EFFECT OF DEFICIT IRRIGATION ON YIELD AND WATER PRODUCTIVITY OF ONION *(Allium cepa L.)* UNDER CONVENTIONAL FURROW IRRIGATION SYSTEM IN BENNATSEMAY WOREDA, SOUTHERN ETHIOPIA

MSc THESIS

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HAWASSA UNIVERSITY, HAWASSA, ETHIOPIA

MARCH, 2019

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A THESIS SUBMITED TO THE DEPARTMENT OF WATER RESOURCES AND IRRIGATION ENGINEERING, FACULTY OF BIO-SYSTEMS AND WATER RESOURCES ENGINEERING
INSTITUTE OF TECHNOLOGY, SCHOOL OF GRADUATE STUDIES
HAWASSA UNIVERSITY, HAWASSA, ETHIOPIA

IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE DEGREE OF MASTER OF SCIENCE IN IRRIGATION AND DRAINAGE ENGINEERING

MARCH, 2019

SCHOOL OF GRADUATE STUDIES
HAWASSA UNIVERSITY
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This is to certify that the thesis entitled **"Effect of Deficit Irrigation on Yield and Water Productivity of Onion (*allium cepa l.)* Under Conventional Furrow Irrigation System, in Bennatsemay Woreda, Southern Ethiopia "** submitted in partial fulfillment of the requirements for the degree of Master's with specialization in Irrigation and Drainage Engineering, the Graduate Program of the Department of Water Resources and Irrigation Engineering, and has been carried out by Tadesse Mugoro ID. No. PGIDE/012/09, under my/our supervision. Therefore I/we recommend that the student has fulfilled the requirements and hence hereby can submit the thesis to the department.

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We, the undersigned, members of the Board of Examiners of the final open defense by Tadesse Mugoro Lebiso have read and evaluated his/her thesis entitled **"Effect of Deficit Irrigation on Yield and Water Productivity of Onion *(allium cepa l.)* Under Conventional Furrow Irrigation System, in Bennatsemay Woreda, Southern Ethiopia",** and examined the candidate. This is, therefore, to certify that the thesis has been accepted in partial fulfillment of the requirements for the degree.

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DEDICATION

I dedicate this thesis manuscript to my father Mugoro Lebiso, my mother Shita Morkeno and my sister Zenebech Mugoro for nursing me with affection and love, and for their dedicate partnership in the success of my life.

STATEMENT OF AUTHOR

First, I declare that this thesis is my original work and that 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 any academic degree, diploma or certificate.

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ACKNOWLEDGEMENT

First of all many thanks is directed to our Lord, the Almighty God, the father of everything for his care, endless love and also he enabled me to begin and accomplish this work successfully.

I would like to express my heartfelt gratitude to my advisor, Dr. Shemelies Assefa and co-advisor Mr. Abel Getahun for their critical supervision, excellent guidance, valuable comments and providing me ceaseless encouragement throughout the entire periods of this thesis work.

My special appreciation also goes to Southern Agricultural Research Institute, Natural Resource Research Directorate for providing the scholarship to undertake graduate study, financial support for the research, and for all technical and material support. My gratitude also goes to Jinka Agricultural Research Center and staffs for their assistance in the field work and by providing laboratory equipments.

My appreciation also goes to all my colleagues and friends, especially Medihin Madebo, Genanew Tessema, Mintesinot Tsegaye, Asmera Adicha and Sintayehu Kibret for their kindness and support by sharing their experiences and materials. They also gave me their ultimate support and encouragement throughout my field works and study period.

I am forever grateful to my beloved Father and Mother for provided me childhood treatments. They had always been the constant source of my strength and hope in every aspect of my life. My special heartfelt and profound gratitude also goes to my sister Zenebech Mugoro and to all brothers for their fascinating encouragement.

LIST OF ABBREVIATIONS

AGP	Agricultural Growth Program
ANOVA	Analysis of Variance
BD	Bulk Density
BOFED	Bureau of Finance and Economic Development
CFI	Conventional Furrow Irrigation
CSA	Central Statistical Agency
CWP	Crop Water Productivity
CWR	Crop Water Requirement
CWUE	Crop Water Use Efficiency
d_{gross}	Gross Irrigation Depth
DI	Deficit Irrigation
d_{net}	Net Irrigation Depth
Ds	Development Stage
dS/m	Deci-Siemens per meter
Ea	Irrigation Application Efficiency
EC	Electrical Conductivity
EPaRDA	Ethiopian Pastoralist Research and Development Association
ET_a	Actual Evapotranspiration
ET_c	Crop Evapotranspiration
ET_o	Reference Evapotranspiration
FAO	Food and Agricultural Organization
g	Gram
ha	Hectare
ICARDA	International Center for Agricultural Research in the Dry Areas
IR_n	Net Irrigation Requirement
Is	Initial Stage
IWU	Irrigation Water Use
IWUE	Irrigation Water Use Efficiency

K_c	Crop Coefficient
Kg	Kilogram
K_y	Yield Response Factor
Ls	Late Stage
LSD	List Significant Difference
masl	Meter above sea level
MC	Moisture Content
MoA	Minister of Agriculture
MoARD	Ministry of Agricultural and Rural Development
Ms	Mid Stage
OC	Organic Carbon
OM	Organic Matter
Pe	Effective Rain Fall
pH	Power of Hydrogen
PWP	Permanent Wilting Point
RAW	Readily Available Water
RCBD	Randomized Complete Block Design
RH	Relative Humidity
SAS	Statistical Analysis System
t/ha	Ton per Hectare
TAW	Total Available Water
TWU	Total Water Use
USDA	United States Department of Agriculture
WDR	World Development Report
WP	Water Productivity
WUE	Water Use Efficiency

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ABSTRACT

Enhancing water productivity is an important strategy for addressing future water scarcity in arid and semi-arid regions. Hence, innovations are needed to increase the water use efficiency that is available. Deficit irrigation is believed to improve water productivity without causing severe yield reductions; which the crop is exposed to a certain level of water stress either during a particular period or throughout the whole growing season. The field experiment was conducted in Bennatsemay Woreda Weyito experimental site of Jinka Agricultural Research Center, Southern Ethiopia, during 2018 season with objective of investigating the effect of deficit irrigation on yield and water productivity of Onion under conventional furrow irrigation system. Six treatments (T1=100% ETc, T2=85% ETc, T3=70% ETc, T4=50% ETc, T5=100% ETc Is, 85% ETc Ds, 70% ETc Ms, 50% ETc Ls and T6=85% ETc Is, 70% ETc Ds, 50% ETc Ms, 0% ETc Ls) were imposed on Onion (Allium cepa L.) Bombay red variety and laid out in randomized complete block design (RCBD) with four replications. Results indicated that the different deficit irrigation levels had highly significant ($p < 0.01$) effect on vegetative growth, yield, yield components and water use efficiency of Onion. Onion bulb yield was reduced with increased water stress, where as water productivity was increased with stress level increased. The highest bulb yield of 21.3 t/ha were obtained from T1 which was significantly different to all other treatments while yield from T6 (12.86 t/ha) was recorded as the lowest one. Similarly, the highest IWUE (2.41 kg/m^3) and CWUE (4.02 kg/m^3) were obtained from T6 which was significantly superior to all other treatments. But, at T4 and T6 high yield reduction was recorded which may not be attractive for producers. On the other hand, the total bulb yield, yield components, IWUE and CWUE observed under T3 and T5 irrigation application levels had no statistically significant variation ($p < 0.01$). However, under T5 the relative yield reduction was greater when compared to T3. So, instead of T5, using T3 (applying 70% ETc) is advisable. Accordingly, made T5 out of the role, compared T1, T2, T3, T4 and T6, high IWUE was observed under T6 and T4 with high yield reduction penalty. From resources conservation point of view, maximum water productivity may be our attention, which could be obtained under this severe deficit irrigation. However, such consequences on yield may not be tolerable from producers view point (at T4 and T6). Therefore, it could be concluded that increased water saving and water productivity through irrigation at 70% ETc deficit irrigation level under conventional furrow irrigation system can solve the problem of water shortage and would ensure the opportunity of further irrigation development in the study area and similar agro-ecology.

Key words: Deficit irrigation, Water productivity, Conventional furrow irrigation system, Onion

1. INTRODUCTION

1.1 Background and Justification

Food insecurity and recurrent droughts has been the critical challenges in Ethiopia for many years. The recent, 2015 El Nino drought is one of the strongest droughts that have been recorded in Ethiopian history were more than 27 million people became food insecure and total population of 18.1 million people required food assistance in 2016. The occurrence of drought in most parts of the country is usually caused by insufficient rainfall to support the seasonal water requirements of the rain-fed crop production (Abduselam, 2017).

About 80% of the country's population is dependent on rain-fed agriculture and inadequate seasonal rainfall has caused serious food shortages that can adversely destabilize the social and economic life of the people (World Bank, 2004). In order to mitigate this food insecurity problem with its roots in the high population growth rate and low food production level, it is imperative to bring large areas of the arid, semi-arid and sub humid regions with uneven rainfall distribution under irrigation and other appropriate technology interventions (World Bank, 2010).

In many developing countries, irrigation development is a means to feed the growing population of the country. A study by Robel (2005) indicated that, rising irrigation development in Ethiopia particularly in water deficit areas is crucial for reliable and sustainable food security. Furthermore, irrigation has a multi-faceted role in contributing towards food security, self-sufficiency, food production and exports (Yenesew, 2015).

In the 20th century, worldwide irrigated area experienced a huge expansion with an increasing from 40 million to 270 million hectare of irrigated land. Such numbers are part of the ability of humankind to produce food fast enough to meet population growth. But, ever increasing world population and the demand for additional water supply by industrial, municipal and agricultural sectors exert a lot of pressure on renewable water resources (Valipour, 2014).

Among the water user sectors, irrigated agriculture is major fresh water consumer which is highly threatened under water scarcity situation in the recent years (FAO, 2012). Globally, irrigated agriculture uses more than 70% of the fresh water withdrawn from the earth's rivers; but these amounts can reach as much as 95% in some developing countries (FAO, 2017).

In Ethiopia, irrigated agriculture is becoming main concern and strongly recognized to ensure the food security which is taken as a means to increase food production and self-sufficiency of the rapidly increasing population of the country. Accordingly, Ethiopia has planned to irrigate over 5 million hectares of the land with existing water resources (Awulachew *et al*., 2010). This 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 necessitated the improvement of water use efficiencies in irrigated agriculture to ensure sustained production and conservation of this limited resource (Mekonen, 2011).

Improving water use efficiency is an important strategy for addressing future water scarcity problem particularly in arid and semi-arid regions (Mdemu *et al.* 2008). Thus, water productivity is an indicator of agricultural productivity in relation to the crop’s consumptive use of water (WDR, 2003). As argued by the Geerts and Raes (2009), and FAO (2010), increasing crop water productivity can be an important pathway for poverty reduction. This would enable growing more food and hence feeding the ever increasing population of Ethiopia or gaining more benefits with less water thus enhancing the household income. Moreover, more water will be available for other natural and human uses. In this context, deficit irrigation provides a means of reducing water consumption while minimizing adverse effects on yield (Mermoud *et al*., 2005).

Accordingly, deficit irrigation (DI) is can be a valuable and sustainable production strategy in arid and semi-arid regions. In this strategy the crop is exposed to a certain level of water stress either during a particular period or throughout the whole growing season with the expectation that any yield reduction will be insignificant compared with the benefits gained through diverting the saved water to irrigate other fields.

The target crop, Onion, is becoming more widely grown in recent years in Ethiopia. Currently, the crop is produced in different parts of the country for local consumption and export. During the 2013/2014 cropping season, the total area under Onion production was estimated to be 24, 375.7 ha with an average yield of about 9.02 tons per hectare and estimated a total production of greater than 2, 19, 735.27 tons (CSA, 2014). This indicates that Ethiopia has 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 Onion response to different deficit irrigation levels and application methods.

1.2 Statement of the Problem

Water scarcity is the most severe constraint for the development of agriculture in arid and semi-arid areas of the Ethiopia. Bennatsemay Woreda is one district of South Omo Zone in Southern Region of Ethiopia where due to low and erratic rainfall; chronic drought and water scarcity is observed recurrently and upsetting agricultural productivity. According to AGP-II (2015) survey report, the economy of the district is highly dependent on agriculture (livestock and crop production), which is in turn dependent on the availability of erratic rainfall and scarce water resources. As result, there was competition for water use between inhabitants for livestock as well as crop production. On the other hand, lack of improved small scale irrigation technologies, less irrigation water management practices and inadequate research supports are a major problem for efficient irrigation water use and agricultural production improvement in the area.

The scarce water resources availability, growing competitions for water use and inefficient on-farm irrigation management practices during crop production in the area will reduce water availability for irrigated agriculture, then endangering food supplies and aggravating rural poverty. Thus, achieving greater water use efficiency will be a primary challenge in the near future in the study area. This calls the use of suitable techniques and practices that deliver a more accurate supply of water to crops.

Deficit irrigation is one of the options and practices currently preferred in many parts of the world to maximize productivity per unit of water used in dry areas.

Also, it is believed to improve water productivity without causing severe yield reductions; which the crop is exposed to a certain level of water stress either during a particular period or throughout the whole growing season. However, this option was not practically and scientifically experienced in the study area. Therefore, practically investigating the effect of deficit irrigation on yield and water productivity of irrigated Onion was found to be important to utilize the limited water resource of the area without severely affecting the crop yield.

1.3 Objectives

1.3.1 General Objective

- ➢ The general objective of this study is to investigate deficit irrigation effect on yield and water productivity of Onion under conventional furrow irrigation system

1.3.2 Specific Objectives

- ➢ To determine the yield variation of Onion under different deficit irrigation levels
- ➢ To determine water use efficiency of Onion under different deficit irrigation levels
- ➢ To identify the level of deficit irrigation which allow achieving optimum Onion yield and water productivity

1.4 Research Questions

This work addressed the following scientific research questions**:**

- ✓ Is the yield of Onion varies with different deficit irrigation levels under conventional furrow irrigation? How?
- ✓ Is water use efficiency of Onion varies with different deficit irrigation levels under conventional furrow irrigation? How?
- ✓ Which level of deficit irrigation practices is best suited to realize optimum onion production and water productivity?

1.5 Scope of the Study

The study specifically focused on investigating the deficit irrigation effect on yield and water productivity of Onion under conventional furrow irrigation system. Climatic parameters, soil physical and chemical properties determination, and irrigation agronomical study of Onion has been used for the analysis of this study.

1.6 Significance of the Study

Irrigated agriculture is a priority in the agricultural transformation and food security strategy of the Ethiopian government. To achieve the strategy this document would have valuable contribution. Moreover, it would lead to a better understanding of how to enhance the yield of Onion, water productivity and help to identify in which level of water stress significantly reduce yield.

2. LITERATURE REVIEW

2.1 Water Scarcity and Irrigated Agriculture

Water is becoming scarce, both in quantity and quality, not only in traditionally prone arid and semi-arid zones, but also in regions where rainfall is abundant (Capra *et al*., 2008). Though water covers about two-thirds of the Earth's surface, it is a scarce resource as most of it is unavailable and too salty for use. About 20% of the fresh water is not accessible, and much of it arrives at the wrong time and place, as monsoons and floods. Globally, less than 0.08% of all the Earth's water is available for humans use. But, of this small proportion of available water more than two-third is used for agriculture (FAO, 2000).

Agricultural production is the major user of the Earth’s water resources and the water demand for this sector is increasing steadily with its root on population growth. These days about 70% of the available water in the world and 86% in the Africa are used for agriculture. In Ethiopia total water withdrawals were estimated to be 5.2 km^3 per year (93.6%) was used for agriculture. From this, irrigated agriculture covers large proportion when compared to other water user sectors (domestic and industrial water use sectors) (FAO, 2012).

Irrigated agriculture provides about 40% of world food production (Fereres and Conner, 2004). Likewise, irrigation in Ethiopia contributed approximately 8.8% to agricultural Gross Domestic Product (GDP) and 3.7% to the overall GDP during the 2009/2010 production year and which is believed that, irrigation has an important role to play in contributing to food security and poverty alleviation (Hagos *et al*., 2009). Consequently, Ethiopia and other developing countries are planning to increase irrigated agriculture and the area equipped for irrigation is expected to have expanded by 20% (40 million ha) by 2030. This means that 20% of total land with irrigation potential but not yet equipped will be brought under irrigation (Awulachew *et al*., 2010).

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 (Mekonen, 2011).

Generally, the efficiency of water use in most irrigated agriculture is low with poor management and improper designs of water application systems. Only a part of agricultural water withdrawals are effectively used in the production of food or other agricultural commodities. According to FAO (1996), of the total applied water only 40 to 60% is effectively used by the crop. The remainder of the water is lost in the system, and in the field, either through evaporation, runoff to the drainage system or by percolation into the groundwater. Perhaps that part of water lost can be recovered, but additional costs are needed to be incurred.

Similarly, there are plenty of evidences pointing that irrigation water management has not received adequate attention as the development of new schemes in arid and semi-arid regions of Ethiopia. So, the big challenges for the coming decades will be the task of increasing food production with less water (Mulu and Alamirew, 2012). Therefore, achieving greater efficiency of water use will require the application of techniques and practices that deliver a more accurate supply of water to crops which are not necessarily based on full crop water requirement.

Deficit irrigation is one of the techniques and practices, which irrigation water is applied below the full crop water requirement to maximize productivity per unit of water used in arid and semi-arid areas. Under these situations, irrigation water will be used more efficiently and crop water productivity becomes increased. On the other hand, it is believed that reduced yield as the result of deficit irrigation, may be compensated by increased production from the additional irrigated area with the water saved by deficit irrigation (Yenesew, 2015).

2.2 Concept and Practices of Deficit Irrigation (DI)

2.2.1 Definition

Several researchers have defined the same concept of deficit irrigation in different ways. For instance, English (1990) describes DI as the "deliberate and systematic under-irrigation of crops". In 1998 Lecler defines; deficit irrigation is an optimization strategy whereby net returns are maximized by reducing the amount of irrigation water applied to a crop to a level that results in some yield reduction caused by water stress. Likewise, study made by Yenesew and Ketema (2009) and Mekonen (2011) revealed that, deficit irrigation is an irrigation practice whereby water supply is reduced below maximum level and mild stress is allowed, during non-sensitive growth stage or throughout the growing season, without significant yield penalty. Thus, the main approach in deficit irrigation is to save water, labor and energy, by eliminating those irrigations with minimal effects on yield (Aguilar *et al*., 2007).

2.2.2 Practices of Deficit Irrigation

Earlier, crop irrigation requirements did not consider limitations of the available water supplies. But, the great challenge for the coming decades will be the task of increasing food production with less water, particularly in areas with limited water resources, due to the overall expansion of irrigated area and the competition for water with other sectors. Therefore, achieving greater efficiency of water use will be the primary challenge for the near future. In this perspective, deficit irrigation provides a means of reducing water consumption while minimize adverse effect on yield (FAO, 2002).

Deficit irrigation has been practiced on varies crops in different parts of the world (Yuan *et al*, 2003; Kirda *et al.,* 2004; Dorji *et al.*, 2005; Samson and Ketema, 2007; Yenesew and Ketema, 2009; Mekonen, 2011; Abd El-Hady *et al.,* 2015; Enchalew *et al*., 2016; Dirirsa *et al.,* 2017; Temesgen *et al.,* 2018; Mebrahtu *et al.*, 2018). For instance, Yenesew and Ketema (2009) conducted an experiment on yield and water use efficiency of deficit-irrigated maize in a semi-arid region of Ethiopia. It was observed that, stressing Maize crop by three-quarter deficit at individual growth stages increased water use efficiency. On the same crop Mekonen Ayana (2011) made experiment at Arba Minch on deficit irrigation practices as alternative means of improving water use efficiencies and the result was showed that, IWUE has increased with decreasing water application level.

Likewise, Mebrahtu *et al.* (2018) conducted experiment on Onion response to deficit irrigation under different furrow irrigation water management techniques in Raya Valley, Northern Ethiopia and the result was indicated that DI increased water saving and water productivity without significant reduction of yield. Other experiments on hot pepper are also reported by Owusu-Sekyere *et al*., (2010) who reported reduction in 20% water need has no significant effect on growth, development and fruiting of the crop.

