EFFECT OF DEFICIT IRRIGATION ON WATER PRODUCTIVITY AND YIELD OF ONION (*Allium cepa L*) AT DIRE DAWA, EASTERN ETHIOPIA

MSc THESIS

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AUGUST 2020
HARAMAYA UNIVERSITY, HARAMAYA

Effect of Deficit Irrigation on Water Productivity and Yield of Onion (*Allium cepa L*) at Dire Dawa, Eastern Ethiopia

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

In Partial Fulfillment ofthe Requirements fortheDegree of MASTER OF SCIENCE IN IRRIGATION ENGINEERING

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August 2020

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Final approval and acceptance of the Thesis is contingent upon the submission of its final copyto the Council of Graduate Studies through the candidate’s department or school of graduate committee.

DEDICATION

I dedicate this thesis to my beloved family SingitanLalisa and AyaneDinbasha for their continuous support and encouragement in my life.

STATEMENT OF THE AUTHOR

By my signature, I declare that this thesis is my own work and all sources of materials used for this Thesis have been duly acknowledged. I have followed all ethical and technical principles of scholarship in the preparation, data collection, data analysis, and compilation of this Thesis. Any scholarly matter that is included in the Thesis has been given recognition through citation. I strongly 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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BIOGRAPHICAL SKETCH

The Author Was Born on September 2, 1992 at Kiltu Kara District West Wellaga Zone of Oromia, from his father Ofga Margo and his mother DinkeAtomsa. He attended his Elementary Education at BecharaGudi Elementary School, Secondary Education at Kiltu Kara Secondary School and Preparatory School at Mendi Preparatory School. After completing his high school education in 2010, he joined Wollega University in October 2010 and graduated with a BSc degree in Water Resource and Irrigation Management In July 2013. Soon aftergraduation, he was employed at Oromia Agricultural Research Institute at Fedis Agricultural Research Center in July 2014 and worked there until he joined the school of graduate studies of Haramaya University in October 2017 to pursuehis MSc Degree Study in Irrigation Engineering.

ACKNOWLEDGMENT

First of all, I would like to thank the Almighty God Jesus Christ for his help by breaking every challenge in my life. Your word is my guide for my long journey. Oho Jesus I thank you!

I am grateful to my major advisor, Dr.TeshomeSeyoum and co-advisor Dr. Mekonen Ayana, without their encouragement, insight, guidance, and professional expertise this work was not completed. My special thanks also to Oromia Agricultural Research Institute for sponsoring me to undertake graduate study, financial support for the research and for all technical, material and moral support. My appreciation also goes to Haramaya University for giving me experimental land to undertake my Thesis. My heart full thanks also goes to Mr. Shibiru -farm manager of Tony farm experimental station for his positive attitude to support me at the experimental site. I would also like to thank fedis agricultural research center for facilitating the services needed for my research work. The last but not the least my heartfelt thank goes to my beloved families who think about the success of my work all the time.

ACRONYMS AND ABBREVIATIONS

ANOVA	Analysis of Variance
CWUE	Crop Water Use Efficiency
DI	Deficit Irrigation
ETB	Ethiopian Birr
Etc	Crop Evapotranspiration
FAO	Food and Agriculture Organization
FC	Field Capacity
ha	Hectare
IWMI	International Water Management Institute
IWUE	Irrigation Water Use Efficiency
Kg	Kilogram
MARC	Malkassa Agricultural Research Center
Mha	Million Hectares
MoARD	Ministry of Agriculture and Rural Development
MoWR	Ministry of Water Resources
OARI	Oromia Agricultural Research Institute
OAS	Organization of American States
PWP	Permanent Wilting Point
TDS	Total Dissolved Salt
USDA	United State Department of Agriculture
USSLS	United State Salinity Laboratory Staf
WP	Water Productivity
WUE	Water Use Efficiency

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Effect of Deficit Irrigation on Water Productivity and Yield of Onion (*Allium cepa L*) at Dire Dawa, Eastern Ethiopia

ABSTRACT

The problem of irrigation water scarcity is the major production constraints in the arid and semi-arid areas of Dire Dawa. The objective of this study wasto evaluatethe effect of deficit irrigation on water productivity and yield of onion crop. The experiment was conducted at Tony farm experimental station of Haramaya University in Dire Dawa under the furrow irrigation system. Seven irrigation treatments were replicated three times in RCBD. In the treatment combination, a full application of irrigation water (100% ETc) was used as a control treatment and Bombay red onion variety was subjected to six deficit level of treatments 90% ETc, 80% ETc, 70% ETc, 60% ETc, and 50% ETc and 40% ETc throughout the growing season. The study revealed that maximum seasonal water demand for onion (423.8 mm) was consumed by control treatment and minimum seasonal water demand was consumed by 40% ETc application level. The study revealed that full application of irrigation water (100% ETc) produces a high number of leaf per plant, plant height, leaf height, and leaf diameter than the others treatment. Maximum yield (38.09 ton/ha) was obtained by non-deficit treatment (T1) while the lowest application level of irrigation water had the lowest yield of 22.23 ton/ha. Maximum WP (12.85 kg/m^3) was obtained by T7 and minimum WP (9.36 kg/m^3) was obtained by T1 (control treatment). Statistically, no significantdifference was observed between T4, T5, T6,and T7 in the case of WP. By saving 30% of irrigation water T4 (70% ETc application level) produce optimum WP (11.20kg/m3) than T1, T2 and T3. This implies that WP decreases with increasing application level of irrigation water up to 30% deficit. The result has shown that the minimum yield response factor (ky) was produced by T4 (application of 70% ETc) by saving 30% of irrigation water. The water saved by T4 can irrigate additional land of 0.43 hector which can produce 13.97 tons of additional onion bulb yield. The benefit cost ratio obtained by 70% ETc application of irrigation level was better than other treatments. Even though the net income of control treatment was high the benefit-cost ratio obtained by this treatment was small. Generally, the finding revealed that 70% ETc application level was the best application-level than the other treatment based on water productivity, economic visibility, total yield, and percent of yield reduction and yield response factor.

Keywords: Deficit Irrigation, Furrow Irrigation, Water Productivity, Onion

1. INTRODUCTION

Water has always been the main factor limiting crop production in much of the world where rainfall is insufficient to meet crop demand. Since both land and water resources, the basis of our food production are isfinite and already under heavy stress future agricultural production will need to be more productive and more sustainable at the same time (FAO, 2011). With the ever-increasing competition for finite water resources worldwide and the steadily rising demand for agricultural commodities, the call to improve the efficiency and productivity of water use for crop production to ensure future food security and address the uncertainties associated with climate change has been more urgent (FAO, 2012).

Agriculture is one of the main consumers of freshwater resources in the world. It is consuming more than two two-thirds of total withdrawals (Gan*et al.,* 2013). In many parts of the world, irrigation water has been over-exploited and over-used (Chai *et al*., 2014), and the freshwater shortage is becoming critical in the arid and semiarid areas of the world. The rapid increase of the world population and the corresponding demand for extra water by sectors such as industries and municipals forces the agricultural sector to use its irrigation water more efficiently on the one hand and to produce more food on the other hand (Raes*et al.,* 2006).

Irrigated systems have expanded in recent years to bring water control, which, together with rapid increases in water productivity, has greatly boosted agricultural production and incomes. However, most irrigated farming systems are performing below their potential, and there is considerable scope for improving land and water productivity (FAO, 2011). Agricultural withdrawals of groundwater are intensifying and some key aquifers are being depleted. Water quality is deteriorating, with impacts from irrigation on both surface and groundwater, and the salinization of irrigated lands is a growing problem (FAO, 2011). Competition for water from domestic and industrial users is growing fast, and many countries and basins face water scarcity with reduced quantities available to irrigation.

In Ethiopia, irrigation development is increasingly implemented more than ever to supplement the rain-fed agriculture. It aims to increase agricultural productivity and diversify in the production of food and raw materials for agro-industry as well as to ensure agriculture to play a pivot for driving the economic development of the country (Mekonen, 2011). Moreover, Ethiopia has planned to irrigate over 5Mha with existing water resources, to contribute around ETB 140 billion per annum to the economy, and to ensure food security for up to six million households i.e. about 30 million direct beneficiaries (Seleshi*et al*., 2010).

Water productivity (WP) represents the relationship between crop yield and crop evapotranspiration (ETc). Recently, the emphasis has been placed on the concept of water productivity (WP), defined here either as the yield or net income per unit of water used (Kijne*et al.,* 2003). Reduction in irrigation water used will result in reduced costs of irrigation water, pumping costs, and total cost of crop production (English, 2002). The water saved can then be used to irrigate additional land thereby increasing total farm profit (English and Raja, 1996; Fereres and Soriano, 2007). Although the reduction in yield is expected when plants are subjected to limited irrigation water, the resulting yield reduction will be small when compared to the benefits gained.

Onion (*Allium cepa*L.) is one of the most important horticultural crops worldwide. Many studies have been carried out regarding its water requirements and the effects of DI on its yield (Igbadun*et al*., 2012; Patel and Rajput, 2013; Tsegaye*et al.,* 2016). It probably originated from Central Asia andhad probably migrated to the Near East (Grubben and Denton, 2004; Bagali*et al*., 2012).

Onion crop is a popular vegetable and its bulb is used raw, sliced for seasoning salads, and cooked with other vegetables and meat. The leaves, whole immature plants called 'salad onion' or leafy sprouts from germinating bulbs are used in the same way. Sliced raw onions have antibiotic properties, which can reduce contamination by bacteria, protozoa or helminthes in salads (Grubben and Denton, 2004).

Onion has an economically important role in Ethiopia. The country has enormous potential to produce the crop throughout the year both for domestic use and export market. Ever since the crop is distributed to different parts of the country, it is widely cultivated as a source of income by many farmers in many parts of the country as a whole. Onion production also contributes to the commercialization of the rural economy and creates many off-farm jobs (Lemma and Shimeles, 2003; Nikus and Mulugeta, 2010). Onion production in the country is increasing from time to time.

In the context of improving water productivity, there is a growing interest in deficit irrigation, an irrigation practice whereby water supply is reduced below maximum level and mild stress is allowed with minimal effects on yield (Kirda, 1999). Under conditions of scarce water supply, the application of deficit irrigation (DI) could provide greater economic returns than maximizingyields per unit of water. The DI has been considered worldwide as a wayof maximizing water productivity by eliminating irrigationthat has little impact on yield (Kirda C.*et al.*, 1999).

With DI, the crop is exposedto a certain level of water stress either during a particular period or throughout the whole growing season Kirda C. (2000). A variety of crops has been found to benefit from DI strategy andmany researchers pointed out that yield loss that may result from DIis offset by the benefits of reduced water use. The response ofOnion to water deficit has been reported by (Hordofa*et al*., 2010)showed thatDI increases the water use efficiency of onion. By applying DI, the crop is exposed to a certain level of water stress but significant water saving could be attained (Kirda, 2000; Fereresand Soriano, 2007).

