RESPONSE OF ONION (Allium *cepa L.*) TO DEFICIT IRRIGATION UNDER SURFACE AND DRIP IRRIGATION METHOD IN CENTRAL RIFT VALLEY OF ETHIOPIA

M.SC. THESIS

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DEDICATION

This manuscript is dedicated to the memory of my mother,

Yasunash Shibiru Betasa

STATEMENT OF AUTHOR

I declare that this thesis is my own fine work and all sources of materials used for this thesis have been duly acknowledged. I solemnly declare that this thesis is not submitted to any other institution anywhere for the award of an academic degree, diploma or certificate.

Name: BENIAM YAZIZ Signature_____________________

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Date of Submission: March,2019

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Thank you very much!

LIST OF ABBREVIATIONS AND ACRONYMS

Aw	Area Wetted
AFI	Alternate furrow irrigation
BD	Bulk Density
CV	Coefficient of Variation
CWUE	Crop Water Use Efficiency
DI	Drip Irrigation
DP	Deep Percolation Ratio
DU	Distribution Uniformity
Dz	Effective Root Depth
ea	Air Vapor Pressure
Ea	Field Application Efficiency
ECe	Electrical Conductivity of saturation extract
Es	Saturation Vapor Pressure
ET	Evapotranspiration
ETc	Crop Evapotranspiration
ETo	Reference Evapotranspiration
FC	Field Capacity
FI	Furrow irrigation
FWUE	Field Water Use Efficiency
ha	hectares
Kr	Ground Cover Reduction Factor
Ky	Yield Response Factor
LR	Amount of Water Required for the Leaching of Salts
LSD	Least Significant Difference
MAD	Management Allowed Deficiency

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ABSTRACT

Onion (Allium cepa L.) is the most important and widely cultivated vegetable crop in the Central Rift Valley of Ethiopia. However, available water resources are the most limiting factor for crop production in the area. A field experiment was conducted on loam soil at the experimental farm of Melkass agricultural research center, Ethiopian Institute of agriculture research with the objective of evaluating the effects of irrigation method and deficit irrigation on yield and water use efficiency of onion. The experiment consisted of two irrigation methods (Drip and furrow) and four deficit irrigation levels (85%ETc, 70%ETc, 60%ETc, and 50%ETc) and control irrigation of 100%ETc and laid out using split plot design in RCBD with three replication. Irrigation methods were used as the main plot and the five irrigation levels as sub-plot. Irrigation water was applied at allowable soil moisture depletion (p=0.25) of the total available soil moisture throughout the crop growth stage. The study has shown a highly significant ($P \leq 0.01$) difference on yield, yield parameters and water productivity of onion. The highest total onion bulb yield (52.1t/ha) was obtained from applying 100%ETc under drip irrigation method and had no significant difference with drip irrigation at 85%ETc irrigation application. Onion bulb yield decreased with an increase in levels of water deficit. Both water productivity and irrigation water productivity increased with increase in water deficit level. The highest water productivity and irrigation water productivity were obtained under furrow and drip irrigation, respectively. Deficit irrigation application of 85%ETc, 70%ETc and 60%ETc under drip method apparently gave a non-significant difference for most yield attributes. Among furrow irrigation techniques, the highest onion yield (43.4t/ha) was obtained from convention furrow irrigation with 100% ETc irrigation application and the highest water productivity and irrigation water productivity were observed in alternate furrow irrigation at 70%ETc irrigation application. Hence, under Melkassa climatic condition, onion could be irrigated under drip and alternate furrow irrigation method at 70%ETc deficit irrigation applications considering the availability of water resources and crop water productivity.

Keywords: Drip irrigation, Alternate furrow, Conventional furrow, Water productivity, Onion

1. INTRODUCTION

Onion (Allium CepaL.) (Olani and Fikre, 2010) is important horticulture and commercial crop categorized under root crops. Of the vegetable crops, onion ranks second after tomatoes in terms of total annual world production, (FAO, 2005). It is widely produced by small farmers and commercial growers throughout the year for local use and export market. It is also a liquid asset for the smallholder's farmers in Ethiopia. Interestingly, onion is one of the most significant and commonly used ingredients in Ethiopian recipe. A large majority of 95% vegetables produced in the country comes from the smallholder. It can be produced throughout the year provided dependable rain and/or irrigation water is available. The majority of onion production is found in the Central Rift Valley (CRV) of Ethiopia; however, rainfall is unreliable and insufficient to support onion production that makes irrigation an indispensable practice.

Irrigation is one of the most important inputs to increase crop yields in arid and semi-arid regions. Agriculture makes use of 70% of all water withdrawn from aquifers, streams, and lakes. Irrigated agriculture accounts for 20% of the total cultivated land but contributes 40% of the total food produced worldwide (Drechsel *et al.,* 2015). Agriculture is the mainstay of Ethiopia's economy, contributing more than 40% to GDP and providing a livelihood to about 80% of the population (Makombe *et al.,* 2017). Agricultural sector is, however, the largest consumer of water not only in Ethiopia but also in the world. Increasing water demand for industrial and domestic use and for environmental sustainability entails efficient water use in agriculture. Agriculture represents the major water user worldwide and a general perception that agricultural water use is often wasteful and has less value than other uses in widespread (Postel, 2000; Jury and Vaux, 2005). Improving water use efficiency or enhancing water productivity in a sustainable manner is crucial to irrigated agriculture and water use. The rapid population growth, on the other hand, necessitates an increase in agricultural production to meet their food and fiber demand and leads to increasing pressure on an existing precious water resource. Hence, increased in food production will largely have to originate from improved productivity per unit water used (Hofwegen Van and Svendsen, 2000). Good performance of irrigated agriculture system is not only a matter of high output but also of efficient use in available water resource. Inefficient use of irrigation water in arid areas is not only leading to great waste but also causes waterlogging and salinization that adversely affects the productivity of most irrigated land (Sijali, 2001) Therefore, innovations are needed to increase towards searching efficient use of this scarce resource to meet the future food demands and for ease of growing competition for water.

The crop is shallow rooted and sensitive to water stress. As result, the crop is commonly given light and frequent irrigation to avoid water stress (Doornebos and Kassam, 1979). Maximum yield could be obtained with the achievement of the entire crop water requirements. The rift valley area is characterized as semi-arid with limited water resources and increasing demand for water combined with high evapotranspiration rates limits the production and productivity of the crop. Hence, a suitable irrigation water management practices needs to be explored for effective and efficient use of exciting water resource in the area to enhance onion water productivity.

Furrow irrigation system is most popular in surface irrigation, as it requires a smaller initial investment compared to other types of irrigation systems. This type of irrigation method is the most widely used in Ethiopia in almost all large and small irrigation schemes. It has been reported by FAO (2001) that 97.8% of irrigation in Ethiopia is done by surface methods of irrigation especially by furrow system in farmer's fields and the majority of the commercial farms. Edossa *et al.,* (2014) also found that vegetable production in the study area is carried out mainly under furrow irrigation. They also reported that almost 98.9% of vegetable grower's household use furrow method of irrigation. Surface irrigation can be efficient (60% or less), in atypical farmers situation less than half of the applied water reaches the plant because of high evaporation and deep percolation below the root zone. For this reason, an adaptation of improving techniques of furrow irrigation system is mandatory in the area to reduce the water lost by deep percolation and prevent the soil from salt abundant due to rising of groundwater to the top surface of irrigated land. An important adaptation of furrow irrigation practice is alternate furrow irrigation (AFI) in which furrows are irrigated alternately rather than conventionally during irrigation water application. This is a form of alternate partial rootzone drying (APRD) system which has been found to increase the production of various vegetables in the arid and semi-arid are as well as saving irrigation water. Partial root drying technique is a water saving technology presently being investigated in many countries in including Ethiopia. Although, a higher percentage of the farmers and commercial farmers in the country still using conventional furrow irrigation technique and they continued to divert excessive irrigation water to irrigate their farmland. Because of this reason, it is difficult to abrupt shift from the above mentioned wasteful irrigation system to a modern one within a short period of time especially in developing countries like Ethiopia. So that adaptation of furrow irrigation technique which is equivalent to an efficient irrigation system is essential to enhance water productivity and agricultural production through application of optimal irrigation water and without incurring additional investment cost.

The drip irrigation system is one of the most efficient forms of irrigation technology. With drip irrigation, it is possible to apply light and frequent irrigation water. The experience from their water use by 30% to 60% and crop yields often increase at the same time (Sijali, 2001). many countries shows that farmers who switch from furrow system to drip systems can cut Drip irrigation, currently used in Ethiopia, especially in central rift valley region for high-value vegetable crop production such as onions, potatoes, peppers, and lettuces, can result in a considerable saving in irrigation water, thus reducing the lost by deep percolation and risks of salinization if the correct management procedures are applied.

Another way to address the issue of water shortage is through the development of new irrigation scheduling techniques such as deficit irrigation, which is not necessarily based on full crop water requirement. Deficit irrigation has been suggested as an alternative strategy for making better use of irrigation water. Deficit irrigation provides a means of reducing water consumption while minimizing adverse effects on yield. In this method, the crop is exposed to a certain level of water deficit either during a particular period or throughout the whole growing season (English and Raja, 1996). The expectation is that any yield reduction will be insignificant compared with the benefits gained through diverting the saved water to irrigate other crops (Eck *et al.,* 1987). However, the grower must have prior knowledge of the crop yield responses to deficit irrigation. Many investigations have been carried out worldwide regarding the effects of deficit irrigation on the yield of mainly horticultural crops. Study on onion (Tilahun and Samson,2007) indicated that deficit irrigation throughout the growing season with 50 and 75% of ETc application reduced yields from full irrigation and resulted in the highest water saving and crop water use efficiency. Kumar *et al.,* (2007) investigated also the impact of deficit irrigation strategies on onion yield and water savings. They reported that applying 80 and 60% of crop water requirements resulted in yield decreases of 14 and 38% and saved 18 and 33% of irrigation water compared to full irrigation respectively.

Considering the scarcity of irrigation water in the study area and the need of high profitability per unit of water and sensitivity of onion crop to moisture stress, this research was undertaken with the aim of to identify the appropriate irrigation method and application level for optimum yield of onion.

1.1 General Objective

The purpose of this study is, to evaluate the effects of irrigation method and irrigation level on yield and water productivity of onion under scarce water resource.

1.1.1 Specific objectives

- To investigate the effect of the alternate furrow and drip irrigation systems on the yield of onion crop
- To investigate the performance of Alternate furrow irrigation as compared to conventional furrow irrigation
- To determine the potential for water savings and yield improvements under drip irrigation as compared to furrow irrigation
- To determine water productivity under alternate furrow and drip irrigation

2. LITERATURE REVIEW

2.1 Water for Irrigated Agriculture

Irrigation is one of the most important inputs to increase crop yields in arid and semi-arid regions. Agriculture makes use of 70% of all water withdrawn from aquifers, streams, and lakes. Irrigated agriculture accounts for 20% of the total cultivated land but contributes 40% of the total food produced worldwide (Drechsel *et al.* 2015). Irrigated agriculture, however, use (divert or withdraw) much more water than consumed by the crop. An earlier estimate made by (FAO, 1993) for average irrigation water utilization showed that farm distribution losses constitute 15% of irrigation water; while field application system losses constitute 25%, irrigation system losses 15% and the water effectively used by crops constitutes only about 45%. The non-consumed fraction of the water causes a variety of undesirable effects ranging from water-logging and salinity within the irrigated area to downstream water pollution (Bos *et al.,* 2008).

Each day, the continuing growth of the world population places new demands on our water resources. More water is needed for all the processes of life: food production, municipal supply, industrial water use, power generation, navigation, recreation, etc. At the same time, environmental water needs are increasingly being recognized, limiting the sources of new water and further increasing the competition for available supplies. Improved management of our water resources is needed to ensure the equitable distribution of water to competing users. There are especially significant opportunities for conservation and more effective water use by the world's largest user: agriculture. Agriculture uses up more than 60% of available water supplies and, as such, it is the single largest consumer of water (Ali, 2010). To a great extent, agriculture threatens global water resources in terms of both quantity and quality. The needs for improving water-use efficiency (WUE) in crop production and sustainable use of water resources are clearly urgent. In irrigated areas, improvement of water management on farms is the first step toward the conservation of a diminishing natural resource, and it is therefore important to find production systems able to use water more efficiently (Wallace, 2000). Accurate delivery of the necessary amounts of water at the correct times can both conserve water and improve the quantity and quality of agricultural products.

2.2 Irrigated Agriculture in Ethiopia

Agriculture is the mainstay of Ethiopia's economy, contributing more than 40% to GDP and providing a livelihood to about 80% of the population (Makombe *et al.,* 2017). The Ethiopian economy's heavy reliance on rain-fed subsistence agriculture leaves its economic performance '…virtually hostage to its hydrology' (World Bank, 2006). Webb and Braun (1994) estimated that a 10 percent decline in rainfall below the long-term national average would result in a fall in all cereal yields by an average of 4.2 percent. Such a failure in agricultural production has caused great distress and famine on society in the past three or four decades. On contrary, Ethiopia has abundant water resources that could be developed for, among other things, irrigation, in order to de-link the performance of the economy from rainfall variability. Given the importance of agriculture to the Ethiopian national economy, the Government of Ethiopia has embarked on an agriculture-led development programmed with irrigation development a central component. It is estimated that only 5% of 3.5 million ha of land that could be irrigated is currently developed (Seleshi *et al.* 2005 and Fitsum *et al.* 2010). Irrigation is one of the means by which agricultural production can be increased to meet the growing demands in Ethiopia. A study also indicated that one of the best alternatives to consider for sustainable food security development is expanding irrigation development on various scales, through river diversion, constructing micro-dams and water harvesting structures (Seleshi *et al.,* 2005). Irrigation development including large and medium-scale irrigation development in the form of public schemes, commercial farming is getting importance since 2004 under the earlier government plan. Now a day, the government of Ethiopia is giving more emphasis to the sub-sector by way of enhancing the food security situation in the country. Efforts are being made to involve farmers progressively in various aspects of management of small-scale irrigation systems, starting from planning, implementation and management aspects, particularly, in water distribution and operation and maintenance to improve the performance of irrigated agriculture.

2.2.1. Irrigation water management in Ethiopia

Irrigation development is increasingly implemented in Ethiopia more than ever. The main objectives are to increase agricultural productivity and diversify the production of food and raw materials for agro-industry as well as to ensure that agriculture plays the role of driving the economic development of the country. 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. Under such conditions, water is sometimes not available where and when it is required. Under conventional practices of irrigated agriculture, agriculture is considered as the major consumer of water compared to other sectors. The expansion of irrigated agriculture to feed the ever-increasing population on one hand and the increasing competition for water due to the development of other water use sectors on the other hand, as well as increasing concerns for environment, necessitated the improvement of water use efficiencies in irrigated agriculture to ensure sustained production and conservation of this limited resource.

In the study area, vegetable production is carried out mainly under furrow irrigation. Almost 98.9% of all household vegetable growers use furrow method of irrigation. However, a very small percentage (1.02%) used flood irrigation in the study areas (Etissa *et al.,* 2014). Lifting water by small pumps from different sources to the farm and then irrigating vegetable fields by gravity through narrow furrows (for onion) and broad bed furrow (for tomato) traditional irrigation types are the most common irrigation methods. Many references are available (Bos *et al.,* 2009) that, together with poor flow control, furrow irrigation leads to low uniformity of water application and the field application ratio is often less than 40%, rendering it the least efficient water application method. Strategies to improve the water use efficiency of irrigated crops are among others; deficit irrigation, precision irrigation technologies such as drip irrigation, improved furrow irrigation technique and soil and water conservation practices.