A review of about 100 papers dealing with deficit irrigation by Capra *et al*., (2008) on different crops has shown that, considerable reduction in applied water may result in higher water use efficiency with insignificant decrease in yield. Also, selected research works around the world reviewed by Geerts and Raes (2009), confirms that deficit irrigation successfully increased water productivity for various crops. Similarly, Zwart and Bastiaanssen (2004) reviewed and measured crop water productivity for several crops around the world and concluded that the crop water productivity could be significantly increased if irrigation was reduced and crop water deficit was intentionally induced.

Another practices conducting DI experiment might be considering the characteristic of soil, crop type and its varieties. According to Kirda (2002) in order to ensure deficit irrigation is successful, it is necessary to consider the water retention capacity of the soil. In sandy soils plants may undergo water stress quickly under deficit irrigation, whereas plants in deep soils of fine texture may have plenty time to adjust to low soil water matric pressure, and may remain unaffected by low soil water content. Therefore, success with deficit irrigation is more probable in finely textured soils.

Crops or crop varieties that are most suitable for deficit irrigation are those with a short growing season and are tolerant of drought (Stewart and Musick, 1982). Since drought tolerance varies considerably by genotype and by phenological stage, it is necessary to know crop yield responses to water stress, either during defined growth stages or throughout the whole season (Kirda *et al*., 1999).

2.2.3 Benefits of Deficit Irrigation

Deficit irrigation increases irrigation efficiency, reduces costs of irrigation and the opportunity costs of water (English, 1990). That means water saved by DI can be used to irrigate more land on the same farm or in the water user's community, which, given the high opportunity cost of water, and may largely compensate for the economic loss due to yield reduction (Ali *et al*., 2007). In other words, deficit irrigation aims at stabilizing yields and at obtaining maximum water productivity (WP) rather than maximum yields (Zhang and Oweis, 1999).

In the context of improving water productivity, there is a growing attention in deficit irrigation, an irrigation practice whereby water supply is reduced below maximum levels and mild stress is allowed with minimal effects on yield. Because, under conditions of scarce water supply and drought, deficit irrigation can lead to greater economic gains than maximizing yields per unit of water for a given crop (FAO, 2002).

Maximizing water productivity by deficit irrigation in water scarcity areas is often economically more profitable for the farmer than maximizing yield. In those areas for crop production, farmers must choose crops and irrigation approaches carefully to maximize the value of their crop production activities, while ensuring the sustainability of agriculture. Deficit irrigation will play an important role in on farm water management approaches, with consequent increases in the output generated per unit of water used in agriculture (Geerts and Raes, 2009).

Another benefit of deficit irrigation is decreasing the risk of fungal plant diseases by creating a less humid environment around the crop than full irrigation (Cicogna *et al*., 2005). Moreover, yield reductions from disease and pest, storage and arising from insufficient application 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 instance, Kirda

(2002) report that 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.

In generally observed, several literatures on deficit irrigation focused on management approaches supplying lower levels of water with respect to full ETc, targeting to obtain maximum crop yield and saving water. In this sense, it is believed that deficit irrigation can improve the water use efficiency with insignificant decrease in crop yield and may be economically more profitable for the farmer. Therefore, in view of those overall benefits, practicing deficit irrigation is very important particularly in water scarcity areas.

2.3 Concept of Water Productivity (WP)

Crop water productivity (CWP) with dimensions of kg/m^3 is defined by Kassam and Smith (2001) as the ratio of the mass of yield (Y) in kilograms to the volume of water consumed by the crop (ET) in m^3. Furthermore, 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 less water resources’. Water productivity (WP) mainly refers to the ratio between output derived from water use and the water input (Clement *et al*., 2011). In other way, water productivity is directly related to either enhancing production or reducing water consumption (Temesgen *et al*., 2018).

It is widely believed that an increase in agricultural water productivity is the key approach to mitigate water shortage and to reduce environmental problems in arid and semiarid regions. In the dry areas, water, not land, is the most limiting resource for improving agricultural production. Maximization of yield per unit of water (WP), and not yield per unit of land (land productivity), is, therefore, a better strategy for dry farming systems (English, 1990). This is the fact in the study area. So, improvement of water productivity in irrigated agriculture is very essential.

Deficit irrigation has been widely investigated as a valuable and sustainable production strategy in dry regions (Fereres *et al*., 2003). By limiting water applications to drought-tolerant growth stages or throughout the growth period, this practice aims to maximize water productivity and to stabilize rather than maximize yields. Research results confirm that DI is successful in increasing water productivity for various crops without causing severe yield reductions. Nevertheless, a certain minimum amount of seasonal moisture must be guaranteed (Geerts and Raes, 2009).

In irrigated agriculture, we are interested to produce more yields with less water because water is a limiting factor not only in traditionally prone arid and semi-arid zones, but also in regions where rainfall is abundant (Capra *et al*., 2008). In this case WP can be used in the evaluation of deficit irrigation strategies. Also, commonly used as synonymous with WP is the term water use efficiency (WUE) to clearly refer to the physiological processes of biomass production. Relative to irrigation, it is preferable to assess the WP relative to either total water use (TWU) or irrigation water use (IWU) when that assessment aims at evaluating the performance of given irrigation systems (Steduto *et al*., 2007).

Several studies have been conducted to determine irrigation water use efficiency (IWUE) of Onion crops, mostly in semi-arid and arid climates, in order to improve productivity and save water (Sarkar *et al*., 2008). For instance, Samson and Ketema (2007) made regulated deficit irrigation experiment on Onion in semi-arid regions of Ethiopia and results showed that deficit irrigation throughout the growing season as 50% and 75% of ETc reduced yields from full irrigation and resulted in the highest water saving and crop water use efficiency.

2.4 Effect of Water Deficit on Onion Yield and Water Productivity

Irrigation is the major input to vegetable crops production like Onion. Onion (*Allium cepa* L.) is considered as the most important vegetable crops grown on small scale in Ethiopia. The area under Onion production is increasing from time to time mainly due to its high profitability per unit area and easy of production and the expansion of small scale irrigation (Nigussie *et al*., 2015).

Onion is a shallow-rooted crop that requires frequent and adequate irrigation to achieve good yield (Gebregwergis *et al*., 2016). The level of crop's response to water application depends on the crop phenological stages (Dirirsa *et al.*, 2017).

The knowledge of the sensitivity of Onion to a certain level of water stress and the consequences on yield as a result is important for on-farm irrigation management. This enables saving of water during less water stress sensitivity growing stages and fully meeting the water requirement of the crop during high sensitivity stages (Temesgen *et al*., 2018). Through such practices significant water savings can be achieved for a variety of crops by deliberately stressing the crop to a certain profitable level (Enciso *et al*., 2009). Such irrigation management technique is widely known as deficit irrigation. With increasing scarcity of water in many areas, deficit irrigation is found to be a vital strategy to save water and hence enhance water use efficiency by maintaining satisfactory yield of Onion.

By using Onion as test crop a large number of published researches have evaluated the feasibility of deficit irrigation and whether significant savings in irrigation water are possible without significant yield penalties.

Samson and Ketema (2007) conducted regulated deficit irrigation experiment in Sekota Agricultural Research Center on Onion. The result revealed that, the average Onion yield was 19.34 t/ha and the minimum yield (5.5 t/ha) occurred in the fully-stressed treatment. The maximum yield (25 t/ha) was obtained in 100% ETc. It was observed that water deficit at first and fourth growth stages, gave non-significantly different yields from the optimum application. During all stages as 25% ETc, 50% ETc, and 75% ETc water deficit, the yields were significantly different from optimal irrigation. They concluded that, all deficit irrigations increased the water use efficiency of Onion from a minimum of 6% by stressing the crop during the first growth stage to a maximum of 13% by partially stressing the crop at 75% ETc of the optimum application throughout the growing season.

Enciso *et al.,* (2009) was conducted experiment in the Rio Grande Valley in Texas to evaluate yield and quality of subsurface drip irrigated Onions (*Allium cepa* L.) using different scheduling strategies and water stress levels. The strategy was to replace 100%, 75%, and 50% of crop evapotranspiration (ETc) weekly. The results indicated that, yields were not affected when water applications were reduced from 100% to 75% ETc. Total yields dropped significantly when ET reduced to the 50% ETc treatment.

Leskovar *et al.,* (2010) studied on the impact of deficit drip irrigation and plant density on the growth, yield and quality of short-day Onions. Researchers used irrigation amounts of 100%, 75% and 50% of ETc. Results showed that deficit irrigation at the 50% ETc had a significant impact on yield. As they concluded, specifically a 75% ETc level has high-price bulb sizes without reducing yield and flavor content.

Mulu and Alamirew (2012) reported on deficit irrigation application using center pivot sprinkler irrigation for Onion production at Lay Bir farm, West Gojam Zone, with 100%, 75%, and 50% of ETc levels. The result indicated that water stress had significant effect on yield and yield components of Onion. The dry matter obtained with 50% ETc was significantly lower than that obtained under 75% ETc and 100% ETc. Nevertheless, there was no significant difference between 75% ETc and 100% ETc of the irrigation applications. IWUE and CWUE values among the three treatments however were not statistically significant. Researchers concluded that Onion yield is highly dependent on the amount of water applied.

Enchalew *et al.,* (2016) carried out experiment on clay loam soil at Melkassa Agricultural Research Center with the objectives to estimate water productivity of Onion and evaluate the effect of water deficit on Onion yield and quality using drip irrigation. The experiment contained five DI treatments of 90%, 80%, 70%, 60%, and 50% ETc and the control (100% ETc). The results revealed that plant height was not affected by the level of DI while, leaf number, bulb diameter and total bulb yield had shown a highly significant ($P < 0.01$) differences among DI treatments. The highest bulb diameter was observed from 100% ETc that was significantly different to all other treatments. The highest total bulb yield of 15,690 kg/ha was observed from a control treatment which was not significantly different with treatment receiving 90% ETc.

Highest water productivity of Onion bulb yield was observed from treatment receiving 70% ETc and better Onion bulb diameter was observed from treatment receiving 100% ETc to 70% ETc. As they concluded, the practice of DI application up to 20% saved 45 to 108 mm depth of water from the gross Onion irrigation water requirement.

Dirirsa *et al*., (2017) were investigated a field experiment at Melkassa Agricultural Research Center to investigate the sensitivity of Onion (Nafis variety) yield and water productivity to deficit irrigation at different growth stages. The result showed that the different deficit irrigation level had significant ($p < 0.01$) impact on bulb yield. The control treatment gave the highest bulb yield of 40.38 t/ha with no significant difference from 25% deficit treatments except the deficit at bulb formation stage. Crop water productivity (kg/m^3) was the highest with no deficit irrigation at the bulb formation stage with 25% deficit at other stages. The result also revealed that, Onion bulb yield was most sensitive to water deficit that occurred at bulb formation stage.

Temesgen *et al*., (2018) evaluated the effects of deficit irrigation on yield and water productivity (WP) of Onion crop at Ambo Agricultural Research Center in Ethiopia. The results showed that, largest total Onion yield (46.7 t/ha) was obtained from 100% ETc which was not statistically different from treatments that were not irrigated during initial growth stage and irrigated with 75% ETc during the rest of phenological stages. Irrigation with 50% ETc resulted high water saving and yield reduction which may not be attractive for producers. Water productivity varied from 7.7 kg/m^3 for control and 14.9 kg/m^3 for the 50% ETc. However, such penalties on yield may not be tolerable from producers view point. The researchers recommended that, 75% ETc during development, bulb formation, maturity stages and skipping during initial growth stage for more water saving and WP enhancement potential with tolerable level of yield reduction.

Onion plant stressed prior to bulb formation, result in reduced bulb sizes that are not acceptable for market grades. Those plants stressed after bulb formation are prone to re-growth problems such as thick necks and scallions, which reduce marketable grades and increase storage problems (Casey and Garrison, 2003). A report by Pelter *et al.*, (2004) reveals that a three week stress at the early growth stage reduce Onion yield more than when the same duration of stress is imposed at the end of the growing season (Shock *et al*., 2004).

In principle of above researches reviews, maximum yield is obtained when the crop water requirements are fully met. However, applying deficit irrigation in growing stage or through the whole growing season of the crop may lead to a certain level of yield reduction based on sensitivity of the crop to water stress. Also, it is pointed out, the expectation of practicing deficit irrigation approach is that, the advantages from increased water use efficiency and use of saved water to irrigate other additional areas would balance the yield reduction as a result of imposed water stress.

2.5 Crop Yield Response Factor to Deficit Irrigation

The upper limit for crop yield is set by soil fertility, climatic conditions and management practices. Where all of these are optimal throughout the growing season, yield reaches the maximum value, as does evapotranspiration. Any significant decrease in soil water storage has an impact on water availability for a crop and, subsequently, on actual evapotranspiration and actual yield. When water deficit occurs during a specific crop development period, the yield response can vary depending on crop sensitivity at that growth stage (Moutonnet, 2002).

Crop yield response factor also varies depending on species, variety, irrigation method and management when deficit evapotranspiration is imposed. 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 and FAO, 2002).

The relationship between crop yield and water use is very unique. When climatic and agronomic conditions are adequate, crop yield completely depends on the amount of water available for use by the crops. According to Bhagyawant *et al.*, (2015), when soil fertility, climatic conditions and management practices do not restrict crop production and in a constraint free condition, crop yield is at maximum when full water requirements are met.

When water supply does not meet crop water requirement, actual evapotranspiration (ETa) falls below maximum evapotranspiration (ET_m) resulting to evapotranspiration deficit in plant which may develop to a point where crop growth and yield are adversely affected. The effect of the magnitude and the timing of occurrence of water deficit on crop growth and yield is therefore of major importance in the scheduling available but limited water supply for the growing period of the crop and in determining the priority of water supply amongst different crops during the growing season.

Doorenbos and Kassam (1979) provided a standard formula which stated, the yield response factor (Ky) is a ratio of relative yield reduction ($1 - Y_a/Y_m$) to relative evapotranspiration deficit ($1 - ET_a/ET_m$). They concluded that the Ky values are crop specific and vary over the growing season and crop growth stages with Ky > 1 crop response is very sensitive to water deficit with proportional larger yield reductions when water use is reduced; if Ky < 1, crop is more tolerant to water deficit and recovers partially from stress, exhibiting less than proportional reductions in yield with reduced water use. Also, if Ky = 1, yield reduction is directly proportional to reduced water use. However, they reported the yield response factor (Ky) value in the range of $0.3 < Ky < 1.1$ for Onion under deficit irrigation at a specific growth stages and during the whole growing season.

2.6 Onion Production and its Agronomy

Onion is currently becoming a popular crop relatively despite to its recent introduction to the country because of its yield potential per unit areas, the ease of propagation method both by seed and bulb method, and the presence of high domestic and export markets (Assefa *et al*., 2015).

Onion is a shallow rooted crop whose roots are mostly found in the upper 30 cm of soil and with a few roots extending to 60 cm deep. For optimum crop development, mean daily temperature varies between 15^0c and 24^0c before bulbing, and 20^0c and 25^0c for bulb development is preferred. Crop development slows down when the temperatures rise beyond 27^0c (FAO, 1996). It can grow from 500 - 2400 m.a.s.l., but the best growing altitude so far known in Ethiopia is between 700 - 1800 m.a.s.l. (Lemma and Shimeles, 2003).

Onion grows on a variety 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). Onion does not thrive in soils below pH 6.0 because of trace element deficiency, or occasionally, aluminum or manganese toxicity. Onions could be produced on slightly alkaline soils, but are sensitive to soil salinity. According to the FAO (2002), a soil salinity level of 4.3 dS/m or more could decrease the yield of Onion by up to 50%.

Onion can be transplanted after 40 - 50 days of sowing in the nursery site (NRMD, 2011). It can be planted in double row or single row per ridge. In double row, mother bulbs are planted at 30 cm space between rows on a ridge and 20 cm between plants on a row; this gives higher yield. However, producers mostly use single row per ridge with a spacing 60 cm between rows and 20 cm between plants for ease of weeding and pesticides applications (Enchalew *et al.*, 2016).

Onion is harvested when 80% of the bulbs become completely mature, which is evident by the collapse of 20 to 50% of the neck tissue and falling of the tops. That is usually 100 to 150 days after transplanting (Brewster, 1990).

2.7 Concept of Furrow Irrigation System

Furrow irrigation water application system is most popular form of surface irrigation, as it requires a smaller initial investment compared to other types of irrigation water application systems. This type of irrigation method is the most widely used in our country in almost all large and small irrigation schemes. 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 farmers' fields and majority of the commercial farms.

Separately from the conventional method, the use of furrow irrigation can be modified to alternate or fixed furrows so that it can maintain relatively drier soil condition. Alternate furrow irrigation (AFI) is the technique of irrigation water application in which one of the two neighboring furrows alternately irrigated during consecutive watering. Fixed furrow irrigation

(FFI) means that irrigation is fixed to one of the two neighboring furrows. Conventional furrow irrigation (CFI) or traditional irrigation means irrigating all furrows during consecutive watering (Mebrahtu *et al*., 2018).

2.8 Concept of CropWAT Model

Generally, CropWAT 8.0 for Windows is a decision support tool developed by the Land and Water Development Division of FAO. CropWAT is meant as a practical tool and a computer program to carry out standard calculations for reference evapotranspiration (ETo), crop water requirements (ETc) and crop irrigation requirements (IR), and more specifically the design and management of irrigation schemes based on soil, climate and crop data as input. It allows the development of recommendations for improved irrigation practices, the planning of irrigation schedules under varying water supply conditions, and the assessment of production under rain fed conditions or deficit irrigation. All calculation procedures used in CROPWAT 8.0 are based on the two FAO publications of the Irrigation and Drainage Series, namely, No. 33 titled "Yield response to water" and No. 56 "Crop Evapotranspiration: Guidelines for computing crop water requirements" (Thorsten, 2006).

3. MATERIALS AND METHODS

3.1 Description of the Study Area

3.1.1 Location

The study was conducted at Weyito experimental site of Jinka Agricultural Research Center in Southern Agricultural Research Institute. The site is situated in the eastern part of Bennatsemay Woreda at Enchete kebele a distance of 82 km away from Jinka town, capital of South Omo Zone, Southern Ethiopia. Geographically, the experimental site is located at 5˚18'0'' to 5˚31'33'' N latitude and 36˚52'30'' to 37˚5'0'' E longitude, and at an altitude of 550 m above sea level (AGP-II, 2015). Likewise, it is found 668 km south west of Addis Ababa and about 438 km west of Hawassa, the capital of Southern Nations Nationalities and Peoples Regional State (EPaRDA, 2005).

