD under plastic mulch and no mulch, a significant decreasing green leaves per plant was observed. The maximum green leaves per plant was recorded from treatment received 75%MAD with plastic mulch (13.0 ) followed by 75% MAD under nomulch (12.8) . Based on the results, the drip irrigation method resulted in increased leaf number by 12.8% as compared to furrow irrigation method. Channagoudar and Janawade (2010) and Bagali *et al.* (2012) reported that scheduling of drip irrigation significantly increased the growth parameters.

### 4.8.2. Plant height

The analysis of variance (Appendix table 12)has indicated that there was significant ($p<0.05$) effect on plant height due to irrigation application methods. The mean value of plant height recorded from drip irrigation method was higher and significantly ($p<0.05$)different from furrow irrigation. These findings agree with those of Bhonde *et al*. (2003); Bhasker *et al.* (2018) who reported that maximum plant height was recorded under drip irrigation method.

As shown in table 9,the highest plant height (66.0 cm) was obtained from 75%MAD level under pilastic mulch and was not significantly different from 100% MAD level under pilastic mulch, while the shortest mean plant height (58.9 cm) was observed on the application of 125% MAD level under no mulch and statistically different with 100% MAD level with and without mulch. The result obtained agrees with observations in other irrigation studies on onion by different researchers. The increasing of plant height with adequate soil moisture application is related to water in maintaining the turgid pressure of the plant cells which is the main reason for the plant growth (Doorenbos and Pruitt, 1992). This study outcome is in line with the research that was done by El-Noemani *et al*. (2009), indicated that soil water supply is directly proportional with plant height growth.The findings of many researchers suggest that the fairly shorter interval of irrigation replenishes soil moisture on 15-20 percent depletion, depending upon the type of soil, climate and season of cultivation. The reason for the better performance of this growth parameter due to the shorter interval of irrigation may be attributed to optimum soil- water-air balance around plant root zone. These results were in line with the results of Abbey and Joyce (2004) and Kadam *et al.* (2006).However, the analysis of variance (Appendix table 12) showed that the interaction of irrigation methods and MAD levels had significant effect on plant height.

The effects of irrigation level under mulching on plant height were highly significant at ($p <0.05$). Table 9, shows that, as the application of irrigation level increased from 75% MAD under no mulch and plastic mulch to125% MAD , a significant decreasing plant height was observed. The maximum plant height was recorded from treatment received 75% MAD with plastic mulch (73.1 cm) followed by 75%MAD no mulch (69.5 cm) while, the shortest mean plant height was observed on the application of 125% MAD under no mulch (58.9cm). Paul *etal.* (2013) found that the height of plant under treatment 100% irrigation requirement(78.6 cm) was found to be significantly highest among all other treatments and was 55 % higher than the height of plant under surface irrigation without mulch. However the analysis of variance (Appendix Table 12) showed that, the interaction of irrigation methods and irrigation level under mulching had no significant effect on plant height.

### 3.8.3 Leaf height

Analysis of variance in Appendix table 13 indicated that irrigation application methods and MAD level had asignificant($P<0.05$) effect on onion leaf height. The taller mean leaf height (54.9 cm) was recorded from drip irrigation method which was significantly different from that of furrow irrigation (Table 8). The tallest mean  leaf height of 53.8 cm was observed for 75% MAD level with mulch which was not significantly different from the 100% MAD irrigation level. The least mean leaf height (48.0 cm) was recorded from 125% MAD level whithout mulch and had significant difference from100% MAD irrigation level. Generally, increasing trend in leaf height was observed with a decreasing MAD level indicating direct relationship between vegetative growth and irrigation frequency. This might be because plants did not suffer from water deficit in short irrigation intervals. Reducing the time interval between successive irrigations in order to maintain constant, optimal water content in the root zone may reduce the variations in nutrient concentration, thereby increasing their availability to plants (Silber *et al*., 2003). According to Radin *et al*. (1989), frequent irrigations prevent the large fluctuation in plant water stress caused by infrequent irrigations. The interaction effect of irrigation methods and MAD levels had no significant impact on leaf height (Appendix table 13).

## 4.9. Effects of Irrigation Methods and MAD Levels on Crop Yield and yield components

Table 9. Effects of irrigation method and Mad levels under mulching on crop yield and yield components

| Treatment | Marketable bulb yield(ton) | Total Bulb yield(ton) | Bulb diameter(cm) | Bulb height(cm) |
|---|---|---|---|---|
| DI | $32.9^{a}$ | $36.9^{a}$ | $5.6^{a}$ | $5.8^{a}$ |
| FI | $25.8^{b}$ | $30.1^{b}$ | $4.9^{b}$ | $4.9^{b}$ |
| LSD (0.05) | 9.3 | 4.3 | 0.4 | 0.9 |
| CV (%) | 4.3 | 8.6 | 4.3 | 4.3 |
| SEm (±) | 1.5 | 1.4 | 0.1 | 0.1 |
| 75% MADPM | $33.1^{a}$ | $37.1^{a}$ | $5.6^{a}$ | $5.8^{a}$ |
| 75% MADNM | $29.7^{b}$ | $34.6^{b}$ | $5.3^{c}$ | $5.6^{ab}$ |
| 100% MADPM | $29.9^{b}$ | $35.2^{b}$ | $5.4^{b}$ | $5.5^{ab}$ |
| 100% MADNM | $28.3^{bc}$ | $32.9^{c}$ | $5.2^{c}$ | $5.3^{bc}$ |
| 125% MADPM | $28.6^{bc}$ | $30.7^{d}$ | $5.1^{c}$ | $5.1^{cd}$ |
| 125% MADNM | $26.7^{c}$ | $30.5^{d}$ | $5.0^{d}$ | $4.8^{d}$ |
| LSD (0.05) | 25.7 | 10.5 | 0.1 | 0.3 |
| Cv (%) | 8.08 | 4.1 | 2.1 | 5.1 |
| SEm (±) | 1.2 | 5.0 | 0.03 | 0.1 |

### 4.9.1. Total bulb yield

The yield of onion crop was significantly ($p < 0.01$) affected by irrigation methods (Appendix Table 14). Table 10, indicates that the furrow irrigation method was resulted in low total yield of (30.1 ton/ha) as compared to that obtained under drip irrigation (36.9 ton/ha) method. This might be due to water stress during the critical growth period, coupled with aeration problem in first few days immediately after irrigation. Another reason to get low yield by furrow irrigation might be due to less availability of nutrients for crop growth due to leaching with high weed infestation between the crops Pattanaik*et al*.(2003). This result is supported by the findings of Tiwari *et al*. (1998a); Tiwari *et al*. (1998b) and Singh (2007). In drip irrigation system, water is applied at a low rate for a longer period at frequent intervals near the plant root zone through lower pressure delivery system, which increases the availability of nutrients near the root zone with a reduction in leaching losses. Based on the results, drip irrigation method was resulted inincreased yield by 22.4% as compared to furrow irrigation method.There was also significant difference observed between mean at ($p < 0.05$). These results are in agreement with those Yohannes and Tadesse (1998) reported that a higher yield of tomato was obtained with drip irrigation as compared to furrow irrigation. Raina et al.,(1998) reported that drip irrigation gave 49.5% higher yield than the surface irrigation of pea crop. Mustafa(1999) found that the highest yield was obtained by drip irrigation as compared to furrow irrigation under the same condition for two varieties of okra. On the other hand, Mateo et al., (1992) obtained 5 and 3t/ha of cotton yield for the drip and furrow irrigation methods, respectively. In addition, total yield of the crop was also highly significantly affected ($p < 0.01$) due to different level of water application under mulching. Table 9 revealed that, the application of 75% MAD under plastic mulch and 125% MAD under plastic mulch showed a significant decreasing total yield of the crop as compared to 100% MAD under plastic mulch respectively. However, total yield were decreasing within the same water application level under mulch respectively. The maximum total yield was obtained from treatment received 75% MAD under plastic mulch (37.1 ton/ha) followed by 100% MAD underplastic mulch (35.2 ton/ha) while, the lowest mean total yield was observed on the application of 125%MAD under no mulch (30.5ton/ha).