1.1. Statement of Problem

The scarcity of irrigation water in arid and semi-arid areas of Ethiopia is increasingly threatening crop production in many areas of the country. The problem of irrigation water scarcity is the major production constraints in the Dire Dawa (Kibret *et al.,* 2017). Due to a shortage of irrigation water,much of the potential farmland is not cultivated during the dry season and even in the rainy season, rains cannot meet the amount of water required to sustain crop production. Therefore, there is a competition between farmers for the limited irrigation water in the study area. To satisfy many farmers in the area, water productivity should be increased. Deficit irrigation is known to increase water productivity with insignificant or minimum yield reduction.

Even though there is ascarcity of irrigation water, farmers of the study area are using the traditional irrigation system by loosingmuch water. If carefully applied, deficit irrigation is found to be alternative method of water saving in irrigated agriculture. Reduced water application can be done in several ways. These techniques were found to be effective in water and labor-saving. Therefore, evaluation of different deficit levelsforhigher water productivity without significant onion yield reduction is important technology under limited irrigation water.

1.2. General Objective

The general objective of this study was to evaluate the effect of deficit irrigation on water productivity and yield of onion.

1.3. Specific Objectives

The specific objectives of this study were;

- Toevaluate and compare water saving and productivity potential of varying water application depths at a different level of deficit irrigation
- To evaluate the effect of deficit irrigation on yield and yield components of onion crop
- To evaluate the effect of deficit irrigation on the economical value of irrigation water at the different application level

2. LITERATURE REVIEW

2.1. Irrigation Water Management in Agriculture

As the world, the area equipped for irrigation is projected to increase by about six percent by 2050 (Tubiello and Vander, 2010). Water withdrawals for irrigation are projected to increase by about 10 percent by 2050. Irrigated food production is projected to increase by 38 percent, due to projected increases in cropping intensities and increases in productivity. Overall, the scope to improve both land and water productivity on irrigation schemes is considerable, as illustrated by the large discrepancies observed between schemes and within schemes.

Although Ethiopia's water resource is large, very little of it has been developed for agriculture and other purposes. Climate change has altered hydrological cycles and weather patterns, resulting into an increase of intensity and frequencies of extreme weather conditions, with significant impacts on the agricultural sector (Gregory *et al*., 2005; Jarvis *et al*., 2010; Thorton *et al*., 2011; IPCC, 2014). These affect both cash and food crops all over the world (Challinor *et al*., 2009 and Ahmed *et al*., 2011).

Reducing agricultural water use and make water resources more sustainable is an increasingly urgent question. It is a question that requires combined agronomic, physiological, biotechnological/genetic and engineering approaches, which may be collectively described as 'water-saving agriculture (Morison *et al*., 2008). The application of water-saving irrigation techniques involves limiting application depths, such that a portion of the field is under irrigated, and controlling irrigation timing and frequency to optimize water use in agriculture; so, it implies three main choices: when, how much and how to provide water.

Ethiopia is endowed with vast cultivable land and good potential of surface and subsurface water resources. Out of the total 112 million hectares of Ethiopia's land, cultivable land area estimates vary between 30 to 70Mha. However, only about one-third of that is currently cultivated which is approximately 15Mha. Among this cultivated land, only 4 to 5 percent is irrigated with existing irrigation schemes covering about 640,000 hectares (Seleshi, 2010).

2.2. Concept ofWater Productivity

Heydari (2014) indicated that WP is distinct from WUE as WP refers to crop production in relation to total water consumed while theWUE is a dimensionless ratio of the total amount of water used to the total amount of water applied, “as WP terms are not dimensionless, i.e. cannot be categorized in efficiency terms, they are just some ratios with different units in the numerator and denominator. In a crop production system, water productivity (WP) is used to define the relationship between crop produced and the amount of water involved in crop production, expressed as crop production per unit volume of water (Ali and Talukder, 2008).

Perry *et al*. (2009) mentioned that, conventionally, water use efficiency was defined in the past as a productivity term output of crop per unit of water. However, the term was so widely misused and confused with the real term of WUE (the proportion of water used that is consumed by the crop) that it became meaningless and confusing for those who used the real meaning of the term water productivity defined as the output of crop per unit of water consumed.

It is widely believed that an increase in agricultural water productivity (WP) is the key approach to mitigate water shortage and to reduce environmental problems in arid and semiarid regions. In dry areas, water is the most limiting resource for improving agricultural production rather than land. 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). So, the enhancement of WP in irrigated agriculture is very important.

2.3. Deficit Irrigation and Water Productivity Relation

In the past, crop irrigation requirements did not consider the limitations of the available water supplies. The traditional irrigation development is based on providing sufficient water to avoid water deficits at all times, so as to achieve maximum yields (Doorenbos and Pruitt, 1992). Because of water supply constraints, this paradigm is changing nowadays (English *et al*., 2002). The challenge for the coming decades will, therefore, be the task of increasing food production with less water, particularly in countries with limited water, land resources, and inefficient water use (FAO, 2002).

In arid and semi-arid regions, increasing municipal and industrial demands for water are necessitating major changes in irrigation management and scheduling in order to increase the efficiency of the use of water that is allocated to agriculture (FAO, 2002). In the context of improving water productivity, there is a growing interest in deficit irrigation, an irrigation practice whereby water supply is reduced below maximum levels and mild stress is allowed with minimal effects on yield (FAO, 2002). 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. However, this approach requires precise knowledge of crop response to water as drought tolerance varies considerably by species, cultivar, and stage of growth.

Much published research has evaluated the feasibility of deficit irrigation and whether significant savings in irrigation water are possible without significant yield penalties. Deficit irrigation (DI) has been widely investigated as a valuable and sustainable production strategy in dry regions (Pereira *et al*., 2002; 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.

Different research results confirm that DI on the growth stage is successful in increasing water productivity for various crops without causing severe yield reductions (Samson and Ketema, 2007 and Dirirsa *et al.,* 2017). Nevertheless, a certain minimum amount of seasonal moisture must be guaranteed (Geerts and Raes, 2009). In agriculture, we are interestedto produce more with less water because water is a limiting factor in many parts of the world. In this case, WP can be used in the evaluation of DI 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. In areas with limited water resources, where water is the greatest limitation ofproduction, WUE is the main criterion for evaluating the performance of production systems (FAO, 2002).

The main advantage of DI is that it maximizes the productivity of water. Although a certain reduction in yield is observed, the quality of the yield (e.g. sugar content, grain size) tends to be equal or even superior to rain-fed or full irrigation (Cui *et al*., 2008; Hueso and Cueva, 2008). An additional advantage is that DI creates a less humid environment around the crop than full irrigation, decreasing the risk of fungal diseases (Cicogna *et al*., 2005). Related to the issues of individual and communal benefits, farmers might consider communal advantages of allowing sub-optimal yields on their individual yields, by practicing DI, so that the water saved might be used to irrigate additional land in the community (Kipkorir *et al*., 2001).

The report of Enchalew B. *et al.* (2016) shows that the highest water productivity of onion bulb yield was observed from treatment receiving 70% ETc than the treatment receiving full irrigation (100% ETc). Abdelattar *et al.* (2019) also report that deficit irrigation increases water productivity by 20% than the full application of irrigation water (100% ETc). Therefore, the development of new irrigation scheduling techniques thatare not necessarily based on full crop water requirement is important.

2.4. Types of Deficit Irrigation

The crop is exposedto a certain level of deficit irrigation either during a particular stageor throughout the whole growing season Kirda C. (2000). Stage-based deficit irrigation is defined as deficit irrigation applied at different stages of plant development, with water applied to meet full-plant evapotranspiration (ET) at the critical growth stages and less applied in the non-critical growth stages. The principle behind this approach is that the response of plants to DI induced water stress varies with growth stages and that less irrigation applied to plants in non-critical stages may not causea significant negative impact on plant productivity even though it may reduce normal plant growth. To apply this approach effectively, one must predetermine the critical growth stages for a specific crop species and cultivar and evaluate the relative sensitivity of crop plants to water deficit at various stages in their life cycle (Chai *et al*., 2016).

2.5. Crop Water Requirement

The term 'water requirement of the crop' means the total quantity of water and the way in which a crop requires water, from the time it is sown to the time it is harvest(Garg, 1989). Crop water requirement is defined as the depth of water needed to meet the water loss through evapotranspiration of a disease-free crop growing in a large field under a non-restricting condition, soil water, and fertility achieving full production potential under given growing environment (Allen *et al*., 1998). The growth and yield of any crop arerelated to the amount of water used. The variable amount of water contained in soil and its energy state are important factors affecting the growth of plants (Hillel, 2004). The accuracy of the determination of crop requirements largely dependent on the type of the climatic data available and the accuracy of the method chosen to estimate the evapotranspiration (Nuha and Henery, 2000).

The effect of climate on crop water requirement is given by reference crop evapotranspiration (ETo) which is defined as the rate of evapotranspiration from an extensive surface of 8 to 15 cm tall, green grass cover of uniform height, actively growing, completely shading the ground not short of water. This referenceETo is calculated byFAO Penman-Monteithequation (Allen *et al*., 1998).

The crop water requirement is determined by multiplying the ETo by crop coefficient. Cropcoefficients that relate crop evapotranspiration with reference crop evapotranspiration describe the crop effect on evapotranspiration, either as average season distributions. Most often, the coefficients account for the combined effect of crop canopy, phonological development, and soil evaporation (Allen *et al.,* 1998).

$$ETc=Kc*ETo \qquad (2.1)$$

Where, ETc is the crop evapotranspiration in mm/day; Kc is crop coefficient, ETo is the reference crop evapotranspiration mm/ day.

2.6. Onion Crop Production and Its Importance

Onion (*Allium cepa* L.) is one of the most important vegetable crops commercially grown in the world. It probably originated from Central Asia between Turkmenistan and Afghanistan where some of its relatives still grow in the wild. Onion from Central Asia, the supposed onion ancestor had probably migrated to the Near East (Grubben and Denton, 2004; Bagali *et al*., 2012). It is an important bulb crop produced in Ethiopia. It is relatively a recently introduced crop in Ethiopia and it is rapidly becoming a popular vegetable among the people. Onion is grown by both small scale farmers and commercial growers, especially under irrigation. Ethiopia has great potential to produce the crop throughout a year. The major onion production regions are Amhara, Tigray, Oromia, Benishngule-Gumuz, Gambela, and (SNNP) South Nation Nationalities and Peoples Regions (CSA, 2018).