2.3 Water Scarcity and Plant Growth

Of the four soils, physical factors affect that plant growth (mechanical impedance, water, aeration, and temperature) (Hopmans, 2006) water is the most important. Drought causes 40.8% of crop losses and excess water causes 16.4%; insects and diseases amount to 7.2% of the losses. And 25.3% of the soils are affected by drought, and 15.7% limit crop production by being too wet (Hopmans, 2006). People depend upon plants for food. Because water is the major environmental factor limiting plant growth, we need to study soil-plant-water relations to provide food for a growing population.

Water is a challenged resource even in areas of the world that are relatively well endowed with water. The common perception is that water shortage (i.e. an absolute shortage of water supply in a specified domain) is the main reason for this state of affairs. However, the reality is that water scarcity, (i.e. an excess of water demand over available water supply) is by far the more important global challenge (FAO, 2012). Changing climate patterns will have important implications for water availability in Africa. According to the IPCC (2014), by 2030 an additional of 75 to 250 million people in Africa are projected to be exposed to increased water stress due to climate change.

The most important pressure on renewable water resources is linked to the agricultural sector in which irrigation represent the maximum demands (Valipour, 2014). Based on projections of the population growth and the increase in the standard of living, there are various views on the speed of increase in food production required to cope with the rapidly increasing mouths to be fed. The sector vision of Water for Food and Rural Development indicates the need for doubling the food production over the coming 25 years whereas the International Food Policy Research Institute suggests duplication in food production would be required in the forthcoming 50 years (Schultz *et al.,* 2005). The food production principally depends on the availability of water and an increase in production necessarily requires more water to be set aside for the agriculture sector. However, it is estimated that between 2000 and 2025, the global average annual water availability per capita will fall from 6,600 m^3 to 4,800 m^3. Besides, due to uneven distribution of water resources some 3 billion people will live in countries wholly or partially arid to semi-arid having less than 1,700 m^3 per capita per year water availability. Countries or regions are broadly considered water-stressed when the annual per capita availability is between 1,000 and 2,000 m^3. With availability below 1,700 m^3 per capita per year, a country is deemed ‘water scarce’; with less than 1,000 m^3per capita per year, it becomes ‘severe’ (ICID, 2002). This fact about the availability of water could be among the reasons for the general consensus that exists among scholars that the major part of the increase in production (about 90%) would have to come from already cultivated land, among others, by water saving, improved irrigation, and drainage practices, and increase in storages. The remaining 10% of the increase in food production would have to come from new land reclamations, either in the High lands or in the Lowlands (Hofwegen and Svendsen, 2000 and Schultz, *et al.,* 2005).

Ethiopia receives an average annual rainfall of 744 mm apparently adequate for food crop production, and pasture growth for livestock. However, the distribution of rain varies from region to region. Much of the eastern parts and countries like Somalia and Djibouti receive very little rainfall, less than 100 mm/year, while the Southwest highlands receive

2400mm/year. In the Southern and Eastern Highlands, there is a bimodal rainfall distribution, with the first and generally smaller rains peaking in April, and the second in September. The main dry season extends from October to February, being longer and drier in the North. Hence, the production of sustainable and reliable food crops is almost impossible due to temporal and spatial imbalance in the distribution of rainfall and the consequential non-availability of water in the required period. Intense rainfall sometimes causes flooding, particularly along the Awash River and in the Lower Baro Akobo and Wabe Shebelle river basins, causing damage to standing crops (Welderufael, 2006). Sometimes, even the Western Highlands of the country suffer from food shortage owing to the discrepancies in the rainfall distribution (MoWIE, 2001).

2.4 Water Productivity

The concept of water productivity in agricultural production systems is focused on 'producing more food with the same water resources' or 'producing the same amount of food with fewer water resources'. Water productivity (WP) mainly refers to the ratio between output derived from water use and the water input (volume or value of water depleted or diverted) (Clement *et al.,* 2011). The more commonly used concept of 'water productivity' and its measurement at various scales is a robust measure of the ability of agricultural systems to convert water into food. Increasing water productivity is particularly important where water is scarce compared with other resources involved in the production (Drechsel *et al.,* 2015).

In crop production system, water productivity is used to define the relationship between crops produced and the amount of water involved in crop production, expressed as crop production per unit volume of water (Kassam and Smith, 2001). Usually, water productivity is defined as a mass (kg), monetary ($) or energy (calorific) value of production per unit of water evapotranspired (Molden *et al.,* 2010), and, as such, it is a measure of the ability of agricultural systems to convert water into food.

According to Dang *et al.* (2001), water productivity defined in three different ways.

The water productivity per unit of evapotranspiration (WPET) is the mass of crop production divided by the total mass of water transpired by the crop and lost from the soil. The water productivity per unit of irrigation (WPI) is the crop production divided by irrigation flow. The water productivity per unit of gross inflow (WPG) is the crop production divided by the rain plus irrigation flow. Water productivity with reference to evapotranspiration WPET takes into accounts only water evaporated or transpired and is therefore focused on plant behavior whereas WPI and WPG include not only ET but also water used in other ways for crop products and water that is wasted.

Increasingly water productivity is being flagged as an important issue in relation to global and regional food security (Molden *et al.,* 2010). Increasing the WP of irrigated and rainfed agriculture is thereby seen as the critical element in increasing agricultural production without major increases in freshwater diversion to agriculture particularly in regions facing increasing water scarcity (FAO, 2012).

2.5 Crop Water Requirement

The term crop water requirement is defined as the amount of water required to compensate for 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 are related to the amount of water used. The variable amount of water contained in the soil and its energy state are important factors affecting the 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 the CROPWAT model.

Reference evapotranspiration (ETo) is calculated based on the FAO Penman-Monteith method (Allen *et al.,* 1998) as:

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma\frac{900}{T + 273}U_{2(e_s - e_a)}}{\Delta + \gamma(1 + 0.34U_2)} \qquad 2.1$$

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 the saturation vapor pressure deficit (kPa), Δ is slope of vapor pressure curve (kPa/°C), ϒ 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 obtained from Allen *et al.* (1998).

$$ETc = ET_o \times Kc \qquad 2.2$$

where, ETc = crop evapotranspiration; Kc = crop coefficient and 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).

Based on the above discussion reference evapotranspiration (ETo) can be estimated using the Penman-Monteith equation. Various crop growth stages and their respective lengths are identified for the locations of interest, and then Kc values for the various stages of the crop are determined. Kc values are then adjusted for the frequency of wetting condition for rain or irrigation. Then crop coefficient curves are developed to determine Kc values for periods of any length, e.g. monthly or daily periods. Crop ET is then calculated for well-watered conditions for each period of interest as the product of ETo and Kc. Having ETc and all necessary meteorological data, crop water requirement can compute with the aid of CROPWAT program. The gross water requirement will be then computed by taking application efficiency of 60% and 90% for furrow irrigation and drip irrigation method respectively as suggested by (FAO, 1989).

2.6 Irrigation Systems

2.6.1 **Surface irrigation**

Surface irrigation refers to a group of irrigation methods in which water is applied and distributed by gravity over the surface of the field. These methods of application include basin, border strip, and furrow irrigation. Water is applied at a high point or along the edge of a field and allowed to cover the field by overland flow. The efficiency and uniformity of irrigation are dependent on soil uniformity, quality of land grading, field topography, and control of the relationship between stream size, soil infiltration rate and duration of application. The disadvantage of this system is the inability to evenly apply small depths of water with high application efficiency (FAO, 1989).

2.6.1.1 Furrow irrigation method

Furrow irrigation method is one of the 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, maize, cotton, and potatoes, etc). Furrows are particularly well adapted to irrigating crops, which are susceptible to fungal root rot since water ponding and contact with plant parts can be avoided (Michael, 2008).

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, 2008).

Using furrows for irrigation necessitates the wetting of only part of the surface (one half to one fifth), thus reducing evaporation losses, lessening the pudding 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 the land of uneven topography. Furrow irrigation is adaptable to a great variation in slope (Hansen *et al.,* 1980).

2.6.1.1 Techniques of furrow irrigation

2.6.1.1.1 Alternate furrow irrigation technique

Alternate furrow irrigation (AFI) also known as irrigating every other furrow where one of the two neighboring furrows alternately being irrigated during consecutive irrigation periods.

Zhang *et al.* (2000) reported that the alternate furrow irrigation method uses less irrigation water but can maintain the same grain yield production as that of conventional furrow irrigation with high irrigation amounts. This is believed to be because of continuous regulation by root drying signal on stomata opening.

Total water use efficiency (TWUE) and net irrigation water use efficiency (NWUE) were larger in alternate furrow irrigation than in conventional furrow irrigation and Fixed Furrow irrigation with the same irrigation amount (Kang *et al.,* 2000).

Kang *et al.* (1999) investigation also reported that alternate furrow irrigation maintained high grain yield with up to 50% reduction in irrigation amount, while FFI and CFI all showed a substantial decrease in yield with reduced irrigation. As a result, water use efficiency for irrigated water was substantially increased and concluded that alternate furrow irrigation was an effective water-saving irrigation method in arid areas (Kang *et al.,* 2000). Water was saved using alternate furrow irrigation mainly achieved by reduced evaporation from the soil surface, as in the case of drip irrigation.

2.6.1.1.2 Fixed furrow irrigation systems

Fixed furrow irrigation (FFI) also known as irrigating every other furrow where one of the two neighboring furrows constantly being irrigated during consecutive irrigation periods. Research findings indicate that fixed furrow irrigation method also uses less irrigation water but can maintain the comparable grain yield production as that of conventional furrow irrigation with high irrigation amounts. Total water use efficiency (TWUE) and net irrigation water use efficiency (NWUE) were higher in fixed furrow irrigation than in conventional furrow irrigation (Kang *et al.,* 2000)

2.6.1.1.3 Conventional Furrow Irrigation System

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

2.7 Drip Irrigation System

Drip irrigation involves supplying water to the soil very close to the plants at very low flow rates (0.2 – 20 lt/hr) from a plastic pipe fitted with outlets (drip emitters) (Isaya, 2001). 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 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).

2.8 Deficit Irrigation

Deficit irrigation (DI) is an optimization strategy in which irrigation is applied during drought-sensitive growth stages of a crop. Outside these periods, irrigation is limited or even unnecessary if rainfall provides a minimum supply of water. Water restriction is limited to drought-tolerant phonological stages, often the vegetative stages and the late ripening period. Total irrigation application is therefore not proportional to irrigation requirements throughout the crop cycle. While this inevitably results in plant drought stress and consequently in production loss, DI maximizes irrigation water productivity, which is the main limiting factor (English, 1990). In other words, DI aims at stabilizing yields and at obtaining maximum crop water productivity rather than maximum yields (Zhang and Oweis, 1999).

Deficit irrigation (DI) is one way of improving water productivity and reduces the irrigation application. The crop is exposed to a certain level of water stress either during a particular period or throughout the whole growing season (English and Raja, 1996). In the past, crop irrigation requirements did not consider the limitations of the available water supplies. The design of irrigation schemes does not address situations in which moisture availability is the major constraint on crop yields. However, in arid and semi-arid regions, increasing municipal and industrial demands for water are necessitating major changes in irrigation management and scheduling in order to increase the efficiency of use of water that is allocated to agriculture. Furthermore, yield reductions from disease and pests, losses during harvest and storage, and arising from insufficient applications of fertilizer are much greater than reductions in yields expected from deficit irrigation. On the other hand, deficit irrigation, where properly practiced, may increase crop quality. For example, the protein content and baking quality of wheat, the length and strength of cotton fibers, and the sucrose concentration of sugar beet and grape all increase under deficit irrigation (Kirda,2002). According to English, (1990), the acceptance of a certain yield reduction is mandatory in the DI concept and crops are subjected to under-irrigation during the entire biological cycle.

2.9 Onion Crop Agronomy and Its Importance

Onion (Allium cepa L.) is since ancient times a valuable vegetable crop for people all over the world (Jaims and Fernando, 2008). Nowadays one can find onions with different colors, tastes, and bulb shapes, making the crop an important ingredient in all types of dishes around the world. On the list of worldwide cultivated vegetable crops, onions rank second only preceded by tomatoes (FAOSTAT, 2006). On a worldwide scale, around 58 million Metric tons (Mtons) are produced annually. China is by far the top onion producing country in the world, accounting for approximately 46% of the world's onion production, followed by India, USA, Turkey, Iran, Pakistan, and Japan. The worldwide onion exports are estimated at around 4 million Mtons. In Africa, the major producers of onion are Egypt, Algeria, Morocco and South Africa in which onion occupies an area of 40000, 28000,28000 and 19000 ha with a corresponding national yield of 25, 13.6, 18.2 and 21.1 ton per ha, respectively (Bosch *et al.,*2002). In Ethiopia, the crop is one of the most important vegetables produced by smallholder farmers mainly as a source of cash income and for flavoring, the local stew 'wot' (Lemma and Shimeles, 2003 and Fekadu and Dandena, 2006). In 2002, the total area under onion and shallot production in Ethiopia is estimated to be 10000 ha with an average yield of about 7.5 ton per ha (Kebede, 2003).

According to World Bank report (2004), in the year 2001, the crop shared one-fourth of the vegetable export quantities and stood third following green beans and peas contributing about 20% of the total vegetable export value which is about 244,000 US dollar of export earnings. This indicates that Ethiopia has a high potential to benefit from onion production. To utilize the genetic yield of onion and achieve high economic performance, it is necessary to gain knowledge of the crop response to different irrigation levels and to different irrigation application methods.

Health beneficial properties are frequently ascribed to onions (and even more to garlic); however, the evidence for this is often conflicting (Koch and Lawson, 1996; Keusgen, 2002). Especially in the area of cardiovascular disease, and to a lesser extent cancer, claims have been made, however, still, we do know too few about the action of Allium health beneficial compounds in the human body and its effects on human health (Kik *et al.,* 2001, 2005). As health-promoting compounds in Alliums, organosulphur species, flavonoids, and fructans have been suggested. The first indicated compounds, the organosulphur species, give Allium species like onion, garlic, and leek, their specific taste, and smell.

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 of 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 (Corgan *et al.,* 2000). 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 a 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 are 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 off 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).

2.10 Economic Analysis

Irrigation is essential for increasing the efficiency of input use, adoption of high-yielding varieties, and improving cropping intensity and crop yields. The water requirement is bound to increase with the expansion and intensification of agriculture in addition to the increased demand from the industrial and domestic sectors. There is still a wide gap between the created irrigation potential and utilization in Ethiopia (Seleshi *et al.* 2005, Hagos *et al.* 2010 and Makombe *et al.* 2007). Since water is a scarce resource, it is important to conserve and manage it efficiently. The over-exploitation of water has cropped up the problem of depletion and rise in water table which has resulted in creation of salinity and waterlogging problems. The question of economic efficiency in water use has remained largely unattended. When an efficient irrigation methods tied with deficit irrigation scheduling have been identified as promise irrigation practices that largely save irrigation water through improving water productivity. The trade-off between reduced yield and higher water productivity needs to be quantified in economic terms before recommending deficit irrigation (FAO, 2003). Both water productivity and irrigation water productivity can be increased by practicing deficit irrigation in parts of the field receiving the minimum water application depth. The most economical deficit irrigation level depends on the uniformity of application of the irrigation water and the associated cost of the irrigation water, any cost of remediation treatment on the drainage water, and the value of a unit of the crop (Wu, 1988, 1995). The efficient irrigation methods also increase the productivity per unit of irrigation water, thereby resulted in high economical return (Luhach *et al.,* 2004). So that a new irrigation practices needs to be evaluated in terms of its impact on productivity, profitability, acceptability and sustainability of the farming system.