There were no significant difference between $T_2$ and $T_3$ and $T_5$ and $T_6$ (Table 10). The result of this study indicates that, increasing in the irrigation water application level in the order of plasic mulching and no mulch resulted a corresponding decreasing of mean yield values. Since increased yield is directly related with the plant availability of moisture in the root zone, it can be inferred that higher yield of onion recorded from plastic mulch treatments of the same level of water application implies the effectiveness of plastic mulches to conserve moisture. This supports the similar findings by Comlekcioglu*et al.* (2008).

The combined effect of irrigation methods and irrigation levels under mulching on crop yield was analysed and the results obtained are presented in (Appendix Table 14 and Table 10). The interactive effects between irrigation methods and irrigation level under no mulch and plastic mulching was highly significant at ($p < 0.01$). The mean maximum value of crop yield (42.1 ton/ha) was observed with treatment combination $T_1$ followed by (39 ton/ha) in case of $T_3$ and the minimum value of crop yield (27.6 ton/ha) was observed in $T_{12}$ treatment combination.

In addition to this, the mean yield of onion was increased with in both drip and furrow irrigation methods under irrigation level with mulch as compared to drip and furrow irrigation methods under irrigation level without mulch. Drip irrigation with plastic mulch treatments ( $T_1$, $T_3$, and $T_5$ ) increased in yield by 3.32ton/ha, 3.68ton/ha and 0.34ton/ha respectively as compared to drip irrigation without mulch treatments ( $T_2$, $T_4$, and $T_6$ ) .But, furrow irrigation with mulch treatments ( $T_7$, $T_9$, and $T_{11}$ ) increased in yield by 0.61ton/ha, 0.68 ton/ha and 0.19ton/ha respectively as compared to furrow irrigation without mulch treatments ( $T_8$, $T_{10}$, and $T_{12}$ ) . The result indicates that, when the application of irrigation water increases from 75 % MAD to 125% MAD under plastic mulch and no mulch respectively, the crop yield were decreased via irrigation methods.

### 4.9.2 .Marketable bulb yield

The statistical analysis indicated that irrigation methods, MAD levels and their interaction had a highly significant ($P<0.01$) effect on marketable onion bulb yield (Appendix table 15). As indicated in table 10 ,furrow irrigation method has resulted in a low marketable bulb yield of (25.8 ton/ha) as compared to that obtained under drip irrigation method (32.8 ton/ha). Based on the results, the drip irrigation method was resulted in increased marketable bulb yield by 21.2% as compared to furrow irrigation method.The low marketable bulb yield from furrow irrigation might be due to less availability of nutrients for crop growth due to leaching (Pattanaik *et al.,*2003). In drip irrigation system, water is applied at a low rate for a longer period at frequent intervals near the plant root zone through lower pressure delivery system, which increases the availability of nutrients near the root zone with a reduction in leaching losses. Drip irrigation ensures optimum growth, better bulbing and early maturity of crops by assuring optimum soil moisture, water, air and nutrients throughout the crop growing period resulting uniform bulb obtained and correlated to the highest bulb size and productivity, whereas in surface irrigation yield decreased due to deep percolation and water is lost beyond the active absorption zone of the root system as an onion is shallow rooted crop. These results agree with the results of Hanson and May (2003), Tripathi *et al*. (2010) and Bhasker *et al. (*2018).

The highest marketable bulb yield (33.1 ton/ha) was obtained under 75% MAD level under mulch and the smallest marketable bulb yield (26.7 ton/ha) was observed under 125% MAD level under no mulch.

This reveals that there was a decreasing trend in bulb yield for an increase in MAD level,indicating that increasing the irrigation application interval resulted in a corresponding decreasing of mean yield values. Increased bulb yield of onion by ashorter interval of irrigation may be due to the better performance of growth parameters like plant height and number of leaves. The shorter interval of irrigation ensures the optimum growth of the crop by assuring balanced water and nutrient supply throughout the crop growth period. The current result agreed with study result of Quadir *et al.* (2005) and Bagali *et al.* (2012).

As shown in table 10, the highest marketable bulb yield of 33.1 ton/ha was obtained from drip irrigation at 75% MAD with plastic mulch application and significantly different to all other treatments. The lowest yield of 26.7 ton/ha was obtained from furrow irrigation at 125% MAD with out plastic mulch application and had significantly different to all other treatments. The current result was in confirmation with study result of Bagali *et al.* (2012) who reported that scheduling of drip irrigation at shorter intervals significantly increased the growth parameters and significantly higher bulb yield as compared to flood irrigation. This was because of the balanced availability of moisture, air,and nutrients throughout the crop growth period. The crop like onion performs better when irrigation is given on depletion of 15-20 percent soil moisture of the field capacity. Drip irrigation system maintains soil physical conditions in congenial form for plants growth by maintaining optimum soil-water-balance around plant bases. This is the reason for higher yield by the treatments with drip irrigation method at shorter intervals of irrigations.

In addition, marketable yield of the crop was also highly significantly affected ($p < 0.01$) due to different level of water application under mulching. Table 11 revealed that, the application of 75% MAD under plastic mulch to 125 MAD under plastic mulch showed a significant decreasing marketable yield of the crop respectively. Therefor, marketable yield were decreasing within the same water application level under mulch as irrigation levels increase. The maximum marketable yield was obtained from treatment received 75% MAD under plastic mulch (33.1 ton/ha) followed by 100% MAD under plastic mulch (29.9 ton/ha) while, the lowest mean marketable yield was observed on the application of 125%MAD under no mulch (26.7 ton/ha).

There were no significant difference between $T_2$, $T_3$, $T_4$ and $T_5$ , $T_4$, $T_5$ and$T_6$ , $T_6$ and $T_7$, $T_7$, $8_4$ ,$T_9$ and $T_{10}$, $T_9$, $T_{10}$, and $T_{11}$ and T10,$T_{11}$and $T_{12}$ (Table 11). The result of this study indicates that, increasing in the irrigation water application level in the order of plastic mulching and no mulch resulted a corresponding decreasing of mean yield values. Since increased yield is directly related with the plant availability of moisture in the root zone, it can be inferred that higher yield of onion recorded from plastic mulch treatments of the same level of water application implies the effectiveness of plastic mulches to conserve moisture. This supports the similar findings by Comlekcioglu*et al.* (2008).

The mean maximum value of crop yield (38.35 ton/ha) was observed with treatment combination $T_1$ followed by (32.67 ton/ha) in case of $T_3$ and the minimum value of crop yield (23.49 ton/ha) was observed in $T_{12}$ treatment combination.

In addition to this, the mean Marketable yield of onion was increased with in both drip and furrow irrigation methods under irrigation level with mulch as compared to drip and furrow irrigation methods under irrigation level without mulch. Drip irrigation with plastic mulch treatments ( $T_1$ , $T_3$, and $T_5$ ) increased the in yield by 5.86ton/ha, 1.68ton/ha and 3.20ton/ha respectively as compared to drip irrigation without mulch treatments ( $T_2$, $T_4$, and $T_6$ ) . But, furrow irrigation with mulch treatments ( $T_7$ , $T_9$, and $T_{11}$ ) increased in yield by 1.14ton/ha, 1.59ton/ha and 0.44ton/ha respectively as compared to furrow irrigation without mulch treatments ( $T_8$, $T_{10}$, and $T_{12}$ ) . The result indicates that, when the application of irrigation water increases from 75 % MAD to 125% MAD under plastic mulch and no mulch respectively, the crop yield were decreased via irrigation methods.

### 4.9.3. Bulb diameter

The analysis of variance indicated that MAD level had a highly significant ($P<0.01$) effect on bulb diameter. The irrigation method and interaction had a significant ($P<0.05$) effecton bulb diameter (Appendix table 16).As indicated intable 10, the largest bulb diameter (5.6 cm)was obtained from the drip irrigation method which was significantly ($P<0.05$) different from that obtained from furrow irrigation method (4.9 cm).

The largest bulb size (5.6 cm) was obtained from 75% MAD with mulch and was significantly different to all other treatments, while the smallest bulb diameter (5.0 cm) was obtained from

125% MAD. This reveals that there was a decreasing trend in bulb size for an increase in MAD level, indicating that increasing the irrigation application interval was resulted in a corresponding decreasing of mean bulb size. The shorter irrigation interval ensures the optimum growth of the crop by assuring balanced water and nutrient supply throughout the crop growth period. Al-Moshileh (2007), reported that bulb diameter increased with increasing soil moisture level.The study by Ayas and Demirtaș (2009) indicates that bulb diameter has an increasing trend with the level of irrigation application.