Onion is a popular vegetable and its bulb is used raw, sliced for seasoning salads, and cooked with other vegetables and meat. Onion bulbs are essential ingredients in many African sauces and relish. The leaves, completely immature plants called 'salad onion' or leafy sprouts from germinating bulbs are used in the same way. In some parts of West Africa, leaves still green at bulb harvest are propounded, and then used to make sun-dried and fermented balls, which are used later for seasoning dishes. Sliced raw onions have antibiotic properties, which can reduce contamination by bacteria, protozoa or helminthes in salads (Grubben and Denton, 2004).

Onions grow on different soil types ranging from sand to clay loams. However, they prefer loamy soil, which is fertile, well-drained, and high in organic matter, with a preferredpH range of between 6.0 and 8.0 (Olani and Fikre, 2010). Onions do not thrive in soils below pH 6.0 because of trace element deficiency, or occasionally, aluminum or manganese toxicity. Onions could be produced on slightly alkaline soils, but are sensitive to soil salinity.

According to FAO (2002), onion yield could decrease up to 50% in areas where soil salinity level is 4.3 dS/m or more. Onions require frequent irrigation throughout the growing season due to shallow root system, thus very little water is extracted from a soil depth deeper than 0.6 m, and most arefrom the top 0.3 m. Onion roots are mostly non-branching and all roots originate at the stem or basal plate of the plant. This indicates that upper soil areas must be kept moist to stimulate root growth.

Onions show little capacity for reducing leaf water potential by osmotic adjustment to compensate for reduced water availability at the root. Onion crop fields that frequently experience water stress would suffer growth retardation and produce excessive numbers of doubles or splits, reducing the grade of bulbs. For optimum yield, onions require 350-550 mm of water but may use more than that in areas where ET is appreciably higher (FAO, 2013). Onions are harvested when 80% of the bulbs become completely mature, which is evident by the collapse of 20 to 50% of the neck tissue and falling of the tops. That is usually 100 to 140 days after transplanting and 40-45 days for nursery development (MOA, 2011). After harvesting, the roots are trimmed and the tops cut away carefully.

Bulbs are usually put into an appropriate case and allowed to cure outdoors. After bulbs are properly cured, onions are graded according to the local standards of the country. According to the United State Department of Agriculture (USDA) standard, onions are graded for size and shape, proper maturity, and firmness (Shock *et al.,* 2000). Onions must also be free of splits, seed stems, dry sunken areas, roots, tops, translucent or watery scales, moisture, disease, and insects.

3. MATERIALS AND METHODS

3.1. Descriptionof Study Area

The experiment was conducted at Tony farm experimental station of Haramaya University in Dire Dawageographically located between $9^0$27' to $9^0$49'N latitude and $41^0$38'to $41^0$40'E longitude and at 1160m above sea level. Dire Dawa is found at 515 km East of Addis Ababa. It is situated in the semi-arid tropical zone of Eastern Ethiopia. The area experiences a bimodal type of rainfall and the mean annual rainfall is 604mm. The mean annual maximum and minimum temperatures vary from 29^0C to 35.4^0C and 14.5^0C to 22.6^0C, respectively. The Soil textural class of the study area is classified as clay loam soil.

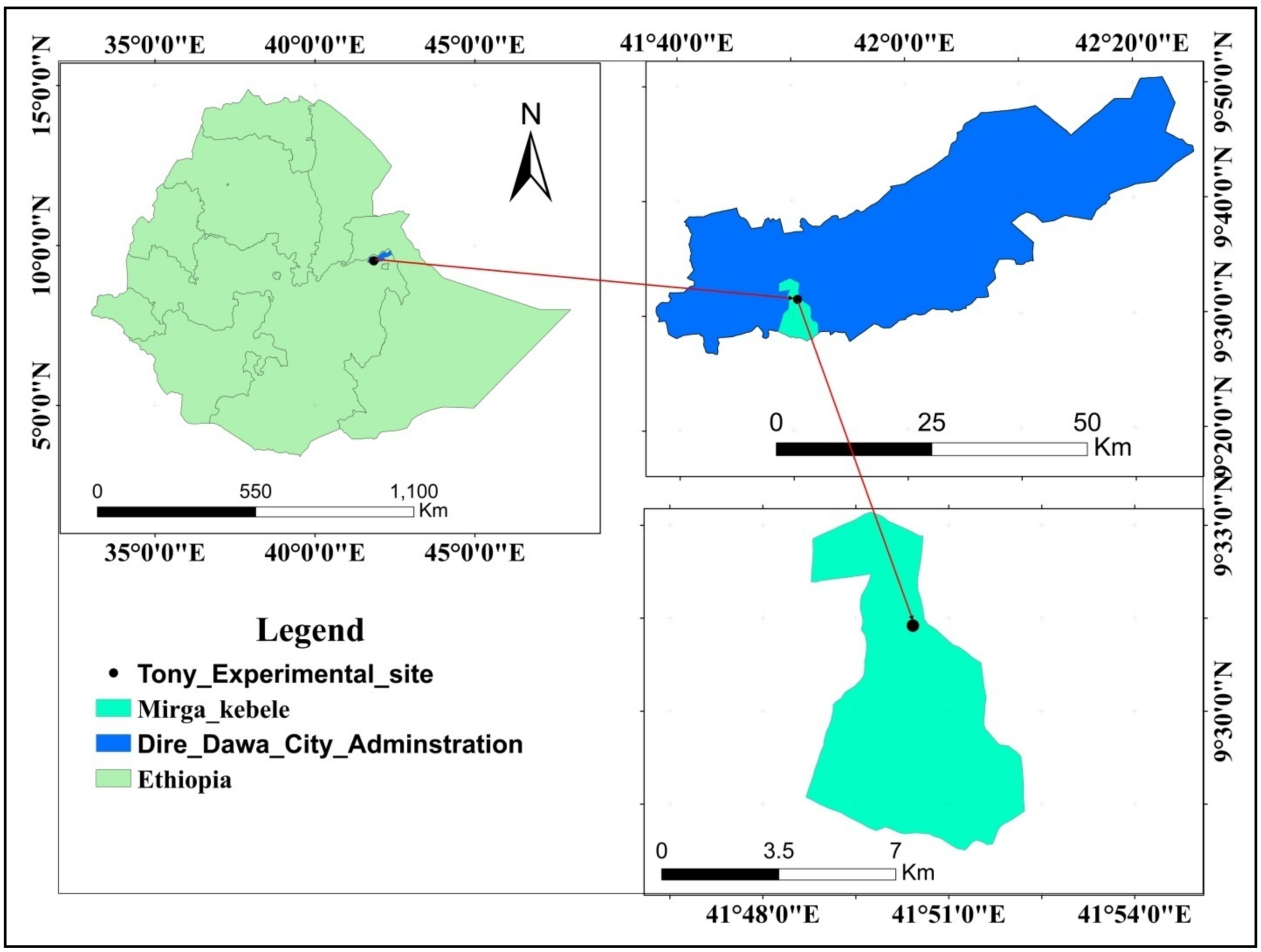

Figure 1: Location Map of the Study Site

3.1.1. Climate of the Study Area

From long term (1988-2018) Dire Dawa meteorological data, the rainfall pattern of the Dire DawaAdministration has a bimodal characteristic with peaks in April and August (Figure 2). The two seasons are 'Meher', which occurs in months of July, August, and September, and 'Belg' that occur in March, April, and May. April and August receive the highest of the annual rainfallwhile December, January, and September receive the less temporaldistribution of rainfall (Figure 2).

Since there was strong variability in long term climate data collected, the rainfall of the study area was first changed to dependable rainfall (80% probability of exceedance). A simple method of computing dependable rainfall was done by grouping the rainfall data by 10 mm interval and then selecting the high-frequency rainfall (Allen *et al,* 1998). Since not all dependable rainfall is effective, determination of effective rainfall was computed bythe equation:

Peff = 0.6 * P - 10 for precipitation less or equal to 70mm 3.1

Peff = 0.8 * P - 24 for precipitation greater than 70 mm 3.2

Where
Peff – Effective Precipitation (mm)
P- Precipitation (mm)

The climate of the administration is characterized under a semi-arid zone(Adnew, 2005). The mean monthly maximum temperature ranges between29°C to35.4°C and the mean monthly minimum temperature ranges from 14.5°C to 22.6°C. The mean monthly air temperature values (maximum, minimum, and average) steadily increases from January to June and then decrease gradually towards December.

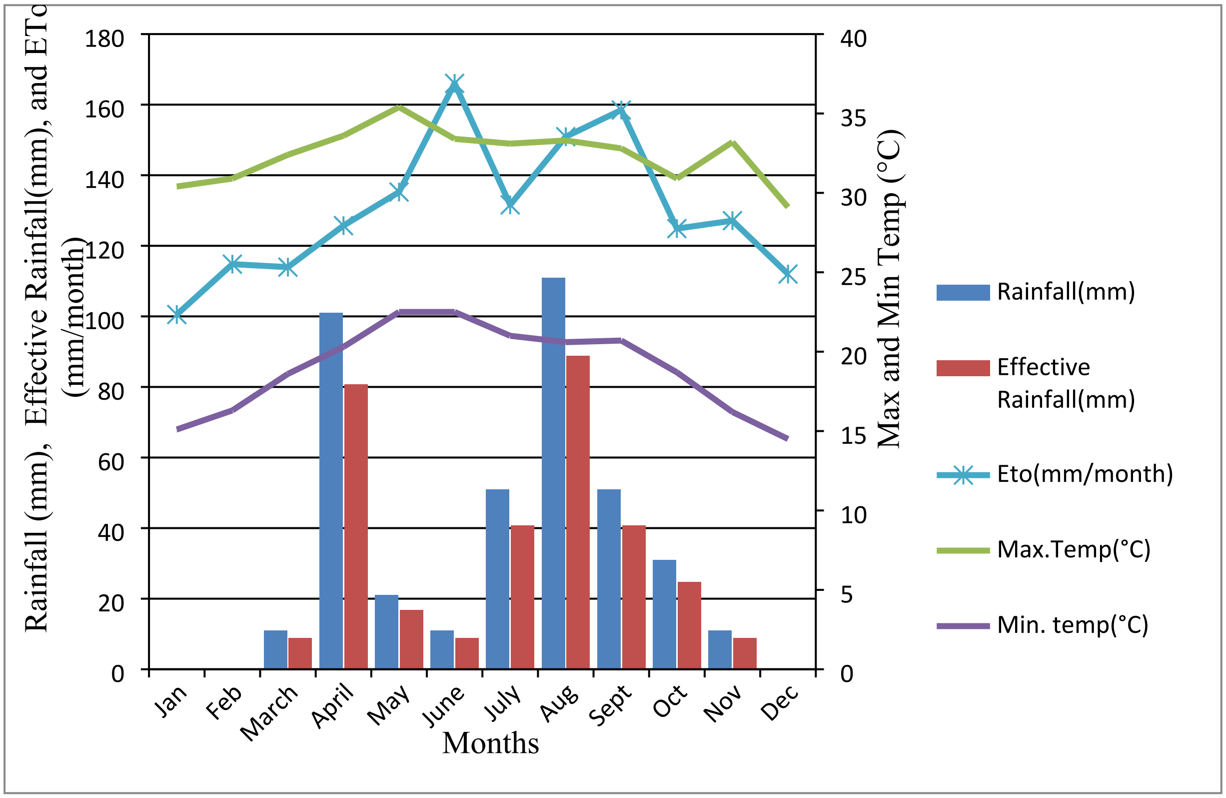

Figure 2: Rainfall, Effective Rainfall, ETo, and Temperature of the study area.