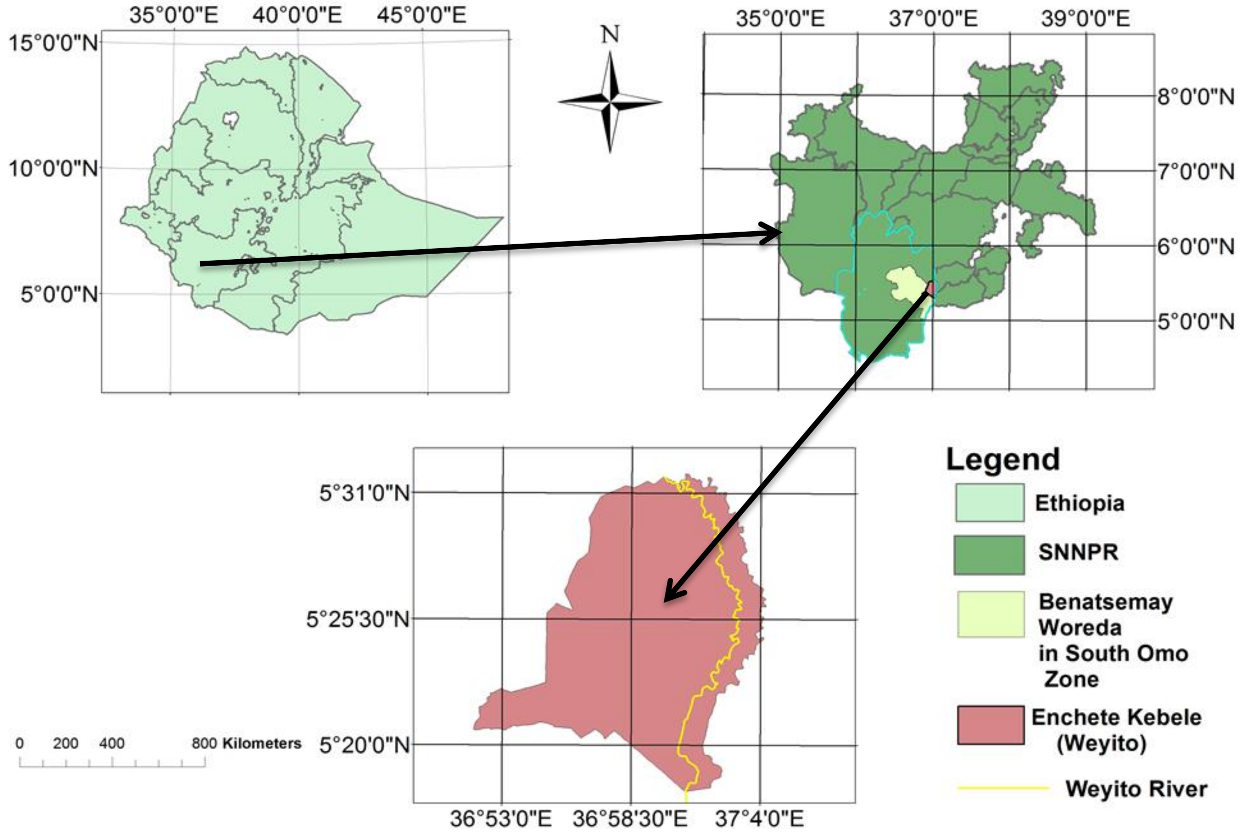


Figure 1. Map of Study Area

3.1.2 Climate and Agronomic Characteristics

The rainfall distributions in the area is erratic and uneven with mean annual rainfall ranges from 400 mm to 1400 mm and mean annual temperature ranges from 26 °C to 40 °C. The area has a long dry season from November to the beginning of March, while June and July is a short dry season. Agro-ecologically, the area is classified as hot arid and semi-arid climate, and it is characterized by recurrent water shortage, intermittent famine, overgrazing and dry-land cultivation (BOFED, 2015). Farmers grow crops twice a year, one during the dry season (March - July) by irrigation, the other during the partial rainy season (August - October) by using supplementary irrigation. Major irrigated crops grown in the area includes maize, sesame, onion, tomato, cotton and banana (AGP-II, 2015).

3.2 Determination of Soil Physical Properties

3.2.1 Soil Texture and Bulk Density

Primarily the gradient, management and cropping practices in the experimental site were recognized by visual survey in order to demarcate the field for soil sampling. Then, the field was demarcated into two parts diagonally and five sampling points were selected on the diagonal of the experimental field randomly. Before soil sampling, surface debris and any loose materials were removed from each point. Then , for textural analysis, disturbed soil samples were collected from 0 cm – 20 cm, 20 cm – 40 cm and 40 cm – 60 cm depth using screw type soil auger at five locations along the diagonal of the experimental field before planting based on ICARDA (2013) soil, plant and water analysis manual.

The collected soil samples were composited based on each depth and were analyzed in Hawassa Agricultural Research Center soil laboratory. Hydrometer method was employed for analyzing particle size distribution in the laboratory and textural class was determined based on percent of sand, silt and clay in textural triangle (Basu, 2011).

The soil bulk density was determined from undisturbed soil samples were collected by using core sampler of size 5 cm internal diameter and 5 cm height. Soil samples were taken from 0 – 20 cm, 20 – 40 cm, and 40 – 60 cm at three locations along the diagonal of the experimental field and oven dried for 24 hours at 105^0c in Jinka Agricultural Research Center soil laboratory. Then, the bulk density was calculated as the ratio of dry weight of the soil to known cylindrical core sampler volume (ICARDA, 2013).

$$\mathrm{BD} = \frac{\mathrm{Ms}}{\mathrm{Vs}} \ldots\ldots 3.1$$

Where Ms is the weight of oven dry soil in gram, and Vs is the volume of the same soil in cm^3.

3.2.2 Field Capacity and Permanent Welting Point

Soil samples for the determination of moisture content at field capacity (FC) and Permanent wilting Point (PWP) was collected from 0 – 20 cm, 20 cm – 40 cm and 40 cm – 60 cm depth at five locations along the diagonal of the experimental field and then composited and determined in Ethiopian Construction, Design and Supervision Works Corporation soil laboratory in Addis Ababa.

In the laboratory, the collected soil samples were saturated before keeping in pressure plate apparatus with plastic rings. Then, the pressure plate was closed properly and the gauge from the compressor was at 0.33 and 15 bar for field capacity and permanent wilting point respectively. After, no more drop of water observed, the samples was collected from the pressure plate apparatus, weighed and oven dried for 24 hours at 105^0c. Then, the dry weight was recorded and the moisture content at FC and PWP was calculated using equation (Jaiswal, 2003).

$$\theta m\ (\%) = \frac{(\mathrm{Wws} - \mathrm{Wds})}{\mathrm{Wds}} * 100 \ldots\ldots 3.2$$

Where θm is mass based soil moisture content at FC or PWP (%), Wws is weight of wet soil (gm) and Wds is weight of dry soil (gm).

3.2.3 Soil Infiltration Rate

Before starting the experimental plots and layout preparation, soil infiltration rate test was done at three locations along the diagonal of the experimental field using double ring infiltrometer as conducted by Amreeta (2014). The inner ring and outer ring with 30 cm and 40 cm diameter respectively were driven 15 cm deep into the soil by hammer in order to prevent lateral movement of the water through the soil. Infiltration rate measurement was recorded for the total of 210 minutes continuously until the last two reading became the same result. The depths of water levels infiltrated were measured at increasing time intervals starting from 15 second to 30 minutes (Appendix Table 1).

Figure 2. Soil infiltration rate test in the experimental field

3.3 Determination of Soil Chemical Properties

Selected soil chemical properties like pH, electrical conductivity (EC), organic carbon (OC) and organic matter (OM) content were analyzed in Hawassa Agricultural Research Center soil laboratory. Following the procedure given in Basu (2011) soil testing laboratory manual, the electrical conductivity (EC) and power of hydrogen (pH) of the soil was determined by using electrical conductivity meter and pH meter respectively in the laboratory.

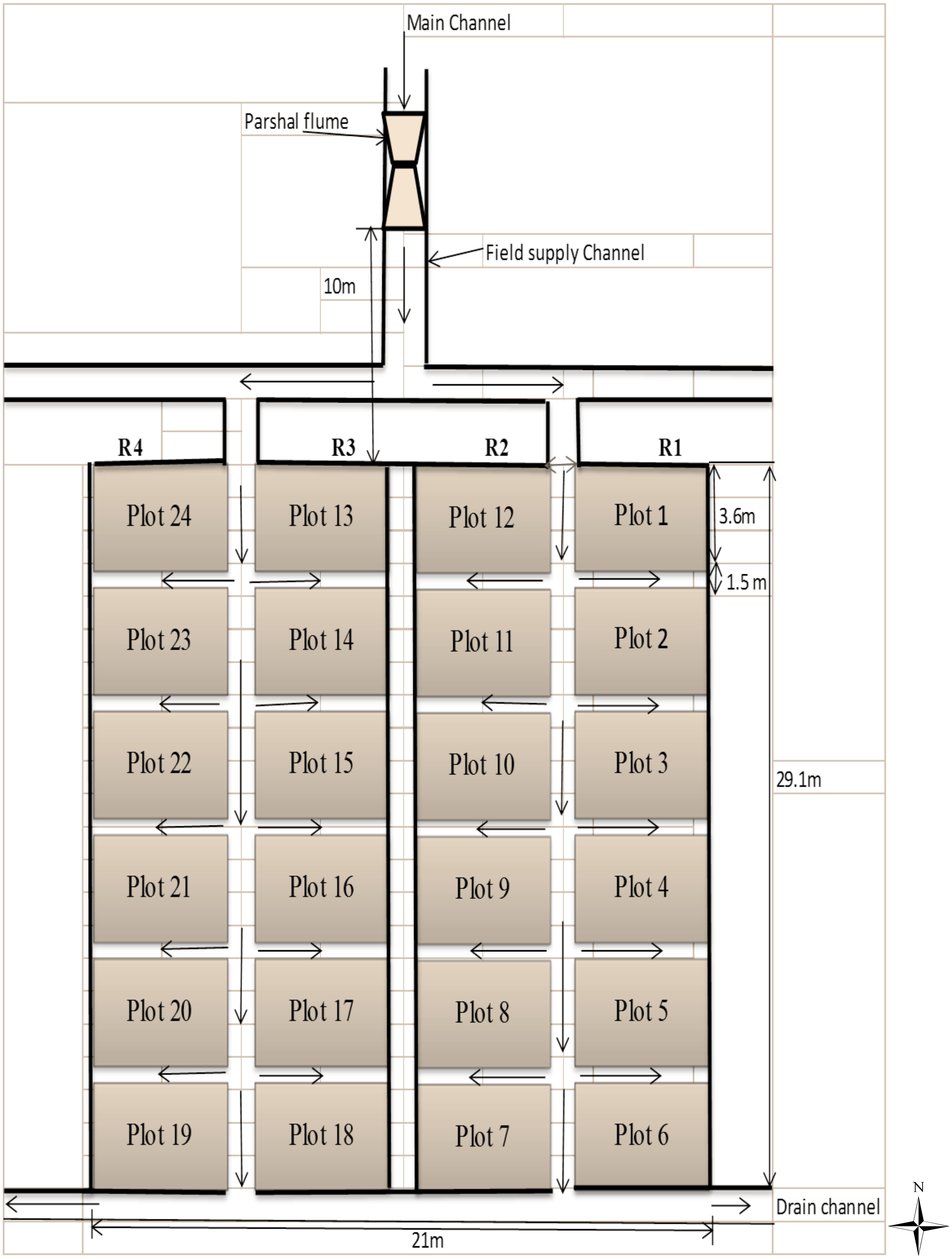
The organic carbon was analyzed with colorimetric method by the help of Spectrophotometer device in the laboratory and organic matter (OM) content was determined by multiplying organic carbon (OC) by constant factor 1.724 (Basu, 2011).

3.4 Experimental Design and Procedure

3.4.1 Experimental Land Preparation and Plot Layout

The study was conducted at Jinka Agricultural Research Center (JARC) Weyito experimental site which is found in Bennatsemay Woreda Enchete Kebele during 2018 dry season. Primarily, the experimental field was ploughed on 20th and 25th of March 2018 two times by oxen. The big clods was broken into small size and incorporated with soil. All the weeds and crop residue was removed from the experimental field. Then, the land was leveled by man power so that it was suitable for laying the experiment and to make appropriate slope for the experiment. After the land was leveled, all the experimental area was subdivided in to four blocks, then within blocks, experimental plots were prepared and the ridge was created within each plot without including free spaces between blocks as well as plots. Each plot was consisted of five ridges and six furrows.

Once, the layout prepared, and then one main canal outside the experimental field and two field channels in the field were constructed for the conveyance of irrigation water. Double bund was constructed in the free space (buffer zone) between the first and the second, the third and the fourth blocks to form field channel that irrigate both blocks simultaneously. Finally, in the bottom border of the experimental field, one drain canal was constructed to remove remained irrigation water in the channel after the irrigation application (figure 3).



R = Replication

Figure 3. Plot layout and its dimensions

3.4.2 Experimental Design and Treatments

The experiment was designed with five deficit irrigation level treatments (T) and one control irrigation of 100% ETc, under conventional furrow irrigation methods. To minimize the effect of soil fertility differences, water gradient and other biases (Mick, 2011) the experiment was laid out in a Randomized Complete Block Design (RCBD) with four replications of six level treatments. The experimental field was divided into 24 plots and each plot size was 3.6 m by 3 m dimension (10.8 m^2) to accommodate six furrows with spacing of 60 cm and having 3 m length. Each furrow was contained 15 Onion seedlings which accommodated 90 plants per plot. The space between plots and replications (blocks) was 1.5 m and 3 m respectively which was used to eliminate the influence of lateral water movement. The total area of the experimental field was 611.1 m^2 and the net irrigated plot area of the experiment was 259.2 m^2.

Treatments (T)

- T1 = Irrigation water application of 100% ETc (Control)
- T2 = Irrigation water application of 85% ETc
- T3 = Irrigation water application of 70% ETc
- T4 = Irrigation water application of 50% ETc
- T5 = Irrigation water application of 100% ETc initial stage (Is), 85% ETc development stage (Ds), 70% ETc mid stage (Ms) and 50% ETc late season (Ls)
- T6 = Irrigation water application of 85% ETc initial stage, 70% ETc development stage, 50% ETc mid stage and 0% ETc late season.

The treatments was arranged and laid in the experimental field in the following form:

Table 1. Randomized arrangements of treatments in the plots

Replication (R1)	P_1T_1	P_2T_2	P_3T_3	P_4T_4	P_5T_5	P_6T_6
Replication (R2)	$P_{12}T_6$	$P_{11}T_5$	$P_{10}T_1$	P_9T_2	P_8T_3	P_7T_4
Replication (R3)	$P_{13}T_4$	$P_{14}T_3$	$P_{15}T_6$	$P_{16}T_5$	$P_{17}T_1$	$P_{18}T_2$
Replication (R4)	$P_{24}T_2$	$P_{23}T_1$	$P_{22}T_4$	$P_{21}T_3$	$P_{20}T_6$	$P_{19}T_5$

Note: - P = Plots, T = Treatments

3.4.3 Seed Bed Preparation and Transplantation

In the beginning 1 m by 5 m seed bed was prepared in the nursery site. Onion seed variety called Bombay red was used as seed material. Since Bombay Red is more preferred by the farmers, mainly due to better market demand and of course, its productivity level has also significant role for its acceptance (NRMD, 2011). Moreover, as reported by Olani and Fikre (2010), Bombay red variety produce higher seed yield under relatively high temperature and in rift valley areas.

On the prepared seedbed, slight rows were opened with in 10 cm space and selected Bombay red seed variety was drilled on 18th February 2018 in 1cm depth at seedbed. Immediately, after sowing, the seedbed was covered by soil slightly and dry grass until germination. The bed was irrigated slightly with watering-can in the afternoon till transplanting to the experimental field.

After 45 days of sowing in the nursery site, the seedlings were transplanted on 5th April 2018 in well prepared experimental plots. Before one day of transplanting the seed bed was irrigated for ease of uprooting seedlings and to minimize damage to roots as well as the experimental plots for better establishment in the experimental field.

The seedlings were planted on one sides of a furrow at row spacing of 60 cm and space between plants 20 cm. Before the commencement of treatment, two common light irrigations were supplied to all plots at two days interval depending on the prevailing climatic condition, to ensure better plant establishment. All other cultural practices other than treatment variables were done in accordance to the recommendation made for the area.

3.5 Irrigation System Management of the Experiment

As specified in the objectives, one of the aims of this experiment is to determine the water productivity of irrigated Onion under conventional furrow irrigation system. The irrigation treatments are the only variables whose effect is expected from the experiment. The source of irrigation water was from the nearby water channel which was diverted to the irrigated farm from Weyito River by diversion canal. The water was then brought to the experimental field by small earthen channel and was distributed carefully to the each experimental plot by furrows based on its crop water requirement, schedule and application time which is described in detail in the following sub-sections. The amount of water applied to the experimental field was measured by 3-inch Parshall flume which was made from metal sheet and was installed at 10 m away from the nearest plot to it in the field canal. It was set inside straight and uniform section of the field channel and pieces of stones was put in the downstream side below the canal bottom level to minimize the soil scouring and erosion in downstream of Parshall flume. For this experiment, the water applied and flow through the Parshall flume was at 5cm head with discharge of 1.7 l/s (Appendix Table 16) for the given time of each treatments.

3.5.1 Crop and Irrigation Water Requirement

According (Allen *et al*., 1998), to compute the crop water requirement (ETc) estimation of reference crop evapotranspiration (ETo) and crop coefficient (Kc) is required. In this experiment, reference crop evapotranspiration (ETo) on daily basis was estimated (Appendix Table 18) by using FAO CropWAT software version 8.0 (Allen *et al*., 1998). The input data used to compute the ETo, was altitude, latitude, longitude and 20-years (1997-2016) climatic data of Weyito experimental site (monthly maximum and minimum temperature, relative humidity, wind speed, sunshine hours and rainfall) which was collected from National Meteorological Agency Hawassa Branch Directorate (Appendix Table 17-21).

In this study, Onion coefficient (Kc-value) estimated by Allen *et al.*, (1998) was used as 0.6 for the initial stage, $0.6 < kc < 1.1$ for the development stage, 1.1 for the mid-season stage and $0.9 < kc < 1.1$ for the late season stages. Based on the Kc values of the crop and length of each growth stages, daily crop coefficient was calculated by using Microsoft excel for development and late stage as linear equation. Length of growth stages 20, 35, 45 and 45 days were used for initial, development, mid and late season, respectively. As observed by Lemma and Shimeles, (2003) Onion is a shallow rooted crop whose roots are mostly found in the upper 30 cm of soil and with a few roots extending to 60 cm deep. Accordingly, for this experiment the maximum effective root depth of the Onion was taken as 60 cm deep.

Table 2. Crop coefficient (Kc - values for Onion)

	Crop Growth Stages			
	Initial	Development	Mid	Late Season
Crop coefficient (Kc-values)	0.6	0.6 < kc < 1.1	1.1	0.9 < kc < 1.1

Source: Allen *et al.*, 1998

The crop water requirement (ETc) was estimated from the expression (FAO, 2009):

$$ETc = ETo \times Kc \quad \text{……………………..……………………………………………...…......3.3}$$

Effective rainfall (Pe) which is part of the rainfall that entered into the soil and made available for crop production in mm. The effective rainfall can be calculated from the expression (Brouwer and Heibloem, 1986):

$$Pe = 0.8\ P - 25 \text{ if } P > 75 \text{ mm/month} \quad \text{……………….……………..…………………………….…3.4}$$

Or

$$Pe = 0.6\ P - 10 \text{ if } p < 75 \text{ mm/month} \quad \text{………………………………………………….…………3.5}$$

3.5.2 Irrigation Schedule

The amount of water that can be extracted by plant roots is held in the soil in an ‘available’ form. The actual volume of water that can be obtained from the soil profile depends on the depth of the root system. All of the water found in the root zone may not be actually taken up by roots (Allen *et al.*, 1998). Hence, the total available water (TAW), stored in a unit volume of soil, is approximated by taking the difference between the water content at field capacity (FC) and at permanent wilting point (PWP). Therefore, the total available water was expressed by (Jaiswal, 2003):

$$TAW = \frac{(FC - PWP) * BD * Dz}{100} \quad \text{…………………………………………..………………..3.6}$$

Where, TAW is total available water in **mm/m**, FC is field capacity and PWP is permanent welting point in percent (%) on weight basis which was calculated in equation (3.2), BD is the bulk density of the soil in gm/cm^3 in equation (3.1), and Dz is the maximum effective root zone depth of Onion in **mm**.

As revealed by FAO (1996), Onion is sensitive to water deficit and thus, for high yield, soil water depletion should not exceed 25% of the total available water (that is $p = 0.25$). Also, for maximum crop production, the irrigation schedule was fixed based on readily available soil water (RAW). The RAW is the amount of water that crops can extract from the root zone without experiencing any water stress. Therefore, RAW was computed from the expression (Allen *et al.*, 1998):

$$RAW = p * TAW \qquad \text{3.7}$$

Where, RAW is readily available soil water in (mm), p is in fraction for allowable or permissible soil moisture depletion for no stress (for Onion $P = 0.25$) and TAW is total available water in (mm) from equation (3.6). Considering the daily ETc, TAW, Dz and p, the irrigation interval was computed from the expression (FAO, 2009):

$$\text{Interval (days)} = \frac{RAW}{ETc} \qquad \text{3.8}$$

Where, RAW in mm from equation (3.7) and ETc in mm/day from equation (3.3). Moreover, depth of irrigation (d_{net}) is amount of irrigation water that is to be applied at one irrigation and the readily available portion of the soil moisture (Demba, 2014). Accordingly; readily available soil water is the same as the net irrigation water application depth (d_{net}).

3.5.3 Irrigation Application Efficiency and Gross Irrigation Application Depth

Furrow irrigation could reach a field application efficiency of 65% when it is properly designed, constructed and managed. The average varies from 50% to70%. However, the more common figure is 60% (FAO, 2002). Moreover, the application efficiency of a short, end diked furrow is taken as 60% (Brouwer and Prins, 1989).