3. MATERIALS AND METHODS

3.1.Description of the Study Site

The study was conducted during the cool cropping season of the year 2017-18 at Melkassa Agricultural Research Center (MARC) experimental farm of the Ethiopian Institute of Agricultural Research. The center is located in the Oromia National Regional State, East Shoa Administrative Zone. It is found in the Central Rift Valley of the country and contained within the Awash River Basin. It geographical extent range from $08^0 24' 05''$ to $08^0 25' 58''$ North latitude and $39^0 18' 55'$ to 39^0 $20'$ $04''$ East of longitude at an average altitude of 1550 m.a.s.l. The analysis of long-term meteorological data (1977-2017) reveals that average annual rainfall and potential evapotranspiration in the area is 824.9 mm and 220.77 mm, respectively (Table 1). The climate of the area is characterized as semi-arid with low, erratic and unimodal rainfall pattern. About 67.4% of the total rainfall of the area occurs from mid-June to mid-September, with its peak in the month of July and August. The mean maximum and minimum monthly rainfall values are 204.2 mm and 9.6 mm occur in the month of July and December, respectively. The mean maximum temperature varies from 26.3^0C to 31 ^{0}C while the mean minimum temperature varies from 10.4^0C to 16.4 ^{0} C, with the average value of 28.7^0C and 13.8^0C.

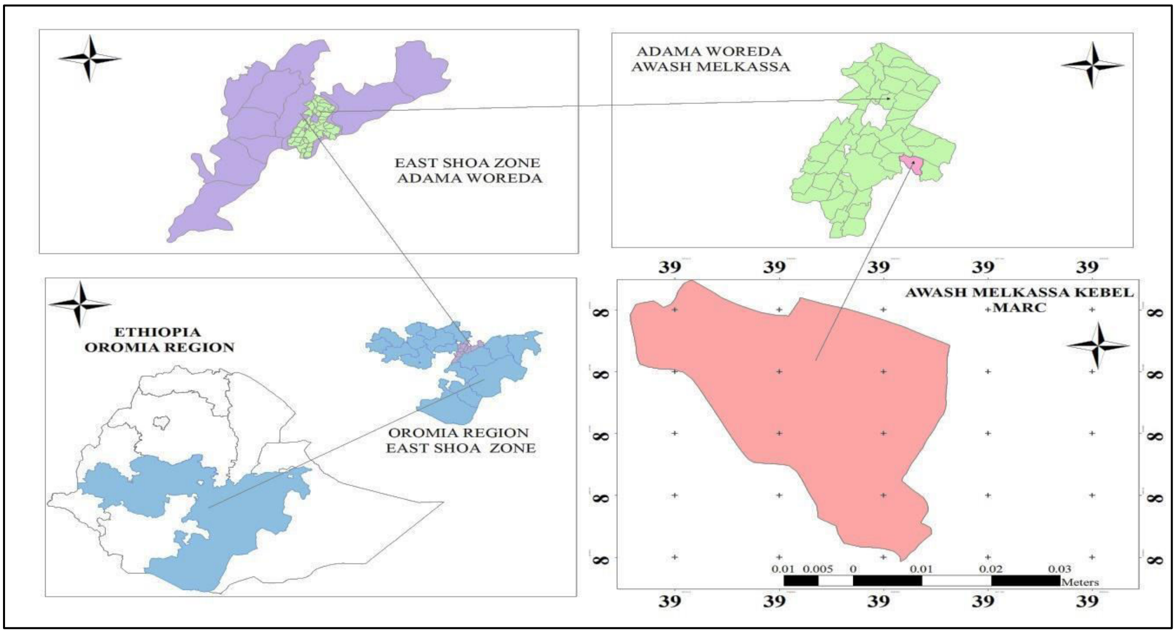

Figure 1 Study area

Loam and clay loam soil textures are the dominant soils of the area. Onion one of the major horticultural crops produced in the area.

Table 1 Long-term (1977 – 2017) mean monthly climatic data of the study area

Month	Rainfall mm/m	Air temperature Max (°C)	Air temperature Min (°C)	Humidity %	Wind Ms^{-1}	Sun (Hrs)	ETo $mmday^{-1}$	ETo mm/month
Jan.	16.0	11.7	27.9	51.0	8.6	9.0	7.3	226.6
Feb.	24.1	13.4	29.1	49.0	9.1	9.2	8.1	227.9
Mar.	52.3	15.1	30.5	49.0	8.6	8.5	8.5	262.3
April	53.9	15.5	30.5	51.0	7.8	8.2	8.1	241.5
May	61.0	15.5	31.0	51.0	7.5	8.8	8.1	250.2
June	69.0	16.4	30.2	53.0	9.0	8.4	8.1	242.4
July	204.2	15.7	26.8	66.0	9.1	7.0	5.9	183.8
Aug.	183.1	15.4	26.3	69.0	7.0	7.1	5.3	164.6
Sep.	99.8	14.5	27.6	66.0	4.9	7.3	5.4	161.1
Oct.	39.3	11.7	28.8	50.0	6.6	8.7	7.2	223.8
Nov.	12.6	10.8	28.3	47.0	8.3	9.6	7.8	233.1
Dec.	9.6	10.4	27.6	49.0	8.9	9.5	7.5	231.9
Avg.	68.7	13.8	28.7	54.3	8.0	8.4	7.3	220.8

3.2 Experimental Design and Layout

Deficit irrigation viz., 85%ETc, 70%ETc, 60%ETc and 50%ETc including a control irrigation of 100%ETc together with irrigation methods, viz., drip irrigation (DI), alternate furrow irrigation (AFI) including conventional furrow irrigation (CFI) as a control treatment were evaluated using split plot design in RCBD with three replication. The treatment combination is described in Table 2.

Table 2 Experimental treatments and treatment combination

Treatment	Treatment combination	Treatment description
T1	D*100%ETc	Drip irrigation with 100% ETc../control/
T2	D*85% ETc.	Drip irrigation with 85% ETc.
T3	D*70% ETc.	Drip irrigation with 70% ETc.
T4	D*60% ETc	Drip irrigation with 60% ETc.
T5	D*50% ETc	Drip irrigation with 50% ETc.
T6	AFI*85%ETc.	Alternate furrow irrigation 85%ETc.
T7	AFI*70% ETc.	Alternate furrow irrigation 70% ETc.
T8	AFI*60%ETc.	Alternate furrow irrigation 60% ETc.
T9	AFI*50%ETc.	Alternate furrow irrigation 50% ETc.
T10	CFI*100%ETc	Convectional furrow irrigation

Drip and furrow irrigation were the main plots and the five deficit irrigation levels were allotted to the subplots.

A field plot of 58*16.8m was selected for the experiment. It was divided into 30 plots of 4×3.6m to accommodate six furrows and five laterals with 4m length and representing a single treatment (Fig.2). The plots and replications had a buffer zone of 2 m and 3 m between plots on none supplying and supplying canal sides, respectively to eliminate the influence of lateral water movement. An overhead tank was used as a pressurized water source for the drip irrigation system. The main line of size 32mm and sub-main line of size 25mm both made of HDPE delivered irrigation water through LDPE laterals of 16 mm outer diameter with 4m length, built-in drippers with the discharge of 1lph/20cm spacing at 1 bar operating pressure.

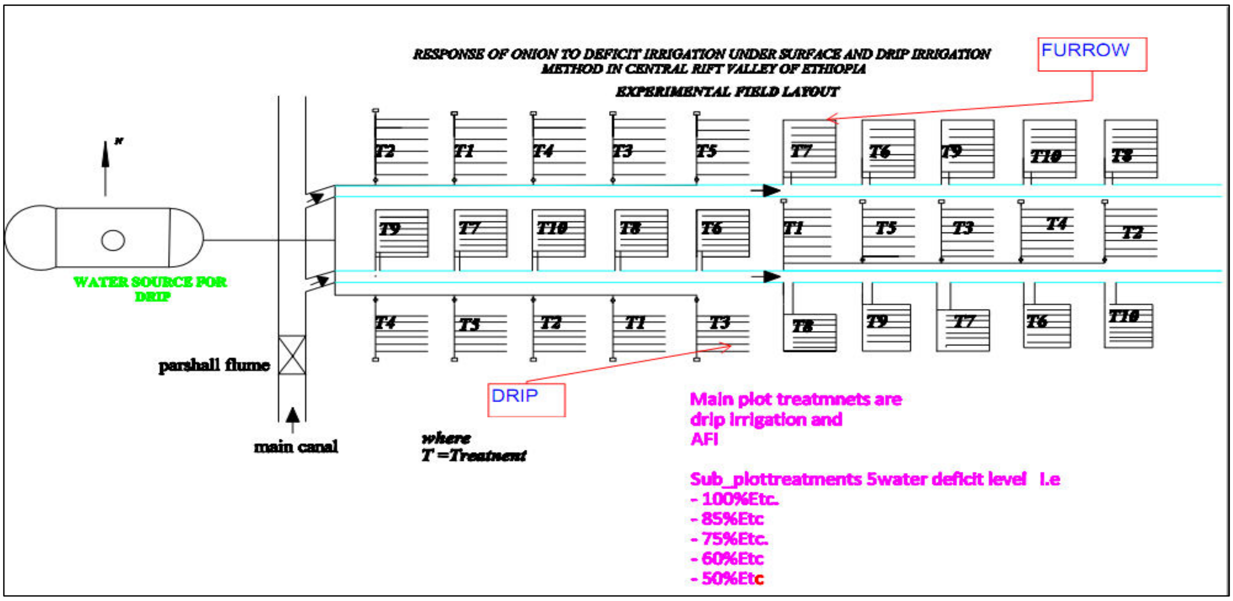

Figure 2 Experimental Design Layout and Drip Installation Description

3.3 Crop Management Practices

Onion (Allium cepa.L) seeds variety Nafis was used as a test crop. The selected variety seed was sown on 03 September 2017 on nursery field. The seedlings were then transplanted on 14 October 2017 on well prepared experimental plots on both sides of furrow ridge at the row and plant spacing of 20cm and 10cm, respectively. Onion seedling transplanted to experimental field received three common light irrigations in four days interval to ensure better plant establishment. Single fertilization with DAP at transplanting and split application of Urea at transplanting and 10 days after transplanting was done by hand placement at a rate of 150kg/ha and 75kg/ha, respectively (Olani and Fikre, 2010). The chemicals selecron and ridomil gold were used to safeguard the crop against harmful insects and fungal diseases. All other cultural practices other than treatment variables were done in accordance with the prevailing local condition and the recommendations made for the area.

3.4 Crop Water Requirement and Irrigation Management

The crop has a shallow root system with roots concentrated in the upper 0.3 m soil depth. In general 100 percent of the water, uptake occurs in the first 0.3 to 0.5 m soil depth. To meet full crop water requirements the soil is provided with sufficient moisture to sustain reference evapotranspiration rate of 5 to 6 mm/day. The rate of water uptake starts to reduce when about 25 percent of the total available soil water has been depleted (p = 0.25, where p is the fraction of soil water depletion) (Doorenbos and Kassam, 1979).

The crop requires frequent, light irrigations which are applied when about 25 percent of available water in the first 0.3 m soil depth has been depleted by the crop. The common practice is to apply irrigation every 2 to 4 days before harvesting or when 20-30% of the tops collapse. Over-irrigation sometimes causes spreading of diseases such as mildew and white rot. Irrigation can be discontinued 15 to 25 days before harvest (Doorenbos and Kassam, 1979).

Onion performs well and produces optimum yield under application of 350 to 550 mm of water throughout the growing season. Water stress affects onion development during transplanting, yield formation, and during the flowering period for seed crop. The crop is less sensitive to water deficit during the vegetative growth period and late season stage (Doorenbos and Kassam, 1979).

3.4.1 Irrigation scheduling and management

The reference evapotranspiration (ETo) was estimated using the FAO Penman-Monteith equation (CROPWAT8.0) employing daily actual climatic data from Malkassa Agricultural Research Center meteorological station. The growth period of onion in the experimental site is 110-days and it was divided into four stages, namely, initial stage (16days), Dev't. Stage, (30days), Mid.stage (40 days) and late.stage (24 days). The crop water requirements were calculated by multiplying the ETo values with the onion crop coefficients (Kc) given by (Doorenbos and Kassam, 1979) as 0.4 for the initial; 0.685 for the Dev;t, 0.95 for the mid.stage and 0.85 for the late growth stages (Table 3).

Table 3 Date of onion growth stage and crop coefficient (Kc)

Growth stage	Initial	Dev't	Mid	Late
Dev't days	16	30	40	24
Root depth (m)	0.3	0.40	0.6	0.6
Kc	0.4	0.68	0.95	0.85

100%Etc or ‘‘no deficit’’ irrigation (control) was calculated as the net amount of irrigation required to recharge the soil moisture deficit with daily application of irrigation water. The depth for other treatments was taken based on the percentage of full irrigation throughout the growing season.

Total available water (TAW) was computed from the moisture content of field capacity and permanent wilting point using the following equation as indicated by (Allen *et al.,* 1998)

$$TAW = (FC - PWP) \times \frac{BD_s}{BD_w} \times D_Z \qquad 3.1$$

Where: TAW is the total available water in the root zone (mm), FC and PWP are moisture content at field capacity and permanent wilting point in % (weight basis), BDs is the bulk density of the soil, BDw is density of water in g/cm3, and Dz is the maximum effective root zone depth of onion at times of each irrigation water application (mm). Readily available water (RAW) was computed using the following equation:

$$RAW = \rho \times TAW \qquad 3.2$$

Where: RAW is in mm, P is allowable permissible soil moisture depletion and TAW is total available water in mm.

The permissible soil moisture depletion (RAW) was taken as 100% ETc, accordingly, the Irrigation application with 0% deficit represents 100% ETc application. The 50%, 40%, 30%, 15% ETc deficit irrigation water applications indicate 50%, 60%, 70% and 85% of ETc application respectively. The soil moisture depletion depth for each treatment at any time was computed from the expression:

$$SMD = (FC - SMC) \times BD_s \times D_z \qquad 3.3$$

Where: SMD is the depth of soil moisture depleted at the time of moisture testing (mm) and it is the net maximum amount of water which can be applied and stored in the root zone during irrigation without deep percolation loss. FC is soil moisture contents in percent by weight at field capacity; ρb is the bulk density of the soil, Dz is the maximum effective root zone depth at times of sampling (mm) and SMC is soil moisture content in percent by weight at the time of moisture testing determined by using the following equation

$$SMC(\%Wt.\,base) = \frac{\text{the weight of wet soil(gm)} - \text{the weight of dry soil (gm)}}{\text{the weight of dry soil (gm)}} * 100 \qquad 3.4$$

The weight of dry soil was determined after placed the wet soil samples in an oven set at a temperature of 105°C and dried for 24 hrs.

3.4.2 Irrigation efficiency and gross irrigation water requirement

Field irrigation application efficiency (Ea) is the ratio of water directly available to the crop to water received at the field inlet. It is affected by the rate of supply, infiltration rate of the soil, the storage capacity of the root zone and land leveling. Water is mostly lost through deep percolation at the head end and through runoff at the tail end in furrow irrigation and deep percolation and evaporation in the basin.

Furrow irrigation methods reach application efficiencies of 60 – 70 % in high management systems and drip irrigation can achieve 90 –95% efficiency (Isaya, 2001). For this particular experiment, irrigation efficiency was taken as 60% and 90% furrow and drip irrigation method respectively. Based on the net irrigation depth and irrigation application efficiency, the gross irrigation water requirement was calculated based on the following formula.

$$D_{gross} = \frac{Dnet}{E_a} \qquad 3.5$$

Where:-

Dg: gross irrigation (mm)

Date: net irrigation depth (mm)

Ea: irrigation application efficiency

3.4.3. Water delivery and discharge measurement for each plot

For drip irrigation system treatments gross irrigation water (liter) was calculated via multiplying the total emitter discharge (number of emitters per plot * average emitter discharge) with the time required to irrigate that specific plot. Thus, by taking the time required to irrigate each plot the calculated amount of irrigation water was released from the source (tanker) up to the predetermined volume of water reaches for each drip irrigated plot.