As depicted in table 10, the highest bulb diameter of 5.6 cm was obtained from drip irrigation at 75% MAD with mulch application and significantly different from all other treatments.The lowest bulb diameter of 5.0 cm was obtained from furrow irrigation at 125% MAD without mulch application and significantly different from all other treatments.

### 4.9.4. Bulb height

The analysis of variance indicated that MAD level had a highly significant (P<0.01) effect on bulb height. The irrigation method and interaction had a significant (P<0.05) effecton bulb height (Appendix table 17).As indicated intable 10, the largest bulb height (5.8 cm)was obtained from the drip irrigation method which was significantly (P<0.05) different from that obtained from furrow irrigation method (4.9 cm).

The largest bulb height (5.8 cm) was obtained from 75% MAD with mulch and was significantly different to all other treatments, while the smallest bulb height (4.8 cm) was obtained from 125% MAD without mulch. This reveals that there was a decreasing trend in bulb height for an increase in MAD level, indicating that increasing the irrigation application interval was resulted in a corresponding decreasing of mean bulb size. The shorter irrigation interval ensures the optimum growth of the crop by assuring balanced water and nutrient supply throughout the crop growth period. Al-Moshileh (2007), reported that bulb height increased with increasing soil moisture level.

## 4.10. Crop Water Use Efficiency (CWUE)

Analysis of variance on effect of irrigation methods and diffrent irrigation level under mulching and their interaction has shown a significant ($p < 0.01$) influence on CWUE of onion. The analysis of variance (Appendix Table 18) crop water use efficiency indicated that there was significant effect at ($p < 0.01$) due to irrigation methods. The mean values of crop water use efficiency were observed as 0.58 and 0.72kg/m$^3$ for irrigation methods of furrow and drip irrigation methods respectively (Table 11). The mean value of drip irrigation method was higher than that of furrow method and the means were significantly different at ($p<0.05$) (Table 12). The results resembled the findings of Begum et al., (2001).

The analysis of variance also shows (Appendix Table 19) that there was effect due to levels of water application under mulching on IWUE of onion at ($p < 0.05$). Table 10 revealed that, crop water use efficiency was decreased as the application of irrigation level increased from 75% MAD under the mulching order of plastic mulch and no mulch to 125% MAD the mulching order of plastic mulch and no mulch respectively. The maximum crop water use efficiency was recorded from treatment received 75% MAD under plastic mulch (0.88 $kg/m^3$) followed by 100% MAD under plastic mulch (0.80 $kg/m^3$) while, the lowest mean irrigation water use efficiency was observed on the application of 125% MAD under no mulch (0.48 $kg/m^3$). The result of this study indicated that, increasing in the irrigation water application level in the order of plastic mulching and no mulching respectively resulted a corresponding decreasing of mean crop water use efficiency values.

The combined effect of irrigation methods and irrigation level under mulching on crop water use efficiency was analysed and the results obtained are presented in (Appendix Table 18 and Table 12). The interactive effects between irrigation methods and irrigation level under no mulch and plastic mulching was highly significant ($p < 0.01$).The mean maximum value of crop water use efficiency (0.88 $kg/m^3$) was recorded with treatment combination $T_1$ followed by (0.84 $kg/m^3$) in case of $T_3$ and the minimum value of irrigation water use efficiency (0.48 $kg/m^3$) was observed in $T_{12}$ treatment combination. There were no significant difference mean among $T_2$ and $T_4$, $T_7$ and $T_9$ and between $T_8$ and $T_{10}$ at ($p < 0.05$).

## 4.11. Irrigation Water Use Efficiency (IWUE)

Analysis of variance on effect of irrigation methods and diffrent irrigation level under mulching and their interaction has shown a significant ($p < 0.01$) influence on IWUE of onion. The analysis of variance (Appendix Table 19) irrigation water use efficiency indicated that there was significant effect at ($p < 0.01$) due to irrigation methods. The mean values of irrigation water use efficiency were observed as 0.35 and 0.64$kg/m^3$ for irrigation methods of furrow and drip irrigation methods respectively (Table 11). The mean value of drip irrigation method was higher than that of furrow method and the means were significantly different at ($p<0.05$) (Table 12). The results resembled the findings of Begum et al., (2001).

The analysis of variance also shows (Appendix Table 19) that there was effect due to levels of water application under mulching on IWUE of onion at ($p < 0.05$). Table 11 revealed that, irrigation water use efficiency was decreased as the application of irrigation level increased from 75% MAD under the mulching order of plastic mulch and no mulch to 125% MAD the mulching order of plastic mulch and no mulch respectively. The maximum irrigation water use efficiency was recorded from treatment received 75% MAD under plastic mulch (0.80 kg/m$^3$) followed by 100% MAD under plastic mulch (0.75 kg/m$^3$) while, the lowest mean irrigation water use efficiency was observed on the application of 125% MAD under no mulch (0.29 kg/m$^3$). The result of this study indicated that, increasing in the irrigation water application level in the order of plastic mulching and no mulching respectively resulted a corresponding decreasing of mean irrigation water use efficiency values.

The combined effect of irrigation methods and irrigation level under mulching on crop water use efficiency was analysed and the results obtained are presented in (Appendix Table 18 and Table 11). The interactive effects between irrigation methods and irrigation level under no mulch and plastic mulching was highly significant ($p < 0.01$).The mean maximum value of crop water use efficiency (0.80 kg/m$^3$) was recorded with treatment combination $T_1$ followed by (0.75 kg/m$^3$) in case of $T_3$ and the minimum value of irrigation water use efficiency (0.29 kg/m$^3$) was observed in $T_{12}$ treatment combination. There were no significant difference mean among $T_2$ and $T_4$, $T_7$ and T8 and between $T_8$ and $T_{10}$ at ($p < 0.05$).

Table 10. Effects of irrigation methods and Mad levels on crop and irrigation water use efficiency

| Treatment | CWUE | IWUE |
|---|---|---|
| DI | 0.72$^{a}$ | 0.64$^{a}$ |
| FI | 0.58$^{b}$ | 0.35$^{b}$ |
| LSD (0.05) | 2.327 | 4.3 |
| CV (%) | 1.12 | 0.34 |
| SEm (±) | 0.306 | 2 |
| T1 | 0.88$^{a}$ | 0.80$^{a}$ |
| T2 | 0.63$^{e}$ | 0.57$^{d}$ |
| T3 | 0.84$^{b}$ | 0.75$^{b}$ |
| T4 | 0.61$^{ef}$ | 0.55$^{d}$ |
| T5 | 0.73$^{c}$ | 0.66$^{c}$ |
| T6 | 0.59$^{f}$ | 0.51$^{e}$ |
| T7 | 0.67$^{d}$ | 0.41$^{f}$ |
| T8 | 0.53$^{g}$ | 0.32$^{h}$ |
| T9 | 0.67$^{d}$ | 0.40$^{f}$ |
| T10 | 0.53$^{g}$ | 0.32$^{h}$ |
| T11 | 0.61$^{ef}$ | 0.36$^{g}$ |
| T12 | 0.48$^{f}$ | 0.29$^{i}$ |
| LSD (0.05) | 2.572 | 2.08 |
| Cv (%) | 2.55 | 2.51 |
| SEm (±) | 1.27 | 5.2 |

## 4.12. Economic analysis of different irrigation treatments

Table 12 presents the economic analysis of production of onion from 1 ha area. The highest and lowest total cost of 241098 birr and 230239 birr were incurred for treatments T1 and T12, respectively. The economic analysis revealed that the net return was found to be highest (208428 birr) for T1 followed by the T3. The highest benefit-cost ratio of about 0.86 was also obtained from T1 followed by the T3. This shows that T1 was the most economically attractive treatment. This could be because it was frequently irrigated with drip irrigation method which made favorable soil moisture condition for plant growth and thus resulted in optimum bulb yield and benefit-cost ratio. Therefore, where water resource is limiting factor for onion production T1 is highly profitable even though initial investment cost was high. On the other hand, the lowest benefit-cost ratio of 0.25 was obtained from T12 might be attributed to the long irrigation interval with furrow irrigation method without mulch which resulted in low bulb yield.