The mean monthly relative humidity is between 36.8% to 43.8%. The maximum mean monthly wind speed value is between 129.6km/day to 319.7 km/day. The mean daily wind speed steadily increases from January to July and then decreases steadily towards December. The study area enjoys a sunny climate. The mean monthly sunshine varies between 7.5 hrto and 9.3 hr while the mean monthly solar radiation varies between 20.4 MJ/m^2/day to 22.7 MJ/m^2/day.

3.2. Materials Used

Materials such as parshal flume, soil augers, core samplers, double ring infiltrometers, caliper, ruler, meters, and sensitive balance weretaken from Haramaya University and Fadis Agricultural Research Center. Pressure Plate apparatus was used for the determination of soil field capacity and permanent wilting point. Onion seed (Bombay red onion variety) was collected from Melkassa Agricultural Research Center. Fertilizers and chemicals were from Fadis Agricultural Research Center.

3.3. Experimental Design and Treatment

The experiment was laid out in RCBD consisting of seven treatments with three replications. The treatments contain different amounts of irrigation water application levels which are listed in Table 1 below. The experimental field was divided into 21 plots and the size of each plot was 3m * 4m dimension to accommodate five furrows with a spacing of 60cm and has4m length. Onion is known by two-row plant so transplanting was done row to row spacing 40cm; space between ridge 20cm and plant spacing was 10cm. The buffer zone of plot and replication was 2m from the water supplying canal and 2m between plots to eliminate the influence of lateral water movement. For each plot, division box structures were constructed to dissipate the energy of water diverted to the plots. The Experimental treatment combinations are given in Table 1 below.

Table 1: Description of Treatments

Treatment	Treatment Combination
T1	Optimum Irrigation of 100%ETc (Control)
T2	Irrigation Water Application Level of 90%ETc
T3	Irrigation Water Application Level of 80%ETc
T4	Irrigation Water Application Level of 70%ETc
T5	Irrigation Water Application Level of 60%ETc
T6	Irrigation Water Application Level of 50%ETc
T7	Irrigation Water Application Level of 40%ETc

The experiment had twenty-one experimental units. Blocking was taken as replication. All of these treatments were randomly assigned to each experimental unit to avoid any bias towards the selection. The layout of the experiment was as in Figure 3 below.

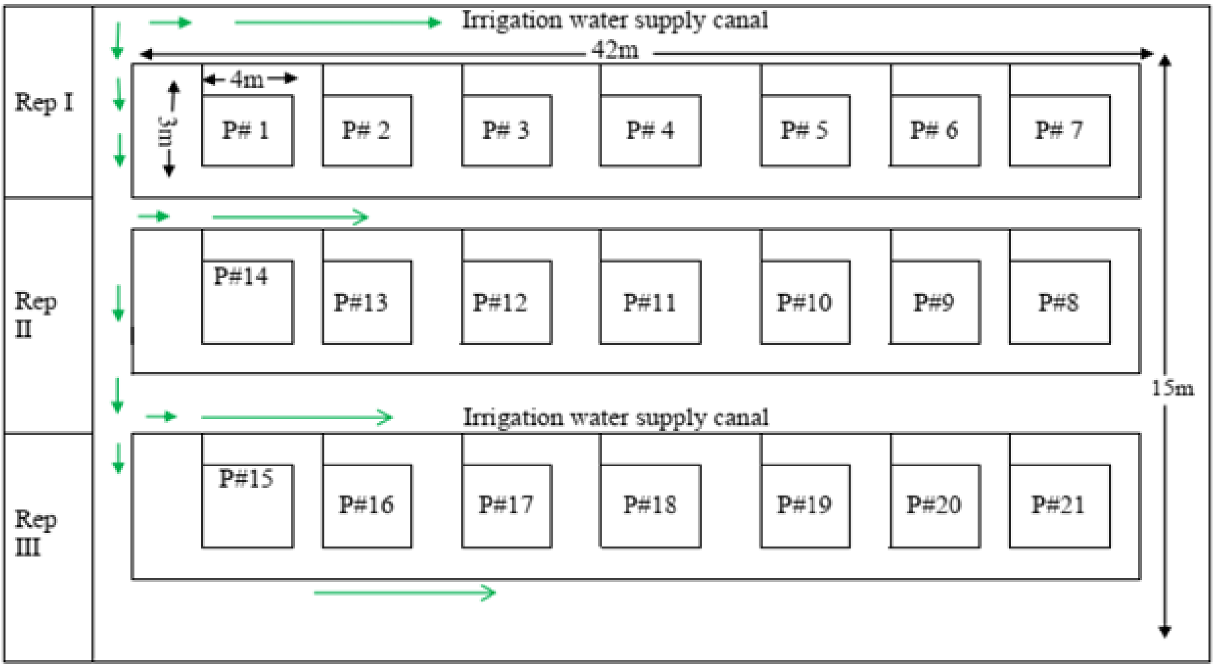

Figure 3: Layout of the Experimental Site

The amount of irrigation water was applied by the furrow irrigation method and measured using ParshallFlume. Out of the experimental field, ParshallFlumewas set at 10m away from the experimental plot in the main canal. It was set inside a straight and uniform section of the canal. The crop water requirement was computed by using meteorological data of the study area with the aid of CROPWAT model version 8.0 (FAO, 2009).Onion Seeds (Bombay Red variety) was sown in a nursery on a well prepared seedbed size of 1m*5m.Seedlings were transplanted on the experimental field by hand after the land was prepared well and pre irrigated.

3.4. Land Preparationand Crop Management Practice

Onion (*Allium cepa L*) Bombay red variety was used as seed material. This variety was released in 2010 by MARC under the Ethiopian Institute of Agricultural Research with high yield and quality. The recommended seeding rate is 5 kg/ha and 60 g of seeds for a size of 1m*5m seed bed nursery and prepared accordingly at tony farm experimental station on November10, 2018. Seedling developed at the nursery was watered and uprooted for transplanting. The land was plowed and leveled using a tractor to make it suitable for laying the experiment and to create a suitable slope for the experiment. After the land is leveled, ridge preparation had been done with ridge maker, spaced at 60cm using a tractor.

Subsequently, the layout of the experiment was prepared based on experimental design. All the experimental area was subdivided into three blocks including free space between blocks and field channels according to the dimensions provided in the layout of the experiment (Figure 2). Then, each block subdivided into seven experimental units and free space between each plot, maintaining the desired spacing. The bunds around individual plots were made enough to control water movement between plots. Once the layout was prepared, the main canal outside the experimental field and field channels constructed for the conveyance of irrigation water.

Seedlings were transplanted to the experimental field in January; 2019.The Furrow irrigation method was used to grow the plant. Furrow spacing and plant space weredone according to the agronomic recommendation of the area. For transplanting the seedling was buried 3-5cm deep in the soil and covered by hand. By keeping plant spacing which is 10cmtransplanting was done.

UREA and DAP were the two fertilizers applied equally for each treatmentwith a rate of 100 kg/ha and 200 kg/ha, respectively (Olani and Fikre, 2010). The fertilizer dose per plot was calculated to plot level and applied for each plot. Fertilizer was applied by drilling in a single row by 5cm far away from the root of onion. First, weeding was done after 15 days of transplanting, and then weeding was done as required, as there is any weed in the field was seen. Hoeing was also done two times, during the second urea fertilizer application and head formation, and then hoeing was done as required.

There were pests and diseases in the areas of the experiment. To protect the experiment both bacticide and pesticide chemicals (Proof, menchozem, and Ridomil Gold) were used according to their rate of application. To achieve the aim of trial onion diseases and pests were controlled.

3.5. Common Irrigation

Common irrigation was applied for all plots uniformly without considering the variation of the treatment for transplanting and enhance the better establishment of transplanted onion. It was applied before and after transplanting as the establishment of transplanted onion was valid.

3.6. Water Sampling

The main source of irrigation water in the study area was underground water. The sample of this irrigation water was takenusing a sampling bottle and a proper sampling kit at the pump. Plastic bottles (one liter) were used to collect the water samples. Before collecting the samples, the bottles were washed properly with distilled water to remove any contamination. The sample was transported carefully to the laboratory and analyzed for selected chemical composition. The collected irrigation water sample was analyzed for PH and electrical conductivity of water (ECw) in the laboratory. Electrical conductivity and PH of the water samples were measured using TDS by conductivity meter and a digital PH meter, respectively (USSLS, 1954).

3.7. Soil Sampling

Before the start of treatments, soil samples were taken from three spots at random from the diagonal of the experimental field. The samples were taken from four depths (0-15cm, 15-30cm, 30-45cm, and 45-60cm). The soil samples collected were, air-dried, mixed, and sieved and analyzed for different physical and chemical characteristics. The soil properties analyzed include bulk density, water retention at field capacity (FC), permanent wilting point (PWP), soil texture, soil PH, organic carbon, and electrical conductivity of the soil.

3.7.1. Soil Texture

For textural analysis of the soil, disturbed soil samples were collected from four depths 0-15 cm, 15-30 cm, 30-45 cm, and 45-60 cm at three points along the diagonal of the experimental block. The hydrometermethod was used foranalyzing particle size distribution and the textural class was assigned using USDA textural triangle.

3.7.2. Electrical Conductivity of the Soil

The EC of soil was determined by extracting the soil sample with water in (1:2.5 soil: water mixture ratio) by measuring the conductivity of saturated soil extract using the electrical conductivity meter (Sahlemedin and Tesfaye, 2000).

3.7.3. Soil PH Measurements

Soil PH was measured in 1:2.5 soils to water mixture by using a PH meter. Distilled water was used to form the soil/water suspension. Ten-gram air-dried soil with particle size < 2 mm soil was weighed into 100 ml beakers and 25ml distilled water was added to the beaker to form 1:2.5 soil/water suspension and the soil/water suspension was stirred using automatic stirrer for 30 minutes and the PH was measured by inserting the PH mater rod into the upper part of the suspension (Sahlemedin and Tesfaye, 2000).