Hence, for this particular experiment, irrigation efficiency was taken as 60% which is common for surface irrigation method in furrow irrigation. Based on net irrigation depth and irrigation application efficiency, the gross irrigation water requirement was calculated by the following formula (Brouwer and Prins, 1989):

$$\mathrm{dg} = \frac{\mathrm{dnet}}{\mathrm{Ea}} \qquad \text{…...………………….……………....……………..….…………………….3.9}$$

Where, $\mathbf{d_g}$ is the gross irrigation depth in **mm** and **Ea** is the field irrigation application efficiency (60%). This calculated gross irrigation water was finally applied to experimental plots based on the treatment of the experiment.

3.5.4 Irrigation Application Time

The amount of irrigation water to be applied at each irrigation application was measured using 3-inch Parshall flume. The time required to deliver the desired depth of water into each plot was calculated using the equation (Kandiah, 1981):

$$\mathrm{t} = \frac{\mathrm{dg} \times \mathrm{A}}{6 \times \mathrm{Q}} \qquad \text{...3.10}$$

Where: d_g = gross depth of water applied (cm),

t = application time (min),

A = Area of experimental plot (m^2) and

Q = flow rate (discharge) (l/s)

The irrigation depth was converted to volume of water by multiplying it with area of the plot (Valipour, 2012).

V = A* dg…..…………...3.11

Where: V = Volume of water in (m^3)

A = Area of plot (m^2)

d_g = Gross irrigation water applied (m)

3.6 Data Collected

Soil samples were collected from the experimental field using auger and core sampler from the soil depths of 0 – 20 cm, 20 – 40 cm and 40 – 60 cm for determining physical and chemical properties of soil as explained in the above section (3.2 and 3.3). Depth of water applied and date of watering during the growing period was recorded for each treatment.

Date of Onion seed sowing, transplanting and date of harvesting was recorded. Data on vegetative growth (plant height, leave number per plant, leave length and leaf dry matter), yield and yield components such as average bulb weight, bulb and neck diameter, bulb length and dry matter of bulb was recorded from five randomly selected plants from two middle rows of each experimental plot as reported by David *et al*., (2016).

3.6.1 Vegetative Growth Parameters

Plant Height (cm): Plant height was recorded from five randomly selected plants from two middle rows of each experimental plot and these plants were tagged for subsequent measurement. The height of these five plants was measured from the soil surface to the tip of the plant using ruler. Then average value of the five plant heights were recorded as plant height of each plot.

Leave Number per Plant: Total number of leaves of five randomly selected plants were counted at maturity stage in the field from each plot and divided by the number of plants to get average leaf number per plant of each experimental plot.

Leave Length (cm): The longest leaf of those sampled five plants at maturity stage was measured from the sheath to tip of the leaf by using a ruler from each plots and the average leaf length was calculated with in each plots.

Leaf Dry Matter Content (%): This indicates the above ground biomass of five representative plants which was harvested from two middle rows of each plot. By cutting the plant at the top part (above ground) and the fresh weight was taken by using spring balance in gram then dried in the oven at the temperature of 70 ^{0}C for 24 hours. Then, oven dried leaf weight was recorded and finally percent leaf dry matter was calculated by dividing the oven dried leaf samples weights by their respective fresh weights.

3.6.2 Yield and Yield Components

Bulb Length (cm): Bulb length or polar diameter refers to the length of randomly selected five plant bulbs from each plot measured using vernier caliper in centimeter. Then, average bulb length was calculated for each treatment with in each replication.

Bulb Diameter (cm): Bulb diameter or equatorial diameter of five randomly selected Onion bulbs were measured at the widest point in the middle portion of the matured bulb from each plot of the experiment using a vernier caliper. Then, average bulb diameter was calculated for each treatment with in each replication.

Neck diameter (cm): Indicates the thickness of Onion bulb neck in centimeter which was recorded from five randomly selected Onion bulbs from two middle rows of each plot by using vernier caliper. Then, the average neck diameter was calculated with in each replication.

Bulb Dry Matter Content (%): In this case five bulb yields was randomly selected from each plots and fresh weight was taken by using digital balance. Then, it was chopped, put in to paper bag and dried at a temperature of 70 °C in the oven for 24 hours. Finally, percent dry matter was calculated by dividing the oven dried bulb weights by their respective fresh weights.

Average Bulb Weight (g): Indicates a single bulb weight of five randomly selected bulbs from two middle rows of each plot and weighed using spring balance. Then, the average was recorded as individual average bulb weight in gram.

Marketable Bulb Yield (t/ha): Indicates yield of Onions greater than 3 cm in diameter, free from physiological disordered and pest damaged bulbs (Lemma and Shimeles, 2003). It was collected from the two middle rows of each plot and weighed by using spring balance in kilogram (kg), finally converted in to t/ha.

Unmarketable Bulb Yield (t/ha): Indicates small sized (less than 3cm in diameter), discolored, physiological disordered and pest damaged bulbs (Lemma and Shimeles, 2003) which was harvested from the two middle rows of each plots and the weight in kilogram (kg) was recorded by using spring balance, then converted in to t/ha.

Total Bulb Yield (t/ha): Indicates the sum of marketable and unmarketable bulb yields collected from two middle rows of each plots and the weight in kilogram (kg) was recorded by using spring balance, then converted in to t/ha.

3.6.3 Crop Water Use Efficiency (CWUE)

CWUE is the yield harvested in kilogram per ha-mm of total water used. It was calculated using formula as the ratio of crop yield to the amount of water consumptively used by the crop (Ibragimov *et al*., 2007):

$$\mathrm{CWUE} = \frac{\mathrm{Y}}{\mathrm{ET_C}} \quad \ldots\ldots 3.12$$

Where: CWUE = crop water use efficiency (kg/m^3)
Y = yield in kg ha^{-1} and
ETc = is crop evapotranspiration (mm)

3.6.4 Irrigation Water Use Efficiency (IWUE)

IWUE is usually defined as the ratio of yield per unit of total irrigation water applied and calculated by the formula (Ofori, 1994).

$$\mathrm{IWUE} = \frac{\mathrm{Y}}{\mathrm{IW}} \quad \ldots\ldots 3.13$$

Where: IWUE is irrigation water use efficiency of Onion (kg/m^3), Y is yield of Onion in kg/ha and IW is total amount irrigation water applied in m^3/ha.

3.7 Yield Response Factor

The yield response factor (K_y) defined as the decrease in yield with respect to the deficit in water consumptive use (ET) and was calculated according to the procedure mentioned by Doorenbos and Kassam (1979) as follows:

$$1-\frac{Ya}{Ym} = K_y\left(1-\frac{ETa}{ETm}\right) \quad \text{.......} 3.14$$

Where: K_y is yield response factor, Y_a is actual bulb yield obtained from each deficit treatments (t/ha), Y_m is maximum bulb yield obtained from the control treatment with full irrigation (t/ha), ET_a is the net depth of irrigation applied for each deficit treatments (mm), ET_m is the net depth of irrigation water applied for the control treatment with full irrigation (mm), $(1-\frac{Ya}{Ym})$ is the decrease in relative yield due to deficit water application and $(1-\frac{ETa}{ETm})$ is the relative water saved (decrease in relative crop water consumptive) due to deficit irrigation.

3.8 Economic Water Productivity

Economic water productivity analysis was begun by considering the general relationship between the crop water use and crop yield per hectare of land at the different deficit irrigation application levels using the partial budget analysis. Partial budget is a method of organizing experimental data and information about the costs and benefits of various alternative treatments (CIMMYT, 1988). Economic analysis was done using the prevailing market prices during experimentation and at the time the crop was harvested. All costs and benefits were calculated on hectare basis in Ethiopian Birr (Birr/ha).

The adjusted yield was obtained by reducing the average yield by 10% as indicated in CIMMYT (1988). The average cost the local people were paying for daily labor was 60.00 Birr per day.

Thus, for computing the analysis labor cost of 60.00 Birr per day was used. The farm gate price of Onion during the harvesting time was 12.00 Birr/kg and the price of irrigation water was taken as 1.00 Birr per 0.5 m^3 of water. Net income (NI) in Birr/ha, generated from Onion crop was computed by subtracting the total variable cost (TVC) in Birr/ha from the total return (TR) in Birr/ha obtained from Onion sale as:

$$NI = TR - TVC \quad \text{……………………………………………………………………..…3.15}$$

Fixed costs (FC) are those that do not vary between irrigation treatments, i.e. Onion seeds, pesticides, land rent and farm implements. Variable costs (VC), on the other hand, are those that do vary between irrigation treatments, i.e. irrigation water and labor.

The dominant analysis procedure as detailed in CIMMYT (1998) was used to select potentially profitable treatments from the range that was tested. The selected and discarded treatments using this technique are referred to as undominated and dominated treatments, respectively. The undominated treatments were ranked from the lowest to the highest variable cost. For each pair of ranked treatments, a % marginal rate of return (MRR) was calculated by the following formula:

$$MRR = \frac{\Delta NI}{\Delta VC} * 100\% \quad \text{……………………………………………………………...…3.16}$$

Where; ΔNI is the difference of the net income in Birr and ΔVC is additional unit of expense in Birr, between two consecutive undominated treatments.

3.9 Statistical Analysis

Data analysis was under taken according to the data collected by using SAS software 9.1 for windows. Whenever treatment effects were found significant, treatment means were compared using the least significant difference (LSD) at 5% probability level (Steel *et al.,* 1997). The input data used was plant height, leaf number plant, leaf length, bulb diameter, neck diameter, bulb length, average bulb weight, marketable bulb yield, unmarketable bulb yield, total bulb yield, bulb dry matter and leaf dry matter.

4. RESULTS AND DISCUSSION

4.1 Soil Characterization of Experimental Site

The result of laboratory soil analyses and field tests on physical and chemical characteristic, like, soil texture, BD, FC, PWP, soil pH, electrical conductivity (EC), organic carbon (OC) content, organic matter (OM) content and soil infiltration rate were discussed below.

4.1.1 Soil Physical Properties

The result of the soil textural analysis from the experimental site was presented in Table 3. The texture (40.8% sand, 32% silt, 27.2% clay), (38% sand, 38% silt, 24% clay), (45.6% sand, 30.8% silt, 23.6% clay) at a depth of 0 – 20 cm, 20 – 40 cm, 40 – 60 cm, respectively. Thus, according to USDA soil textural classification system, the soil of the experimental field could be classified as loam at all depths.

Table 3. Particle size distribution of the experimental site

Depth (cm)	Particle size distribution (%)			Textural class
	Sand	Clay	Silt	
0 – 20	40.8	27.2	32.0	Loam
20 – 40	38.0	24.0	38.0	Loam
40 – 60	45.6	23.6	30.8	Loam
Average	41.5	24.9	33.6	Loam

Texture may affect the ease with which soil can be worked, the amount of water and air it holds and the rate at which water can enter and move through the soil. However, loam soils are best suited for Onion production because sand, silt and clay together provide desirable characteristics (Olani and Fikre, 2010).

The bulk density (BD), total available water (TAW), water content at field capacity (FC) and permanent wilting point (PWP) values were presented in Table 4.

Table 4. Bulk densities, field capacity, permanent welting point and TAW of the soil

Depth (cm)	BD (g/cm^3)	FC (%)	PWP (%)	TAW (mm/depth)	TAW (mm/m)
0 – 20	1.26	29.31	12.78	41.66	208.28
20 – 40	1.28	28.13	12.46	40.11	200.55
40 – 60	1.31	26.04	10.72	40.15	200.74
Average	1.28	27.83	11.98	40.64	203.18

The average bulk density of the soil from experimental site showed a slight variation with depth. It varied from 1.26 g/cm^3 at the top root zone (0 – 20 cm) to 1.31 g/cm^3 at the lower root zone layer (40 – 60 cm). The bulk density shows slight increase with depth. This could be because of slight increases of soil compaction with depth due to the weight of the overlying soil layer (Brady and Weil, 2002). But, the average soil bulk density is (1.28 g/cm^3) and which was in suitable range for crop growth (NRMD, 2011). The average total available water (TAW) of experimental site was found to be 203.2 mm/m which was nearly upper range of loam soil (140 to 220 mm/m) (Majumdar, 2000).

The average soil infiltration rate and the cumulative intake curves based on the test result of the soil were presented (Appendix Table 1 and Appendix Figure 8). The basic infiltration rate of the soil was about 27.3 mm/hr. This rate of infiltration is the characteristic of loam soils (Brouwer and Heibloem, 1986).

4.1.2 Soil Chemical Properties

As indicated in Table 5, the average pH value of the experimental site through the analyzed depth was found to be nearly alkaline, with average value of 7.83. It is suitable result, since 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 0.182 dS/m through 60 cm profile which is below the threshold value for yield reduction, i.e. 1.2 dS/m (Smith *et al.*, 2011).The OM content and OC content of the soil had average values of 2.67% and 1.55%, respectively which indicates high soil fertility level (OC > 1%) and suitable for vegetable production (Basu, 2011).

Table 5. Soil chemical properties of the experimental site

Depth (cm)	pH	ECe (dS/m)	OC (%)	OM (%)
0 – 20	7.69	0.210	1.43	2.46
20 – 40	7.93	0.173	1.65	2.85
40 – 60	7.87	0.178	1.58	2.72
Average	7.83	0.182	1.55	2.67

4.2 Crop Water Requirement of Onion

The calculated daily reference evapotranspiration (ETo) from long term (20 years) climatic data was presented in Appendix Table 21. The result showed that the minimum (6.0 mm/day) and maximum (7.15 mm/day) ETo value was occurred in June and February months respectively. Generally the evaporative power of the atmosphere was under arid and semi-arid ranges (6 - 8 mm/day) (Brouwer and Heibloem, 1986).

The test crop Onion was harvested on September 5 2018 G.C. The seasonal net and gross irrigation water depth applied (starting from April 9 2018 until August 26 2018 G.C.) for each treatment was presented in Table 6 below. The seasonal net and gross irrigation water depth applied under T1 was 826.4 mm and 1377.5 mm respectively and were maximum to all other treatments. The seasonal net and gross irrigation water depth applied under T6 was 320.1 mm and 533.6 mm which respectively and were minimum to all other treatments. The total net and gross irrigation water applied on this experiment was 3403.8 mm/season and 5673.8 mm/season. During this field experiment implementation season, no rainfall was occurred in the area. Consequently, irrigation was the sole source of water for the crop throughout the whole growth period. Thus, net irrigation water requirement (IRn) was equal to crop water requirement (ETc).

Table 6. Seasonal net and gross irrigation water depth applied for each treatment

Treatments (T)		Net irrigation water depth (mm)	Gross irrigation water depth (mm)
T1		826.4	1377.5
T2		702.4	1170.9
T3		578.5	964.3
T4		413.2	688.8
T5		563.2	938.9
T6		320.1	533.6
	Total	**3403.8**	**5673.8**

4.3 Effect of Deficit Irrigation on Vegetative Growth and Yield Components

4.3.1 Plant Height

Analysis of variance (Appendix Table 2) showed that different deficit irrigation application levels resulted highly significant ($P < 0.01$) effect on Onion plant height. As shown in Table 7 below, there was statistically significant ($P < 0.01$) difference among all the deficit levels except between the T5 and T3 application levels has no significant variation. The highest plant height was recorded from control treatment (100% ETc irrigation application) which is 59.33 cm while the minimum plant height (48.48 cm) was observed from T6 (irrigation water application of 85% ETc initial stage, 70% ETc development stage, 50% ETc mid stage and 0% ETc late season) and this was significantly inferior to all other treatments. The second highest plant height was observed from treatment T2 which is 57.53 cm. The plant height observed from T4 (50% ETc irrigation application) was 50.68 cm.

Generally, the mean table showed that, Onion plant height was decreased as the stress level increased through the whole crop growing season and its phenological stages. On the other hand, higher plant height was associated with higher irrigation water application and shorter plant height was resulted because of application of minimum irrigation water (Figure 4).

This finding is in agreement with the finding of Dirirsa *et al.* (2017) and Mebrahtu *et al.* (2018) who reported that the plant height of Onion increased with increased irrigation water application levels and also decrease with the decrease of irrigation water application level. Likewise, Metwally (2011) indicated that plants which received larger amount of water showed significantly taller plants compared with plants which received lower amounts of water and Al-Moshileh (2007) observed that with increasing soil water supply plant height, number of green leaves and bulb diameter were significantly increased. Kumar *et al*. (2007) also reported that irrigation had significant effect on plant height; which subsequently influenced the crop yield.

4.3.2 Number of Leaves per Plant

The analysis of variance (Appendix Table 3) has indicated that there was highly significant leaf number variation due to different deficit irrigation application level ($P < 0.01$). As indicated in Table 7 below, the highest leaf number per plant was observed from T1 (100% ETc) where as the lowest leaf number per plant was recorded from T6 and had no significant difference ($P < 0.01$) with T4 as shown in Table 7. Moreover, there was no significant difference of leaf number per plant between T3 and T5. The higher leaf number per plant resulted from application of 100% ETc irrigation depth is due to the irrigation effect that facilitates nutrient availability and photosynthesis for undisrupted growth of the plant, similarly the reduced number of leaves per plant at 50% ETc of irrigation level or depth may be attributed to effects of water stress on cell expansion (Abbey and Joyce, 2004).

This result is in line with other findings which reported that Onion bulbs of irrigated treatments gave highest leaves number per plant than the non-irrigated one, where as Onion grown without supplemental irrigation gave lower number of leaves (Biswas *et al.*, 2003). Similarly, experiment carried out by Metwally (2011) showed that larger amount of water was associated with more Onion leaves per plant. Gebregwergis *et al.* (2016) also reported that the leaf number of Onion plants was significantly affected ($P < 0.01$) by irrigation depth. Furthermore, study result by Enchalew *et al*. (2016) revealed that leaf number, bulb diameter and total bulb yield had shown a highly significant ($P < 0.01$) difference among different deficit irrigation levels. So, this shows irrigation water application level had significant effect on vegetative growth of Onion and subsequent variations on yield. Also, the effect is further illustrated on figure 4 below.

4.3.3 Leaf Length

According to analysis of variance (Appendix Table 4) the effect of irrigation level on leaf length of Onion plants was highly significant ($P < 0.01$). As shown in the Table 7 below, highly significant differences were observed between the control treatment T1 and other treatments. In such a way that the T1(100% ETc irrigation depth) gave the longest (49.83 cm) Onion leaves where as the shortest leaf length (40.6 cm) was obtained under T6 which had no significant differences with T4 (50% ETc irrigation level). Similarly, between treatments T2 and T5 as well as T3 and T5 there was no significant difference on leaf length.

This result is supported by Gebregwergis *et al.* (2016) and Mebrahtu *et al.* (2018) who reported leaf length of Onion plants was significantly ($P < 0.01$) affected by irrigation levels. As reported by Mebrahtu *et al*. (2018), significantly higher leaf length were recorded by 100% of irrigation level, followed by 85, 70, 55 and 40% of irrigation levels. The result also supported by observation of Bagali (2012) who reported longer leaves at 100% crop water requirement compared to treatments of deficit irrigation. Water deficit leads to retarded plant growth as it results in closure of stomata and interfere with photosynthesis ability and nutrient uptake of plants and consequently, reducing cell division and growth then resulting in stunting of leaves. Similarly, Smith *et al*. (2011) quoted that the rate of transpiration, photosynthesis and growth are lowered by even mild water stresses. In general, based on this observation it is obvious that Onion leaf length increased with increasing irrigation water application level and which is further visualized on the figure 4 below.