The amount of water delivery to each furrow treatments was measured by using a Parshall flume device. The Parshall flume is a critical depth measuring device, which may be installed in a canal, ditch or a furrow to measure the rate of flow of water. It is a particular form of a venture flume. The flume has been standardized and calibrated for a wide range of capacities. For this purpose, out of the experimental field, 3-inch Parshall flume made from metal was set at 10 m away from the nearest plot to it in the main canal. The Parshall flume was set inside a straight and uniform section of the canal. The leveling in all direction in the converging part was checked. Leveling for the diverging part checked only across the waterway, as the base of the diverging part of Parshall flume is slightly slope upward. The bottom of the converging part was set 3 cm above the bed of the canal in the upstream side and stone riprap was put in the downstream side below the canal bottom level to minimize the erosion downstream of Parshall flume. A gauge of Parshall flume was written at a point two-thirds the length of the entrance section upstream from the flume crest. The gross irrigation calculated was finally applied to experimental plots based on the treatment. The volume of water applied for every treatment was determined based on the multiplication of the plot area and gross irrigation requirement. The irrigation time required to irrigate each treatment was calculated based on the discharge head relation of 3-inch Parshall flume. Since the discharge level might vary at field condition, the time required to irrigate each treatment was calculated from 5 cm to 15 cm head levels.

3.4.4. Hydraulic characteristics of drip irrigation system installed

After the installation of the drip irrigation system, the hydraulic characteristics of the system were evaluated for emitter flow rate, emitter flow rate variation, uniformity coefficient, emission uniformity, and application efficiency using the following equation:-

Emitter flow rate the average flow rate of the emitters used in the experiment was measured from plots in which catch cans were randomly assigned plots and volumes of flow caught over a time period. The discharge or flow rate out of single outlet emitter at a specified head was estimated thus:

$$q = \frac{V}{\Delta t} \qquad 3.6$$

Where q = single emitter discharge, liter/hour; V = volume of water collected from the emitter, liters; and Δt = time duration of discharge collection, an hour. The Christiansen uniformity coefficient was calculated as:

$$Cu = 100 - \left[80 * \frac{S_d}{V_{avg}}\right] \qquad 3.7$$

Where

Cu=Uniformity coefficient (%),

Sd=Standard deviation of observations,

Vavg = Average volume collected.

Emitter flow rate variation (qvar) was calculated using the equation

$$q_{var} = \frac{q_{max} - q_{min}}{q_{max}} \qquad 3.8$$

Where qvar = Emitter flow variation, qmax = the maximum emitter flow rate

qmin = the minimum emitter flow rate and the coefficient of variation, CV, was calculated using the equation

$$C = \frac{S}{\bar{q}} \qquad 3.9$$

Where: - S represents the standard deviation of emitter flow rate, and q is the mean emitter flow rate.

Emission uniformity, Eu (Kruse, 1979), was calculated using the equation

$$Eu = 100\frac{\overline{q_{lq}}}{\overline{q}} \quad 3.10$$

Where qlq is the mean of the lowest one -fourth of emitter flow rate and q is the mean emitter flow rate.

Application efficiency the overall application efficiency of the drip irrigation system was estimated from the relationship of (Vermeiren and Jobling, 1980) given as

$$E_a(\%) = K_s * E_u \quad 3.11$$

where Ea = Application efficiency, %; Ks = Average water stored in the root zone over average depth of water applied and is a coefficient which expresses the storage efficiency of the soil taking into account the pressure variation in the drip system (Ks=1 for loam soil) as in (Vermeiren and Jobling, 1980) and Eu = as given in Eq. (3.11).

3.5 Percentage Wetting Area (Pw)

In drip irrigation, water is applied close to plants so that only part of the soil in which the roots grow is wetted, unlike surface and sprinkler irrigation, which involves wetting the whole soil profile. This is one of the major advantages of drip irrigation over other methods. Indeed, irrigation is scheduled based on the soil volume in the root zone, which is only partially wetted. Soil moisture depletion is controlled to keep available moisture in the wetted area. The Percentage wetted area (Pw) is the average horizontal area wetted within the top 30 cm of the crop root-zone depth relative to the total crop area. The proper minimum value for PW has not been established. A reasonable approach is to wet at least one-third of the potential root volume of soil for widely spaced crops, i.e., 33 %< Pw< 67% (Keller and Bliesner, 1990). It is important to determine and use an appropriate percentage of the wetted area for both the system design and water use efficiency. The wetted area approaches 100% for closely spaced crops with rows and drip laterals spaced less than 1.8m apart.moderately loam soil a wetted percent area (Pw) of 55% used to determine the gross irrigation water requirement using drip irrigation.

3.6 Crop Sampling, Harvesting and Data Collection

For vegetative data collection randomly five onion plants were selected and the growth parameters data viz. leaves height, plant height and number of leaves were measured and recorded at the different growth stage. The onion was harvested on March 29, 2018, from the net harvested area of 5.4 m^2 while keeping four corners raw of onion for border effect when 50% of the tops are down.

Plant height (cm)

The plant height was measured from soil surface up to the tip of fully opened leaves with the help of measuring scale (ruler) and the average was worked out. The height of the five randomly selected and tagged plants were measured at different growth stage after transplanting and at harvesting stage.

Leaves height (cm) the length of the longest leaves of five randomly selected plants were measured using measuring scale (ruler) at physiological maturity and their averages were computed

Number of leaves per plant

The number of leaves per plant was counted in five randomly selected and tagged plants at different growth stage after transplanting and at harvesting stage.

Bulb height (cm)

The bulb height of five bulbs from each plot was measured by using digital caliper at the harvesting stage. Average was worked out and expressed in centimeter.

Bulb diameter (cm)

The Bulb diameter of five bulbs from each plot was measured by using digital caliper at the harvesting stage and the means were worked out and expressed in centimeter.

The average weight of bulb (g)

To calculate the average weight of the bulb in each plot, five plants were randomly selected and weighed on electronic balance after cutting the leaves from 2-2.5 cm above the neck. Finally, the average weight of the bulb in each plot was calculated in grams.

The dry weight of bulb per plant (g)

The fresh bulb from three randomly selected plants was weighed and dried in an oven at 65 0C temperature till constant weight. The weight of such dried bulb was recorded at harvest

The total yield of the bulb (t/ha)

After cutting the leaves (2-2.5 cm above the neck), bulbs were weighed on the electronic balance and bulb yield per net plot was recorded in kilogram which was converted into ton per hectare as given below:

$$\text{Bulb yield (t/ha)} = \frac{\text{Bulb yield (kg/plot) x 10}}{\text{Net harvested area of the plot m}^2} \qquad 3.13$$

3.6 Onion Yield Response Factor

The effect of water stress on yield was quantified by calculating the yield response factor (Ky) (Doorenbos & Kassam, 1979):

$$1-\frac{Y_a}{Y_m}=K_y\left[1-\frac{ET_a}{ET_m}\right] \quad 3.14$$

Where: Ya = actual yield (kg/ha),

Ym = maximum yield (kg/ha),

ETa = actual evapotranspiration (mm),

ETm = maximum evapotranspiration (mm), and

Ky = yield response factor.

3.7 Water Productivity (WP)

Araya *et al.* (2011), the WP (kg m-3) was calculated by dividing harvested total onion yield in kilogram to unit volume of water in cubic-meter or hectare-meter. The total water productivity is also known as water use efficiency (WUE, Kg m-3) and Irrigation water Productivity (IWUE, Kg m-3) was estimated.

$$WUE=\frac{Y_a}{ET_c} \quad 3.15$$

$$IWUE=\frac{Y_a}{D_{gross}} \quad 3.16$$

Where Ya= Actual bulb yield obtained (Kg)

ETc= Actual water applied to the soil throughout onion growing period (mm or m-3)

Dgross= Gross irrigation water applied throughout onion growing period (mm or m-3)

3.8 Economic Analysis and Evaluation

The Net income was carried out to determine the economic feasibility of the crop using surface and drip irrigation. The analyses include both fixed and operational costs. All calculations were done based on a unit area of 1 ha (Cetin and Uygan, 2008). The seasonal system cost of drip irrigation system included depreciation, bank interest rate, and repair and maintenance cost of the system. The fixed cost was concerning drip irrigation system components. The annual fixed cost was calculated by the following approach (James and Lee, 1971)

$$CRF=\frac{i(1+i)^n}{(1+i)^n-1} \quad 3.17$$

Where CRF is the cost recovery factor; i is the interest rate (fraction) and n is the useful life of the component (years).

ˆ $\text{Annual fixed}\frac{\text{cost}}{\text{ha}}=\text{CRF}*\text{fixed cost/ha}$

The total production cost, gross income and net return under different drip irrigation methods were estimated on the following assumptions

The useful life of the drip system was considered to be 7 years. The system cost was evaluated by distributing the fixed cost of the system over life period of drip irrigation set. For calculating depreciation, the life of the drip irrigation set and 10 % salvage value was considered. The interest was calculated on the average of investment of the drip irrigation set taking into consideration the value of the set in the first and last year @ 10 % per annum. Cost of repairs and maintenance of set is @ 2 % of the initial cost of the drip irrigation set per year.

The operating cost, including labor, land preparation, seeds, fertilizers, chemicals, diesel and oil, and repair and maintenance, was calculated. The total cost of production under different irrigation scenario was estimated by adding fixed and operating cost.

The gross income for different irrigation scenarios was estimated taking into account the marketable yield and market price of onion.

Subsequently, the net return under different irrigation scenarios was calculated considering the total cost of production and gross income. The benefit-cost ratio (B/C) under different irrigation schedules was calculated as follows:

$$\frac{C}{B} = \frac{Gross\ revenue\ (\frac{birr}{ha})}{Total\ cost\ of\ production(\frac{birr}{ha})} \qquad 3.18$$

3.9 Irrigation duration and water valuing

For drip treatments, a total of 83333 drip emitters with a discharging of 38333 l/h per hectare were used. Therefore, the total drip irrigation duration was calculated based on the total irrigation water applied for each drip irrigated treatments per ha. On the other hand, to determine the irrigation duration required for furrow irrigated treatment an average Parshall flume head of 8cm with a discharge rate of 3.52l/s was considered. For both methods of irrigation total cost for irrigation labor was worked out by taking the labor cost for the area was 60 birr and considering 8 h working time per day.

Even if, the water charge for irrigation purpose has not been implemented in any section of the country, 3.8 Birr m^{-3} was taken for economic analysis of this work which was derived from Jansen *et al.* (2007). They were studied on land and water resources in Ethiopia Central Rift Valley and was reported the irrigation water productivity for various irrigated crops in the Central Rift Valley area. To calculate the gross returns we assumed an average fresh market price of 6.5 birrs/kg. We also assumed that price did not vary by year, and that all production would go to the fresh market.

3.10 Statistical Data Analysis

The data were subjected to analysis of variance (ANOVA) appropriate to the experimental design (Gomez and Gomez,1984) using the general linear model of SAS software (Statistical Analysis Institute, Inc.2002 version 9) for split- plot experiment in a randomized complete block design (RCBD). Simple correlation analysis was made for yield and yield components. Significance differences among treatment means were evaluated using LSD at least 0.05 levels of significances.

4. RESULT AND DISCUSSION

4.1. Soil Sample Analysis

The result of laboratory soil analyses and field tests on physical and chemical characteristic including soil infiltration are given in Table 4, 5 and Figure 3.

4.1.1 Physical soil properties

The laboratory results of soil physical properties of the experimental site are presented in Table 4. The particle size distribution indicated that loam texture was the dominant texture.

Table 4 Physical soil properties of the experimental site

Depth (cm)	Texture				Bulk density (g/cc)	FC (%wt bases)	PWP (%wt bases)	TAW (mm)
	%Clay	%Silt	%Sand	Class				
0-15	26.5	45	28.5	Loam	1.09	33.8	20.8	21.24
15-30	24	42.5	33.5	Loam	1.16	36.5	21.1	26.85
30-45	29	35	36.0	Clay loam	1.18	39.3	23.5	27.87
45-60	26.5	37.5	36.0	Loam	1.19	37.7	22.9	26.47
Average	26.5	40	33.5	Loam	1.15	36.8	22.1	25.44

The bulk density of the experimental soil showed a slight variation with depth. It varied from 1.089g/cm^3 at the top root zone (0 – 15 cm) to 1.192 g/cm^3 at the lower root zone layer (45 – 60 cm). This could be because of a slight decrease in organic matter with depth and compaction due to the weight of the overlying soil layer (Brady and Weil, 2002). The weighted bulk density of the experimental site was 1.15g/cm^3. The average value of TAW was 169.63mm/m and this value is within the range of 100 – 175 mm/m and this characteristic for loam soil (Brouwer *et al.,* 1985)

4.1.2 Chemical properties

The average pH value of the experimental site through the analyzed soil profile was found to be nearly neutral with an average value of 7.02 (Table 5). However, onion can grows best in soils with pH range of 6.0 and 8.0 (Olani and Fikre, 2010) The soil had an average electrical conductivity of soil 0.262 dS/m through 60 cm profile which is below the threshold value for onion, i.e. 1.2 dS/m (Smith *et al*, 2011). The OM content, OC content and TN of the soil had average values of 5.68%, 3.3%, and 0.29% respectively.

Table 5 Average chemical soil properties of the experimental site

Depth (cm)	pH	ECe (ds/m) at 25^{0}c	Total organic matter (%OM)	Total nitrogen (%TN)	Total organic carbon (%)
0-15	6.74	0.215	7.4	0.37	4.29
15-30	7.07	0.229	6.72	0.34	3.90
30-45	7.08	0.299	5.24	0.26	3.04
45-60	7.18	0.305	3.36	0.17	1.95
Average	7.02	0.262	5.68	0.29	3.30

4.1.3 Infiltration characteristics of experimental soil

The infiltration test result and the cumulative intake curves of experimental soil are presented in Figure 3. The basic infiltration rate was found to be about 20mm/hr. As reported (Brouwer and Heibloem, 1990) the range of infiltration rate of loam soil is 10-20mm/hr. This is under the category of moderate infiltration rate. This means that a water layer of 20 mm on the soil surface will take one hour to infiltrate

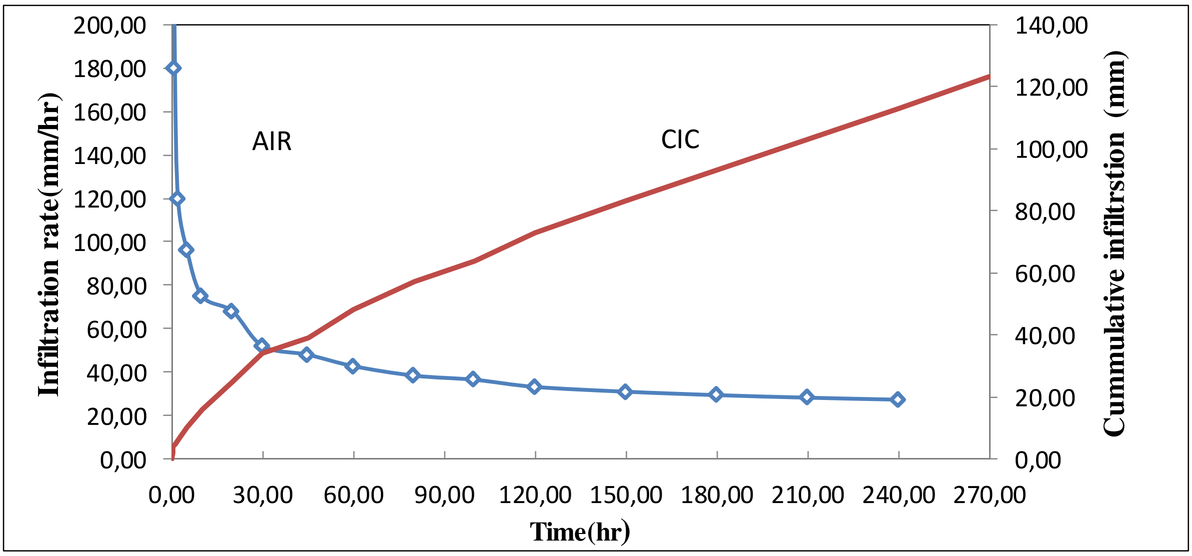

Figure 3 Infiltration curve of the experimental site

4.1.4 Drip Irrigation System Performance

Analysis of data on emitter discharge observation for emitter flow variation, field Emission uniformity, Coefficient of variation and uniformity of coefficient are presented in Table 6. The performances of emitters in all evaluation parameters were found to be good to excellent. Based on ASAE (1985) recommendation the field Emission uniformity and uniformity coefficient were excellent, emitter coefficient of variation was good and according to Bralts (1986) emitter flow variation was acceptable.