3.7.4. Soil Bulk Density

The soil bulk density was determined from undisturbed soil samples which werecollected by core samplers, (similar locations as mentioned above for texture). Undisturbed soil samples were collected by using a cylindrical soil core sampler. The samples were then being dried in an oven at 105 °C for 24 hours and the bulk density was then be calculated using the following equation given by Hillel (2004).

$$\rho b = \frac{wd}{Vc} \qquad 3.3$$

Where, ρbis bulk density of the soil (g/cm^3)

Wd - Mass of dry soil (g)

Vc-Volume of soil in the core (cm^3)

3.7.5. Soil Moisture Determination

A soil moisture measurement by the gravimetric method was used to know the soil moisture condition for the monitoring of irrigation. Determination of moisture content of the soil was carried out for the determination of moisture content at FC and PWP. The collected sample was weighted using sensitive balance and oven-dried at 105^{0}C until the change in weight is constant. Then, the oven-dried sample was weighed. The water content in the soil was determined in volume base using equation 3.2.

$$\theta V = \frac{Ww \text{ - } Wd * \rho b * 100}{Wd}$$

3.4

Where:

θ**v -**Volumetric Moisture Content (%)

Wd - Weight of Dry Soil (g)

Ww - Weight of Wet Soil (g)

ρb - Soil Bulk Density (g/cm3)

3.7.6. Determination of Infiltration Rate of the Soil

An infiltration characteristic of the soil was determined with a double ring infiltrometer. Hammer was available to install the double-ring infiltrometer ring up to the desired depth. The test was conducted by pouring water into the rings (inner and outer) at the same time to approximately up to the same depth. To record the water level in the inner cylinder point ruler was used. A stopwatch was used to record the time against the corresponding depth of infiltration recorded by point ruler. The procedure was repeated until at least three consecutive uniform infiltration depths wereobserved and the steps outlined according to Walker (2003) wereobserved to install and recording the parameters.

3.7.7. Field Capacity and Permanent Wilting Point

Undisturbed Soil samples were collected by core sampler for the determination of moisture content at field capacity (FC)and disturbed soil sample for determination of soil moisture content at PWP from four depths 0-15 cm, 15-30 cm, 30-45 cm, and 45-60 cm at similar locations as texture and bulk density. Soil samples werethen saturated for two to three days and using a pressure plate apparatus a pressure of 1/3 bar (for field capacity) and 15 bar (for permanent wilting point) was provided until no further change in soil moisture content be observed. Then by using this apparatus soil moisture content at FC and at PWP was determined (Appendix Table 12 and 13 respectively). After getting soil moisture values corresponding to these constants, the available water holding capacity of the soil was calculated. The total available water (TAW) for the use by the plant in the root zone was estimated as the difference in moisture content between field capacity and permanent wilting point using the following equation 3.2 as FAO (1998).

$$TAW = 1000(\theta FC - \theta PWP) * \rho b * Dz \qquad 3.5$$

Where:

TAW - the total available water in the root zone (mm)

θFC -moisture content at field capacity (weight basis)

θPWP- moisture content at permanent wilting point (weight basis)

ρb is the bulk density of the soil in gm cm^{-3}, and

Dzis the maximum effective root zone depth (m).

3.8. Determination of Crop Water Requirement of onion

Long term climatic data (1988 -2018) records such as rainfall, maximum and minimum temperature, wind speed, relative humidity, and sunshine hours were collected from Dire Dawa meteorological station for determination of Onion water requirements. Reference evapotranspiration (ETo) of onion was computed using CROPWAT model version 8.0 (FAO, 2009) from DireDawa meteorological station. The CROPWAT model calculates ETo based on theformulaof FAO Penman-Monteith using the equation.

Evapotranspiration of the crop was determined by multiplying the crop coefficient (Kc) of the crop by the reference evapotranspiration (ETo) using equation 2.2. Crop coefficient was collected from FAO Irrigation and Drainage Paper 56 (FAO, 1998) for Onion. The crop coefficient values for respective growth stages were 0.7, 1.05, and 0.95 for the initial, mid and end-stage, respectively. Based on the Kc values of the crop and length of each growth stages, crop coefficient was interpolated for development and late season. The length of growth stages of onion crop during the experiment was 20, 30, 40, and 25 days for initial, development,mid-season, and late season, respectively. The graph of interpolated Kc value for development and late-season stage of onion was developed as in Figure 4 below.

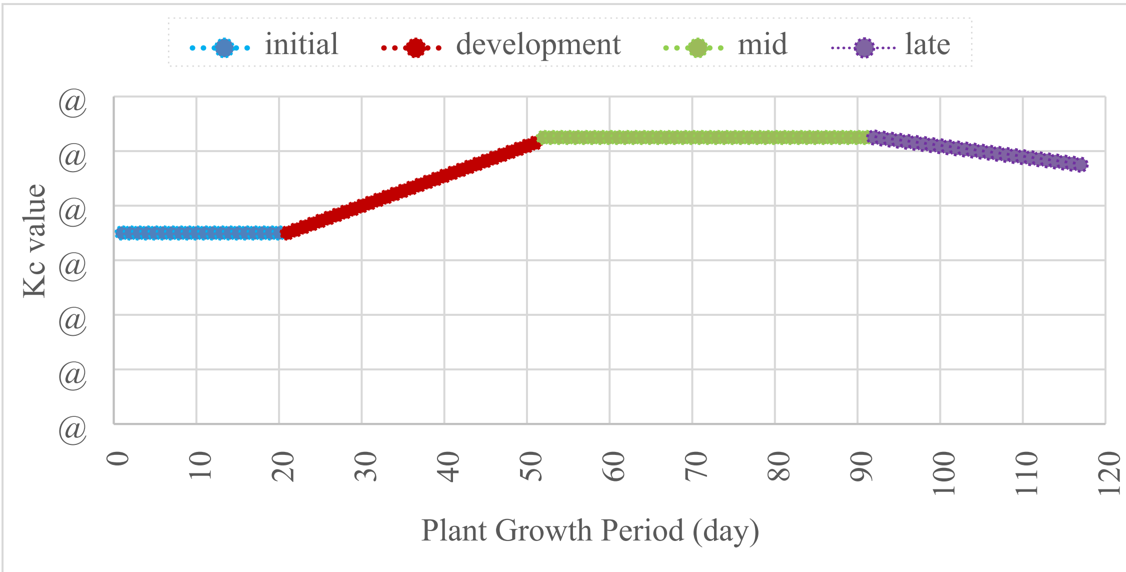

Figure 4: Crop Coefficient for Different Growth Stage of Onion

3.9. Determination of Net Irrigation Water Requirement

The net depth of irrigation supplied at any time is obtained from a simplified water balance equation as:

$$In = ETc - Pe \qquad 3.6$$

Where;

In-Net Irrigation Depth (mm)

ETc- The Crop Water Requirement (mm) and

Pe -The Effective Rainfall (mm)

3.10. Determination of Effective Rainfall

For agricultural production, effective rainfall refers to the portion of rainfall that can effectively be used by plants to germinate or maintain its growth. This is to say that not all rainfall is available to the crops as some of it is lost through runoff and deep Percolation. Based on the rainfall recorded at Dire Dawa meteorological station, effective rainfall during the experimental season was determined using the CROPWAT 8.0 model daily by using equation 3.1 and3.2 and deducted from the net irrigation depth of next irrigation.

3.11. Application Efficiency and Gross Irrigation Depth

Field irrigation application efficiency (E_a) is the ratio of water directly available in the crop root zone to water received at the field inlet. It is affected by the rate of supply, infiltration rate of the soil, the storage capacity of the root zone, and land leveling. Furrow irrigation could reach a field application efficiency of 70% when it is properly designed, constructed, and managed. The average ranges vary from 50 to 70%. However, a more common value is 60% (FAO, 2002). For this particular experiment, irrigation efficiency was taken as 60%, which is common for surface irrigation methods in furrow irrigation. Based on the net irrigation depth and irrigation application efficiency, the gross irrigation water requirement was calculated based on equation 3.7.

$$Ig = \frac{In}{Ea} \qquad 3.7$$

Where;

I_g-Gross Irrigation Depth (mm)

I_n-Net Irrigation Depth (mm) and

E_a-Furrow Application Efficiency (%).

3.12. Calibration and Discharge Measurement of Parshall Flume

Irrigation water applied to each experimental plot was measured by calibrated 3-inch Parshall flume(PF) made from metal sheet and install 10 m away from the nearest plot along the main canal. Leveling in all directions of the converging section was checked. Leveling for the diverging section checked across the waterway, as the base of the diverging part of PF is slightly slope upward. The entrance section was set 4 cm above the canal bed to avoid submergenceflow. Sandstone riprap was put in the downstream side on the canal bed to minimize downstream scouring. The height of the water from the gauge of PF written on two third surface wall of the entrance section was used to determine the flow rate of free-flow condition.

Calibration of Parshal flume of 3 inches (7.62 cm) was first done at the experimental field to measure the amount of water applied for each treatment. To know the discharge delivered by parshalflume in a given second,a bucket was first placed in an excavated hole under the parshal flume in the furrow bed level. The time was on a stopwatch to know the amount of water passed per second at the different head of parshal flume. Then the amount of water passed in parshal flume which collected in the bucket was measured and the time taken was recorded. Then the discharge of parshalflume at the different head was determined by dividing the amount of water passed through parshal flume for the time taken. Then the 3 inch parshalflume discharge graph and table at different head for the study area were developed as in Figure 5 below and Appendix Table 11 respectively.