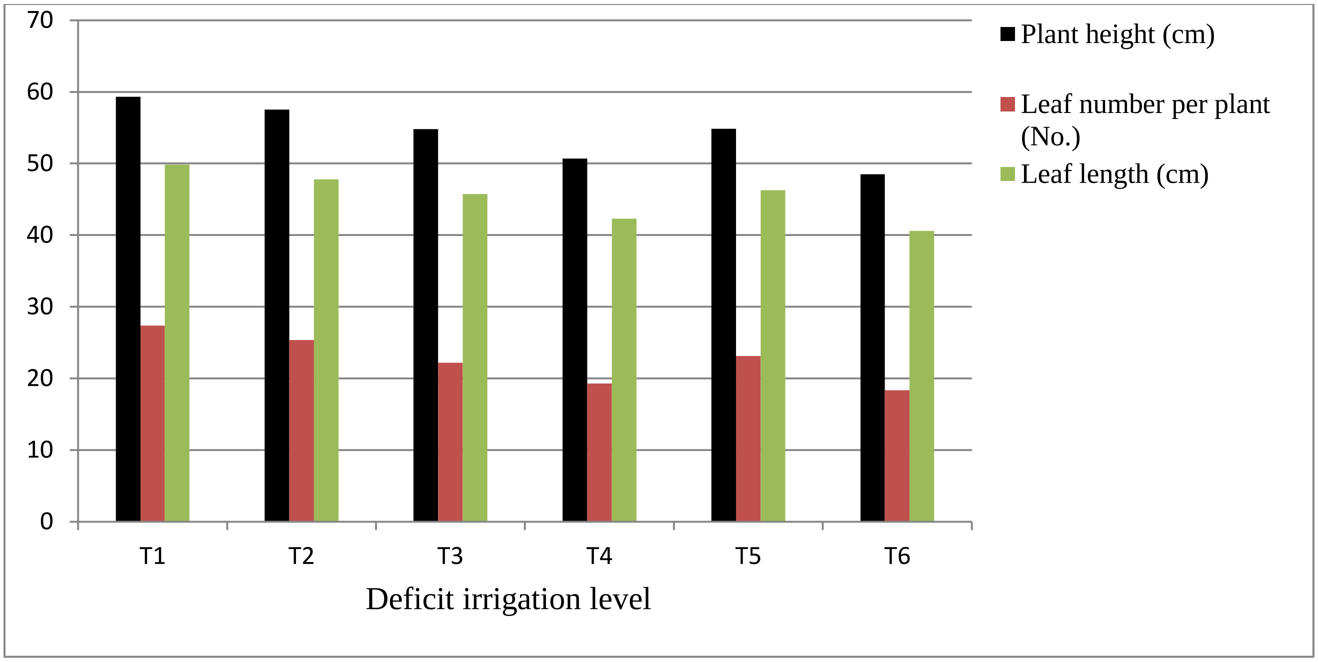


Figure 4. Effect of deficit irrigation on plant height, leaf number per plant and leaf length

4.3.4 Bulb Diameter

The deficit irrigation water application affected the size of Onion bulb. As the analysis of variance (Appendix Table 5) indicates, bulb diameter obtained from the different irrigation levels showed highly significant ($P < 0.01$) variation. As indicated in Table 7 below, the largest bulb diameter (7.67 cm) was observed at T1 (100% ETc application level) which was significantly ($P < 0.01$) different to all other treatments. In similar way, the least bulb size was (4.84 cm) recorded at T6 then followed by T4 which was significantly ($P < 0.01$) different to all other irrigation application levels. The second largest bulb size (6.63 cm) was recorded from treatment (T2) which received 85% ETc throughout the whole growing season and this was not significantly different to treatment receiving 70% ETc (T3). Furthermore, there was no significant difference between treatment T3 (70% ETc) and T5 (100% ETc Is, 85% ETc Ds, 70% ETc Ms and 50% ETc Ls).

This implies application of 15% ETc deficit at development stage, 30% ETc deficit at mid stage and 50% ETc deficit at maturity (late) stage gave comparable bulb diameter with 30% ETc deficit at whole the growing season. However, the 15% ETc, 30% ETc, 50% ETc and 100% ETc deficit irrigation water applied at initial, development, mid and late stage respectively, resulted significantly smaller bulb diameter than the control and other treatments of deficit irrigation application.

This result is in agreement with that of a study conducted by Al- Moshileh (2007) who reported that high amount of soil moisture application leads to large photosynthesis area (plant height and large number of leaves), results to large bulb diameter. The same study by Serhat and Demirtaş (2009) indicated that bulb diameter has increasing trend with the level of irrigation application. Also, the obtained data by Abd El-Hady *et al.* (2015) revealed that increasing ETc level could increase bulb diameter value by 0.04 and 0.03% over control. Likewise, a study conducted by Enchalew *et al*., (2016) revealed that the maximum bulb diameter was recorded from the plots which received 100% ETc irrigation water. Furthermore, Mebrahtu *et al.* (2018) pointed out as high irrigation levels increased photosynthetic area of the plant (height of plants and number of leaves), which increased the amount of assimilate partitioned to the bulbs and increased bulb diameter. From this, it is evident that larger Onion bulb sizes were observed for larger irrigation water application levels. The result also more specifically presented on figure 5 below.

4.3.5 Neck Diameter

The analysis of variance (Appendix Table 6) indicates, the different deficit irrigation levels had a highly significant ($P < 0.01$) effect on Onion neck diameter. As indicated in Table 7 below, the highest neck diameter (3.58 cm) was obtained from control treatment (100% ETc) which was significantly ($P < 0.01$) different to all other treatments. The neck diameters of T2, T3 and T5 were 3.05 cm, 2.85 cm and 2.97 cm respectively, and had no statistically significant difference with each other while 2.51cm was recorded from treatment T4 (50% ETc) and had statistically high significant ($P < 0.01$) difference to all other treatments. The lowest neck diameter (2.06 cm) was recorded from T6 and inferior to all other treatments. This result is consistent with findings of Al-Moshileh (2007) and Metwally (2011) who reported that higher level of applied water resulted in a significantly thicker necks. In general the result shows decreasing irrigation water application level caused significant effect on Onion neck diameter (see figure 5 below).

Table 7. Deficit irrigation effect on vegetative growth and yield components

Treatments (T)	Plant height (cm)	Leaf number per plant (No.)	Leaf length (cm)	Bulb Diameter (cm)	Neck diameter (cm)	Bulb Length (cm)	Average bulb weight (kg)	Bulb dry matter (%)	Leaf dry matter (%)
T1	59.33^{a}	27.35^{a}	49.83^{a}	7.67^{a}	3.58^{a}	8.09^{a}	0.20^{a}	20.58^{a}	18.80^{a}
T2	57.53^{b}	25.35^{b}	47.80^{b}	6.63^{b}	3.05^{b}	7.35^{b}	0.18^{b}	19.75^{ab}	16.43^{b}
T3	54.78^{c}	22.20^{c}	45.73^{c}	6.22^{bc}	2.85^{b}	6.79^{c}	0.16^{c}	18.80^{bc}	14.95^{bc}
T4	50.68^{d}	19.30^{d}	42.30^{d}	5.49^{d}	2.51^{c}	5.58^{d}	0.13^{d}	17.00^{d}	12.40^{d}
T5	54.85^{c}	23.13^{c}	46.25^{bc}	6.06^{c}	2.97^{b}	6.85^{c}	0.16^{c}	17.90^{cd}	14.48^{c}
T6	48.48^{e}	18.36^{d}	40.60^{d}	4.84^{e}	2.06^{d}	5.10^{e}	0.12^{d}	15.08^{e}	10.03^{e}
LSD (0.05)	1.79	1.31	1.81	0.29	0.45	0.56	0.01	1.07	1.55
CV (%)	2.2	3.86	2.64	6.01	6.83	4.46	4.92	3.92	7.07

Note: *The letters indicate the significance relation of treatments. Treatment values within a column followed by the same letter are not significantly different ($P < 0.01$). LSD = least significant difference; CV = Coefficient of variation.*
T1 = 100% ETc, T2 = 85% ETc, T3 = 70% ETc, T4 = 50% ETc, T5 = 100% ETc Is, 85% ETc Ds, 70% ETc Ms and 50% ETc Ls, T6 = 85% ETc Is, 70% ETc Ds, 50% ETc Ms and 0% ETc Ls

4.3.6 Bulb Length

The analysis of variance (Appendix Table 7) has indicated the different deficit irrigation levels had a highly significant ($p < 0.01$) effect on Onion bulb length. As indicated in Table 7 above, the first and the second longest bulb length of 8.09 cm and 7.35 cm was recorded from the plots received 100% ETc (T1) and 85% ETc (T2) respectively; in such a way that had highly significant ($p < 0.01$) difference between each other and to all other treatments. The bulb lengths of T3 and T5 were 6.79 cm and 6.85 cm respectively, and had no statistically significant difference with each other. The first and the second lowest bulb length of 5.1 cm and 5.58 cm were recorded from T6 and T4 respectively which had statistically highly significant ($p < 0.01$) difference to each other and to all other treatments.

This result is in line with that of Olalla *et al.* (2004) who observed smaller sized bulbs in mild water stressed Onion plants. Also, Kamble *et al.* (2009) reported significant increase in bulb yield and yield components is attributed to adequate moisture in the root zone which did not show any visual stress on various physiological processes resulting in better uptake of nutrients and finally increased plant growth, yield and yield components (like bulb length and bulb diameter). Moreover, Gebregwergis *et al.* (2016) revealed that compared to the 50 and 75% ETc irrigation treatments, 100% ETc irrigation level produced 15% and 14% longer bulbs, respectively. This indicates that higher level of irrigation water resulted in maximum Onion bulb length (see figure 5 below).

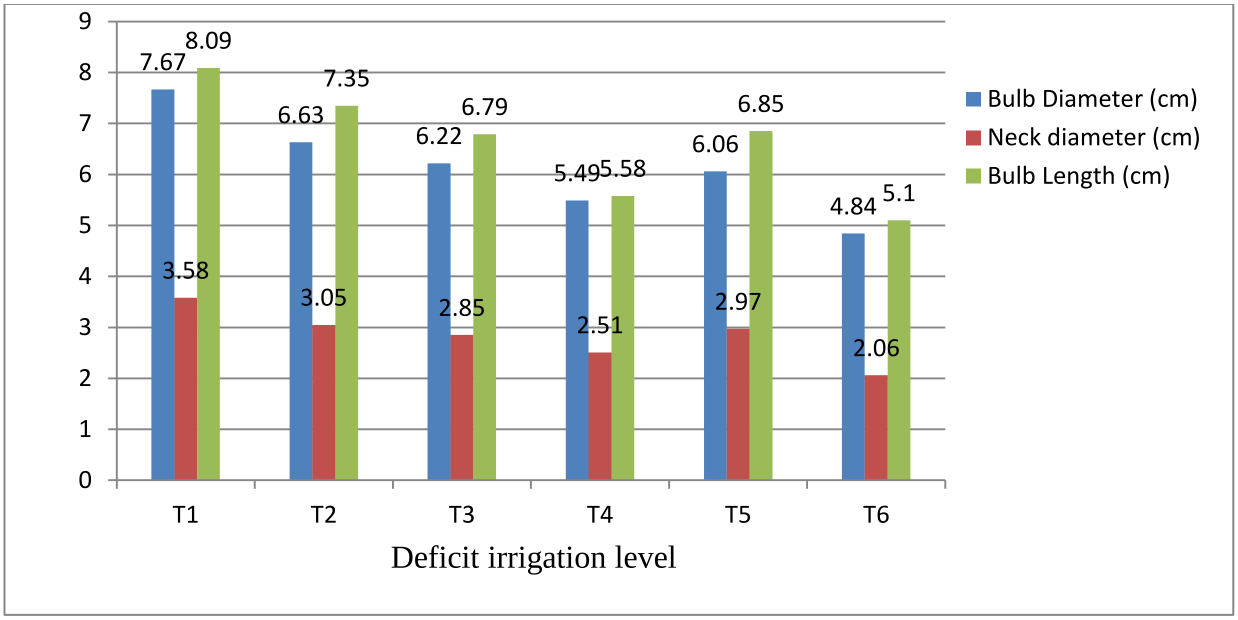


Figure 5. Effect of deficit irrigation on bulb diameter, neck diameter and bulb length

4.3.7 Average Bulb Weight

The analysis of variance (Appendix Table 8) indicates average bulb weights differed significantly due to the level of deficit irrigation water applied ($P < 0.01$). As shown in Table 7 above, the highest bulb weight (0.20 kg) was obtained at T1 irrigation water application level which was significantly different ($P < 0.01$) and superior to all other treatments. Similarly, the lowest bulb weight (0.12 kg) was recorded at T6 and was not significantly different to that recorded at T4 irrigation water application level. Also, the average bulb weight recorded under T3 and T5 had no statistically significant variation ($p < 0.01$). There was a bulb weight reduction of 40%, 35%, 20%, 20% and 10% observed under the T6,T4,T3,T5 and T2, respectively, when compared with the T1(100% ETc) irrigation water application level. This fact reveals, there was an increasing trend in bulb weight for an increase in water application level whether throughout whole growing season or in a specific growth stages and indicating that irrigation water application level positively influenced bulb weight (Figure 6). This means that water stress affects negatively the weight of individual bulbs.

In agreement with the present result, David *et al.* (2016) reported that the highest mean weight of Onion bulb was obtained from treatment with the highest supply of water while the treatment with the lowest quantity produced the least mean Onion bulb weight and there is a positive linear relationship between water stress and Onion bulb mass. Likewise, Kandila *et al*. (2011) reported increasing the soil water tension, significantly decreased the mean Onion bulb weight. The increment in Onion bulb weight due to increase in irrigation levels might be due to the fact that growth of taller plants is depicted by higher number of leaves causing for better synthesis and transportation that assimilates from source to sinks (Biswas *et al.*, 2003).

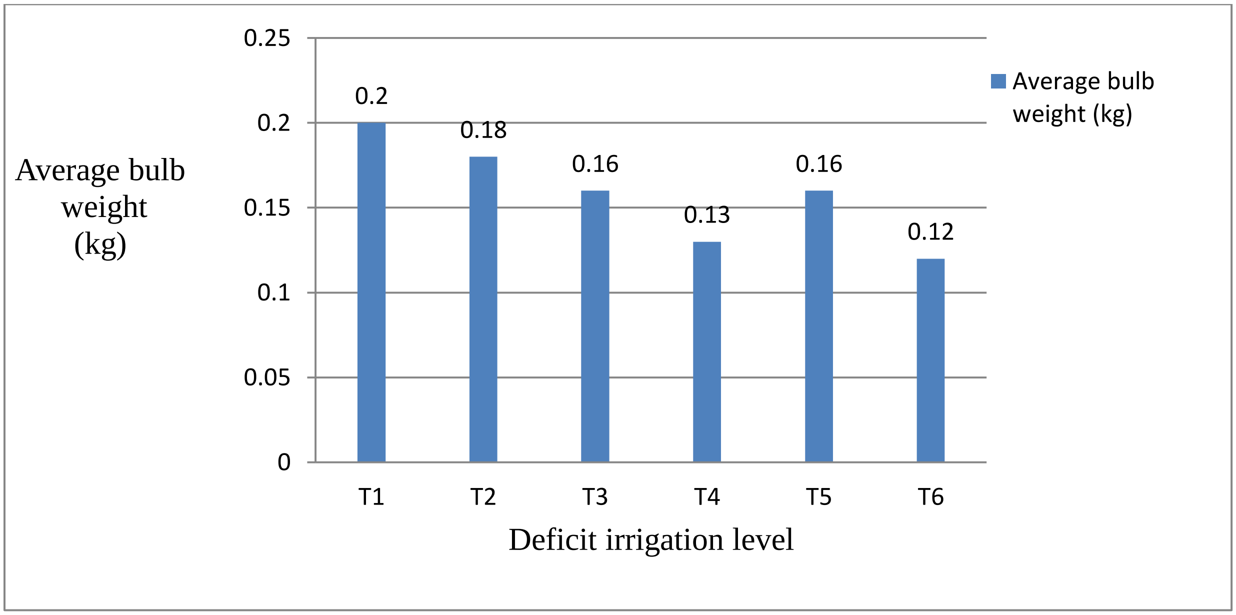


Figure 6. Effect of deficit irrigation on average bulb weight

4.3.8 Bulb and Leaf Dry Matter

According to the analysis of variance (Appendix 9 and 10) the effect of irrigation level on dry matter content of Onion bulb and leaf was highly significant ($P < 0.01$). As Table 7 above indicates, the highest bulb and leaf dry matters were 20.58% and 18.80% respectively, obtained from T1 (at 100% ETc irrigation application level) while the lowest bulb and leaf dry matter contents were 15.08% and 10.03% respectively, obtained from T6,which is inferior to all other treatments. The bulb dry matter obtained at 100% ETc (T1) and 85% ETc (T2) irrigation levels were not significantly different ($P < 0.01$). Similarly, the bulb dry matter content obtained between at T2 and T3, T3 and T5, T4 and T5 were not significantly different (Table 7). Also, leaf dry matter content recorded between at T2 and T3, T3 and T5 were not significantly different ($P < 0.01$).

This result is in line with Kumar *et al*. (2007) studied the effect of water application and fertigation on Onion dry matter production and reported that irrigation at high water supply and nutrient level Onion produced higher dry matter yield. Accordingly, the dry matter content both in bulbs and leaves decreased with increasing water deficit level (Figure 7).

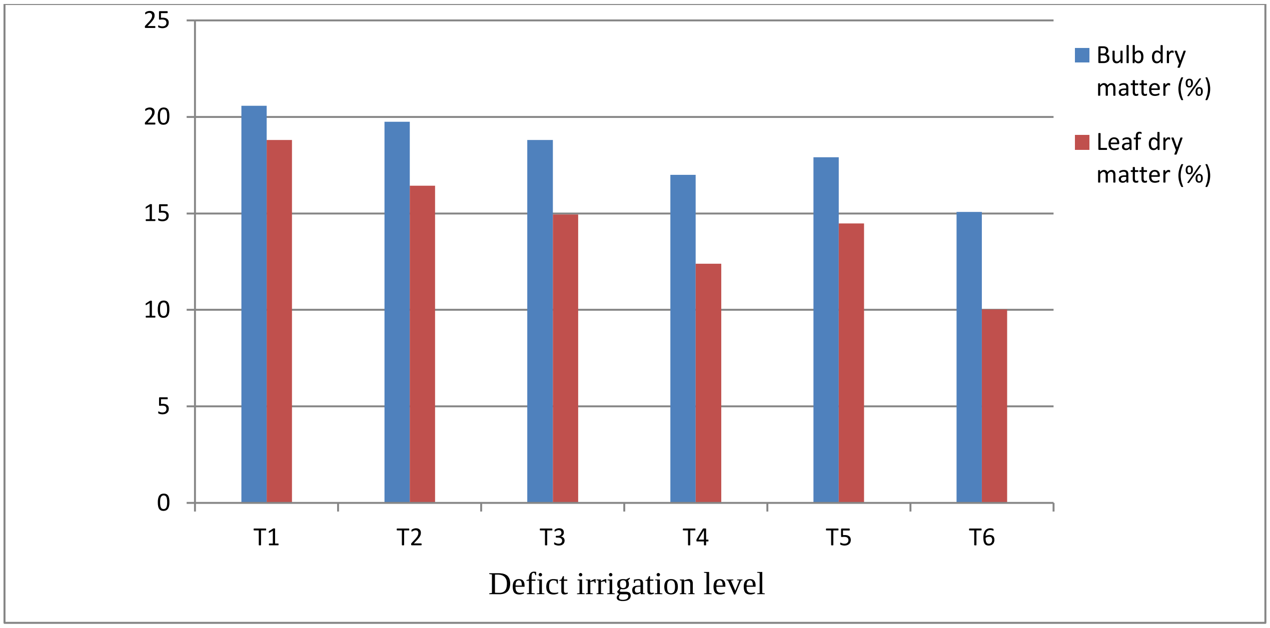


Figure 7. Effect of deficit irrigation on bulb and leaf dry matter

4.4 Effect of Deficit Irrigation on Yield of Onion

4.4.1 Marketable Bulb Yield

The analysis of variance (Appendix Table 11) indicated different deficit irrigation levels exhibited a highly significant ($P < 0.01$) influence on the marketable yield. As the mean yield values in Table 8 below shows, the yield obtained from all deficit levels were significantly different from each other except yield from T3 and T5. Highest marketable bulb yield (21.3 t/ha) was recorded from the control treatment (T1) and had highly significant difference ($p < 0.01$) to all other treatments. The lowest marketable bulb yield (12.85 t/ha) was observed from treatment T6 and statistically inferior to all other treatments which shows increasing deficit level at specific Onion growth stages particularly 100% water stress in late season caused significant effect on marketable bulb yield. The second lowest bulb yield (15.18 t/ha) was observed at T4 (50% ETc irrigation water application level throughout the growing season). This indicates that the highest marketable yield reduction was occurred when the water stress was imposed at the plant phenological stages as well as whole growing season. In other way, while the stress level increase through plant phenological stages as well as whole growing season and the amount of water applied reduced then marketable bulb yield reduced gradually.