Table 6 Performance of drip emitter

Parameters	unit	Average	Grade	Source
Emission uniformity (Eu)	%	90.23	Excellent	ASAE, 1985
Emitter flow rate variation (q_{var})	%	4.66	Acceptable	Bralts ,1986
Coefficient of variation (CV)	%	2.69	Good	ASAE, 1985
Uniformity coefficient (UC)	%	97.84	Excellent	ASAE, 1985
Application Efficiency (Ea)	%	90.23	Excellent	

Over the three separate tests, the average emission uniformity was found to 90.23% while the mean of the uniformity coefficient was 97.84%, signifying even distribution of water throughout the system. These results are supported by (Merriam and Keller, 1978) who stated that a drip system with both emission uniformity and uniformity coefficient of 85% or greater, and with a discharge variation of less than 20% should be considered satisfactory.

The application efficiency obtained averaged 90.23%; this compared favorably to the results of (Sijal, 2001 and IDN, 2007) who stated that drip irrigation systems are typically about 90% efficient as compared to sprinklers that are about 75% efficient.

4.1 Irrigation Water Used

The crop water requirement of onion crop varies according to the treatments. For uniform seedling establishment, a common irrigation depth of 20 mm was applied irrespective of treatments after transplantation. The highest and minimum seasonal crop water requirement obtained was 468 mm and 134.2 mm at 100% ETc under drip and CFI and 50% ETc under AFI technique, respectively (Table 7).

Table 7 Seasonal net irrigation water depth applied for each treatment

Treatments	Common irrigation mm	Dnet (mm)	Total irrigation mm	Ea (%)	wa (%)	Dg (mm)
D*(100%)	20	448.0	468.0	90	55	286.0
D*(85%)	20	380.8	400.8	90	55	244.9
D*(70%)	20	313.6	333.6	90	55	203.9
D*(60%)	20	268.8	288.8	90	55	176.5
D*(50%)	20	224.0	244.0	90	55	149.1
AFI*(85%)	20	190.4	210.4	60	100	350.7
AFI*(70%)	20	161.8	181.8	60	100	303.1
AFI*(60%)	20	133.3	153.3	60	100	255.5
AFI*(50%)	20	114.2	134.2	60	100	223.7
CFI*(100%)	20	448.0	468.0	60	100	780.0

Dnet= irrigation during treatment application (mm), Ea = Application efficiency (%), wa=Wetted area (%) and Dg= Gross Irrigation water applied (mm)

4.5 Onion Crop Response to Irrigation Treatments

Deficit irrigation application under drip and Alternative furrow irrigation methods significantly affected onion growth and yield components like leaf number per plant, plant height, bulb height, bulb diameter and bulb weight, dry matter content in bulbs.

4.5.1 Onion growth parameters

The results of growth parameters including a number of leaves per plant, leaf height and plant height recorded at different growth stage as affected by the application of different treatment. The data shows a significant ($P<0.05$) difference between treatments due to irrigation method and irrigation levels on onion growth parameters.

Plant height (cm)

Table 8 shows that there was a significant effect observed on plant height due to Irrigation level and interaction, but the irrigation method had no significant effect on plant height. Among the irrigation levels, the maximum plant height was observed from 100%ETc application and significantly different to all deficit irrigation. The minimum plant height was recorded from 50%ETc deficit irrigation application and had no significant difference to all other deficit irrigation application.

This increased plant height may be related to the increase in turbidity of the cells with the increase in available soil moisture leading to quicker cell division and enlargement and findings are accordances with Neeraja *et al.* (1999) and Metwally (2011). This result was also similar with Yemane, *et al.* (2018), Shimeles (2009) and Takele and Desalegn (2009) who reported that the plant height of pepper decreased with decreased irrigation levels and also increase with the irrigation level.

Wien (1997) indicated that plant height had a linear correlation with the availability of soil moisture. The present result was also in agreement with the work of Al-Moshileh (2007) who reported that with increasing soil water supply, plant growth parameters (plant height) were significantly increased.

Among the interaction effect of irrigation method and irrigation levels, conventional furrow irrigation with 100%ETc application gave significantly ($P<0.05$) higher plant height and significantly different to all other treatments. These result associated with treatment which received a larger amount of water that showed significantly taller plants compared with plots which received lower amounts at the same date of sampling.

Number of leaf per plant

According to a number of leaves per plant and its production data in Table 8 indicate that there was an increase in the number of leaf /plant using drip irrigation method and increase in depth of water application. The number of leaf/plant of onion was significantly affected ($P\geq0.05$) by irrigation method and irrigation level but not by their interaction effect.

Among irrigation level, a higher number of leaf/plant of 12.13 was observed at 100%ETc followed by 85%ETc, 70%ETc and 60% ETc irrigation level with the value of 10.6, 10.5 and 10.4 respectively. There was no significant difference between the last four treatments with irrigation level including 50% ETc level. The minimum leaf number was recorded at irrigation depth of 50%ETc irrigation level (10.1). The result was in agreement with the Wien (1997) who reported that leaf number had a linear correlation with the availability of soil moisture. Combined treatments also showed a statistically significant influence on a number of leaves. The multiple numbers of onion leaves were recorded treatment receiving full irrigation under drip irrigation method and which had no significant difference to treatments gave 85%, 70%, and 60% ETc under the same irrigation method and to conventional furrow irrigation method. Whereas, Treatment receiving 50% ETc using alternate furrow irrigation technique was gave the least number of leaves.

Leaf height (cm)

The interaction of irrigation method and irrigation level has shown a highly significant ($P \leq 0.01$) effect on the leaf height. Significantly higher leaf height of 63.5 cm was recorded from CFI with 100%ETc and significantly different to all interaction.

Treatment	Plant height (cm)	No. of leaves per plant	Leaf height (cm)
Irrigation method (IRRI)			
D	52.13^{b}	11.3^{a}	47.2^{b}
F	56.53^{a}	10.2^{b}	50.8^{a}
S.Em±	1.39	0.05	0.77
LSD(0.05)	5.99	0.23	3.30
CV (%)	7.01	1.36	4.28
Level of irrigation (LI)			
100%	62.43^{a}	12.13^{a}	57.1^{a}
85%	54.46^{b}	10.6^{b}	50^{b}
70%	52.4^{b}	10.5^{b}	47.1^{bc}
60%	52.16^{b}	10.4^{b}	46.8^{bc}
50%	50.2^{b}	10.1^{b}	44.1^{c}
S.Em±	1.88	0.42	1.41
LSD(0.05)	5.75	1.29	4.31
CV (%)	5.98	6.77	4.97
Interaction (IRRIXLI)			
D*(100%ETc)	54.5^{b}	12.4^{a}	50.7^{bc}
D* (85%ETc)	53.2^{b}	11.5^{ab}	48.9^{bc}
D* (70%ETc)	51^{b}	11.4^{ab}	48.7^{bc}
D* (60%ETc)	51.6^{b}	11.1^{abc}	45.7^{bc}
D* (50%ETc)	50.2^{b}	9.7^{bc}	45.5^{bc}
AFI* (85%ETc)	55.6^{b}	10.1^{bc}	51.1^{b}
AFI* (70%ETc)	53.3^{b}	10.1^{bc}	48.7^{bc}
AFI* (60%ETc)	53.1^{b}	9.8^{bc}	48^{bc}
AFI* (50%ETc)	50.2^{b}	9.4^{c}	42.7^{c}
CFI*(100%ETc)	70.3^{a}	11.8^{ab}	63.5^{a}

S.Em±	2.65	0.60	1.99
LSD(0.05)	9.66	2.17	7.25
CV (%)	5.98	6.77	4.97

Table 8 Mean of onion growth parameters

Among the interaction effect, AFI with 85%ETc application level gave the highest leaf height of 51.1 cm and had no significant difference with all drip treatments and AFI with 700%ETc and 60%ETc deficit irrigation application (Table 8). The lowest leaf height of 42.7 cm was recorded from AFI with 50%ETc deficit irrigation level.

The different irrigation level has also affected onion leaf height significantly ($P<0.05$). The highest leaf height was observed from treatment receiving optimum irrigation depth i.e. 100%ETc irrigation level and significantly different from all deficit irrigation level.

Among deficit irrigation, 85%ETc application gave the highest leaf height and had no significant difference with 70%ETc and 60%ETc deficit application. The minimum leaf height recorded at the irrigation level of 50%ETc levels and had no significant difference with 60%ETc deficit application level. This result is in harmony with (Metwally, 2011)who indicated that the higher water supply resulted in higher vegetative parameters: Plant height, number of leaves per plant, bulb and neck diameter.

Among irrigation method furrow irrigation significantly affected the leaf height as compared to the drip irrigation method. This is due to the fact that a larger amount of water was associated with higher leaf height.

4.5.2 Onion Yield Parameters

Yield attributes viz. bulb diameter, bulb height, average bulb weight, marketable bulb yield and total bulb yield per hectare significantly affected by irrigation levels and irrigation method.

Bulb height (cm)

Bulb height (BH) was recorded at the harvesting stage and the data revealed there was an effect of irrigation methods and irrigation levels on onion bulb height. Among the irrigation levels, the maximum height of bulb was recorded with irrigation level 100%ETc which had no significant diffidence from its immediate deficit level 85 %ETc.Whereas, the minimum height of the bulb was observed from the irrigation level of 50%ETc application. Neeraja *et al.* (1999), Sharda *et al.* (2006) and Metwally (2011) have also found a similar effect of irrigation levels on the height of the onion bulb. On the other hand, Irrigation method did not significantly influence the bulb height. However, highs mean of onion bulb was observed in the application of irrigation water using drip irrigation method (Table 9).

The combined effect of irrigation method and different irrigation levels showed a significant influence on the height of the onion bulb. The highest onion bulb was recorded applying irrigation water using conventional furrow irrigation technique at the application level of 100%ETc and had no significant difference with drip irrigation method at 100%ETc and 85%ETc irrigation application.

Bulb weight (gm)

There was a significant effect of irrigation levels on the average weight of bulb. Among the irrigation levels, the maximum average weight of bulb was recorded with irrigation level (100%ETc) and it had no significant difference to application level 85%ETc. The minimum average weight of bulb was obtained in case of irrigation level 50%ETc. These findings are similar in Neeraja *et al.* (1999) and Sharda *et al.* (2006). Irrigation method also shows a significant effect on the average onion bulb weight. The weightiest onion was obtained through applying irrigation water using drip irrigation method.

The interaction effect also shows a significant effect on the average weight of the onion bulb. Treatment receiving irrigation water at 100%ETc under drip irrigation scores the heaviest onion bulb and this was not significantly different to treatment receiving 85% and 70% ETc under the same irrigation method and 100%ETc using furrow irrigation application method. The lightest onion bulb was observed treatment receiving 50% ETc using alternate furrow irrigation technique.

Bulb diameter (cm)

Irrigation method and level of irrigation influence the size of the onion bulb. Among the different levels, full irrigation application recorded higher bulb diameter (7.18 cm) and this was not significantly different to treatments receiving 85% and 70%ETc.The minimum bulb diameter was obtained treatment which receives 50% ETc irrigation level (5.5cm). This result fitting to Abdulaziz, 2003 and Biswas *et al.,* 2003 they indicated that the bulb diameter of onions was increased at higher levels of irrigation. Similarly, Olalla *et al.* 2004 reported that treatment which received the greatest volumes of water yielded harvests with higher percentages of large-size bulbs whereas water shortages led to higher percentages of small-size bulbs. Irrigation method on the other hand, significantly ($p \leq 0.05$) affected the bulb size of an onion. The maximum bulb size was achieved using drip irrigation method (6.7cm) and the minimum bulb size was recorded by using furrow irrigation method. This result associated with the application of the required depth irrigation water and makes to create favorable condition around the crop root zone in the way of efficiently utilized the available water and nutrient by the growing crop and this leads to encouraging vegetative growth as well.

The combined treatments also gave a significantly onion bulb size difference. Therefore, a combination of drip irrigation method and 100ETc depth application was given the largest onion bulb size and this was not significantly different to treatment receiving 85% and 70% under the same irrigation method. Moreover, 85% and 70% ETc application level under drip irrigation method not showing a significant difference to 100%ETc using CFI, 85% and 70% ETc under AFI. This is due to the availability of irrigation water around the root zone within 15 to 30 cm below the surface and forced the root mass to concentrate within that level and thereby, encourage the bulb formation which determines the size of onion bulb size.

The dry weight of bulb (gm)

The dry weight of bulb was significantly ($P<0.05$) affected by irrigation method and irrigation levels. The maximum dry weight of bulb observed from irrigating 100%ETc and had no significant difference from treatments receiving 85% ETc level and 70%ETc levels. While the minimum dry weight of onion bulb was recorded in the case of 50%ETc irrigation level (Table 9). More frequent irrigation resulted in the higher dry weight of bulb accumulation in the plant. These findings corroborate with those of Neeraja *et al.,* (1999), Olalla *et al.* (2004), Sharda *et al*., (2006).

In the present study, the drip irrigation method recorded a higher mean value of the dry weight of bulb than furrow irrigation method. And the interaction of irrigation method and irrigation level had shown significant influence on the dry weight of bulb. The maximum dry weight of onion bulb was obtained treatment applied full irrigation using drip irrigation method. This result associated with the availability of an onion bulb near the surface thereby made onion bulb exposed to sunlight.

Marketable bulb yield

The combination of irrigation methods and levels of irrigation application were demonstrated that a significant effect on marketable bulb yield of onion. Irrigating onion using drip irrigation method at full irrigation level was scored higher marketable bulb yield 49.13t/ha. This result had no significant yield difference to treatment receiving 15% below irrigation using the same irrigation method. Moreover, the result reveals that even if 15% less quantity of irrigation amount was supplied through drip method irrigation show a significant yield difference over conventional furrow irrigation method. Based on the result obtained using the drip irrigation method can increase by 18.18% of marketable bulb yield over using the conventional furrow irrigation method. Among irrigation level, the higher marketable yield was obtained in application of full irrigation and reduced significantly from full irrigation to deficit irrigation level.

The result is in agreement with (Postel *et al.,* 2001 and Howell, 2001) findings and reported that drip irrigation system can reduce irrigation requirements from 20 to 70% while increasing crop yields by 20–90% compared with surface irrigation.