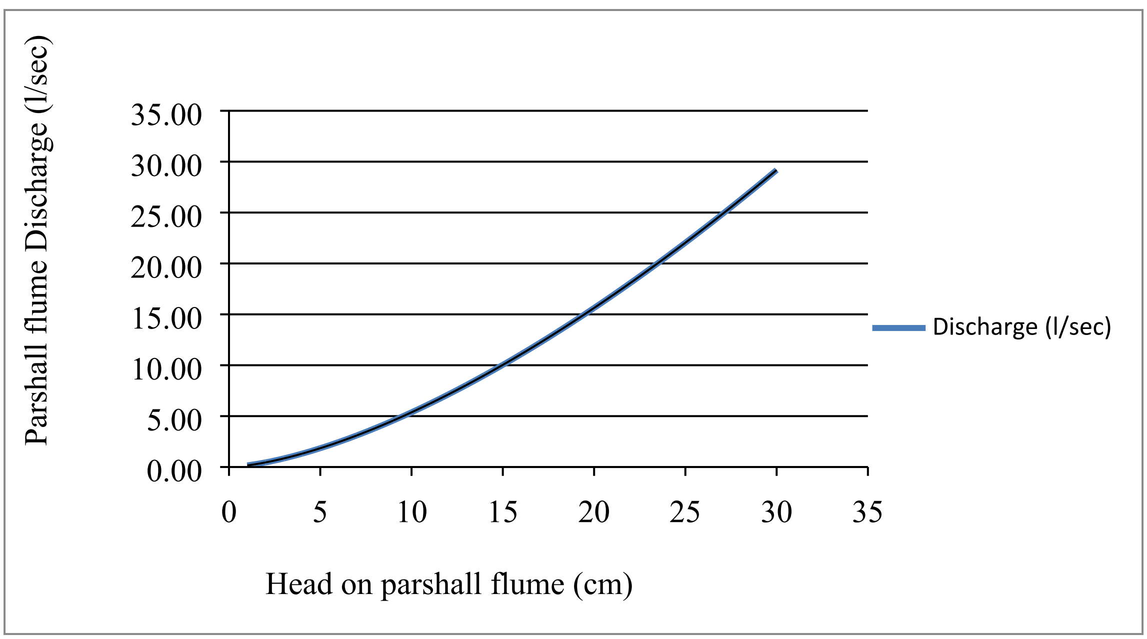

Figure 5: Parshall Flume Calibration

Calculated gross irrigation was finally applied to each experimental plot based on the proportion of the treatment. The volume of water applied for every treatment was determined from the plot area and depth of the gross irrigation requirement. The time required to irrigate each treatment was calculated from the ratio of the volume of applied water to the discharge-head relation of 3-inch PF. The time required to deliver the desired depth of water into each furrow was calculated using equation 3.8 given by Michael (2008).

$$T = \frac{Ig * W * L}{6Q} \quad 3.8$$

Where; Ig = gross depth of water applied (cm)

T = Application Time (min),

W= Space of Furrow ofthePlot (m),

L= Length Furrow of the Plot (m)

Q= Flow Rate (l/s)

To apply calculated water, the canal was wet until the head becomes constant at peak head discharge to reduce the variation of water divert to plots far from and near to the PF.

3.13. Irrigation Scheduling and Management

Irrigation scheduling was done based on control treatment (100% ETc). The control treatment (optimum irrigation) was irrigated based on the allowable moisture depletion level in the effective root depth that aims to refill the soil moisture to field capacity. Since onion is sensitive to water deficit, allowable moisture depletion was 25% of the TAW (ρ=25%) (Doorenbos and Kassam, 1979). The six treatments received a lower amount of irrigation water than the control treatment based on their level of deficit percentage.

3.14. Water Productivity

Water productivity is defined as crop yield per unit volume of water supply to the crops, Molden (1997), and is estimated by dividing crop yield by total applied water. In this study crop, water productivity was estimated as the ratio of onion bulb yield to the total irrigation depth applied to Onion during the season. It is expressed as:

$$WP = \frac{Y}{W} \quad 3.9$$

Where, Y is onion bulb yield (kg/ha) and W is irrigation depth applied during the season (m^3/ha).

The amount of water saved (SW) per hectare of land from irrigation deficit was computed by subtracting deficit water application levels from the irrigation treatment that used the highest irrigation water level, i.e. 100% ETc. The extra irrigable land area (A) in hectare which was served by the saved irrigation water was determined by dividing the total saved water per hectare of land (SW) in m^3 by the irrigation water use for a hectare of land (IWU) in m^3/ha as:

$$A = \frac{SW}{IWU} \quad 3.10$$

The net income from saved water (NI_{sw}) in Birr that was obtained from irrigating extra land of area (A) in hectare was expressed as:

$$NIsw = \Delta NI * A \quad 3.11$$

3.15. Data Collection

To evaluate the effect of deficit irrigation treatments on onion yield, samples were collected from the central ridge to avoid border effects. Data on the growth parameter of onionwas recorded from five randomly selected plants in three middle rows of each experimental plot and the same plant was used for subsequent measurement. Data on total yield and marketable onion yield was collected from three central rows by leaving the border effect on both sides from each experimental plot. Then the yield results were converted to a hectare basis using the following formula.

Yield obtained per ha = Yield obtained per square meter x 10^4

3.15.1. OnionGrowth Parameters Data

Plant Height (cm)

This was measured from the ground to the tip of the leaves from five randomly selected plants at maturity stage.

Leaf Number per Plant

The total number of leaves per plant was counted from five randomly selected plants at maturity stage.

Leaf Diameter (cm)

The diameter of leaves at three different places of the leaves was measured from five randomly selected plants using veneer caliper.

Leaf Length (cm)

This was measured at physiological maturity from the sheath to tip of the leaf from the ten leaves of the representative plants which wereused to count the number of leaves per plant using a ruler.

3.15.2. Yield and Yield Components

Average bulb weight (g)

The average weight of five randomly taken mature bulbs was measured by using sensitive balance and finally then expressed in grams.

Bulb diameter (cm)

Five samples of onion bulbs were taken randomly from the harvesting area of each plot.Thenequatorial diameter (mm) of onion bulbs was measured using a digital caliper. Thediameter measured was the maximum width of the onion in a plane perpendicular to the pole. Bulb diameter was determined as one of the parameters of the crop quality (Murthy, 2007).

Marketable Bulb Yield (t ha^{-1})

This referred to the weight of healthy and marketable bulbs that range from 20 g to 160 g in weight. Bulbs below 20 g in weight were considered too small to be marketed according to Lemma and Shimeles (2003). This parameter was determined from the net plot at the final harvest and expressed as t ha^{-1}.

Total bulb yield (t ha^{-1})

The total bulb yield was measured from the total harvest of the net plot as a sum weight of marketable and unmarketable yields that was measured in kg per plot and finally converted into t ha^{-1}.

3.16. Yield Response Factor

Yield response factor (Ky) is one of the important parameters that indicate whether moisture stress due to deficit irrigation is advantageous or not in terms of enhancing water productivity. The yield response factor relates to relative yield reduction to the corresponding relative deficit in evapotranspiration (ETc). The relationship between the decrease in relative water use and the decrease in relative yield is linear. It is an indication of the response of yield to water use reduction.

The yield response factor is the ratio of yield reduction to evapotranspiration deficit from optimum irrigation. The relative yield decrease values are the reduction of onion bulb yield obtained from each treatment after the bulb yield was analyzed from the full irrigation treatment (100% ETc) and a decrease in evapotranspiration was the reduction in irrigation amount due to stress level from 100% ETc treatment. The yield response factor was determined based on the ratio of relative yield decrease to relative evapotranspiration deficit expressed indecimal, using the equation 3.17 formula (FAO, 2002).

$$Ky = \frac{1 - \left(\frac{Ya}{Ym}\right)}{1 - \left(\frac{ETa}{ETm}\right)} \qquad 3.12$$

Where:

Ya-actual yield of each treatment (kg/ha)

Ym -maximum yield from full irrigation treatment (kg/ha)

ETa -actual evapotranspiration of each treatment (mm)

ETm-maximum evapotranspiration by full irrigation treatment (mm)

Ky-yield response factor

3.17. Economic Water Productivity

The partial budget analysis was used for economic water productivity analysis by considering the general relationship between the crop water use and crop yield per hectare of land at the different deficit irrigation application levels. Total revenue, the total variable cost, total fixed cost, total cost, net income and Benefit-cost ratio, of each treatment, were analyzed by partial budget analysis based on CIMMYT procedure (CIMMYT, 1988). The data used for economic analysis were fixed cost and variable cost. Fixed costs include seed cost, fertilizer cost, farm implement cost,and chemical cost. Variable cost includesthe cost of irrigation water for each treatment and labor cost for each treatment.

For the calculation of total revenue,the average marketable yield of each treatment was taken and then adjusted by multiplying 10% following the procedure of CIMMYT. The assessment was undertaken to take the price of onion at the local market. Based on the assessment done 1kg of onion was 8ETB at a time at field level. For calculation of labour cost, the price of human laborwas 50ETB inthe field. For calculation of irrigation water costfor each treatment, the price of water was taken as 3 ETB/1000m^3 (Ayana *et al.,* 2015).Net income (NI) in ETB/ha, generated from onion crop, was computed by subtracting the total cost (TC) in ETB/ha from the total return (TR) in ETB/ha obtained from onion sale (Kuboja and Temu, 2013).

$$NI = TR - TVC \qquad 3.13$$

TC is the sum of FC and VC. Fixed costs (FC) are those that do not vary between irrigation treatments, i.e. onion seeds, fertilizer, pesticides, land rent, and farm implements. Variable costs, on the other hand, are those that do vary between irrigation treatments, i.e. irrigation water and labor. Benefit cost ratio (BCR) of each treatment was computed as the ratio of NI earned to the TC expended.

$$BCR = NI/TC \tag{3.14}$$

3.18. Statistical Analysis of Data

All collected data were subjected statistical analysis system (SAS) version 9.0 statistical package using all of its procedures (SAS, 2002) for the variance analysis. Mean comparisons were executed using the least significant difference (LSD) at 5% probability level tocompare differences among treatments mean.

4. RESULT AND DISCUSSION

4.1. Analysisof Soil Physical Propertyof Experimental Site

4.1.1. SoilTexture and Bulk Density

The result of soil physical property analysis shown that the average composition of clay, silt, and sand percentages was32.25, 24.75, and 43, respectively (Table 2).Thus, according to the USDA soil textural classification, the particle size distribution of the experimental site revealed that the soil textural class is clay loam.

The soil bulk density of the study area shown that there was variation with soil depth. The result has shown that at 0-15 cm depth there was a slight increase in bulk density (1.21 g/cm^3) whereas at 15-30cm and 30-45 cm there was a little decrease (1.02 g/cm^3 and 1.12 g/cm^3 respectively) in bulk density then increase in bulk density (1.16 g/cm^3) was observed at depth of 45-60 cm as from the Table 2 below. The maximum bulk density was recorded in the topsoil layer (1.21 g/cm^3).

Generally, bulk density of experimental site was found between the range of 1.02 g/cm^3-1.21 g/cm^3. The critical value of bulk density for restricting root growth varies with soil type (Hunt and Gilkes, 1992). It is generally desirable to have soil with a low bulk density (<1.5 g/cm^3) (Hunt and Gilkes, 1992) for optimum movement of air and water through the soil.

4.1.2. Field Capacity, Permanent Wilting Point and Total Available Water

Analysis of FC, PWP, and TAW are shown that there was a variation between different soil depths. Accordingly 30.40%, 30.00%, 33.30% and 38.51% (weight basis) of FC was obtained at soil depth of 0-15, 15-30, 30-45 and 45-60cm respectively. There was also variation among a different depths of soil for PWP. So 19.05%, 15.00%, 14.28% and15.78% (weight basis) of PWP value was obtained at soil depth of 0-15, 15-30, 30-45 and 45-60 cm respectively (Table 2). The summation of total available water that onion crop can extract inthe effective root zone of 60 cm was 115.05 mm (Table 2).