Though water saving was very high and high marketable bulb yield was recorded with drip irrigation method, benefit-cost ratio obtained from drip treatments was not much greater than those obtained under furrow irrigation treatments. This is because unit price of irrigation water (1 birr/238 m$^3$), was very low. As a result the direct impact of water saving in generation benefit-cost ratio was very low. Therefore, to clearly notice the impact of irrigation water saving due to irrigation treatments (drip) it is apparent to evaluate each tested irrigation protocol in terms of the net return that could be obtained from saved irrigation water.

Table 11. Economic analysis of onion bulb production under different irrigation treatments

| Treatment | UMY (kg/ha) | AMY (kg/ha) | TC (birr/ha) | TR (birr/ha) | NR (birr/ha) | B/C ratio |
|---|---|---|---|---|---|---|
| T1 | 44953 | 40866 | 241098 | 449526 | 208428 | 0.86 |
| T2 | 40656 | 36960 | 239598 | 406560 | 166962 | 0.70 |
| T3 | 41125 | 37386 | 239498 | 411246 | 171748 | 0.72 |
| T4 | 37356 | 33960 | 237998 | 373560 | 135562 | 0.57 |
| T5 | 37481 | 34074 | 238697 | 374814 | 136117 | 0.57 |
| T6 | 34954 | 31776 | 237197 | 349536 | 112339 | 0.47 |
| T7 | 33675 | 30614 | 233659 | 336749 | 103090 | 0.44 |
| T8 | 32904 | 29913 | 232159 | 329043 | 96884 | 0.42 |
| T9 | 32957 | 29961 | 232379 | 329571 | 97192 | 0.42 |
| T10 | 31525 | 28659 | 230879 | 315249 | 84370 | 0.37 |
| T11 | 29568 | 26880 | 231739 | 295680 | 63941 | 0.28 |
| T12 | 28674 | 26067 | 230239 | 286737 | 56498 | 0.25 |

UMY = Unadjusted marketable yield, AMY = Adjusted marketable yield, Adjustment coefficient was 10%, TC = Total cost, TR = Total return, NR = net return, B/C = benefit-cost ratio, Field price of water and onion bulb was 1 birr/238 m$^3$ (Mekonen *et al.*, 2015) and 11 birr/kg, respectively.

## 4.13. Correlation between yield and other components

The calculated values of correlations coefficient (r) between crop physiological parameters, yield and yield components are presented in table 13. The correlation coefficient values showed high degree of association of the crop parameters with each other. Accordingly, all the parameters had positively and high degree of correlation. This indicates that drip irrigation method at shorter interval increased bulb yield of onion by positively affecting the important yield components of the crop. Moreover, crop water water use efficiency and irrigation water use efficiency had positive correlation with all parameters considered. The positive and high degree of correlation observed among the yield and crop physiological parameters indicating that the final yield and water productivity is directly dependent on the values of these parameters.

The current result was in confirmation with study result of Teferi (2015). A study by Metwally (2011) indicated that plant height and bulb diameter had apositive and significant correlation with bulb yield. Abd El-Hady *et al*. (2015) found that there is a significant and positive correlation between bulb diameter and bulb yield.

Table 12.The Correlation Matrix Of Onion Attributes

| | Tby | Ph | Bh | Bd | Ln | Lh | CWUE | IWUE |
|---|---|---|---|---|---|---|---|---|
| Tby | 1 | | | | | | | |
| Ph | 0.8** | 1 | | | | | | |
| Bh | 0.753** | 0.6821** | 1 | | | | | |
| Bd | 0.851** | 0.8316** | 0.7887** | 1 | | | | |
| Ln | 0.7189** | 0.6818** | 0.7694** | 0.7869** | 1 | | | |
| Lh | 0.7999** | 1** | 0.6804** | 0.8311** | 0.6817** | 1 | | |
| CWUE | 0.7089** | 0.6347** | 0.5592** | 0.6768** | 0.6132** | 0.6357** | 1 | |
| IWUE | 0.8297** | 0.7788** | 0.6868** | 0.8267** | 0.7855** | 0.7794** | 0.9108** | 1 |

** = high degree of correlation, Yld = bulb yield (t/ha), Bd = bulb diameter (cm), Bh = bulb height (cm), Ph = plant height (cm), Lh = leaf height (cm), Ln = leaf number , CWUE = crop water use efficiency (kg/m$^3$) and IWUE= irrigation water use efficiency (kg/m$^3$)

# 5. SUMMARY, CONCLUSION AND RECOMMENDATION

## 5.1 Summary

Water has been identified as one of the most scarce inputs, which can severely restrict agricultural production and productivity unless it is carefully conserved and managed. To meet future food demands and growing competition for water, a more efficient use of water in irrigated agriculture will be essential. Traditionally, farmers in the central rift valley of Ethiopia have been using the most conventional surface irrigation system, most commonly the furrow irrigation system, for growing crops during the dry season. Furrow irrigation is often characterized by low irrigation efficiency. However, water resources are becoming scarce in the area for crop production due to increasing competition for irrigation water.

Drip irrigation is one of the most efficient forms of irrigation technology. With drip irrigation, it is possible to apply light and frequent irrigation. The experience from many countries show that farmers who switch from furrow system to drip systems can cut their water use by 30% to 60% and crop yields often increase at the same time(Sijali, 2001).

Mulches can be used to conserve moisture and increase growth. In order to maximize water use efficiency by the plant and to improve the quality of produce, the use of mulch has become an important cultural practice in many regions of the world. The use of mulches has aided growers in increasing crop production efficiency by promoting favorable moisture and temperature conditions.The microclimate surrounding the plant and soil is significantly affected by mulch. This study was under taken to compare drip and furrow irrigation methods under diffirent irrigation level and mulching on growth, yield and water productivity of Onion at Melkassa, Central Rift Valley of Ethiopia.

The experimental design of the trial was split plot design in RCBD with three replications, in which the irrigation methods were used as main plot and the three irrigation application together with the two mulching technique were used as sub-plot.

Some of the soil properties of the experimental site were analyzed and agronomic data like number of leaves per plant, plant height, leaf height, total bulb yield, marketable bulb yield, bulb height and bulb diameter and water productivity were recorded and analyzed by using SAS software.

The result of gravimetric soil moisture content was used a basis for the amount of irrigation water to be applied for each treatment plots. The mean value of number leaves per plant, plant height and leaf height in furrow irrigation method was shorter than that of drip irrigation method. Data also indicated that the mean values of total bulb yield, marketable bulb yield, bulb height, bulb diameter and water productivity recorded in drip irrigation method were high as compare to furrow irrigation method.

Number of leave per plant, plant height and leaf height were high in drip irrigation method interaction with 75% MAD under plastic mulch as compared to furrow irrigation method interaction with 75% MAD under plastic mulch. Data also indicated that the interaction effect of irrigation methods and irrigation level under no mulch and plastic mulch on total bulb yield and marketable bulb yield, were significant at ($p < 0.01$). Total bulb yield, marketable bulb yield, bulb height, bulb diameter were high in drip irrigation method interaction with 75% MAD under plastic mulch as compared to furrow irrigation method interaction with 75% MAD under plastic mulch. The minimum mean value of number of leaves per plant, plant height and leaf height were observed on furrow irrigation method interaction with 125% MAD under no mulch. The highest mean value of total bulb yield, marketable bulb yield, bulb height, bulb diameter were recorded in drip irrigation method interaction with 75% MAD under plastic mulch as compared all treatments treated under both drip and furrow irrigation methods interaction with diffirent irrigation level under no and plastic mulch. The lowest mean values of these parameters were recorded on furrow irrigation method interaction with 125% MAD under no mulch. Generally among all tested treatments drip irrigation method with 75% MAD under plastic mulch was the best practice because of its high total yield and moisture conserve.

There were significant difference between the IWUE and CWUE obtained in the irrigation methods, diffirent irrigation level under mulching and interaction of irrigation methods with diffirent irrigation level under mulching. Drip irrigation method resulted with higher values of IWUE and CWUE than furrow irrigation method while the highest mean value of IWUE and CWUE were observed for 75% MAD under plastic mulch. From the interaction effect the highest mean value of both IWUE and CWUE were recorded in drip irrigation method interaction with 75% MAD under plastic mulch as compared to all treatments treated under both drip and furrow irrigation methods interaction with diffirent irrigation level under no mulch and plastic mulch.