Table 9 Mean of onion Yield attributes

Treatment	Bulb diameter (cm)	Bulb height (cm)	Bulb weight (g)	Bulb dry matter (g)	MBY (t/ha)	TBY (t/ha)
Irrigation method (IRRI)						
D	6.7[a]	5.88[a]	78.80[a]	42.66[a]	43.08[a]	46.30[a]
F	6.3[b]	5.92[a]	67.38[b]	34.64[b]	27.95[b]	29.96[b]
S.Em±	0.10	0.08	2.65	0.30	1.66	1.18
LSD (0.05)	0.44	0.34	11.42	1.30	7.16	2.49
CV (%)	4.46	3.71	9.58	2.14	2.48	2.22
Level of irrigation(LI)						
100%	7.18a	6.53[a]	83.73[a]	48.01[a]	44.67[a]	46.72[a]
85%	7.03a	6.12[ab]	77.63[ab]	44.12[a]	39.95[b]	42.14[b]
70%	6.90a	5.63[c]	73.98[bc]	43.85[a]	38.01[b]	40.25[b]
60%	6.03b	5.58[bc]	70.60[c]	33.83[b]	29.46[c]	32.61[c]
50%	5.56c	5.6[d]	59.50[c]	23.46[c]	25.51[d]	28.84[d]
S.Em±	0.20	0.22	3.07	3.31	1.12	1.18
LSD(0.05)	0.419	0.46	6.50	6.95	2.37	2.49

CV (%)	5.23	6.38	10.90	14.69	6.11	6.14
Interaction (IRRIXLI)						
D*(100%ETc)	7.56[a]	6.46[ab]	88.26[a]	55.73[a]	49.13[a]	52.10[a]
D*(85%ETc)	7.26[ab]	6.40[abc]	83.60[ab]	44.7[b]	46.56[ab]	49.53[ab]
D*(70%ETc)	7.20[ab]	5.50[d]	80.06[abc]	44.63[b]	45.21[b]	47.93[b]
D*(60%ETc)	6.13[cd]	5.46[d]	79.20[bc]	43.56[b]	39.43[c]	42.89[c]
D*(50%ETc)	6.03[de]	5.60[d]	78.70[de]	24.7[c]	35.10[d]	39.06[d]
AFI*(85%ETc)	6.80[bc]	5.83[bcd]	71.66[bcd]	43.53[b]	33.33[de]	34.75[e]
AFI*(70%ETc)	6.7[bc]	5.73[cd]	67.90[cd]	43.06[b]	30.80[e]	32.59[e]
AFI*(60%ETc)	6.13[cd]	5.86[bcd]	65.0d[e]	24.10[c]	19.50[f]	22.34[f]
AFI*(50%ETc)	5.4[d]	5.56[d]	60.93[e]	22.23[c]	15.92[g]	17.49[f]
CFI*(100ETc)	6.80[bc]	6.60[a]	142.0[abc]	40.3[b]	40.20[c]	41.34[cd]
S.Em ±	0.31	0.31	4.34	4.63	1.85	1.66
LSD(0.05)	0.66	0.65	9.20	9.83	3.9	3.53
CV (%)	5.23	6.38	7.01	14.69	6.11	6.14

Means followed by the same letter in a column are not significantly different from each other at the 5% probability level.

Total onion yield

The irrigation method and irrigation level had shown a significant (P≤0.05) effect on total yield of the onion bulb. Amongst irrigation levels, the maximum total yield of the bulb was recorded with irrigation level 100%ETc 46.72t/ha which was followed by immediate deficit level (85%ETc) 42.14t/ha. While the minimum onion bulb yield of 28.84t/ha was obtained from treatment receiving 50%ETc deficit irrigation level (Table 9). The significant increase in yield components and yield was attributed to sufficient moisture in the rhizosphere which did not show any visual stress on various physiological processes resulting in better uptake of moisture and finally increased plant growth, yield and yield attributes (Neeraj *et al*, 1999). These findings are similar to Sharda *et al.* (2006) and Spehia *et al.* (2013). And also the higher yield was obtained in full irrigation and reduced significantly from full irrigation to deficit irrigation level. The result is in conformity with those obtained by Zayton (2007), Tilahun and Samson, (2007), Kumar *et al.* (2008) and Owusu-Sekyre, (2010).

The irrigation methods also affected the bulb yield significantly. Data recorded in the present study indicated that drip irrigation was scored the higher mean value of total yield of the bulb over the furrow irrigation method (Table 10). This is because that onion is a shallow-rooted crop (Drinkwater and Janes, 1995) that requires frequent irrigation to achieve a good yield. Onion under water deficiency decreases in its evaporation and consequently, yields (Sammis *et al.,* 2000). On the other hand, the combination of irrigation method and irrigation level was showed the promising result to maintain the onion bulb yield according to applied irrigation water. A Significant higher yield (52.1t/ha) was observed applying full irrigation under drip irrigation method. This result reveals that 15% deficit application had no significant difference using the same irrigation method. The significant lowest 17.49t/ha was recorded from treatment receiving 50%ETc using alternate furrow irrigation technique. This shows that the highest yield reduction was occurred due to double deficit practices in alternate furrow irrigation technique. The explanation of this result is for deficit treatment under AFI exposed to double reduction of irrigation water one due to deficit irrigation, the other is due to alternate irrigation (in this technique some furrows are irrigated, while adjacent furrows are not).

4.5.3 Yield and irrigation production efficiency

The relation between applied water and total onion bulb yield was evaluated for each interaction of irrigation method and deficit irrigation level (Fig. 4). The relationship between applied water and total bulb yield was quadratic.

Small irrigation amounts increased yield, more or less linearly up to a level where the relationship was curvilinear because part of the water applied is not used in ETc. At a point of 468 mm (i.e., 0% deficit level) of irrigation water amount under drip irrigation, yield reached its maximum value (52.1t/ha). Moreover, the regression equation shows that additional amounts of irrigation did not increase it any further (Figure 4).

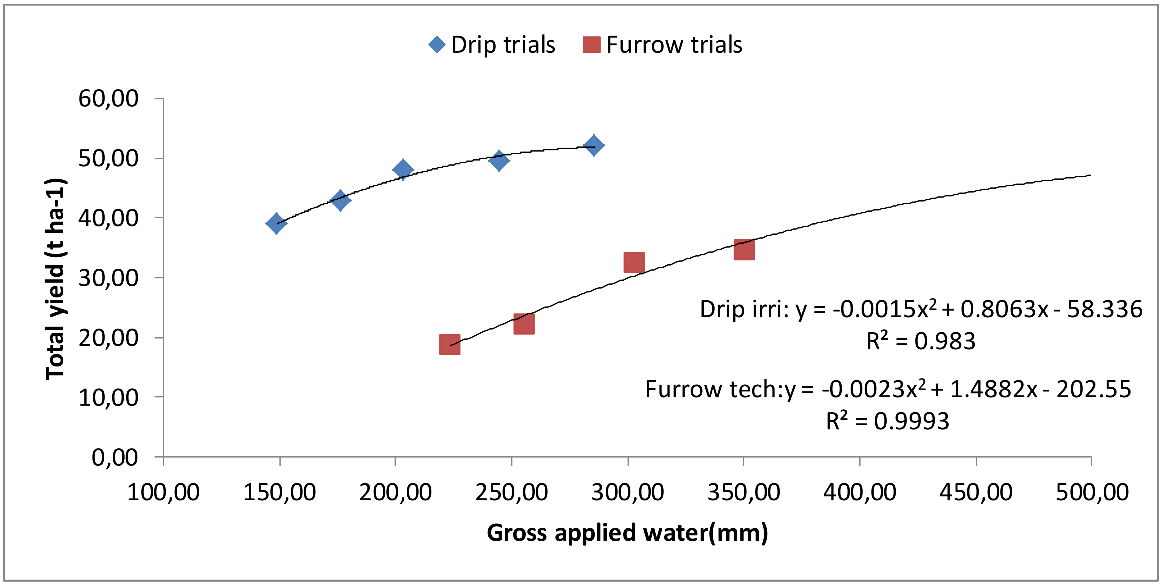

Figure 4 Relationship between onion bulb yield and applied water under drip and furrow irrigate

The significant coefficient, 0.98** and, 0.99** for treatment under drip and furrow techniques of irrigation method clearly indicated that the increased water supply causes the increase in yield of onion only to certain limit, after which it stagnates and decreases. The highest onion bulb yields were obtained application of irrigation water in the range between 200mm - 300mm using drip irrigation method and under furrow irrigating techniques. These values are a good predictor for the onion growers in the CRV area, but also create a good platform for the whole region around this area.

Table 10 Onion water production function according to applied irrigation water

Treatments	Applied water (mm)	Actual Yield (t/ha)	Water production function	r^2	Maximum yield (t/ha)
D*(100%)	2860.0	52.1			52.1
D*(85%)	2449.3	49.53			49.5
D*(70%)	2038.7	47.92	$y=-0.0015x^2+0.8063x -58.336$	0.983	47.9
D*(60%)	1764.9	42.89			42.9
D*(50%)	1491.1	39.05			39.1
AFI*(85%)	3506.7	34.75			34.8
AFI*(70%)	3030.7	32.59	$y=-0.0023x^2+1..4882x-202.55$	0.999	32.6
AFI*(60%)	2554.7	22.34			22.3

AFI*(50%)	2237.3	18.83	18.8
CFI*(100%)	7800.0	41.34	41.3

4.2 Effects of Irrigation method and Irrigation level on WP and IWP of onion crop

Both water productivity and irrigation water productivity were influenced by irrigation method and irrigation levels. Considering, irrigation method, higher mean value of water productivity and irrigation water productivity were observed under drip method with a mean value of 11.1 kg m^{-3} and 18.22 kg m^{-3} respectively, which have 20.9% and 70.9% higher over conventional furrow irrigation method (respectively 8.8 and 5.3 kg m^{-3}). And also the result revealed there was 63.3% higher water saved under drip irrigation method. This may be due to the uniform distribution of moisture in the effective root zone of onion crop in the soil profile under drip irrigation method and consequently minimal runoff, evaporation and percolation losses. This result in agreement with Sharma, (2001) found that the average drip irrigation saved up to 80% of water as compared to the furrow irrigation system. In a study (Camp *et al*, 2001) reported that on the average, drip irrigation saves about 70 to 80% water as compared to conventional flood irrigation methods. Moreover, (Ibragimov *et al.,* 2007) found that yield was higher by 18-42% and water use efficiency by 35 to 103% in drip mode. In drip treatment, there was an increasing trend of both water productivity and irrigation water productivity when the deficit level increase. This result was in covenant with (Mekonen, 2011) with an increasing amount of water supply, the water use efficiency decreases.

On the other hand, in furrow irrigation treatment the highest WP & IWP was obtained through irrigating onion crop using AFI at 70%ETc application level and followed by AFI at 80%ETc application level (Table 10). The lowest WP & IWP was recorded using CFI at full irrigation application. These results are in line with Abdel Maksoud *et al.* (2002) who concluded that AFI improved crop water utilization efficiency for the crop under study. Results show that AFI saved water by approximately 50.5% and 43.5%, respectively, as compared to CFI. The lowest amount of applied water under AFI treatments as compared with CFI might be due to the great reduction of wetted surface in AFI; almost half of the soil surface is wetted in AFI as compared with CFI. The highest ETc occurred in the CFI obviously owing to an adequate soil water supply during the growing season (780 mm). This result supports the outcome obtained by Geraterol *et al.* (1993), who found that AFI methods can supply water in a way that greatly reduces the amount of wetted surface, with leads to less evapotranspiration and less deep precipitation. Reduced irrigation water due to the alternate furrow management reported by El-Sharkawy *et al.* (2006), Sepaskhah and Ghasemi (2008), Shayannejad and Moharreri (2009), Ibrahim and Emara (2010) for sugar beet; Nelson and Kaisi (2011). AFI management, by reducing outlet drainage, can avoid the reduction of groundwater level and deep earth subsidence. AFI management, because of lateral infiltration water in furrow among watering, can cause decreased vertical infiltration. As in the case of deficit irrigation practice, the lowest level of application not scores the highest WP & IWP, this due to the exposer of the onion crop to double deficit level which was resulted in severe yield reduction.

Table 11 Water Productivity of Irrigation Treatment for Onion Crop

Treatments	Total irrigation water mm	Total irrigation water $m^3\ ha^{-1}$	Onion total yield kg ha^{-1}	WP kg m^{-3}	IWP kg m^{-3}	% of water saved
D (100%)	286.0	2860.00	52098.77	11.13	18.22	63.33
D (85%)	244.9	2449.33	49529.23	12.36	20.22	68.60
D (70%)	203.9	2038.67	47924.31	14.37	23.51	73.86
D (60%)	176.5	1764.89	42890.05	14.85	24.30	77.37
D (50%)	149.1	1491.11	39054.81	16.01	26.19	80.88
AFI (85%)	350.7	3506.67	34751.98	16.52	9.91	55.04
AFI (70%)	303.1	3030.67	32590.66	17.92	10.75	61.15
AFI (60%)	255.5	2554.67	22335.68	14.57	8.74	67.25
AFI (50%)	223.7	2237.33	18827.16	14.03	8.42	71.32
CFI	780.0	7800.00	41341.11	8.83	5.30	0.00

AFI at 70% and 80% application level reduce the irrigation water use by more than 50% over CFI. This enables us to incorporate more land under irrigation and enhance the bulb yield per unit of land. In AFI, some furrows are irrigated, while adjacent furrows are not, and WP is increased mainly by reduced evaporation from the soil surface, as in the case of drip irrigation. General, the use of such methods of irrigation results in a lower yield in spite of a higher WP (Sepaskhah *et al.,* 2015).When water was insufficient for full irrigation, the relative bulb yield (yield per unit water applied) of onion under AFI was higher than those under CFI.

4.3 Onion Yield Response to Water

The crop yield response factor gives an indication of whether the crop is tolerant of water stress. A response factor greater than unity indicates that the expected relative yield decrease for a given evapotranspiration deficit is proportionately greater than the relative decrease in evapotranspiration (Kirda *et al.,* 1999). The yield response factor was affected by irrigation method and irrigation level. The result reveals that the highest Ky (0.90) was observed when alternate furrow irrigation combined with 50%ETc irrigation application and under drip irrigation, the lowest yield response factor was recorded applying 50%ETc irrigation level. Therefore, irrigating onion using alternate furrow irrigation with 50%ETc levels could cause considerable yield penalty.

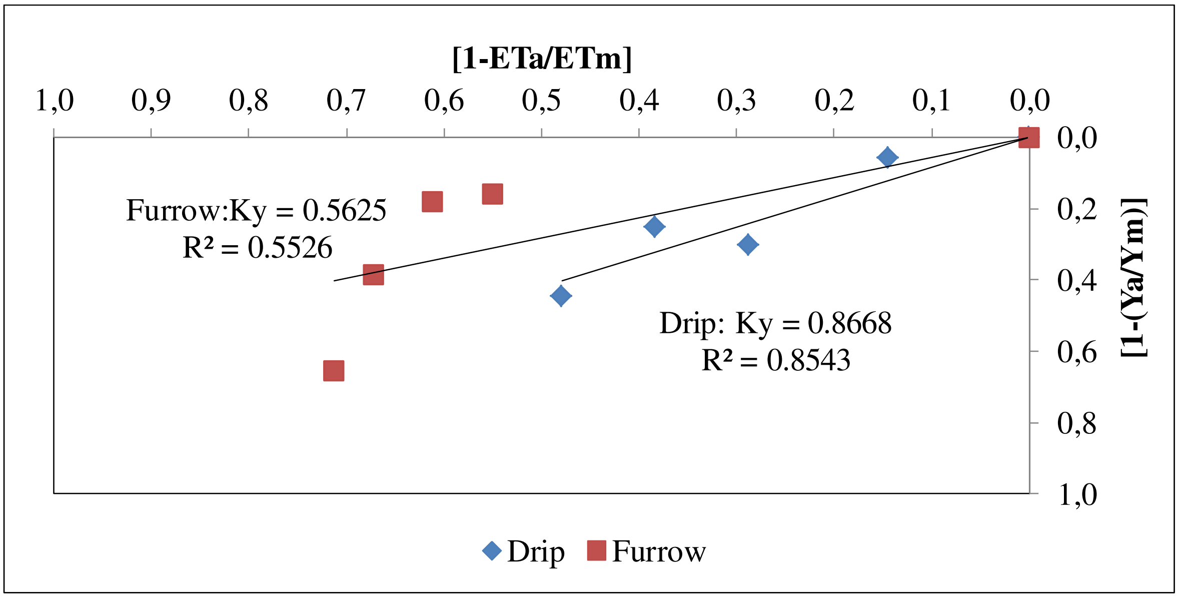

Figure 5 The relationship between relative bulb yield decrease and relative ET deficit for onion

4.4 Correlation Coefficient of Marketable Bulb Yield and Its Component in Onion

Correlation coefficient analysis is a statistical measure which is used to find out the degree and direction of the relationship between two or more variables. Association among different plant growth parameters, yield, and yield attributing characters s presented in

Table 12. The marketable bulb yield showed significant ($P \leq 0.05$) positive correlation with leaf height, leaf number, average bulb weight, bulb height, bulb diameter, and bulb dry weight and non-significant negative correlation with plant height. And similar finding was reported by (Sahu *et al.,* 2018).