The current result is in agreement with Neeraja *et al*. (1999) who reported the increment in marketable bulb yield due to application of irrigation water could be attributed to the increment in vegetative growth and increased production, which is associated with increment in leaf area index, bulb diameter and average bulb weight. Also, Dirirsa *et al.* (2017) indicated, bulb formation stage was observed to be the most sensitive stage to water stress and in addition, the deficit irrigations applied at the bulb formation stage resulted in lower yield than the other stages. Similar to the present observation Patel and Rajput (2013) also reported that water application with no deficit (100% ETc) at any stage of plant growth gave highest marketable yield.

Similarly, Temesgen *et al*. (2018) indicated that yield reduction was associated with increase in soil moisture tension which allowed continuing resulted in loss of turgidity, cessation of growth and yield reduction. Likewise, Mebrahtu *et al.* (2018) pointed out irrigation level, in its main effect, increased higher marketable bulb yield of Onion with full irrigation (100% ETc) and followed by 85%, 70% and 55% irrigation level. Moreover, Temesgen (2018) reported that the increment of marketable yield as the amount of irrigation levels increased.

Therefore, it is evident that there is a direct and positive relationship with the amount of water applied and the marketable bulb yield production. Higher amount of irrigation water application associated with larger amount of marketable bulb yield production and less amount of irrigation water application leads to less amount of marketable bulb yield production.

4.4.2 Unmarketable Bulb Yield

The analysis of variance (Appendix Table 12) indicated that unmarketable bulb yield of Onion was significantly ($P < 0.01$) affected by different deficit irrigation levels. As shown in Table 8 below, highest unmarketable bulb yield was recorded from T6, whereas the lowest unmarketable yield was obtained from T1 and had no significant difference ($P < 0.01$) with T2. Similarly, the result observed from T2 had no statically significant difference with T3. The result recorded from the plots which received 50% ETc irrigation application level (T4) had statically high significant ($p < 0.01$) difference with all other treatments. This shows that increasing soil moistures stress (deficit level) through the whole growing season constantly and at phenological stages of plant results increasing of unmarketable bulb yield.

The result presented in this study is inclusive and similar with previous research done by Casey and Garisson, (2003) who indicated that Onion plant stressed prior to bulb formation, result in reduced bulb sizes that are not acceptable for market grades and those plants stressed after bulb formation are prone to re-growth problems such as thick necks and scallions, which reduce marketable grades and increase storage problems. Also, study result by Kebede (2003) revealed that stressed Onion plants may produce small-sized bulbs too early and bulb splits, and thus, produce high amount of unmarketable yield. This might be due to low rate of transpiration caused by stomata closer under moisture stress condition which brought about reduced photosynthesis and poor bulb growth and developments.

Likewise, Olalla *et al*. (2004) also reported that plots which received the lowest volumes of water during the development and ripening stages produced higher percentage of small size bulbs. Furthermore, the current result is in line with Gebregwergis *et al.* (2016) who reported that yield of very small bulbs increased with deficit irrigation. Based on this evidence, increasing water deficit either constantly through whole growing period or through plant phenological stages had a positive relationship with the production of high yield of under size bulbs.

Table 8. Deficit irrigation effect on yield of Onion

Treatments (T)	Marketable Yield (t/ha)	Unmarketable Yield (t/ha)	Total Bulb Yield (t/ha)
T1	21.299^{a}	2.95E-03^{e}	21.300^{a}
T2	19.133^{b}	3.23E-03de	19.135^{b}
T3	17.363^{c}	3.37E-03^{d}	17.363^{c}
T4	15.175^{d}	4.63E-03^{b}	15.177^{d}
T5	17.125^{c}	3.75E-03^{c}	17.130^{c}
T6	12.847^{e}	5.50E-03^{a}	12.855^{e}
LSD (0.05)	1.1359	2.93E-04	1.136
CV (%)	4.39	4.98	4.39

4.4.3 Total Bulb Yield

The sum of unmarketable and marketable bulb yield gives total bulb yield which was highly influenced by different deficit irrigation levels. A highly significant variation ($P < 0.01$) in total bulb yield (Appendix Table 13) was observed due to the effect of deficit irrigation levels. As shown in Table 8 above, the yield obtained from all deficit levels were significantly different from each other except at T3 and T5. This could be because the yield components like bulb diameter, neck diameter, bulb length, average bulb weight and dry matter at T3 and T5 deficit levels were all not statistically different (Sections 4.3.4, 4.3.5, 4.3.6,4.3.7 and 4.3.8). The highest bulb yield was 21.3 t/ha obtained under T1 (100% ETc) and contrary to this, the lowest bulb yield was 12.86 t/ha obtained under T6 (85% ETc Is, 70% ETc Ds, 50% ETc Ms and 0% ETc Ls irrigation application levels) which was statistically inferior to all other treatments (Table 8). Of the water stress treatments, 85% ETc (T2) irrigation water application constantly through the whole crop growing season showed the least effect on yield, while that of 50% ETc (T4) showed the greatest reduction of yield. This shows that the bulb yield decreased as the deficit level was increased either constantly throughout the whole crop growing season or at plant phenological stages and also the relation was visualized in detail in the figure 8 below.

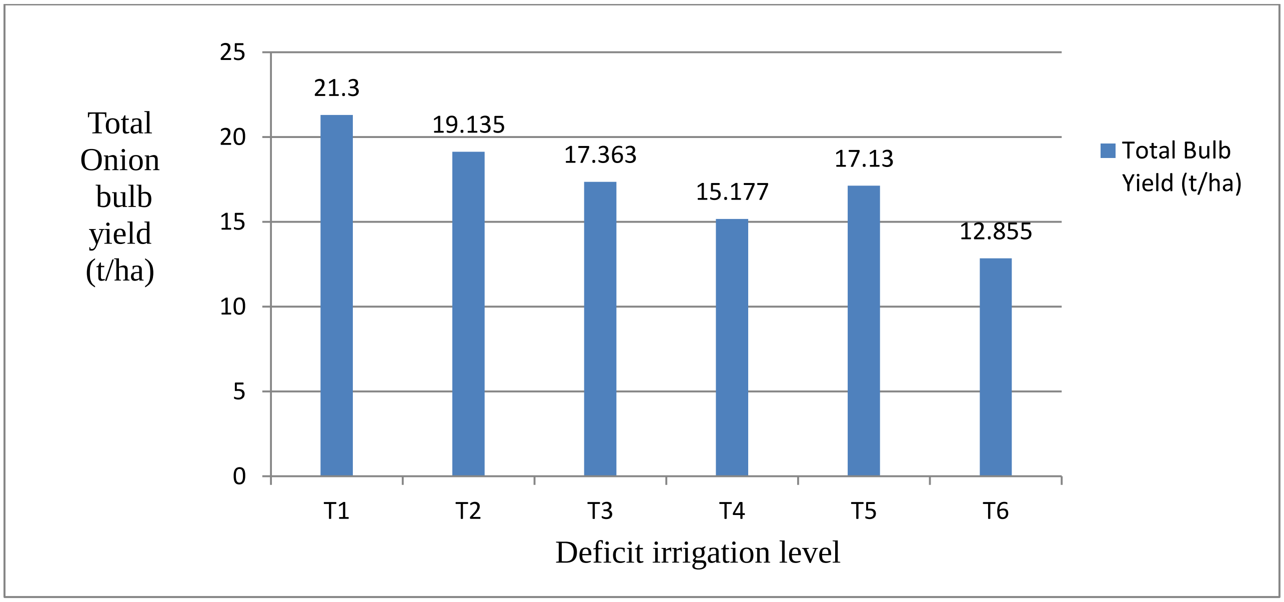


Figure 8. Effect of deficit irrigation on yield of Onion

This result agrees with previous research study by Mekonen (2011) who observed that water stress during different growth stages affected crop water productivity differently. According to David *et al.*, (2016) when crop is subjected to water stress at development and late growth stages at varying levels, soil moisture is depleted through absorption by the roots leading to reduced physiological activities which in turn affect root developments. Similarly, the study by Pelter *et al.*, (2004) showed that total yield was reduced by soil-water stress imposed at any growth stage. The increased total bulb yield by applying full (no deficit) irrigation could have better performance on vegetative growth like plant height, number of leaves and leaf length which increase photosynthetic capacity of the plant, which in turn can improve bulb weight and contribute to increment in total bulb yield (Mebrahtu *et al.*, 2018).

4.5 Effect of Deficit Irrigation on Water Productivity

4.5.1 Crop Water Use Efficiency (CWUE)

The mean values of crop water use efficiency (CWUE) are presented in Table 9 below. The analysis of variance (Appendix Table 14) on irrigation water application levels throughout whole growing season and at growth stages showed that the variability among irrigation level treatments were statistically high significant ($P < 0.01$) on the mean CWUE values. In this experiment, the crop water use efficiency of Onion varied from 2.578 kg/m^3 to 4.02 kg /m^3 (Table and Figure 9).

The highest CWUE (4.02 kg/m^3) was obtained at T6 (85% ETc, 70% ETc, 50% ETc and 0% ETc irrigation water application at initial, development, mid and late season respectively). Plots which received 50% ETc throughout the whole growth season resulted in second largest CWUE (3.673 kg/m^3) which was significantly different to other all treatments. Contrary to this, the crop water use efficiency under T3 and T5 had no statistically significant variation ($p < 0.01$).

The lowest mean value of CWUE (2.578 kg/m^3) was obtained under full irrigation water application (T1) and this was not significantly different with 85% ETc irrigation water application (T2). The probable reason why water use efficiency decreased under optimal irrigation water application may attribute to water loss through evaporation reduced in deficit irrigation treatments (Fereres and Soriano, 2007). Likewise, Meskelu *et al*. (2017) indicated that the lower water productivity at 100% ETc might be attributed to higher irrigation water depth applied, much of which was lost through soil evaporation and deep percolation.

In this experiment, even if the T6 and T4 plots seem to result highest crop water productivity due to high water savings, the yield reduction is also high. Here, it is clearly understood that higher water productivity for lower yield and the saved water may not compensate this severe yield reduction. As summarized by Temesgen *et al.* (2018), attaining higher yields with increased water productivity is only economical when the gains from increased water use efficiency and use of saved water to irrigate extended areas would offset the yield reduction as a result of imposed water stress.

As discussed in section 4.4.3, the total bulb yield production per hectare due to T3 was statistically similar with that of T5. In addition to the total bulb yield, crop water productivity at T3 was statistically the same with that of T5. Contrary to this, water productivity of treatment T3 was significantly higher than T1 and T2 (100% ETc and 85% ETc application through the season respectively). This shows that even if the significant bulb yield reduction occurred under T3 and T5, there was higher crop water use efficiency than that of T1 and T2. On the other hand, T5 had statistically similar Onion yield and yield components, and crop water use efficiency with T3.

In general, the result revealed that with decreasing the amount of water supply through whole growing season or at growth stages, the crop water use efficiency increases (Figure 9). Also, treatments with lower yield due to less water application had higher crop water use efficiency. Similarly, the result indicated that higher yield treatments had low crop water use efficiencies. Specifically, under treatment T3 better crop water use efficiency and tolerable yield reduction was observed but it might be insignificant compared with the benefits gained through diverting the saved water to irrigate other crops in the study area since water scarcity is a critical problem for crop production.

This result is in line with the result of Samson and Ketema (2007) reported that deficit irrigation increased the water use efficiency of Onion. According to, a review of reduced water supplies effect on crop yield by FAO (2002) reported that deficit irrigation maximizes CWUE in a way that crop is exposed to a certain level of water stress either during a particular period or throughout the whole growing season and any yield reduction will be insignificant compared with the benefits gained from the saved water to irrigate other crops. Similarly, Geerts and Raes (2009), by review selected research works around the world confirm that deficit irrigation increase water productivity for various crops. Moreover, Enchalew *et al.* (2016) reported that up to 20% deficit level irrigation application practices saved 45 to 108 mm depth of water from the Onion irrigation water requirement.

4.5.2 Irrigation Water Use Efficiency (IWUE)

In this research, irrigation water use efficiency is considered as the ratio of total bulb yield (kg) to the total gross irrigation water (m^3) applied and has been presented in the analysis of variance table (Appendix Table 15). The analysis of variance revealed that the different deficit irrigation levels throughout and at growth stages had highly significant ($p < 0.01$) effect on irrigation water use efficiency of Onion. As presented in mean Table 9 below, the highest irrigation water use efficiency (2.41 kg/m^3) was obtained under T6 and statistically had highly significant difference ($p < 0.01$) to all other treatments. The second highest result (2.21 kg/m^3) was recorded from plots which received 50% ETc (at T4) throughout the season. This shows that treatments with lower yield due to less water application had higher irrigation water use efficiency.

The lowest irrigation water use efficiency (1.55 kg/m^3) was obtained from T1 and had no statistically significant variation with T2 (1.64 kg/m^3). The IWUE obtained under T3 and T5 were 1.83 kg/m^3 and 1.803 kg/m^3 respectively and had no statistically significant variation between them. This means IWUE obtained at T1 is similar with T2 and T3 is similar with T5. This also shows that treatments with higher yield due to high amount of water application had lower irrigation water use efficiency. This result is in agreement with Kebede (2003) and Sarkar *et al*. (2008) reported that irrigation water use efficiency was higher at lower levels of available soil moisture.

As discussed in the previous sections, the vegetative growth, total bulb yield and yield components observed under T3 and T5 irrigation application levels had no statistically significant difference ($p < 0.01$). This indicates that instead of using T3 (70% ETc) irrigation water application we can use T5 (100% ETc Is, 85% ETc Ds, 70% ETc Ms and 50% ETc Ls) and vice versa. However, in view of crop water productivity, supplying full water requirement at initial stage is not advisable (Dirirsa *et al.*, 2017). On the other hand, under T5 the relative yield reduction was greater when compared to T3 which was discussed in section 4.6 below. So, instead of T5, using T3 (applying 70% ETc through whole growing season) is advisable. Accordingly, made T5 out of the role, compared T1, T2, T3, T4 and T6, high IWUE was observed under T6 and T4 with high yield reduction penalty.

From resources conservation point of view, maximum water productivity may be of interest, which could be obtained under this severe deficit irrigation. However, such consequences on yield may not be tolerable from producers view point (at T4 and T6).

Table 9. Deficit irrigation effect on crop and irrigation water use efficiency

Treatments (T)	Irrigation Water Applied (m^3/ha)	CWUE (kg/m^3)	IWUE (kg/m^3)	Water Saved (m^3/ha)
T1	13775.0	2.578^d	1.545^d	-
T2	11708.8	2.725^d	1.635^d	2066.25
T3	9642.5	3.040^c	1.825^c	4132.50
T4	6887.5	3.673^b	2.205^b	6887.50
T5	9388.7	3.030^c	1.803^c	4386.35
T6	5335.7	4.015^a	2.408^a	8439.35
LSD (0.05)		0.2164	0.1283	
CV (%)		4.53	4.47	

Note: CWUE is crop water use efficiency; IWUE is irrigation water use efficiency.

Furthermore, significant and tolerable yield reduction with high IWUE was observed under T3 with compared to T1 and T2 which had statistically similar irrigation water use efficiency. Under this treatment (T3) has more water saving and water productivity enhancement potential with tolerable level of yield reduction. This means in this experiment, among all irrigation treatments 70% ETc deficit irrigation level applied through whole growing season under conventional furrow irrigation system was efficient in conserving significant irrigation water at the same time attaining acceptable level of yield. Also, it is believed that, the advantages from increased crop water use efficiency and use of saved water to irrigate other additional areas would compensate the yield reduction as a result of imposed water stress.

Clearly, as observed in the figure 9 below, as water deficit level increases either throughout whole growing season or at growth stages the crop water productivity increases. This showed that there was a direct relationship between water productivity and water deficit level. On the other hand, water productivity associated positively with stress levels, where as negatively associated with irrigation amount. So, it is confirmed that deficit irrigation had positive effect on water productivity of Onion under conventional furrow irrigation system.

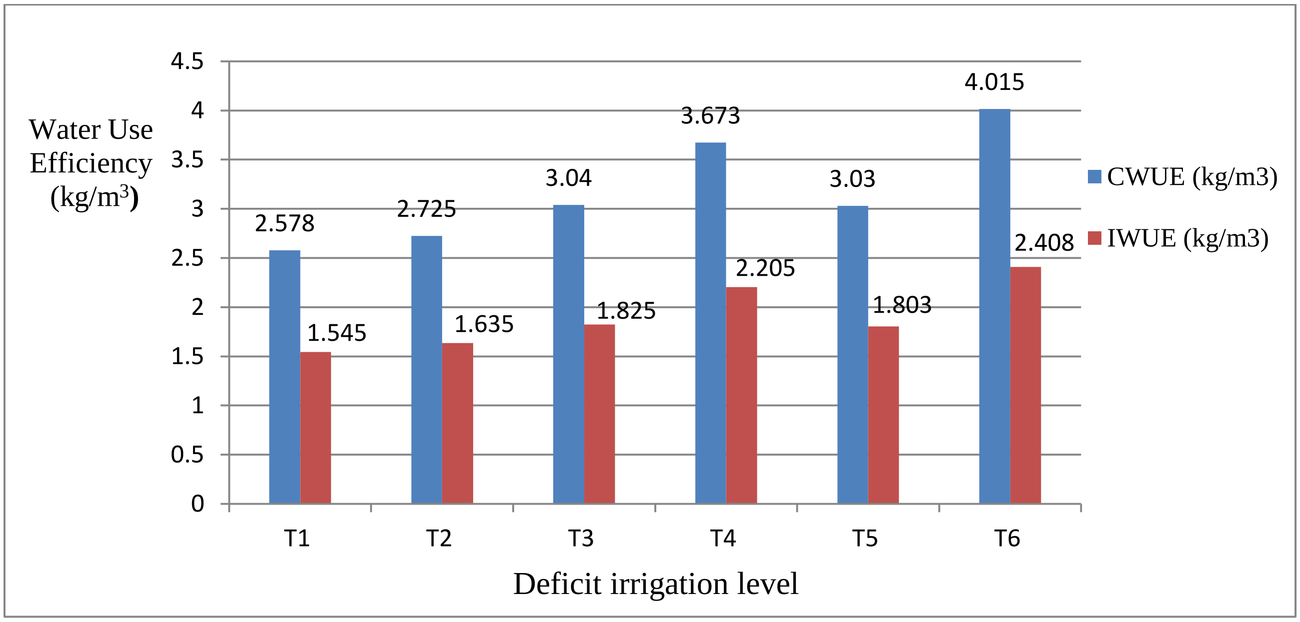


Figure 9. Effect of deficit irrigation on water productivity

The result related to the efficiencies showed that in area where irrigation water is limited, T3 (70% ETc) deficit irrigation levels can be applied by increasing the water use efficiencies with significant and tolerable yield reduction. Therefore, for this particular Onion variety (Bombay red) it could be concluded that increased water saving and water productivity through irrigation at 70% ETc deficit level under conventional furrow irrigation system can solve the problem of water shortage and would ensure the opportunity of further irrigation development in the study area and similar agro-ecology.

4.6 Yield Response Factor (K_y)

The relationship between relative yield reduction and relative evapotranspiration deficit for Onion yield was estimated. As shown in the Table 10 below, the relative yield reduction increased with increasing relative evapotranspiration deficit. Observed yield response factors (K_y) of T2, T3, T4, T5 and T6 were 0.68, 0.62, 0.57, 0.61 and 0.65 respectively which is less than one (Table 10).This shows that deficit levels distributed during whole growing season and at growth stages could tolerate yield reduction ($K_y < 1$) during cropping season in the area. Results obtained were in agreement with those reported by Doorenbos and Kassam (1979). They reported, $K_y < 1.0$ indicates that the decrease in yield is proportionally less with increase in water deficit, while yield decrease in proportionally greater when $K_y > 1.0$.