## 5.2 .Conclusion

Following conclusion were drawn based on the findings of this study:

- Drip irrigation was working efficiently according to its design.
- Drip irrigation method saved 33.3% water and increased yield by 21.6% as compared to furrow irrigation method.
- Higher Crop water use efficiency and Irrigation water use efficiency of about 0.72 kg/$m^3$ and 0.64 kg/$m^3$ were obtained in drip irrigation method respectively; whereas lower Crop water use efficiency and Irrigation water use efficiency of about 0.58 kg/$m^3$ and 0.35 kg/$m^3$ were obtained in furrow irrigation method.
- Generally among all tested treatments drip irrigation method with 75% MAD under plastic mulch was the best practice because of its high total yield and better moisture conservation ability.

## 5.3. Recommendation

From the observation made during this research, the following points were further recommended:

- When there is scarcity of water near small holders farm, farmers can use drip irrigation at the light and frequent (75% MAD level) with plastic mulch to achieve high yield and water use efficiency. However, if there is excess amount of water one can use furrow irrigation with plastic mulch.
- Gravimetric method was used to monitor soil moisture content, but it is also advisable to use other device with more accuracy like neutron prop ,TDR and Tensio meter.
- The experiment was a one season and in one place. Hence, repeating the experiment will improve the validity of findings.
- The test crop here was onion but, comparison should be extended to other commercial crops.
- Growers will need to exercise when and how much to apply in managing the rate, frequency, and duration of water supplies to successfully allocate limited water resource.

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## APPENDICES

## Appendix Table

Appendix 1. The long –term (1977-2017 ) monthly climate data of MARC

| Month | $T_{min}$ (℃) | $T_{max}$ (℃) | RH (%) | $U_2$ (m/s) | n (hr) | RF (mm) | ETo (mm/day) |
|---|---|---|---|---|---|---|---|
| January | 11.71 | 27.93 | 51.04 | 8.59 | 9.05 | 16.02 | 6.3 |
| February | 13.42 | 29.12 | 48.74 | 9.08 | 9.17 | 24.05 | 7.14 |
| March | 15.06 | 30.47 | 49.21 | 8.63 | 8.52 | 52.31 | 7.47 |
| April | 15.47 | 30.49 | 50.76 | 7.84 | 8.23 | 53.88 | 7.2 |
| May | 15.54 | 31.00 | 51.17 | 7.46 | 8.76 | 61.03 | 7.13 |
| June | 16.37 | 30.19 | 53.11 | 9.00 | 8.36 | 69.01 | 7.25 |
| July | 15.67 | 26.85 | 66.36 | 9.07 | 7.03 | 204.21 | 5.39 |
| August | 15.36 | 26.31 | 69.20 | 6.97 | 7.07 | 183.07 | 4.87 |
| September | 14.47 | 27.62 | 65.76 | 4.88 | 7.32 | 99.75 | 4.9 |
| October | 11.68 | 28.76 | 50.02 | 6.58 | 8.66 | 39.35 | 6.22 |
| November | 10.76 | 28.33 | 46.67 | 8.26 | 9.60 | 12.64 | 6.63 |
| December | 10.37 | 27.55 | 48.76 | 8.87 | 9.47 | 9.60 | 6.33 |
| Average | 13.82 | 28.72 | 54.23 | 7.94 | 8.44 | 68.74 | 6.4 |

$T_{max}$ and $T_{min}$= maximum and minimum air temperature(℃) respectively, RH= relative humidity (%), u= Wind speed at 2 m height (m/sec), n= sunshine hour (hr) and ETo= potential evapotranspiration (mm/day)

Source: Melkasa Agricultural Research Center (MARC) meteorological station.

Appendix 2. November meteorological data of the study area

| Day | Rainfall Mm | Min Temp °C | Max Temp °C | Humidity % | Wind m/s | Sun hours | Eto mm/day |
|---|---|---|---|---|---|---|---|
| 20 | 0 | 5.0 | 28.0 | 49 | 1.6 | 10.7 | 4.67 |
| 21 | 0 | 5.5 | 30.5 | 46 | 1.5 | 10.4 | 4.84 |
| 22 | 0 | 7.5 | 30.6 | 46 | 1.7 | 10.2 | 4.98 |
| 23 | 0 | 9.0 | 30.0 | 45 | 2.3 | 10.0 | 5.36 |
| 24 | 4.1 | 13.5 | 29.5 | 51 | 3.0 | 9.2 | 5.49 |
| 25 | 0 | 16.0 | 28.0 | 51 | 4.2 | 8.6 | 5.85 |
| 26 | 0 | 12.5 | 27.5 | 49 | 3.6 | 10.4 | 5.75 |
| 27 | 0 | 12.0 | 28.5 | 51 | 3.4 | 10.4 | 5.70 |
| 28 | 0 | 17.5 | 26.0 | 50 | 3.8 | 8.2 | 5.45 |
| 29 | 0 | 10.0 | 28.2 | 49 | 3.6 | 10.4 | 5.80 |
| 30 | 0 | 14.0 | 27.5 | 40 | 3.4 | 10.4 | 6.01 |

Source: Melkasa Agricultural Research Center (MARC) meteorological station,2017/18

Appendix 3. December meteorological data of the study area

| Day | Rainfall Mm | Min Temp °C | Max Temp °C | Humidity % | Wind m/s | Sun Hours | Eto mm/day |
|---|---|---|---|---|---|---|---|
| 1 | 0 | 6.0 | 28.5 | 45 | 1.8 | 10.4 | 4.81 |
| 2 | 0 | 5.5 | 29.0 | 45 | 2.5 | 10.4 | 5.36 |
| 3 | 0 | 7.5 | 27.5 | 45 | 2.7 | 10.4 | 5.30 |
| 4 | 0 | 6.5 | 27.5 | 41 | 2.8 | 10.6 | 5.48 |
| 5 | 0 | 5.6 | 28.2 | 43 | 2.1 | 10.6 | 5.04 |
| 6 | 0 | 7.5 | 28.8 | 45 | 1.6 | 10.1 | 4.64 |
| 7 | 0 | 9.0 | 28.5 | 46 | 1.9 | 10.1 | 4.83 |
| 8 | 0 | 10.0 | 27.2 | 47 | 3.0 | 10.0 | 5.33 |
| 9 | 0 | 7.5 | 26.5 | 53 | 3.1 | 10.4 | 5.11 |
| 10 | 0 | 6.0 | 26.0 | 50 | 2.8 | 7.4 | 4.63 |
| 11 | 0 | 4.0 | 25.2 | 47 | 2.7 | 10.2 | 4.87 |
| 12 | 0 | 1.5 | 26.0 | 42 | 2.4 | 9.9 | 4.88 |
| 13 | 0 | 0.5 | 27.0 | 36 | 2.3 | 10.1 | 5.08 |
| 14 | 0 | 0.5 | 30.0 | 40 | 1.3 | 10.4 | 4.53 |
| 15 | 0 | 3.5 | 30.8 | 38 | 2.1 | 10.1 | 5.34 |
| 16 | 0 | 6.6 | 30.0 | 44 | 2.1 | 9.9 | 5.11 |
| 17 | 0 | 10.5 | 28.0 | 45 | 2.9 | 10.0 | 5.43 |
| 18 | 0 | 13.5 | 27.5 | 54 | 3.6 | 9.7 | 5.39 |
| 19 | 0 | 12.5 | 25.5 | 53 | 3.7 | 10.0 | 5.23 |
| 20 | 0 | 10.5 | 24.8 | 49 | 3.4 | 9.6 | 5.09 |
| 21 | 0 | 4.0 | 24.0 | 48 | 3.3 | 10.1 | 4.95 |
| 22 | 0 | 3.5 | 24.0 | 52 | 3.1 | 10.0 | 4.73 |
| 23 | 0 | 4.0 | 24.5 | 52 | 2.9 | 6.0 | 4.26 |
| 24 | 0 | 3.0 | 26.5 | 47 | 2.3 | 5.5 | 4.25 |
| 25 | 0 | 2.5 | 28.0 | 49 | 2.3 | 7.5 | 4.62 |
| 26 | 0 | 11.5 | 28.0 | 36 | 3.4 | 6.5 | 5.68 |
| 27 | 0 | 11.0 | 26.5 | 39 | 3.8 | 5.6 | 5.47 |
| 28 | 0 | 4.5 | 26.6 | 41 | 2.8 | 7.5 | 4.95 |
| 29 | 0 | 5.0 | 27.5 | 41 | 2.2 | 9.0 | 4.85 |
| 30 | 0 | 5.5 | 27.2 | 44 | 2.6 | 10.0 | 5.12 |
| 31 | 0 | 5.5 | 28.5 | 44 | 1.9 | 7.5 | 4.52 |