The result reveals that water productivity was correlated negatively with all the studied parameters. This is, the increase in water productivity was with a compromise with reducing the yield and yield components due to the reduction of irrigation water amount.

Table 12 Pearson's correlation coefficient (r) of yield and yield attributes of onion as affected by irrigation method and irrigation level

	MY	TY	LH	PH	LN	BW	BD	BH	BDW	WP
MY	1									
TY	0.998***	1								
LH	0.486*	0.454*	1							
PH	0.349ns	0.317ns	0.939***	1						
LN	0.478*	0.494*	0.289ns	0.318ns	1					
BW	0.819***	0.822***	0.334ns	0.246ns	0.635**	1				
BD	0.845***	0.839***	0.386ns	0.313ns	0.491*	0.708***	1			
BH	0.461*	0.445*	0.600***	0.565**	0.426*	0.375ns	0.585**	1		
BDW	0.833***	0.826***	0.301ns	0.203ns	0.426*	0.791***	0.775***	0.386ns	1	
WP	-0.027ns	-0.033ns	-0.158ns	-0.213ns	-0.605***	-0.378ns	-0.161ns	-0.295ns	-0.111ns	1

***= statistically very highly significant ($p<0.001$), **= statistically highly significant ($p<0.01$),*=statistically significant ($p<0.05$) and ns= statistically not significant ($p>0.05$).LH= Leaf height, PH=Plant height, LN=leaf number, BW= Bulb weight, BD=Bulb diameter, BH= Bulb height, BDW=Bulb dry weight, MY=marketable yield, TY=Total bulb yield and WP=Water productivity of onion

4.5 Economic returns (productivity) analysis

Economical analysis and evaluation were computed by using the results of this study based on investment, operation and production costs.

The production costs were computed by considering all production inputs (i.e. costs of seeds, plowing of land, transplanting, hoeing, pesticides, fertilizers, harvesting, etc.) for onion growth in the study area. Thus, the seasonal production costs were 57,120.00 birrs and 42,720.00 birrs for drip and furrow irrigated treatments respectively. The cost for both individual treatments was the same except the labor cost for irrigation, water charge and the investment cost of the drip irrigation system because of having the same plant density per ha. The cost of a drip irrigation system was determined to be 98,395.06 birr/ha and the annual cost calculated was 17383.4birr/ha/year. On the other hand, for the purpose of calculating the total cost of onion production for a year, the sum of the crop production costs, the annual fixed cost of the drip irrigation system, and the irrigation cost are taken into account. According to the calculation and evaluation, the maximum net income was obtained 252711.0 birr ha^{-1} for treatment which irrigated using a drip system and receiving full irrigation water. The detail evaluation of economic analyses of irrigation treatments has shown that there was an increasing trend of net income for an increase in water application level (Table 13).

Table 13 The economic analysis and results for the treatments

Treatments	Amount of irrig. water	Irrigation water	Irrig. duration for the irrigation period	Labor cost for irrig.	Total cost for irrigation labor	Water price	Water cost	Crop production cost
	mm	m^3 ha^{-1}	h	Birr	Birr	Birr m^{-3}	Birr ha^{-1}	Birr ha^{-1}
D (100%)	286	2860	74.6	60	559.6	3.8	10868	57120
D (85%)	244.9	2449.3	63.9	60	479.2	3.8	9307.5	57120
D (70%)	203.9	2038.7	53.2	60	398.9	3.8	7746.9	57120
D (60%)	176.5	1764.9	46	60	345.3	3.8	6706.6	57120
D (50%)	149.1	1491.1	38.9	60	291.7	3.8	5666.2	57120

AFI (85%)	350.7	3506.7	275.8	60	2068.4	3.8	13325.3	42720
AFI (70%)	303.1	3030.7	238.3	60	1787.6	3.8	11516.5	42720
AFI (60%)	255.5	2554.7	200.9	60	1506.9	3.8	9707.7	42720
AFI (50%)	223.7	2237.3	176	60	1319.7	3.8	8501.9	42720
CFI	780	7800	613.4	60	4600.8	3.8	29640	42720

Treatments	Irrigation system cost 1 ha	Seasonal cost of Drip irrigation system	Total cost for 1 year	Yield	Onion sales price	Gross income	Net income	C:B
	Birr ha^{-1}	Birr ha^{-1}	Birr ha^{-1}	kg ha^{-1}	Birr kg^{-1}	Birr ha^{-1}	Birr ha^{-1}	Ratio
D (100%)	98395.1	17383.4	85931	52098.8	6.5	338642	252711	2.94
D (85%)	98395.1	17383.4	84290.1	49529.2	6.5	321940	237649.9	2.82
D (70%)	98395.1	17383.4	82649.2	47924.3	6.5	311508	228858.8	2.77
D (60%)	98395.1	17383.4	81555.3	42890	6.5	278785.3	197230	2.42
D (50%)	98395.1	17383.4	80461.4	39054.8	6.5	253856.3	173394.9	2.16
AFI (85%)	0	0	58113.7	34752	6.5	225887.8	167774.1	2.89
AFI (70%)	0	0	56024.2	32590.7	6.5	211839.3	155815.1	2.78
AFI (60%)	0	0	53934.6	22335.7	6.5	145181.9	91247.3	1.69
AFI (50%)	0	0	52541.5	18827.2	6.5	122376.5	69835	1.33
CFI	0	0	76960.8	41341.1	6.5	268717.2	191756.4	2.49

For all drip irrigated treatments, the total expenditure and total return vary following the amount of water applied. On the other hand, cost per ha expenditures is expensive for a drip irrigation system. However, initial investment costs can be able to amortize over an expected life of the drip systems. Concerning, the furrow irrigation techniques the highest net income was obtained under conventional furrow irrigation. But the highs C: B was recorded the application of irrigation water using alternate furrow irrigation technique at 85% and 70% ETc, 2.88 and 2.78 respectively. The explanation for this result is the unit price of irrigation water was very lower.

5. CONCLUSIONS AND RECOMMENDATION

An investigation titled "Response of onion (Allium cepa L.) to deficit irrigation under surface and drip irrigation method)'' Was conducted at research Farm of Melkasa agricultural research center in the dry season of 2017-18.Ten treatment combinations comprising of two irrigation method (drip and Furrow irrigation (CFI .AFI) and five Irrigation levels (100%ETc, 85%ETc, 70%ETc, 60%ETc and 50% ETc) were laid out in split plot design with three replications. The results obtained from the study have been summarized as follows:

5.1 Effect of Irrigation Levels

The results of the experiment with respect to growth attributes of onion crop revealed a significant effect of irrigation levels on plant height, a number of leaves and leaf height. The full irrigation (100%Etc) recorded maximum plant height, a number of leaves and leaf height at all stage observation, followed by irrigation deficit (85%ETc and 70%ETc). The minimum value was recorded in (50%ETc) deficit irrigation.

Yield parameters and yield of the onion were studied with respect to bulb diameter, bulb height and an average weight of bulb per plant, and total yield of bulb showed a significant effect for irrigation levels. Maximum, bulb diameter, bulb height, the average weight of bulb and total yield of bulb yield per hectare with irrigation level (100%ETc) which was followed by 85%ETc and 70%ETc. Lowest bulb diameter, bulb height, the average weight of bulb and total yield of bulb per hectare were recorded in irrigation level (50%ETc).

5.2 Effects of Irrigation Method

The results of the experiment with respect to growth attributes of onion crop revealed a significant effect of irrigation method on plant height, leaf height and leaf number recorded at the different growth stage. Furrow irrigation recorded maximum plant height; leave height whereas in drip irrigation the height leaves number was recorded.

Yield parameters and yield of the onion were showed a significant effect of irrigation method. Maximum, bulb diameter, the height of bulb, the average weight of bulb, and total bulb yield per hectare were observed with Drip irrigation method which was followed by conventional furrow techniques of irrigation.

5.3 Combined Effect of Irrigation Method and Irrigation Levels

Interactive effect of irrigation method and irrigation levels showed significant influence on growth and yield attributes viz., plant height, and a number of leaves, leave height, the average weight of bulb per plant and total yield of bulb per hectare.

The combined effect of irrigation method and irrigation levels also showed a higher significant effect on water productivity and irrigation water productivity.

Based on the study and the results obtained on yield, yield component, and water productivity, the following recommendations could be forwarded.

5.4 Recommendation

On the basis of the present experiment, it may be concluded that drip irrigation results in the realization of significantly higher growth attributes and yield attributes of onion crop as compared to furrow irrigation treatments. Among the different irrigation levels, application (100%ETc) proved the best treatment compared with other treatments. In drip treatment the lowest water application score the highest water productivity, whereas in furrow water application the highest water productivity and irrigation water productivity were recorded at 70% irrigation level under AFI followed by 80%ETc with the same water application technique. Beside this AFI method of irrigation can save a substantial amount of water and maintain bulb yield in onion production in areas where irrigation is essential. This result should be of significant value in arid areas with shrinking water resources as the sustainable use of water is increasingly a worldwide problem. AFI with 70% irrigation level can be used as an optional furrow irrigation technique for onion production in arid areas like CRV of Ethiopia, since all onion grower community dominantly have been practicing furrow irrigation method .It could be concluded that the alternative furrow irrigation with 70%ETc irrigation level applied in area where water is the limiting factor for onion production.

Therefore, it is recommended that for non-stress scenario onion could be irrigate at full irrigation application using drip and convection furrow irrigation method. On the other hand, for limited water resource situation it is advisable to irrigate the available water using alternative furrow irrigation technique at 70% ETc for the purpose of higher yield of onion per unit of water. It is also the best water management potion for those farming community not affording to the drip irrigation system and an area where there is water scarcity as well as labor expensiveness, to increase the production of onion and other vegetables.

However, these are on the basis of one-year experimentation, which needs further testing and confirmation.

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7. APPENDICES

Appendix Table 1 Average monthly climatic data during the study period

Year	Month	Min	Max	Humidit	Win	Sun	Rad	ETo

		Temp	Temp	y	d			
						hour	MJ/m?/da	mm/da
		°C	°C	%	m/s	s	y	y
2018	January	8.8	27.8	46	2.7	9.5	21.7	5.32
	February	13.4	30.6	49	2.7	8.7	21.7	5.68
	March	15.8	30.9	44	2.6	8.7	22.8	6.12
	April	16.4	30	59	1.9	7.4	20.8	4.98
2017	September	16	27.7	70	1.8	7.5	20.8	4.44
	October	13.3	29.6	55	2.4	9.1	22.6	5.3
	November	10.8	28.6	48	2.7	10.2	22.8	5.44
	December	6.4	27.2	44	2.6	10	21.9	5.1
Average		12.6	29.1	52	2.4	8.9	21.9	5.3

Appendix Table 2 Mean square of analysis of variance (ANOVA) for leaf number, plant height, and leaf height

Source of Variation	DF	Mean Square values		
		LN	PH	LH
Block	2	1.19	8.87	27.1
IRRI	1	9.63**	145.2ns	94.34*
Block*IRRI	2	0.02	14.51	4.4
DL	4	3.70**	136.7**	147.67**
IRRI*DL	4	1.08	62.32**	48.01**
Error	16	0.53	10.55	5.9
Grand mean		10.77	54.33	49.04
CV(Block*IRRI)		1.36	7.01	4.28
CV(BLOCK*IRRI*DL)		6.77	5.98	4.97

IRRI= irrigation method; DL= deficit level; DF= degree of freedom, LN= Number of leaf per plant; PH= plant height; LH= leaf height, ns =non-significant, * and ** indicates significant difference at probability level of 5% and 1%, respectively

Appendix Table 3 Mean square of analysis of variance (ANOVA) for yield and yield attributes of onion

Source of Variation	DF	Mean Square values					
		BW	BD	BH	BDW	MBY	TBY
Block	2	2.21	6.46	0.09	48.83	5.32	13.22
IRRI	1	978.12*	169.46*	0.012**	482.40**	277.24**	328.02**
Block*IRRI	2	52.80	8.89	0.048	0.69	0.84	0.73
DL	4	488.41**	301.17**	1.011***	597.58**	632.48**	598.95**
IRRI*DL	4	16.05^{ns}	9.47^{ns}	0.211*	114.53*	10.60^{ns}	9.68^{ns}
Error	16	28.28	12.07	0.14	32.27	5.13	5.56
Grand mean		73.09	65.42	5.91	38.66	37.073	38.433
CV(Block*IRRI)		9.94	4.56	3.71	2.14	2.48	2.22
CV(BLOCK*IRRI*DL)		7.28	5.31	6.38	14.69	6.11	6.14

* and ** indicates significant difference at probability levels of 5% and 1%, respectively IRRI= irrigation method; DL= deficit level; DF= degree of freedom BW = Bulb weight, BD=Bulb diameter ,BH= Bulb height ,BDW = Bulb dry weight, TBY = Total bulb yield; MBY = Marketable bulb yield;

Appendix Table 4 Infiltration test data of the experimental soil

Elapsed Time(Hr)	Cum. time (Hr)	Cum. time (mm)	Re. (cm)	Immediate Intake Difference (cm)	Cum. Intake (cm)	Immediate infiltration	Mean infiltration / intake	Cum. infiltration rate (mm)

						(mm/hr)	rate (mm/Hr)	
0.00	0.00	0.00	15.80	0.00	0.00	0.00	--	0.00
0.00	0.00	0.25	15.60	0.20	0.20	479.96	479.96	2.00
0.00	0.01	0.50	15.40	0.20	0.40	479.96	479.96	4.00
0.01	0.02	1.00	15.30	0.10	0.50	120.05	300.05	5.00
0.02	0.03	2.00	15.20	0.10	0.60	59.99	180.00	6.00
0.05	0.08	5.00	14.80	0.40	1.00	80.00	120.00	10.00
0.08	0.17	10.00	14.20	0.60	1.60	72.03	96.02	16.00
0.17	0.33	20.00	13.30	0.90	2.50	54.00	75.01	25.00
0.17	0.50	30.00	12.40	0.90	3.40	54.00	68.00	34.00
0.25	0.75	45.00	11.90	0.50	3.90	20.00	52.00	39.00
0.25	1.00	60.00	11.00	0.90	4.80	36.00	48.00	48.00
0.33	1.33	80.00	10.10	0.90	5.70	27.00	42.75	57.00
0.33	1.67	100.00	9.40	0.70	6.40	21.00	38.40	64.00
0.33	2.00	120.00	8.50	0.90	7.30	27.00	36.50	73.00
0.50	2.50	150.00	7.50	1.00	8.30	20.00	33.20	83.00
0.50	3.00	180.00	6.50	1.00	9.30	20.00	31.00	93.00
0.50	3.50	210.00	5.50	1.00	10.30	20.00	29.43	103.00
0.50	4.00	240.00	4.50	1.00	11.30	20.00	28.25	113.00
0.50	4.50	270.00	3.50	1.00	12.30	20.00	27.33	123.00