Table 10. Deficit irrigation effect on yield response factor of Onion

Treatments (T)	Yield (t/ha)	ET_a (mm)	$\frac{ETa}{ETm}$	$\frac{Ya}{Ym}$	$1-\frac{ETa}{ETm}$	$1-\frac{Ya}{Ym}$	K_y
T1	21.30	826.4	1.00	1.00	0.00	0.00	-
T2	19.14	702.4	0.85	0.90	0.15	0.10	0.68
T3	17.36	578.5	0.70	0.82	0.30	0.18	0.62
T4	15.18	413.2	0.50	0.71	0.50	0.29	0.57
T5	17.13	563.2	0.68	0.80	0.32	0.20	0.61
T6	12.86	320.1	0.39	0.60	0.61	0.40	0.65

$1-\frac{ETa}{ETm}$ *= Relative evapotranspiration deficit,* $1-\frac{Ya}{Ym}$ *= Relative yield reduction,* ET_a *= the net depth of irrigation applied for each deficit treatments (mm),* ET_m *= the net depth of irrigation water applied for the control treatment with full irrigation (mm),* K_y *= Yield response factor.*

The first and the second maximum yield response factors (0.68) and (0.65) were observed under treatment T2 and T6. This reveals, the relative yield decrease was proportionally greater with less evapotranspiration deficit under T2 when compared to other treatments. The result is supported by FAO (2002) stated that yield response factor greater than unity indicates that the relative yield decrease for a given evapotranspiration deficit is proportionately greater than the relative decrease in evapotranspiration. Furthermore, study by Enchalew *et al.*, (2016) revealed higher K_y values indicate that the crop will have a greater yield loss when the crop water requirements are not met.

Stressed treatments with irrigation application under T2, T3, T4, T5 and T6 showed a yield reduction of 10%, 18%, 29%, 20% and 40% respectively compared with the 100% ETc (T1) irrigation water application. This indicates a linear relationship between the decrease in relative water use and the decrease in relative yield (Figure 10). It also, clearly shows the effect of water deficit on crop yield. In other words, it describes the decrease in yield caused by the per unit decrease in water consumption. This relation is closely in line with Bhagyawant *et al.* (2015) who reported that there is a linear relationship between the decrease in relative water consumption and the decrease in relative yield.

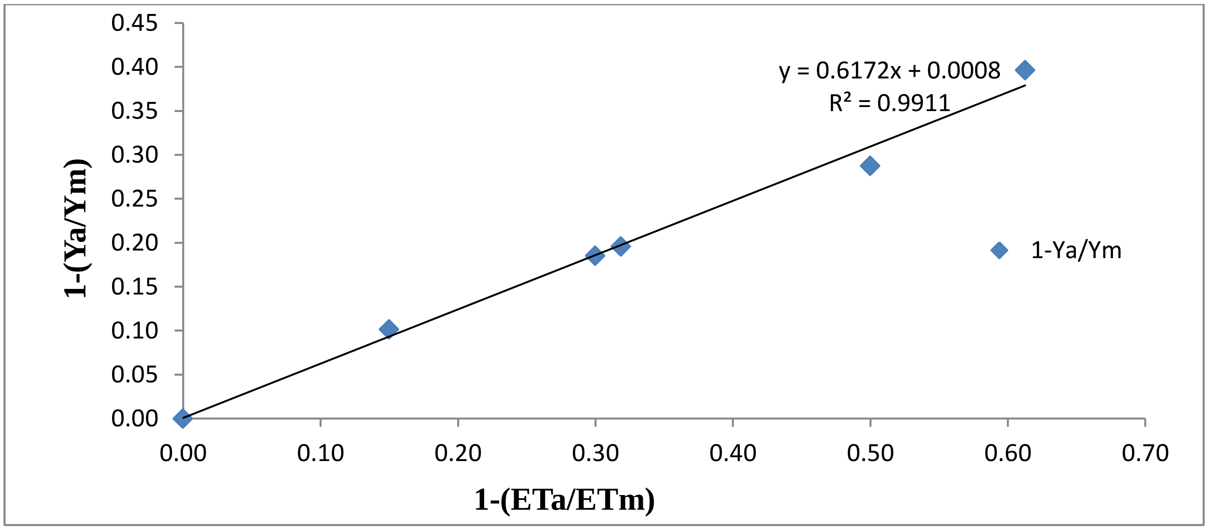


Figure 10. The relationship between relative yield reduction and relative evapotranspiration deficit for Onion

In general, the results of this study reveals, increasing water deficit throughout the whole growing season caused decreasing of K_y values, but increasing water deficit during a specific growth stages (initial, development, mid and late stages) caused increasing of K_y values (Table 10). Precisely, it was found that, with increasing water deficit at specific growth stages, sensitivity of Onion to water stress possibly increases at the cropping season in the area. So, it is advisable to applying water deficit through whole growth season to save water with limited yield reduction rather than applying at a specific growth stages of Onion in the study area during this cropping season.

4.7 Economic Analysis

The partial budget analysis indicated, the economic water productivity of irrigation treatments was increasing trend of net income (NI) for increase in water application level (Table 11). From the result of this study, the average marketable yield of 6 treatments was obtained. According to CIMMYT (1988), the average marketable yield was adjusted down wards by 10%. This is for the reason that, the yields from the experimental plots and farmers' fields are different, thus average marketable yields should be adjusted downward. Based on this, the recommended level of 10% was adjusted from all 6 treatments to get the net yield. Then finally, adjusted yield was multiplied by field price to obtain gross field benefit of Onion.

The partial budget analysis revealed, the highest net benefit of Birr 191368.09 per hectare with higher cost was recorded from T1 with marginal rate of return 290.91% which was followed by net benefit of Birr 173959.54 per hectare from T2 with marginal rate of return 246.21%. However, the highest net benefit of Birr 160365.03 per hectare with least cost production of about Birr 27155.37 per hectare was obtained from T3 with its marginal rate of return 271.02 %.This means that for every Birr 1.00 invested in T3, growers can expect to recover the Birr 1.00 and obtain an additional Birr 2.7102.

The minimum acceptable marginal rate of return (MRR %) should be between 50% and 100% CIMMYT (1988). Thus, the current study indicated that marginal rate of return is higher than 100% (Table 11). This showed that all the treatments are economically important as per the MRR is greater than 100%. Hence, the most economically attractive for small scale farmers with low cost of production and higher net benefit was obtained by application of T3 under conventional furrow irrigation system. However, for resource full producers (investors) and in areas where water is not limiting factor for crop production, application of 100% (T1) is highly profitable with higher cost which is recommended as a second option.

Table 11. Economic analysis of Onion production under different deficit irrigation treatments

Treatments (T)	Irrigation Water Applied (m^3/ha)	Marketable Bulb Yield (t/ha)	Adjusted bulb yield (t/ha)	Total Return (Birr/ha)	Variable cost (Birr/ha)	Net Income (Birr/ha)	MRR (%)
T1	13775.0	21.30	19.17	230029.20	38661.11	191368.09	290.91
T2	11708.8	19.13	17.22	206636.40	32676.86	173959.54	246.21
T3	9642.5	17.36	15.63	187520.40	27155.37	160365.03	271.02
T4	6887.5	15.18	13.66	163890.00	19423.15	144466.85	471.43
T5	9388.7	17.13	15.41	184950.00	26462.59	158487.42	199.17
T6	5335.7	12.85	11.56	138747.60	15023.25	123724.35	-

MRR = Marginal Return Rate

Maximum yield may be obtained with the fulfillment of the entire crop water requirements. However, practicing deficit irrigation can increase the irrigated area or the frequency of cultivation. For many crops, high yields as well as high water use efficiency values can be obtained provided the right choice of the period of water application is made. With a limited yield reduction, the cropped area can be also doubled, with a substantial increase in economic returns (Bazza, 1999).

5. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 Summary and Conclusions

Most Ethiopian farmers still depend on rain-fed agriculture. But, rainfall is very erratic and recurrent drought occurs very frequently. This situation greatly aggravated food insecurity problem in the country. It has been clearly and loudly stated that to combat this problem currently the country give a great attention to bring large area of land particularly in arid and semi-arid regions under irrigation. However, the scope for further irrigation development to meet food requirements in the coming years will be constrained by decreasing water resources and growing competition for water use by other sectors. So, efficient use of irrigation water with appropriate irrigation systems and management is an important concern in the drought prone areas for improved crop production. One of the irrigation management practices which could result in water saving is deficit irrigation, which is conserving the moisture content of the soil below the optimum level throughout the growing season and it is possible to identify which water deficit would have a limited effect on crop production.

This study was proposed to investigate the deficit irrigation effect on yield and water productivity of Onion under conventional furrow irrigation system which was conducted in SNNPR State South Omo Zone in Bennatsemay Woreda at Weyito sub-station of Jinka Agricultural Research Center. An attempt was specifically made to determine yield variation and water use efficiency of Onion under different deficit irrigation levels applied to the crop. The field experiment consist of six treatments with different level of deficit irrigation water application throughout crop growth season and at different growth stages (T1 = 100% ETc, T2 = 85% ETc, T3 = 70% ETc, T4 = 50% ETc, T5 = 100% ETc Is 85% ETc Ds 70% ETc Ms 50% ETc Ls and T6 = 85% ETc Is 70% ETc Ds 50% ETc Ms 0% ETc Ls irrigation water application levels).The treatments were assigned in Randomized Complete Block Design with four replications.

The experimental site soil had loam texture with average bulk density of 1.28 g/cm^3 and basic infiltration rate of 27.3 mm/hr. The total available water (TAW) of experimental site was found to be 203.2mm/m. The effect of irrigation treatments were tested using yield and yield components of Onion like plant height, leaf number per plant, leaf length, bulb diameter, bulb length, neck diameter, average bulb weight, total bulb yield and dry matter of leaf and bulb. The water productivity associated with irrigation treatments were also evaluated by CWUE and IWUE.

As result revealed that, all deficit irrigation treatments had significant effect on vegetative growth, yield and yield components of Onion. The treatment with full irrigation application (100% ETc) has confirmed as the highest performances in all considered vegetative growth, yield and yield components of Onion while T6 (treatment irrigated with 85% ETc, 70% ETc, 50% ETc and 0% ETc respectively in four phenological stages) was recorded the lowest one. However, the vegetative growth, the total bulb yield and yield components observed under T3 and T5 irrigation application levels had no statistically significant difference ($p < 0.01$).

Similarly, as observed on this experiment deficit irrigation applications had significant effect on crop water productivity which was increased from minimum of 2.58 kg/m^3 (at T1) to a maximum of 4.02 kg/m^3 (at T6). The lowest irrigation water use efficiency (1.55 kg/m^3) was obtained from T1 and had no statistically significant variation with T2 (1.64 kg/m^3). The IWUE obtained under T3 and T5 were 1.83 kg/m^3 and 1.803 kg/m^3 respectively and had no statistically significant variation between them. Under treatments T6 and T4 even if water saving and water productivity enhancement potential are high, the level of yield reductions are intolerably high.

As the result also indicated that among all irrigation treatments 70% ETc (T3) deficit irrigation level applied under conventional furrow irrigation system throughout the whole growing season was found to be efficient in conserving significant irrigation water at the same time achieving acceptable level of yield. Therefore, for this particular Onion variety (Bombay red) it could be concluded that increased water saving and water productivity through irrigation at 70% ETc of irrigation application under conventional furrow irrigation system can solve the problem of water shortage and would ensure the opportunity of further irrigation development in the study area and similar agro-ecology.

5.2 Recommendations

Based on the study and the results obtained on yield, yield components and water productivity of Onion, the following important recommendations were made:

- In the study area water scarcity is the major limiting factor for crop production. So, it is possible to get better yield and water productivity of Onion when we apply 70% ETc irrigation water application throughout growing season under conventional furrow irrigation system.
- To achieve maximum Onion bulb yield in areas where water is not scarce, applying 100% ETc irrigation water application level throughout whole growing season under conventional furrow irrigation system is recommended.
- Since this experiment is a one season study in a single location, further research over locations and seasons is necessary to confirm the present results.

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7. APPENDICES

APPENDIX A. TABLES

Appendix Table 1. Soil infiltration rate test data by using double ring infiltrometer

Time		**Test-1**				**Test-2**				**Test-3**						
Elapsed time (min)	Cumulative time (min)	Reading (cm)	Difference (cm)	Cumulative intake (cm)	Infiltration rate (mm/hr)	Reading (cm)	Difference (cm)	Cumulative intake (cm)	Infiltration rate (mm/hr)	Reading (cm)	Difference (cm)	Cumulative intake (cm)	Infiltration rate (mm/hr)	Average intake difference (cm)	Average Infiltration rate (mm/hr)	Average cumulative intake (cm)
0	0	18	0	0	0	17	0	0	0	18	0	0	0	0	0	0
0.25	0.25	17.8	0.2	0.2	480	16.5	0.5	0.5	1200	17.9	0.1	0.1	240	0.27	640	0.3
0.25	0.5	17.4	0.4	0.6	960	16.3	0.2	0.7	480	17.7	0.2	0.3	480	0.27	640	0.5
0.5	1	17	0.4	1	480	16	0.3	1	360	17.6	0.1	0.4	120	0.27	320	0.8
1	2	16.5	0.5	1.5	300	15.9	0.1	1.1	60	17.3	0.3	0.7	180	0.30	180	1.1
3	5	15.6	0.9	2.4	180	15	0.9	2	180	16.7	0.6	1.3	120	0.80	160	1.9
5	10	14.4	1.2	3.6	144	14.1	0.9	2.9	108	16	0.7	2	84	0.93	112	2.8
10	20	12.5	1.9	5.5	114	12.6	1.5	4.4	90	15	1	3	60	1.47	88	4.3
10	30	11	1.5	7	90	11.4	1.2	5.6	72	14.3	0.7	3.7	42	1.13	68	5.4
15	45	9.2	1.8	8.8	72	9.6	1.8	7.4	72	12.7	1.6	5.3	64	1.73	69.3	7.2
15	60	7.8	1.4	10.2	56	8.1	1.5	8.9	60	10.9	1.8	7.1	72	1.57	62.7	8.7
20	80	5.9	1.9	12.1	57	6.1	2	10.9	60	8.6	2.3	9.4	69	2.07	62	10.8
20	100	4.1	1.8	13.9	54	4.4	1.7	12.6	51	6.6	2	11.4	60	1.83	55	12.6
20	120	2.4/13.6*	1.7	15.6	51	2.8/12.8*	1.6	14.2	48	4.8/10.5*	1.8	13.2	54	1.70	51	14.3
30	150	11.7	1.9	17.6	38	10.9	1.9	16.1	38	8.4	2.1	15.3	42	1.97	39.3	16.3
30	180	10.6	1.1	18.7	22	9.2	1.7	17.8	34	7.1	1.3	16.6	26	1.37	27.3	17.7
30	210	9.5	1.1	19.8	22	7.5	1.7	19.5	34	5.8	1.3	17.9	26	1.37	27.3	19.1

* Indicates refill of water to the rings.

Appendix Table 2. Analysis of variance for plant height

Source of Variation	Degree of Freedom	Sum Squares	Mean Squares	F value	P value
Replication	3	17.065	5.6884		
Treatment	5	332.750	66.5501	46.74	0.0000
Error	15	21.356	1.4237		
Total	23	371.171			

Appendix Table 3. Analysis of variance for number of leaves per plant

Source of Variation	Degree of Freedom	Sum Squares	Mean Squares	F value	P value
Replication	3	101.328	33.7760		
Treatment	5	237.878	47.5757	62.58	0.0000
Error	15	11.404	0.7602		
Total	23	350.610			

Appendix Table 4. Analysis of variance for leaf length of plant

Source of Variation	Degree of Freedom	Sum Squares	Mean Squares	F value	P value
Replication	3	15.243	5.0811		
Treatment	5	235.268	47.0537	32.67	0.0000
Error	15	21.602	1.4401		
Total	23	272.113			

Appendix Table 5. Analysis of variance for Onion bulb diameter

Source of Variation	**Degree of Freedom**	**Sum Squares**	**Mean Squares**	**F value**	**P value**
Replication	3	0.3415	0.11382		
Treatment	5	18.7940	3.75881	27.51	0.0000
Error	15	2.0497	0.13665		
Total	23	21.1852			

Appendix Table 6. Analysis of variance for Onion neck diameter

Source of Variation	**Degree of Freedom**	**Sum Squares**	**Mean Squares**	**F value**	**P value**
Replication	3	7.5943	2.53143		
Treatment	5	5.2966	1.05931	28.23	0.0000
Error	15	0.5628	0.03752		
Total	23	13.4536			

Appendix Table 7. Analysis of variance for Onion bulb length

Source of Variation	**Degree of Freedom**	**Sum Squares**	**Mean Squares**	**F value**	**P value**
Replication	3	2.3717	0.79058		
Treatment	5	24.6768	4.93536	56.43	0.0000
Error	15	1.3118	0.08746		
Total	23	28.3604			

Appendix Table 8. Analysis of variance for average Onion bulb weight

Source of Variation	Degree of Freedom	Sum Squares	Mean Squares	F value	P value
Replication	3	0.00159	5.311E-04		
Treatment	5	0.01718	3.436E-03	55.15	0.0000
Error	15	0.00093	6.231E-05		
Total	23	0.01971			

Appendix Table 9. Analysis of variance for bulb dry matter

Source of Variation	Degree of Freedom	Sum Squares	Mean Squares	F value	P value
Replication	3	9.9833	3.3278		
Treatment	5	78.7883	15.7577	31.01	0.0000
Error	15	7.6217	0.5081		
Total	23	96.3933			

Appendix Table 10. Analysis of variance for leaf dry matter

Source of Variation	Degree of Freedom	Sum Squares	Mean Squares	F value	P value
Replication	3	20.781	6.9271		
Treatment	5	187.334	37.4668	35.54	0.0000
Error	15	15.811	1.0541		
Total	23	223.926			

Appendix Table 11. Analysis of variance for marketable bulb yield

Source of Variation	Degree of Freedom	Sum Squares	Mean Squares	F value	P value
Replication	3	3.671	1.2236		
Treatment	5	174.442	34.8883	61.43	0.0000
Error	15	8.519	0.5680		
Total	23	186.632			

Appendix Table 12. Analysis of variance for unmarketable bulb yield

Source of Variation	Degree of Freedom	Sum Squares	Mean Squares	F value	P value
Replication	3	1.833E-07	6.109E-08		
Treatment	5	1.927E-05	3.854E-06	101.58	0.0000
Error	15	5.691E-07	3.794E-08		
Total	23	2.002E-05			

Appendix Table 13. Analysis of variance for total bulb yield

Source of Variation	Degree of Freedom	Sum Squares	Mean Squares	F value	P value
Replication	3	3.673	1.2245		
Treatment	5	174.182	34.8364	61.31	0.0000
Error	15	8.522	0.5682		
Total	23	186.378			

Appendix Table 14. Analysis of variance for crop water use efficiency

Source of Variation	Degree of Freedom	Sum Squares	Mean Squares	F value	P value
Replication	3	0.15881	0.05294		
Treatment	5	6.24217	1.24843	60.56	0.0000
Error	15	0.30921	0.02061		
Total	23	6.71020			

Appendix Table 15. Analysis of variance for irrigation water use efficiency

Source of Variation	Degree of Freedom	Sum Squares	Mean Squares	F value	P value
Replication	3	0.05648	0.01883		
Treatment	5	2.25297	0.45059	62.21	0.0000
Error	15	0.10865	0.00724		
Total	23	2.41810			

Appendix Table 16. Free flow discharge values for 3- inch size of Parshall flume

Head (cm)	Discharge (l/s)
3	0.8
4	1.2
5	1.7
6	2.3
7	2.9
8	3.5
9	4.2
10	5.0
11	5.8
12	6.6
13	7.5
14	8.4
15	9.4
16	10.3
17	11.4
18	12.4
19	13.5
20	14.6
21	15.8
22	16.9
23	18.2

Source: Kandiah A. 1981.