Source: Melkasa Agricultural Research Center (MARC) meteorological station,2017/18

Appendix 4. January meteorological data of the study area

| Day | Rainfall Mm | Min Temp °C | Max Temp °C | Humidity % | Wind m/s | Sun Hours | Eto mm/day |
|---|---|---|---|---|---|---|---|
| 1 | 0 | 4.5 | 29.0 | 42 | 2.0 | 10.1 | 4.97 |
| 2 | 0 | 5.0 | 26.5 | 41 | 2.8 | 10.2 | 5.27 |
| 3 | 0 | 8.5 | 27.0 | 45 | 2.5 | 10.0 | 5.04 |
| 4 | 0 | 7.5 | 28.0 | 49 | 2.2 | 9.6 | 4.85 |
| 5 | 0 | 8.5 | 26.5 | 42 | 3.1 | 9.5 | 5.41 |
| 6 | 0 | 9.5 | 27.0 | 47 | 2.7 | 9.6 | 5.10 |
| 7 | 0 | 10.5 | 27.5 | 47 | 2.7 | 7.5 | 4.92 |
| 8 | 0 | 11.5 | 26.5 | 55 | 2.8 | 9.4 | 4.85 |
| 9 | T.R | 14.5 | 25.5 | 61 | 2.6 | 5.8 | 4.02 |
| 10 | 0 | 15.5 | 23.5 | 49 | 2.3 | 4.6 | 3.95 |
| 11 | 0 | 9.6 | 25.5 | 58 | 2.8 | 7.1 | 4.34 |
| 12 | 0 | 9.0 | 26.0 | 53 | 3.2 | 8.4 | 4.93 |
| 13 | 0 | 5.5 | 26.0 | 43 | 2.8 | 10.3 | 5.25 |
| 14 | 0 | 0.5 | 28.0 | 35 | 2.4 | 10.4 | 5.39 |
| 15 | 0 | 0.0 | 27.5 | 47 | 2.2 | 10.4 | 5.03 |
| 16 | 0 | 1.0 | 27.5 | 37 | 2.1 | 10.5 | 5.14 |
| 17 | 0 | 3.5 | 28.0 | 41 | 1.6 | 10.3 | 4.67 |
| 18 | 0 | 5.0 | 28.5 | 41 | 1.8 | 10.3 | 4.91 |
| 19 | 0 | 6.6 | 29.5 | 41 | 2.7 | 8.6 | 5.52 |
| 20 | 0 | 15.0 | 28.5 | 40 | 3.8 | 9.6 | 6.38 |
| 21 | 0 | 14.5 | 28.0 | 43 | 3.3 | 10.2 | 6.00 |
| 22 | 0 | 15.5 | 29.5 | 47 | 2.8 | 10.2 | 5.79 |
| 23 | 0 | 11.0 | 30.5 | 46 | 2.8 | 10.3 | 5.89 |
| 24 | 0 | 9.0 | 30.0 | 46 | 2.8 | 10.5 | 5.80 |
| 25 | 0 | 7.0 | 30.2 | 41 | 2.2 | 10.4 | 5.50 |
| 26 | 0 | 7.0 | 30.0 | 39 | 2.5 | 10.4 | 5.82 |
| 27 | 0 | 7.5 | 28.0 | 44 | 3.5 | 10.4 | 6.00 |
| 28 | 0 | 14.0 | 28.0 | 45 | 3.2 | 10.0 | 5.86 |
| 29 | 0 | 10.5 | 29.0 | 54 | 3.0 | 10.2 | 5.55 |
| 30 | 0 | 15.0 | 29.5 | 52 | 2.8 | 9.5 | 5.56 |
| 31 | 0 | 10.5 | 28.5 | 43 | 3.6 | 10.3 | 6.22 |

Source: Melkasa Agricultural Research Center (MARC) meteorological station,2017/18

Appendix 5. February meteorological data of the study area

| Day | Rainfall Mm | Min Temp °C | Max Temp °C | Humidity % | Wind m/s | Sun Hours | Eto mm/day |
|---|---|---|---|---|---|---|---|
| 1 | 0 | 13.0 | 28.0 | 46 | 3.3 | 10.0 | 5.90 |
| 2 | 0 | 14.0 | 28.5 | 48 | 3.7 | 10.0 | 6.13 |
| 3 | 3.2 | 14.0 | 28.0 | 45 | 3.0 | 10.1 | 5.83 |
| 4 | 0 | 13.5 | 20.0 | 80 | 3.1 | 0.1 | 2.25 |
| 5 | 0 | 12.5 | 27.0 | 55 | 3.4 | 10.3 | 5.54 |
| 6 | 0 | 10.5 | 26.5 | 49 | 3.5 | 10.4 | 5.73 |
| 7 | 0 | 5.5 | 27.5 | 42 | 3.1 | 10.8 | 5.92 |
| 8 | 0 | 4.0 | 30.0 | 38 | 2.8 | 10.9 | 6.23 |
| 9 | 0 | 3.0 | 29.5 | 39 | 1.9 | 9.9 | 5.31 |
| 10 | 0 | 12.5 | 31.5 | 35 | 2.8 | 10.5 | 6.56 |
| 11 | 0 | 11.5 | 32.0 | 35 | 3.0 | 9.1 | 6.58 |
| 12 | 0 | 14.0 | 32.5 | 45 | 2.2 | 9.7 | 5.86 |
| 13 | 0 | 17.5 | 33.0 | 44 | 2.7 | 8.6 | 6.21 |
| 14 | 0 | 15.0 | 33.5 | 43 | 3.2 | 10.4 | 6.96 |
| 15 | 0 | 16.5 | 33.0 | 44 | 3.6 | 10.2 | 7.12 |
| 16 | 0 | 16.5 | 33.0 | 41 | 2.5 | 10.2 | 6.43 |
| 17 | 0 | 12.5 | 34.0 | 42 | 2.0 | 9.9 | 6.00 |
| 18 | 0 | 18.0 | 31.5 | 49 | 3.2 | 9.9 | 6.47 |
| 19 | T.R | 16.5 | 30.0 | 53 | 3.0 | 5.7 | 5.26 |
| 20 | 2.4 | 17.6 | 32.0 | 52 | 2.5 | 6.8 | 5.44 |
| 21 | 0 | 13.5 | 31.2 | 57 | 2.0 | 8.1 | 5.10 |
| 22 | 0 | 16.5 | 30.5 | 55 | 3.0 | 5.1 | 5.14 |
| 23 | 0 | 14.0 | 34.0 | 49 | 2.6 | 10.4 | 6.48 |
| 24 | 0 | 12.0 | 32.0 | 48 | 2.2 | 10.0 | 5.89 |
| 25 | 1.1 | 16.5 | 34.0 | 46 | 2.1 | 6.5 | 5.50 |
| 26 | 0 | 16.0 | 31.0 | 57 | 1.4 | 3.7 | 3.91 |
| 27 | 10.5 | 13.5 | 30.0 | 68 | 2.0 | 5.2 | 4.19 |
| 28 | 0 | 14.5 | 32.0 | 59 | 1.4 | 10.6 | 5.38 |

Source: Melkasa Agricultural Research Center (MARC) meteorological station,2017/18

Appendix 6. March meteorological data of the study area

| Day | Rainfall Mm | Min Temp °C | Max Temp °C | Humidity % | Wind m/s | Sun Hours | Eto mm/day |
|---|---|---|---|---|---|---|---|
| 1 | 0 | 14.0 | 31.0 | 54 | 1.8 | 10.2 | 5.51 |
| 2 | 0 | 18.0 | 28.5 | 57 | 3.0 | 6.5 | 5.18 |
| 3 | 0 | 16.5 | 27.5 | 61 | 2.6 | 6.1 | 4.65 |
| 4 | 0 | 16.0 | 28.5 | 65 | 2.2 | 5.5 | 4.33 |
| 5 | 0 | 16.0 | 27.5 | 58 | 2.1 | 2.7 | 3.89 |
| 6 | 0 | 16.5 | 28.0 | 52 | 1.4 | 9.2 | 4.93 |
| 7 | 0 | 17.5 | 29.0 | 49 | 2.0 | 7.8 | 5.21 |
| 8 | 0 | 15.0 | 31.5 | 34 | 1.4 | 10.4 | 5.61 |