Appendix Table 5 Data for uniformity determination

Plot .No	Sample Emitter discharge (l/h) 1	2	3	Column Avg.	q-qavg	(q-qavg)^2

1	0.460	0.460	0.480	0.445	0.445	0.198
2	0.480	0.468	0.468	0.444	0.444	0.197
3	0.479	0.485	0.485	0.442	0.442	0.195
4	0.480	0.480	0.490	0.439	0.439	0.193
5	0.490	0.492	0.480	0.435	0.435	0.189
6	0.406	0.428	0.428	0.430	0.430	0.185
7	0.400	0.425	0.450	0.431	0.431	0.186
8	0.426	0.419	0.450	0.432	0.432	0.187
9	0.458	0.454	0.440	0.432	0.432	0.187
10	0.446	0.459	0.452	0.429	0.429	0.184
11	0.388	0.384	0.410	0.426	0.426	0.181
12	0.441	0.410	0.400	0.432	0.432	0.187
13	0.432	0.414	0.416	0.436	0.436	0.190
14	0.432	0.440	0.432	0.441	0.441	0.194
15	0.446	0.434	0.446	0.444	0.444	0.197
Raw Avg.	0.444	0.443	0.448	0.445	sum	2.850
			q avg =	0.445		

Where q = emitter discharge (l/h) qavg = overall average discharge of dripper (l/h)

Appendix Table 6 Effects of Irrigation methods and irrigation levels on onion yield response factor

Treatments	ETa	ETm	Ya	Ym	K_y	[1-ETa/ETm]	[1-(Ya/Ym)]

D*(100%ETc)	468.0	468.0	50.4	50.4		0.00		0.00
D*(85%ETc)	400.8	468.0	47.5	50.4	0.393	0.14		0.06
D*(70%ETc)	333.6	468.0	45.0	50.4	0.373	0.29		0.11
D*(60%ETc)	288.8	468.0	37.8	50.4	0.652	0.38		0.25
D*(50%ETc)	244.0	468.0	28.0	50.4	0.928	0.48		0.44
CFI*(100%ETc)	468.0	468.0	43.4	50.4		0.00		0.00
AFI*(85%ETc)	210.4	468.0	42.4	50.4	0.286	0.55		0.16
AFI*(70%ETc)	181.8	468.0	41.3	50.4	0.295	0.61		0.18
AFI*(60%ETc)	153.3	468.0	31.0	50.4	0.571	0.67		0.38
AFI*(50%ETc)	134.2	468.0	17.5	50.4	0.915		0.71	0.65

Appendix Table 7 WUE, IWUE and yield reduction

Treatments	Dnet (mm)	Dgross (mm)	TAY t/ha	Water used mm	m^{-3}	water saved mm	%	WP Kg $ha^{-1}m^{-3}$	IWP Kg ha^{-1} m^{-3}	Yield reduction Kg/ha	%
D*(100%)	468.0	286.0	48.79	286.0	2860	494.0	63.3	10.43	17.0	0.0	0.0
D*(85%)	400.8	243.1	46.15	243.1	2431	536.9	68.8	11.51	18.9	2.6	5.4
D*(70%)	333.6	200.2	43.52	200.2	2002	579.8	74.3	13.04	21.7	5.3	10.8
D*(60%)	288.8	171.6	35.94	171.6	1716	608.4	78.0	12.44	20.9	12.9	26.3
D*(50%)	244.0	143.0	26.20	143.0	1430	637.0	81.6	10.74	18.3	22.6	46.3
AFI*(85%)	210.4	663.0	41.68	663.0	6630	117.0	15.0	19.81	6.3	7.1	14.5
AFI*(70%)	181.8	546.0	40.32	546.0	5460	234.0	30.0	22.17	7.4	8.5	17.3
AFI*(60%)	153.2	468.0	29.49	468.0	4680	312.0	40.0	19.24	6.3	19.3	39.5
AFI*(50%)	134.2	390.0	15.93	390.0	3900	390.0	50.0	11.86	4.1	32.9	67.3
CFI*(100%)	468.0	780.0	42.76	780.0	7800	0.00	0.0	9.14	5.5	6.0	12.3

AFI = Alternate furrow irrigation, Dnet = Net irrigation water applied (mm), Dross = gross irrigation water applied (mm) and TAY = total average yield

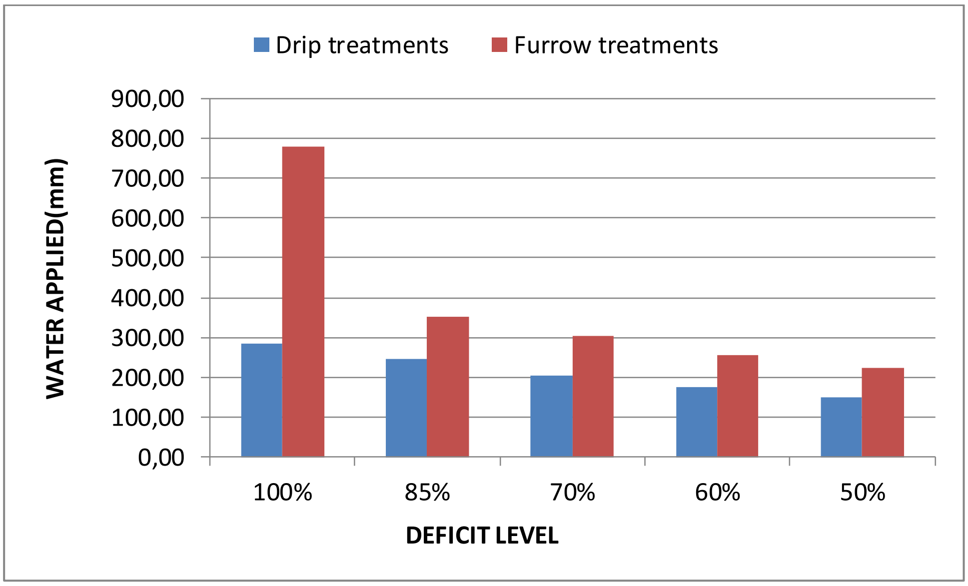
Appendix Table 8   Irrigation water volume and time to irrigate each plot

MP	SP	Dnet (mm)	Ea (%)	Dg (mm)	Plot area (m^2)	Wa	Net area (m^2)	volume (Ltr)	Time require to irrigate (hr)		Plots
Drip	(100%)	35.0	0.9	38.9	14.4	0.55	7.9	308.0	5.6	36	p2,p15,p24
	(85%)	30.0	0.9	33.3	14.4	0.55	7.9	264.0	4.8	48	p1,p11,p23
	(70%)	25.0	0.9	27.8	14.4	0.55	7.9	220.0	4.0	0	p4,,p13,p25
	(60%)	21.0	0.9	23.3	14.4	0.55	7.9	184.8	3.3	18	p3,p12,p21
	(50%)	18.0	0.9	20.0	14.4	0.55	7.9	158.4	2.9	54	p5,p14,p22
AFI	(85%)	30.0	0.6	50.0	14.4	1.00	14.4	720.0	1135.2	Total liter of water required in the tank	
	(70%)	25.0	0.6	41.7	14.4	1.00	14.4	600.0			
	(60%)	21.0	0.6	35.0	14.4	1.00	14.4	504.0			
	(50%)	18.0	0.6	30.0	14.4	1.00	14.4	432.0			
	EFI	35.0	0.6	58.3	14.4	1.00	14.4	840.0	Head of 3' Parshall Flume		

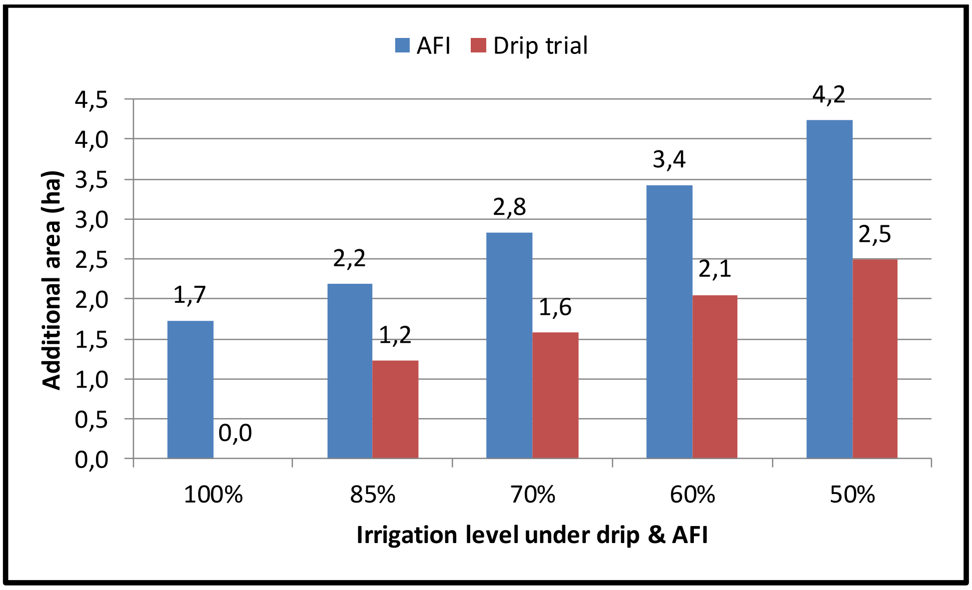
Time to irrigate

PF head(cm)		5		6		7		8		9		10		Plots
Discharge (l/s)		1.705		2.261		2.872		3.532		4.239		4.991		
Trea.	volume (Ltr)	min	sec	min	sec	min	sec	min	sec	min	sec	min	sec	
AFI* (85%)	360.00	3.5	30	2.7	42	2.1	6	1.7	42	1.42	2520	1.2	24	p7,p16,p29
AFI*70%)	300.00	2.9	54	2.2	12	1.7	42	1.4	24	1.18	11	1.0	0	p6,p19,p28
AFI*(60%)	252.00	2.5	30	1.9	54	1.5	30	1.2	12	0.99	59	0.8	48	p10,p17,p26
AFI* (50%)	216.00	2.1	6	1.6	36	1.3	18	1.0	0	0.85	51	0.7	42	p8,p20,p27
EFI*(100%)	840.00	8.2	12	6.2	12	4.9	54	4.0	0	3.30	18	2.8	48	p9,p18,p30

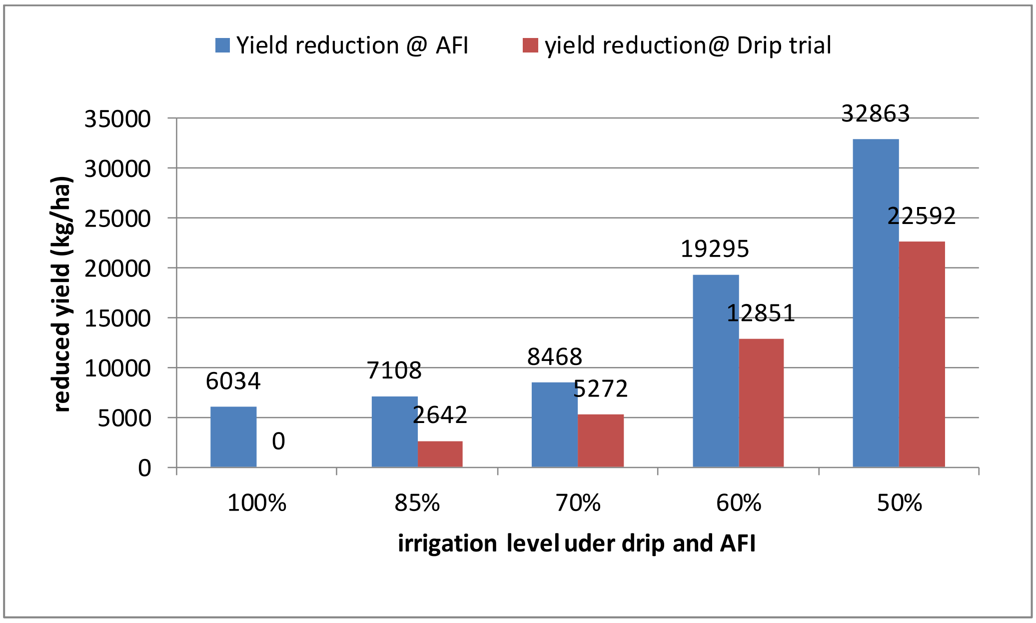
Appendix Figure 1 Applied water as per treatments during the growing period



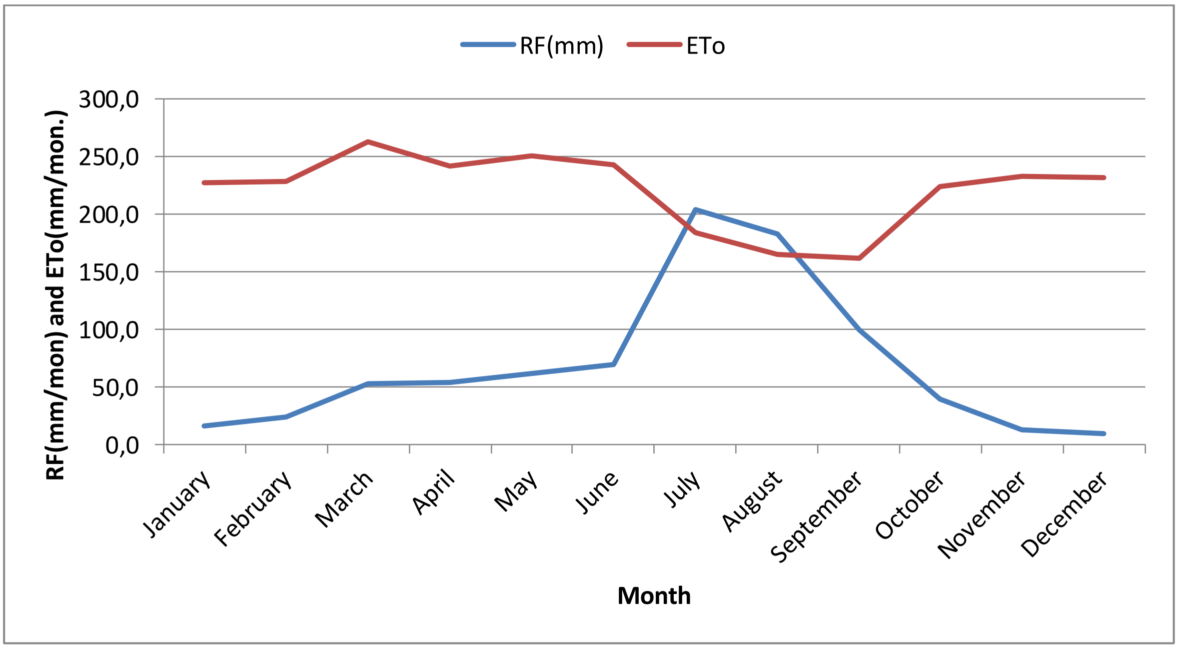
Appendix Figure 2 Additional irrigable land (ha) with saved water under different treatments



Appendix Figure 3 Total onion yield reduction (kg/ha) under different treatments comparing to Drip (100%ETc) treatment



Appendix Figure 4 Monthly Rf and ETo variation in the study area



BIOGRAPHICAL KETCH

The author was born on July 28, 1984, at Zeway (battu), Oromia Region, Ethiopia, from his mother Yasunesh Shibiru and his father Yaziz Muktar . He pursued his elementary school at Adami Tulu Donbosco Catholic Primary School, Adami Tulu and Secondary Education at Zeway Donbosco Catholic Preparatory School, Zeway.

After completing his preparatory school education in 2006, he joined Haramaya University and graduated with BSc degree in Soil and Water Engineering and Management in July 2008. Soon after graduation, he was employed at South Agricultural Bureau at Kaffa and Bech Magi Zone Agriculture and Rural Development Department in the position of soil and water conservation expert and as irrigation expert respectively.

Later in 2013 he joins Ethiopian Agricultural Research Institute at Tepi National Spice Research Center in the position of Junior Researcher in Soil and Water Management Directorate, now it is called Natural Resource Management Directorate and worked there until he joined the School of Graduate Studies of Hawasa University in October 2016 to follow his Master of Science in Water Resource Engineering and Management.