Appendix Table 17. Long term monthly average maximum temperature (^{0}C)

Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1997	37.4	37.1	36.9	33.7	33.5	33.5	33.6	34.0	34.2	33.2	33.1	34.4
1998	36.7	37.8	35.6	32.6	32.0	30.5	31.7	33.3	31.6	31.7	33.8	35.4
1999	38.2	39.0	38.1	31.8	32.0	32.7	33.1	34.5	35.9	31.4	30.4	31.3
2000	34.1	36.0	37.3	34.8	33.4	32.8	33.2	33.3	34.9	33.5	34.9	36.3
2001	38.3	39.4	36.6	34.2	34.0	34.7	33.7	34.4	35.0	33.6	34.4	33.9
2002	39.1	38.9	38.8	35.0	32.4	33.9	35.1	32.7	35.3	32.5	32.9	34.0
2003	36.4	37.2	36.8	32.1	32.9	32.2	32.3	33.1	32.5	32.4	32.8	34.5
2004	35.7	38.4	36.4	34.1	32.0	32.5	33.4	33.8	33.7	32.7	34.0	33.0
2005	35.7	38.5	38.1	33.5	31.3	32.1	32.7	32.0	34.2	34.5	34.2	33.8
2006	36.2	37.2	38.8	32.4	32.9	32.7	34.0	34.5	33.9	33.3	32.4	33.4
2007	36.4	37.9	36.8	33.8	31.0	31.2	32.3	33.1	33.0	32.4	33.3	35.5
2008	38.1	37.1	35.2	32.2	32.1	32.5	32.9	32.7	33.4	32.2	30.9	31.6
2009	34.7	36.8	38.0	33.7	31.9	30.6	31.1	30.8	31.9	31.8	32.2	34.0
2010	37.0	37.6	37.1	31.2	32.2	33.0	32.9	33.3	32.8	31.2	32.3	34.6
2011	36.5	37.0	37.1	32.5	31.4	33.0	34.0	34.8	34.0	32.5	33.1	32.4
2012	35.6	36.4	35.2	32.7	30.9	31.8	31.9	32.8	33.0	32.9	33.5	34.0
2013	37.0	37.4	37.4	34.4	31.7	32.2	32.2	31.9	32.5	31.6	30.1	32.3
2014	35.8	37.5	38.0	32.6	30.5	31.9	31.5	32.3	32.3	32.2	31.4	32.8
2015	36.1	39.3	35.2	31.6	32.0	32.6	33.3	32.0	33.1	31.9	31.7	34.1
2016	37.2	36.4	35.2	33.4	32.7	33.0	33.5	32.0	32.3	30.7	31.5	33.3
Average	**36.6**	**37.6**	**36.9**	**33.1**	**32.1**	**32.5**	**32.9**	**33.1**	**33.5**	**32.4**	**32.6**	**33.7**

Source: Weyito climatic data from National Meteorological Agency Hawassa Branch Directorate

Appendix Table 18. Long term monthly average minimum temperature (^{0}C)

Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1997	22.2	22.8	24.5	23.6	22.2	21.8	22.1	21.6	21.4	20.8	20.3	20.1
1998	22.6	23.6	23.0	21.6	20.7	20.0	20.3	20.5	20.8	21.3	19.5	20.1
1999	23.7	23.8	24.3	21.3	20.4	20.7	20.8	21.2	21.6	20.6	19.9	20.2
2000	22.1	22.7	23.5	23.2	21.5	21.7	21.9	21.6	21.5	21.2	20.5	20.3
2001	22.6	24.0	23.3	23.0	22.2	22.4	21.7	21.6	21.6	21.5	20.8	20.1
2002	23.4	23.5	24.4	23.3	22.1	22.3	22.8	21.3	22.5	21.7	20.8	19.7
2003	22.6	22.6	23.3	21.7	21.1	20.8	21.2	21.8	21.6	20.2	19.9	20.6
2004	22.9	23.5	22.8	21.8	19.7	19.9	20.9	20.8	20.6	20.5	20.6	20.2
2005	21.9	23.3	23.3	21.5	20.5	20.6	20.7	20.3	21.0	20.6	20.6	19.5
2006	22.8	23.4	23.8	21.3	20.8	21.0	21.0	21.8	21.5	21.4	21.0	20.8
2007	22.4	24.4	22.9	22.1	20.2	20.7	20.4	20.9	20.8	20.0	19.8	20.9
2008	23.3	23.6	22.8	21.2	20.9	21.3	21.8	20.5	21.1	21.1	20.1	19.7
2009	21.8	22.6	23.3	22.1	21.2	20.8	20.7	20.7	20.8	20.2	19.9	20.4
2010	23.2	23.4	22.7	21.2	20.4	20.9	21.0	21.2	21.0	19.8	20.1	21.0
2011	23.0	23.7	24.3	22.3	20.9	21.3	21.4	21.6	21.6	21.1	20.9	21.0
2012	23.0	23.2	22.4	21.4	20.7	21.3	21.1	20.7	21.5	21.1	20.9	21.0
2013	23.6	23.4	23.6	21.8	20.8	20.8	21.0	20.8	21.2	20.4	20.1	20.3
2014	22.0	22.5	23.3	20.8	20.1	20.8	20.2	20.6	20.9	20.1	19.8	20.1
2015	22.7	23.9	23.1	21.1	20.9	21.4	21.6	20.7	21.4	20.8	20.7	20.4
2016	23.4	23.5	23.5	22.4	21.4	21.4	22.2	21.4	21.3	20.8	20.4	20.2
Average	**22.8**	**23.4**	**23.4**	**21.9**	**20.9**	**21.1**	**21.2**	**21.1**	**21.3**	**20.8**	**20.3**	**20.3**

Source: Weyito climatic data from National Meteorological Agency Hawassa Branch Directorate

Appendix Table 19. Long term average relative humidity (%)

Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1997	28.9	25.9	26.1	27.5	29.7	29.4	27.1	25.1	24.5	25.7	26.6	23.0
1998	20.9	18.3	24.1	26.2	28.9	28.9	28.6	28.2	25.7	26.9	29.0	26.2
1999	22.6	23.5	25.5	25.8	28.4	29.2	29.2	28.2	26.0	26.1	25.7	25.0
2000	21.0	23.8	27.3	28.3	28.1	30.3	30.1	29.0	26.8	26.5	25.0	23.8
2001	19.7	20.3	22.3	25.4	24.6	26.6	28.0	25.8	22.3	27.7	32.2	30.3
2002	31.3	28.3	27.4	30.1	32.1	32.0	30.9	30.1	27.3	29.6	26.2	20.8
2003	18.7	16.8	28.0	28.8	27.1	26.6	26.0	26.6	25.6	29.3	26.4	25.5
2004	19.3	16.2	19.0	26.5	27.9	27.6	27.8	29.1	26.4	30.5	28.0	24.2
2005	25.1	22.3	25.8	32.8	29.7	30.2	28.8	28.7	29.8	29.5	29.1	24.4
2006	25.9	21.2	28.2	28.7	31.3	28.3	26.1	26.5	24.4	30.4	30.5	31.9
2007	35.2	22.4	25.6	28.1	32.3	29.7	29.6	31.0	27.6	28.6	28.0	28.1
2008	26.0	22.3	20.8	30.8	29.5	26.1	27.0	28.0	28.0	27.9	31.3	29.0
2009	24.4	18.3	25.3	27.6	31.8	29.3	28.4	27.2	27.1	28.4	26.9	18.6
2010	20.9	22.1	28.0	31.3	31.4	29.4	27.6	28.8	25.6	29.5	32.2	33.1
2011	29.6	28.1	25.0	29.1	29.9	32.5	29.7	30.5	29.2	29.0	28.3	22.0
2012	22.1	19.0	21.4	27.8	27.8	26.2	28.8	28.0	27.7	30.2	28.0	21.8
2013	21.2	18.6	23.0	29.1	27.9	25.7	23.0	22.9	24.6	28.2	26.4	28.3
2014	24.4	23.5	28.0	29.8	30.7	28.3	27.3	26.8	27.5	27.8	22.5	19.7
2015	17.8	14.8	20.1	24.7	27.7	29.1	28.6	29.1	28.4	28.0	26.0	23.6
2016	16.7	15.0	19.1	27.7	31.6	31.3	33.0	31.4	30.3	28.2	29.6	21.9
Average	**24**	**21**	**25**	**28**	**29**	**29**	**28**	**28**	**27**	**28**	**28**	**25**

Source: Weyito climatic data from National Meteorological Agency Hawassa Branch Directorate

Appendix Table 20. Long term sunshine hours (hour)

Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1997	8.9	9.8	9.3	7.6	7.7	7.9	8.1	8.2	7.8	8.1	8.1	8.9
1998	9.7	9.9	8.7	7.8	7.8	7.6	8.7	8.1	7.6	7.9	8.2	9.5
1999	8.5	9.5	8.5	7.5	7.5	7.5	8.5	8.5	8.5	8.5	7.8	8.5
2000	9.2	9.2	9.2	6.9	7.2	8.2	8.2	8.2	8.2	8.2	8.2	8.2
2001	9.6	8.3	9.5	6.7	7.3	7.3	8.3	8.3	8.3	8.3	8.3	8.3
2002	9.5	9.4	9.5	8.2	8.1	7.1	8.9	8.5	8.7	8.2	8.1	9.2
2003	9.2	9.2	9.6	8.1	8.2	9.2	9.2	8.9	9.2	8.2	9.2	9.2
2004	9.8	8.8	8.9	7.1	7.1	8.1	7.8	7.8	7.8	7.1	8.1	8.9
2005	8.8	8.8	8.8	8.1	7.7	8.6	7.8	7.8	8.8	7.8	8.8	8.8
2006	8.7	9.1	8.7	8.7	7.6	8.5	7.7	8.2	8.7	7.7	7.9	8.7
2007	8.7	9.6	8.8	7.8	6.8	7.8	7.8	7.8	7.6	7.8	7.8	8.8
2008	9.3	9.3	9.3	9.3	8.1	9.3	8.3	9.3	8.3	8.6	8.3	9.3
2009	8.3	9.3	8.3	7.3	7.3	8.3	8.1	8.3	8.3	8.3	8.3	8.3
2010	8.5	8.9	8.5	8.5	8.5	8.5	8.5	8.5	8.5	7.2	8.5	8.5
2011	8.9	9.6	8.9	7.9	7.9	8.9	8.2	8.9	8.9	7.9	7.9	8.9
2012	9.1	8.7	8.7	7.5	8.7	8.7	8.3	8.7	8.7	7.1	8.7	8.7
2013	7.8	9.7	8.7	7.8	7.8	7.8	7.6	7.8	7.8	7.8	7.8	7.9
2014	8.4	8.9	8.4	7.4	8.4	6.6	8.4	8.4	8.4	7.3	8.4	8.4
2015	8.3	9.9	8.9	7.2	8.2	8.1	8.2	8.2	8.2	7.5	8.2	8.2
2016	8.1	9.3	8.9	7.1	8.1	6.9	8.1	8.1	8.1	7.8	8.1	8.5
Average	**8.9**	**9.3**	**8.9**	**7.7**	**7.8**	**8.0**	**8.2**	**8.3**	**8.3**	**7.9**	**8.2**	**8.7**

Source: Weyito climatic data from National Meteorological Agency Hawassa Branch Directorate

Appendix Table 21. Computed average reference evapotranspiration (ETo) values of the study area

Months	Monthly Minimum Temperature (°C)	Monthly Maximum Temperature (°C)	Humidity (%)	Wind Speed (m/s)	Sunshine hours (hr)	ETo (mm/day)
January	22.8	36.6	24	2.3	8.9	6.90
February	23.4	37.6	21	2.1	9.3	7.15
March	23.4	36.9	25	2.0	8.9	7.07
April	21.9	33.1	28	2.0	7.7	6.40
May	20.9	32.1	29	2.0	7.8	6.06
June	21.1	32.5	29	2.0	8.0	6.00
July	21.2	32.9	28	2.0	8.2	6.13
August	21.1	33.1	28	2.0	8.3	6.30
September	21.3	33.5	27	2.0	8.3	6.45
October	20.8	32.4	28	2.2	7.9	6.37
November	20.3	32.6	28	2.1	8.2	6.07
December	20.3	33.7	25	2.1	8.7	6.13
Average	**21.5**	**33.9**	**27**	**2.1**	**8.3**	**6.42**

Appendix Table 22. Irrigation program of the experiment

Date	Day	Stage	dnet (mm)	dgross (mm)	Flow at 5cm head (l/s)	T1 (mm)	Time (min)	T2 (mm)	Time (min)	T3 (mm)	Time (min)	T4 (mm)	Time (min)	T5 (mm)	Time (min)	T6 (mm)	Time (min)
9-Apr	5	Init	19.9	33.1	1.7	33.1	4	28.1	3	23.2	2	16.6	2	33.1	4	28.1	3
14-Apr	10	Init	19.3	32.2	1.7	32.2	4	27.4	3	22.5	2	16.1	2	32.2	4	27.4	3
20-Apr	16	Init	23.0	38.4	1.7	38.4	4	32.6	3	26.9	3	19.2	2	38.4	4	32.6	3
26-Apr	22	Dev	23.7	39.5	1.7	39.5	4	33.6	4	27.7	3	19.8	2	33.6	4	27.7	3
2-May	28	Dev	25.2	42.0	1.7	42.0	4	35.7	4	29.4	3	21.0	2	35.7	4	29.4	3
8-May	34	Dev	28.1	46.9	1.7	46.9	5	39.9	4	32.8	3	23.5	2	39.9	4	32.8	3
14-May	40	Dev	31.1	51.9	1.7	51.9	5	44.1	5	36.3	4	26.0	3	44.1	5	36.3	4
20-May	46	Dev	32.7	54.4	1.7	54.4	6	46.2	5	38.1	4	27.2	3	46.2	5	38.1	4
25-May	51	Dev	31.4	52.4	1.7	52.4	6	44.5	5	36.7	4	26.2	3	44.5	5	36.7	4
30-May	56	Mid	31.4	52.4	1.7	52.4	6	44.5	5	36.7	4	26.2	3	36.7	4	26.2	3
4-Jun	61	Mid	32.4	54.0	1.7	54.0	6	45.9	5	37.8	4	27.0	3	37.8	4	27.0	3
9-Jun	66	Mid	32.7	54.5	1.7	54.5	6	46.3	5	38.2	4	27.3	3	38.2	4	27.3	3
14-Jun	71	Mid	32.6	54.3	1.7	54.3	6	46.2	5	38.0	4	27.2	3	38.0	4	27.2	3
19-Jun	76	Mid	32.6	54.3	1.7	54.3	6	46.2	5	38.0	4	27.2	3	38.0	4	27.2	3
24-Jun	81	Mid	32.8	54.6	1.7	54.6	6	46.4	5	38.2	4	27.3	3	38.2	4	27.3	3
29-Jun	86	Mid	32.8	54.7	1.7	54.7	6	46.5	5	38.3	4	27.4	3	38.3	4	27.4	3
4-Jul	91	Mid	33.0	55.0	1.7	55.0	6	46.8	5	38.5	4	27.5	3	38.5	4	27.5	3
9-Jul	96	Mid	33.0	55.1	1.7	55.1	6	46.8	5	38.6	4	27.6	3	38.6	4	27.6	3
14-Jul	101	Late	33.0	54.9	1.7	54.9	6	46.7	5	38.4	4	27.5	3	27.5	3	0.0	0.0
19-Jul	106	Late	32.9	54.9	1.7	54.9	6	46.7	5	38.4	4	27.5	3	27.5	3	0.0	0.0
24-Jul	111	Late	32.1	53.5	1.7	53.5	6	45.5	5	37.5	4	26.8	3	26.8	3	0.0	0.0
29-Jul	116	Late	31.9	53.2	1.7	53.2	6	45.2	5	37.2	4	26.6	3	26.6	3	0.0	0.0
3-Aug	121	Late	31.3	52.1	1.7	52.1	6	44.3	5	36.5	4	26.1	3	26.1	3	0.0	0.0
8-Aug	126	Late	30.8	51.4	1.7	51.4	5	43.7	5	36.0	4	25.7	3	25.7	3	0.0	0.0
14-Aug	132	Late	36.2	60.3	1.7	60.3	6	51.3	5	42.2	4	30.2	3	30.2	3	0.0	0.0
20-Aug	138	Late	35.8	59.6	1.7	59.6	6	50.7	5	41.7	4	29.8	3	29.8	3	0.0	0.0
26-Aug	144	Late	34.7	57.9	1.7	57.9	6	49.2	5	40.5	4	29.0	3	29.0	3	0.0	0.0
	Total		**826.4**	**1377.5**	**45.9**	**1377.5**	**146**	**1170.9**	**124**	**964.3**	**102**	**688.8**	**73**	**938.9**	**99**	**533.6**	**56**

Init = Initial stage, Dev = Development stage, Mid = Mid stage and Late stage of the crop

APPENDIX B. FIGURES

Appendix Figure 1. Experimental field ploughing and breaking clods

Appendix Figure 2. Experimental layout, plot and field channel preparation

Appendix Figure 3. Free irrigation before transplanting

Appendix Figure 3. During transplanting in the field

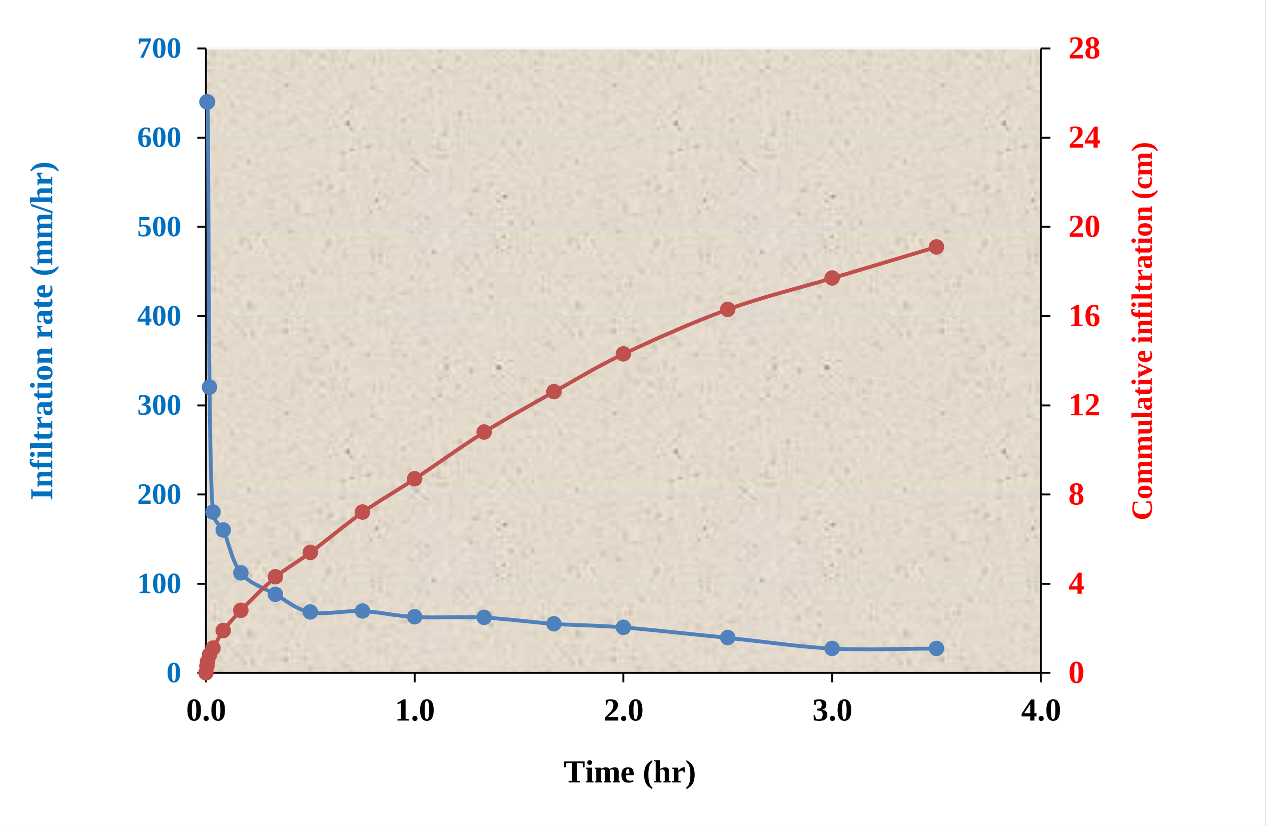
Appendix Figure 4. Free irrigation after transplanting

Appendix Figure 5. Irrigating during initial stage

Appendix Figure 6. Status of trial during plant phenological stages

Appendix Figure 7. Yield and yield components data collection in the field

Appendix Figure 8. Infiltration characteristics of the soil in the study area



BIOGRAPHY

The author was born on July 03, 1985 in Hadiya Zone at Shashogo Woreda, from his father Mugoro Lebiso and his mother Shita Morkeno. He attended his elementary and secondary education at Bonosha Elementary and Secondary School in Bonosha and preparatory school at Wachemo Preparatory School, Hossana. After completing his high school education in 2009, he joined Hawassa University in November 2009 and graduated with BSc degree in Agricultural Engineering and Mechanization in July 2013. Soon after graduation, he was employed at Shashogo Woreda Agriculture and Rural Development Office in the position of Irrigation Expert, and worked there for four months. Secondly, he joined Jinka Agricultural Research Center of South Agricultural Research Institute in the position of Junior Irrigation Researcher-II in June 2014 to September 2016 and worked there until he joined the School of Graduate Studies of Hawassa University in October 2016 to pursue his MSc Degree study in Irrigation and Drainage Engineering.