Source: Melkasa Agricultural Research Center (MARC) meteorological station,2017/18

Appendix 7. Effective rainfall during the growing season of Onion

| S. No. | Date | Rainfall (mm) | Effective rainfall (mm) |
|---|---|---|---|
| 1 | 11-Nov-17 | 0.2 | 0.00 |
| 2 | 24-Nov-17 | 4.1 | 2.48 |
| 3 | 9-Jan-18 | T.R | 0.00 |
| 4 | 3-Feb-18 | 3.2 | 1.70 |
| 5 | 19-Feb-18 | T.R | 0.00 |
| 6 | 20-Feb-18 | 2.4 | 1.08 |
| 7 | 25-Feb-18 | 1.1 | 0.30 |
| 8 | 27-Feb-18 | 10.5 | 6.94 |

Source: Melkasa Agricultural Research Center (MARC) meteorological station,2017/18

Appendix 8. Basic Infiltration rate of experimental field

| Elapsed time (min) | Cumulative time (min) | Reading (cm) | Difference (cm) | Cumulative intake (cm) | Infiltration rate (mm/hr.) | |
|---|---|---|---|---|---|---|
| | | | | | Immediate | Mean |
| 0 | 0 | 15 | 0 | 0 | 0 | 0.0 |
| 0.25 | 0.25 | 14.6 | 0.4 | 0.4 | 960 | 960.0 |
| 0.25 | 0.5 | 14.3 | 0.3 | 0.7 | 720 | 840.0 |
| 0.5 | 1 | 14.1 | 0.2 | 0.9 | 240 | 540.0 |
| 1 | 2 | 13.6 | 0.5 | 1.4 | 300 | 420.0 |
| 3 | 5 | 13.3 | 0.3 | 1.7 | 60 | 204.0 |
| 5 | 10 | 12.7 | 0.6 | 2.3 | 72 | 138.0 |
| 10 | 20 | 12.2 | 0.5 | 2.8 | 30 | 84.0 |
| 10 | 30 | 11.8 | 0.4 | 3.2 | 60 | 64.0 |
| 15 | 45 | 11.2 | 0.6 | 3.8 | 32 | 50.7 |
| 15 | 60 | 10.2/11* | 1 | 4.8 | 48 | 48.0 |
| 30 | 90 | 9.7 | 1.3 | 6.1 | 26 | 40.7 |
| 30 | 120 | 9 | 0.7 | 6.8 | 14 | 34.0 |
| 30 | 150 | 8.2 | 0.8 | 7.6 | 16 | 30.4 |
| 30 | 180 | 7.4 | 0.8 | 8.4 | 16 | 28.0 |
| 30 | 210 | 6.6 | 0.8 | 9.2 | 16 | 26.3 |

* The measuring stich marks before and after water addition

Appendix 9. The measured values of emitter discharge for drip irrigation

| S. No | Block | Plot number | Emitter discharge (lit/hr) |
|---|---|---|---|
| 1 | 1 | 1 | 0.52 |
| 2 | 1 | 1 | 0.53 |
| 3 | 1 | 1 | 0.52 |
| 4 | 1 | 1 | 0.52 |
| 5 | 1 | 1 | 0.52 |
| 6 | 1 | 1 | 0.52 |
| 7 | 1 | 1 | 0.52 |
| 8 | 2 | 18 | 0.53 |
| 9 | 2 | 18 | 0.55 |
| 10 | 2 | 18 | 0.54 |
| 11 | 2 | 18 | 0.55 |
| 12 | 2 | 18 | 0.55 |
| 13 | 2 | 18 | 0.55 |
| 14 | 2 | 18 | 0.54 |
| 15 | 3 | 25 | 0.53 |
| 16 | 3 | 25 | 0.53 |
| 17 | 3 | 25 | 0.53 |
| 18 | 3 | 25 | 0.53 |
| 19 | 3 | 25 | 0.52 |
| 20 | 3 | 25 | 0.53 |
| 21 | 3 | 25 | 0.55 |
| Average | | | 0.53 |

Appendix 10. Wetting diameter of the drip emitters (cm) at three different trials

| Depth (cm) | Trial 1 | Trial 2 | Trial 3 | Average |
|---|---|---|---|---|
| 0 | 33.7 | 33.2 | 34.6 | 33.8 |
| 20 | 32.6 | 32.1 | 32.1 | 32.2 |
| 40 | 29.8 | 29.8 | 28.1 | 29.2 |
| 60 | 27.0 | 25.5 | 27.7 | 26.7 |

Appendix 11. Analysis of variance (ANOVA) for number of leaves per plant

| Source | DF | SS | MS | F | P |
|---|---|---|---|---|---|
| REP | 2 | 0.961 | 0.481 | | |
| MPLOT | 1 | 465.121 | 465.121 | 840.16 | 0.0012 |
| Error REP*MPLOT | 2 | 1.107 | 0.554 | | |
| SUBPLOT | 5 | 141.572 | 28.314 | 3.86 | 0.0131 |
| MPLOT*SUBPLOT | 5 | 45.922 | 9.184 | 1.25 | 0.3232 |
| Error REP*MPLOT*SUBPLOT | 20 | 146.859 | 7.343 | | |
| Total | 35 | 801.542 | | | |

* Significant (p<0.05), ** Highly Significant (p<0.01) and NS Not significant

Appendix 12. Analysis of variance (ANOVA) for plant height

| Source | DF | SS | MS | F | P |
|---|---|---|---|---|---|
| REP | 2 | 1.47 | 0.734 | | |
| MPLOT | 1 | 699.6 | 699.603 | 830.39 | 0.0012 |
| Error REP*MPLOT | 2 | 1.69 | 0.843 | | |
| SUBPLOT | 5 | 213.77 | 42.754 | 3.89 | 0.0127 |
| MPLOT*SUBPLOT | 5 | 67.86 | 13.571 | 1.23 | 0.3304 |
| Error REP*MPLOT*SUBPLOT | 20 | 220.3 | 11.002 | | |
| Total | 35 | 1204.42 | | | |

* Significant (p<0.05), ** Highly Significant (p<0.01) and NS Not significant

Appendix 13. Analysis of variance (ANOVA) for leaf height

| Source | DF | SS | MS | F | P |
|---|---|---|---|---|---|
| REP | 2 | 0.961 | 0.48 | | |
| MPLOT | 1 | 465.121 | 465.121 | 840.16 | 0.0012 |
| Error REP*MPLOT | 2 | 1.107 | 0.554 | | 0.0131 |
| SUBPLOT | 5 | 141.572 | 28.314 | 3.86 | |
| MPLOT*SUBPLOT | 5 | 45.922 | 9.184 | 1.25 | 0.3232 |
| Error REP*MPLOT*SUBPLOT | 20 | 146.859 | 7.343 | | |
| Total | 35 | 801.542 | | | |

* Significant (p<0.05), ** Highly Significant (p<0.01) and NS Not significant

Appendix 14. Analysis of variance (ANOVA) for total bulb yield

| Source | DF | SS | MS | F | P |
|---|---|---|---|---|---|
| REP | 2 | 906.5 | 453.3 | | |
| MPLOT | 1 | 14033.3 | 41033.3 | 1135.44 | 0.0009 |
| Error REP*MPLOT | 2 | 72.3 | 36.1 | | |
| SUBPLOT | 5 | 20220 | 4044 | 53.4 | 0.0000 |
| MPLOT*SUBPLOT | 5 | 2693.5 | 538.7 | 7.11 | 0.0006 |
| Error REP*MPLOT*SUBPLOT | 20 | 1514.6 | 75.7 | | |
| Total | 35 | 66440.1 | | | |