Table 2: Analysis of soil physical property of the experimental site

Depth (cm)	Particle size distribution (%)			Soil textural classes	Bulk density (g/cm3)	FC (%)	PWP (%)	TAW (mm)
	Sand	clay	silt					
0-15	46	28	26	Sandy clay loam	1.21	30.40	19.05	20.60
15-30	44	31	25	Clay loam	1.02	30.00	15.00	22.95
30-45	42	34	24	Clay loam	1.12	33.30	14.28	31.95
45-60	40	36	24	Clay loam	1.16	38.51	15.78	39.55
Total available water in an effective root zone of 60cm								115.05

Note: FC- Field Capacity, PWP –Permanent Wilting Point, TAW- Total Available Water

4.1.3. Soil InfiltrationRate and Cumulative Infiltration of Study Area

The soil infiltration rate of the experimental site was conducted using the double-ringinfiltrometer. The test was done at three locations on a diagonal basis. The average basic infiltration rate of the experimental site was 7.2 mm/hr (Figure 6 and Appendix Table 10).

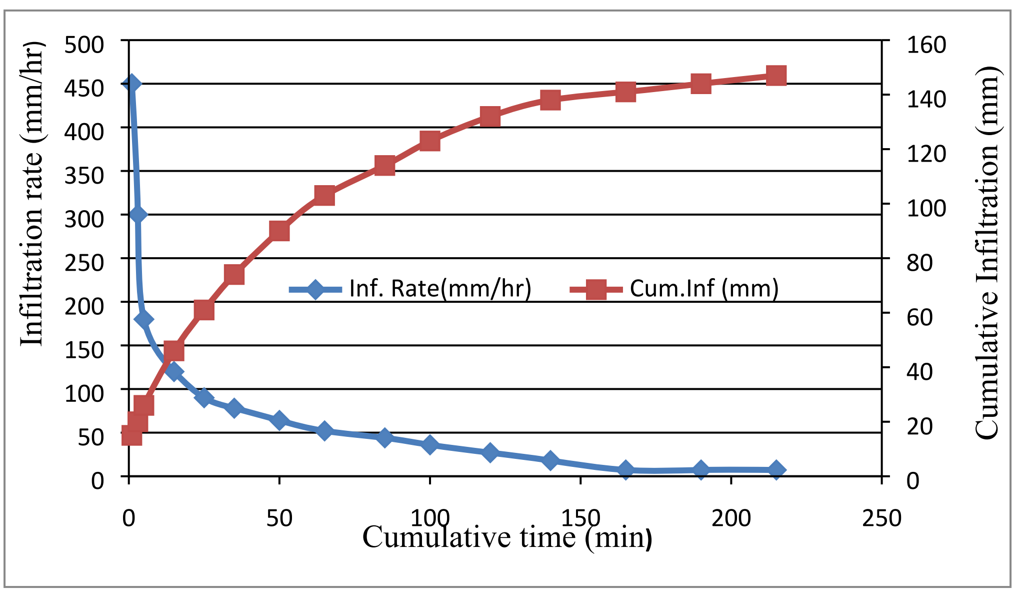

Figure 6: soil infiltration rate and cumulative infiltration of the experimental site

4.2. Soil andWater Chemical Property Analysis

The result of irrigation water quality analysis shown that the average PH value was 7.20 and the electrical conductivity of irrigation water was also 0.37 ds/m. According to FAO (1985) electrical conductivity of irrigation water (ECw) classification of < 0.7 ds/m (no salinity effect), 0.7– 3 ds/m (slight to moderate salinity effect), > 3 ds/m (severe salinity effect). Based on FAO classification the irrigation water quality of the study area was classified as no salinity effect. According to Bryan *et al. (*2007), the irrigation water is classified in terms of pH <7 low, 7-8 slight to moderate, and >8 severe. Based on this classification, the pH value of irrigation water inthe study area shown that slight to moderate.

From the result of soil chemical property analysis, the soil had an average electrical conductivity of 0.29dS/m whichis below the threshold value for yield reduction, which is below 1.2dS/m (Smith *et al*, 2011). From the obtained result the soil is safe in terms of salinity and no need of considering leaching requirementsin the determination of irrigation needed. The result also revealed that theaverage soil PH study area was 7.13 which is suitable for the growth of onion because the result implies that moderate in both acidity and alkalinity. According to FAO (2008) soil reaction (PH) classification, soils are classified as strongly alkaline(> 8.5), moderately alkaline (7.1-8.5), neutral (7,) slightly acidic (6.6 - 6.9), moderately acid (5.6 - 6.5), strongly acid (4.6 - 5.5) and very strong acid (< 4.5). Accordingly, the soil of the study area is classified as moderately alkaline.

The average value of soil OC and OM content of the study area was 2.22% and 3.18% respectively. The organic matter content of the soil was varied from 4.30% to 3.20% (Table 3). Maximum organicmatter content was obtained in the topsoil layer, while minimum value was measured in thelower soil profile. This may be associated with the incorporation of crop residue in the topsoil to increase OM content.

Table 3: Irrigation water and soil chemical property of the experimental site

Soil depth(cm)	Soil chemical property				Irrigation water chemical property	
	PH	EC(dS/m)	OM (%)	OC (%)	PH	EC(dS/m)
0-15	6.70	0.30	4.30	2.50		
15-30	7.41	0.29	4.15	2.41		
30-45	7.30	0.31	3.61	2.10	7.20	0.37
45-60	7.10	0.27	3.20	1.86		
Average	7.13	0.29	3.81	2.22		

* EC-electrical conductivity, OM-organic matter and OC- organic carbon

4.3. Crop Water Requirement of Onion

Seasonal water demand for onion was determined to start from seasonal water application depth from transplanting to harvest and vary between treatments according to their deficit level percentage. The Seasonal crop water requirement of onion determined for the control treatment (100% ETc) was 423.80 mm (Table 4 and Appendix Table 16). There was an occurrence of rainfall during the study which was deducted from total crop water demand (Appendix Table 16). The total rainfall recorded during the experiment was 21 mm which was recorded in March and April 2019. The total effective rainfall was 16.8 mm from two months. The occurrence of the rain was on March 24/ 2019 and April 10/2019 with rainfall of 8 mm and 13mm respectively. The obtained effective rainfall was reduced from the net irrigation requirement of onion.

Common irrigation for all treatment (17 mm) which was used for the establishment of onion before treatment start was applied. The maximum amount of net irrigation (407 mm) was consumed by control treatment (Application level of 100% ETc). The minimum amount of net irrigation (162.80 mm) was consumed by T7 (Application level of 40% ETc). The intermediate treatments obtain net irrigation water between 407 mm to 162.80 mm according to their deficit level percentage (Table4).

The maximum amount of gross irrigation (678.33 mm) was consumed by control treatment (Application level of 100% ETc) and the lowest amount of gross irrigation (271.33mm) was consumed by application level of 40% ETc.For intermediate treatments T2,T3,T4,T5, and T6 the calculated gross irrigation application was 610.50mm, 542.67 mm, 474.83 mm, 407.00 mm,and 339.16 mm. The obtained seasonal water demand for onion in this study is in agreement with the report of Ketame Tazara (2018) and Dirirsa *et al.*(2017) in which they report that maximum gross irrigation (664.30 mm) and 672.16 mm for onion production was consumed by 100% ETc (control treatment) respectively.

Table 4: Seasonal Irrigation Water Applied for Each Treatment

Treatments	Total ETc(mm)	Total net irrigation (mm)	Total gross irrigation (mm)
T1 (100%ETc)	423.80	407.00	678.33
T2 (90%ETc)	381.42	366.30	610.50
T3 (80%ETc)	339.04	325.60	542.67
T4 (70%ETc)	296.66	284.90	474.83
T5 (60%ETc)	254.28	244.20	407.00
T6 (50%ETc)	211.90	203.50	339.16
T7 (40%ETc)	169.52	162.80	271.33

* ETc- Crop-Evapotranspiration.

4.4. Effects ofDeficit Irrigation on Growth Parameters of Onion

4.4.1. Leaf Number per Plant

The result from the analysis of variance shown that there wassignificantdifference between treatments in case of the number of leaf per plant ($p<0.05$). The number of leaveswas affected by the decreasing application of irrigation water. Full application of irrigation water (100%ETc) producesa high number of leaf per plant (12.667). A small amount of leaf number was obtained by the small application of irrigation water (40% ETc) which was (6.667)the number of leaf per plant. Statistically, there was no significantdifference between T1, T2, and T3. This implies that leaf number was not highly affected by irrigation deficit up to 80% ETc application level. In other cases as deficit level increased number of the leaf was reduced especially from 70%ETc application to the smallest one (40%ETc) application level. Minimum leaf numbers were produced by T5, T6 and T7 (7.333, 7.333 and 6.667 respectively).

Moreover, a result has shown that irrigation application-level hada significant effect on vegetative growth. The result obtained in line with the observations in other irrigation findings. Enchalew (2016) reports that vegetative growth of onion decrease as the application level of irrigation water decrease from 100%ETc to 50%ETc.Similarly, the report of Ketama (2018) and Yetagasu (2019) also shown that number of leaves decreased with decreasing soil moisture level and a high amount of leaf number was obtained by application level of 100% ETc.

4.4.2. Plant andLeaf Height

The result has shown that onion plant height was influenced by different deficit application level of irrigation water. The highest plant height of56.67cm was recorded from the control treatment (T1). The minimum plant height 35cm was recorded from treatment T7 and which was significantly different from all other treatments. There was a highly significantdifference ($P < 0.01$) between applications of different deficit irrigation water levels in case of leaf height of onion. The highest leaf height 53 cm was recorded from control treatment T1. The minimum leaf height of32.33cm was recorded from treatment T7.

In general, the results indicated that both plant and leaf height of onion decreased as water application level decrease from optimum irrigation (100% ETC) to low irrigation application level (40% ETC). This indicated that plant and leaf height of onion which received maximum applied water was taller than onion that received a minimum amount of applied water. The results are in agreement with Metwally(2011)who report that the higher water supply resulted in the higher vegetative parameters (plant and leaf height).This finding also in line with the results of Aklilu (2009) and Takele (2009) who reported that plant height of onion decreased with decreased irrigation levels and also increase with the irrigation water level.