* Significant (p<0.05), ** Highly Significant (p<0.01) and NS Not significant

Appendix 15. Analysis of variance (ANOVA) for marketable bulb yield

| Source | DF | SS | MS | F | P |
|---|---|---|---|---|---|
| REP | 2 | 791 | 395.5 | | |
| MPLOT | 1 | 46174.8 | 46174.8 | 1086.42 | 0.0009 |
| Error REP*MPLOT | 2 | 85 | 42.5 | | |
| SUBPLOT | 5 | 13859.7 | 2771.9 | 6.07 | 0.0014 |
| MPLOT*SUBPLOT | 5 | 3516.9 | 703.4 | 1.54 | 0.2227 |
| Error REP*MPLOT*SUBPLOT | 20 | 9139.6 | 457 | | |
| Total | 35 | 73567 | | | |

* Significant (p<0.05), ** Highly Significant (p<0.01) and NS Not significant

Appendix 16. Analysis of variance (ANOVA) for bulb diameter

| Source | DF | SS | MS | F | P |
|---|---|---|---|---|---|
| REP | 2 | 0.07056 | 0.03528 | | |
| MPLOT | 1 | 4.2025 | 0.20255 | 55.42 | 0.0176 |
| Error REP*MPLOT | 2 | 0.15167 | 0.07583 | | |
| SUBPLOT | 5 | 1.54472 | 0.30894 | 55.61 | 0.0000 |
| MPLOT*SUBPLOT | 5 | 0.06917 | 0.01383 | 2.49 | 0.0657 |
| Error REP*MPLOT*SUBPLOT | 20 | 0.11111 | 0.00556 | | |
| Total | 35 | 6.14972 | | | |

* Significant (p<0.05), ** Highly Significant (p<0.01) and NS Not significan

Appendix 17. Analysis of variance (ANOVA) for bulb height

| Source | DF | SS | MS | F | P |
|---|---|---|---|---|---|
| REP | 2 | 2.1606 | 1.08028 | | |
| MPLOT | 1 | 7.7469 | 7.74694 | 21.02 | 0.0444 |
| Error REP*MPLOT | 2 | 0.7372 | 0.36861 | | |
| SUBPLOT | 5 | 3.8714 | 0.77428 | 11.83 | 0.0000 |
| MPLOT*SUBPLOT | 5 | 0.7981 | 0.15961 | 2.44 | 0.0000 |
| Error REP*MPLOT*SUBPLOT | 20 | 1.3089 | 0.06544 | | |
| Total | 35 | 16.6231 | | | |

* Significant ($p<0.05$), ** Highly Significant ($p<0.01$) and NS Not significan

Appendix 18. Analysis of variance (ANOVA) for water CWUE

| Source | DF | SS | MS | F | P |
|---|---|---|---|---|---|
| REP | 2 | 0.00307 | 0.00154 | | |
| MPLOT | 1 | 0.15733 | 0.15734 | 2981.26 | 0.0003 |
| Error REP*MPLOT | 2 | 0.00011 | 0.00005 | | |
| SUBPLOT | 5 | 0.31229 | 0.06246 | 227.58 | 0.0000 |
| MPLOT*SUBPLOT | 5 | 0.01666 | 0.00333 | 12.14 | 0.0000 |
| Error REP*MPLOT*SUBPLOT | 20 | 0.00549 | 0.00027 | | |
| Total | 35 | 0.49496 | | | |

Appendix 19. Analysis of variance (ANOVA) for water IWUE

| Source | DF | SS | MS | F | P |
|---|---|---|---|---|---|
| REP | 2 | 0.00152 | 7.53E-04 | | |
| MPLOT | 1 | 0.76271 | 0.76271 | 274576 | 0.0000 |
| Error REP*MPLOT | 2 | 0.00001 | 2.778-E06 | 268.68 | |
| SUBPLOT | 5 | 0.20673 | 0.04135 | | 0.0000 |
| MPLOT*SUBPLOT | 5 | 0.03566 | 0.00713 | 46.34 | 0.0000 |
| Error REP*MPLOT*SUBPLOT | 20 | 0.00308 | 1.54E-04 | | |
| Total | 35 | 1.0097 | | | |

Appendix 20. Design standards for emission uniformity for arid areas

| Emitter type | Crop spacing | Field topography | Emission uniformity (%) |
|---|---|---|---|
| Point source | Wide[a] | Uniform[c] | 90-95 |
| | | Steep[d] or undulating | 85-90 |
| | Close[d] | Uniform | 85-90 |
| | | Steep or undulating | 80-90 |
| Line source | Close | Uniform | 80-90 |
| | | Steep or undulating | 75-85 |

Source: adapted from ASAE standards EP 405, 1985 Note: a space greater than 4m apart, b spaced less than 2 m apart, c slope less than 2 percent, d slope greater than 2 percent

Appendix 21. General criteria for emitter flow variation

| Emitter flow variation | Recommendation |
|---|---|
| ≤10% | Desirable |
| 10-20% | Acceptable |
| >20% | Unacceptable |

Source: Bralts, 1986

Appendix 22. Recommended emitter classification based on manufacturer's coefficient of variation

| Emitter type | Coefficient of variation | Classification |
|---|---|---|
| Point source | <0.05 | Good |
| | 0.05-0.10 | Average |
| | 0.10-0.15 | Marginal |
| | >0.15 | Unacceptable |
| Line source | <0.10 | Good |
| | 0.10-0.20 | Average |
| | >0.20 | Marginal to unacceptable |

Source: adapted from ASAE standards EP 405, 1985

Appendix 23. Distribution uniformity test of furrow irrigation

| | | Infiltrated depth of water at soil depth | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 0-20 soil depth(cm) | | | 20-40 soil depth (cm) | | | 40-60 soil depth (cm) | | |
| Irrigation levels | Rep | Inlet | Middle | End | inlet | Middle | End | Inlet | Middle | End |
| 100% MAD | 1 | 27.8 | 27.2 | 26.1 | 23.1 | 22.7 | 22.4 | 22.2 | 21.9 | 21.8 |
| | 2 | 27.5 | 27.0 | 24.7 | 22.9 | 22.6 | 22.3 | 22.0 | 21.8 | 20.7 |
| | 3 | 27.4 | 26.9 | 23.5 | 22.8 | 22.5 | 22.3 | 21.9 | 21.8 | 20.5 |
| 75% MAD | 1 | 23.4 | 23.3 | 23.1 | 19.4 | 19 | 18.4 | 18.3 | 17.8 | 16.6 |
| | 2 | 23.7 | 23.2 | 23 | 20.6 | 18.8 | 18.5 | 18.2 | 17.6 | 17.7 |
| | 3 | 23.7 | 23.1 | 22.8 | 22.0 | 18.7 | 18.7 | 18.2 | 17.7 | 17.5 |
| 125% MAD | 1 | 19.5 | 18.6 | 16.8 | 14.5 | 14.4 | 14.0 | 13.9 | 13.5 | 13.5 |
| | 2 | 19.2 | 18.8 | 16.4 | 14.6 | 14.3 | 14.0 | 13.7 | 13.6 | 12.4 |
| | 3 | 19.0 | 18.9 | 15.2 | 14.8 | 14.2 | 14.1 | 13.7 | 13.6 | 12.0 |

## Appendix Figures

Appendix figure 1. Taking soil sample to determine bulk density and other parameter

Appendix figure 2. Recording of infiltration depth  to determine basic infiltration rate

Appendix figure 3. Seedling management  for experiment

Appendix figure 4. Land preparation for furrow Irrigation

Appendix figure 5. Land preparation for drip Irrigation

Appendix figure 6. chemical application to the experimental crop

Appendix figure 7.All field area of experiment

Appendix figure 8.Collection of necessary data during growth

Appendix figure 9. Experimental Field visit with co- advisor

Appendix figure 10. Data recording during harvest

# BIOGRAPHICAL SKETCH

The author was born on March 18,1990 G.C. in Bacho woreda, South west Shoa zone of Oromia regional state. He attended his primary education at Asgori Elementary School from 1998 to 2005 and secondary education at Yehibretfrie Secondary and Preparatory School where he completed his high school education in 2010. Then, he joined Mekelle University and graduated with BSc. Degree in Water Resource and Irrigation Management in 2013 G.C.

After graduation, he was employed by Ethiopia Agricultural Research Institute where he served as junior researcher in Irrigation, Drainage and Water Harvesting research division of Melkasa Agricultural Research Center from January 2015 until he joined the graduate school of the Hawasa University in 2017 as a candidate for Master of Science Degree in water Resource Engineering and Management