4.4.3. Leaf Diameter

There was significantdifference ($p<0.05$) between different application levels of irrigation water on onion leaf diameter. Thus treatment thatirrigated by full irrigation water had the widest leaf diameter (1.810cm) than the others deficit level. The smallest leaf diameter (0.587cm) was obtained by T7 which gets the smallest amount of irrigation water. Statistically, there was no significantdifference between T1 and T2 and also no significantdifference was observed between T2, T3, and T4. The result has shown that decreasing the amount of irrigation required decreases the leaf diameter of onion.

Table 5: Effect of deficit irrigation on the growth parameter of onion

Treatments	Leaf Numberper plant	Plant Height (cm)	Leaf Height (cm)	Leaf Diameter (cm)
T1	12.667a	56.67 a	53.00a	1.810a
T2	11.667ab	55.33ab	48.00a	1.583ab
T3	11.000ab	52.33b	46.67ab	1.257b
T4	10.000b	47.67c	44.00ab	1.113bc
T5	7.333c	40.33d	36.33bc	0.687cd
T6	7.333c	40.33d	36.33bc	0.640cd
T7	6.667c	35.00e	32.33c	0.587d
CV%	7.5	2.3	7.9	14.0
L.S.D.	1.27	1.91	5.97	0.27

Note: Different letters in a column implysignificantly different and those followed by the same letter are not significantly different according to LSD at $P<0.05$ level of significance.

4.5. Effect of Deficit Irrigation on Yield and Yield Component of Onion

The result on the Effect of Deficit Irrigation on Yield and Yield Component of Onion like; total bulb yield, the average weight of onion yield, onion bulb diameter, and marketable yield were presented in Table 6 below.

Table 6: Effect of Deficit Irrigation on Yield and Yield Components of Onion

Treatments	Total bulb yield	Average	Onion bulb	Marketable onion yield

	(t/ha)	bulb weight (g)	diameter(cm)	(t/ha)
T1	38.09a	136.8a	6.923a	37.03a
T2	36.66a	132.0a	6.773a	33.39b
T3	34.33ab	123.6b	6.290b	32.03b
T4	32.49ab	117.0b	6.100b	31.66b
T5	29.08bc	104.7c	5.567c	27.02c
T6	25.21cd	90.8d	4.720d	24.31d
T7	22.23d	80.0e	4.060e	21.13e
CV%	10.4	4.0	4.6	4.6
L.S.D.	5.756	8.02	0.47	2.424

Note: means followed by different letters in a column differ significantly and those followed by thesame letter are not significantly different according to LSD at p<0.05 level of significance.

4.5.1. Total Bulb Yield

ANOVA of total onion bulb yield shown that there was significantdifference between the treatments. Maximum yield (38.09 t/ha) was obtained by non-deficit treatment (T1)while the lowest application level of irrigation water had the lowest yield of 22.23 t/ha. The other treatments T2, T3, T4, T5 and T6 produce yields of 36.66 t/ha, 34.33 t/ha, 32.49 t/ha, 29.08 t/ha, and 25.21t/harespectively. The ANOVA revealed that deficit irrigationlevel significantly ($p<0.05$) influencetotal bulb yield. The total onion bulb yield increased with increasingwater application level (Figure7). Up to 70% ETc application of irrigation water statistically similar yield was obtained (Table 6). But from 60% ETcup to 40% ETc application of irrigation water total bulb yield was reduced and affected by decreased application level of irrigation water.

As irrigation water was more decreased bulb forming of onion and increasing of onion bulb in size was decreased which lead to decreasing total onion bulb yield.Similarly,KetamaTazara (2018) report that thehigher yield was obtainedin full irrigation and reducedsignificantly from non-stress to high stressed level of irrigation water. The result is also in agreement with the finding of David *et al.* (2016) who report that yield decreased with increasing water stress signifying the more stress the crop is subjected to, the slower it is for it to recover leading to progressively lower yield.

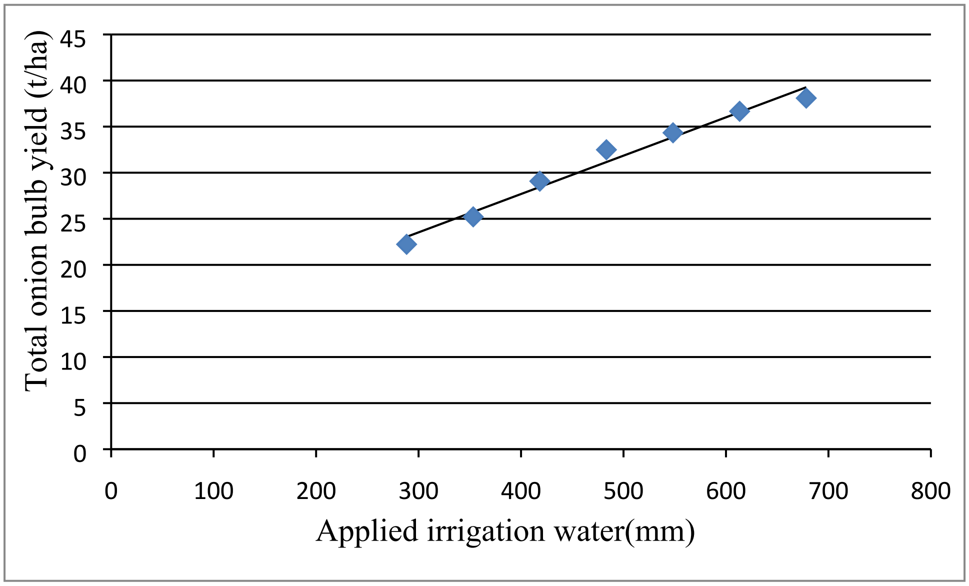

Figure 7: Effect of Deficit Irrigation on Total Bulb Yield of Onion

4.5.2. Average Weight of Onion Yield

The analysis on average onion bulb shown that significantdifference was observed between treatments due to different deficit irrigation levels (Table 6). The maximum weight of onion bulb (136.8g) was produced by T1 (100% ETc of application level).The minimum weight of onion bulb (80.0g) was produced by T7 (40%ETc application level).These findings indicate that individual onion bulb weight was affected by the deficit application level. Up to 30% deficit of irrigation water optimum bulb weight was obtained which produces optimum total onion yield. But from 40% up to 60% deficit of irrigation water,the average weight of onion bulb was reduced. Statistically, no significant difference was observed between T4 and T3.

4.5.3. Bulb Diameter of Onion

The result on onion bulb diameter shown that there was significantly different ($p<0.05$) between treatments due to deficit irrigation level. Thelargest mean diameter of 6.923cm was obtained from T1 which received the optimum amount ofapplied water while treatment T7 produce the smallest diameter of 4.060cmthat receivedthe lowest amount of applied water. Onion bulb diameter was determined as an indicator ofthe size and it was found to be significantly influenced by deficit irrigation level. Statistically, there was no significant difference between T1 and T2. Also, no significant difference was observed between T3 and T4 in case of bulb diameter.

The result implies that optimum bulb diameter was obtained up 30% irrigation water deficit and decrease from 60%ETc to 40%ETc application of irrigation water. David *et al*. (2016) also concluded that bulb sizevaried proportionally with the quantity ofirrigation water applied (the largest from the100% ETc and the smallest from 50% ETc).These results emphasize that adequate soilmoisture content through the growing period encouraged the vegetative growth of the plantand enhanced the development of large and medium bulb size which is considered to be marketable.

4.5.4. Marketable OnionYield

The result ofmarketable yield of onion revealed that there was significantdifference ($p<0.05$) between treatments due to the application level of irrigation water. The maximum amount of marketable yield (37.03t/ha) was obtained by control treatment (100%ETc of application level). Minimum marketable onion yield (21.13t/ha) was produced by the smallest application of irrigation water (40%ETc application).The intermediate treatments produce marketable onion yield between 37.03t/ha and 21.13t/ha (Table 6 and Figure 8).

The analysis showed that there was no significant difference between T2, T3 and T4 in case of marketable onion yield. Up to 70%ETc optimum marketable yield of onion was obtained. The result is in agreement with the finding of Enchalew*et al.* (2016) who report that 70%ETc application level of irrigation water produces statistically similar marketable yield with application-level 90%ETc and 100%ETc.According to Tsegaye*et al.* (2016), higher marketable bulbs of onion at higher irrigation levels might be due to the increase in the formation of growth measurements causing faster synthesis and transportation of photosynthesis.

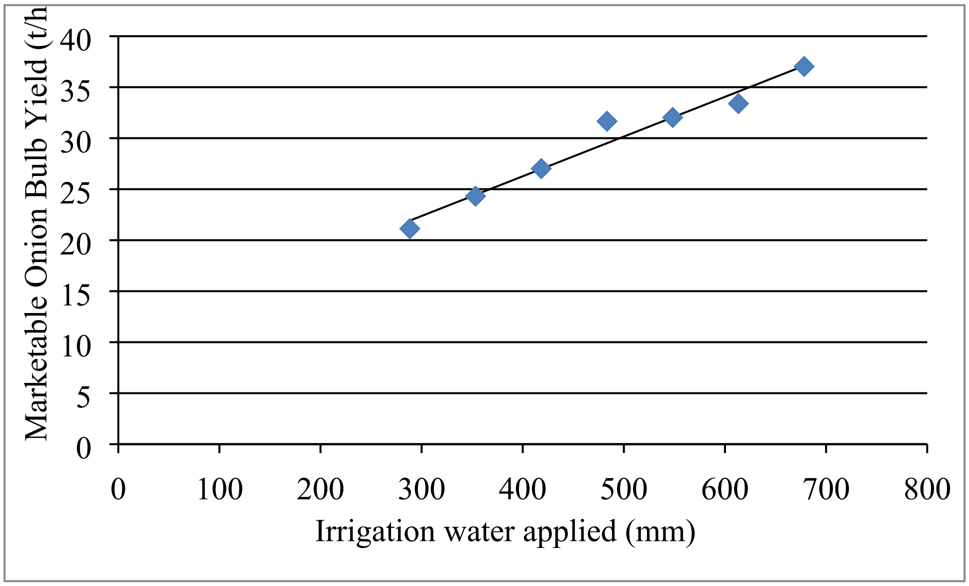

Figure 8: Effect of Deficit Irrigation on Marketable Bulb Yield of Onion

4.6. Effect of Deficit Irrigation on Water Productivity

The result on WP shown that there was significant difference ($p<0.05$) between different deficit irrigation levels. Maximum WP(12.85 kg/m^3)was obtained by minimum application of irrigation water(40% ETc)while the lowest value 9.36 kg/m^3 of WP wasobtained from T1 (100% ETc). Statistically, water productivity of T4 (70% ETc application level) had no significantdifference with the treatment which produce maximum water productivity (40%ETc application) (Table 7). By saving 30% of irrigation water,the application of 70%ETc produces optimum yield which produces optimum water productivity. Yield reduction obtained by T4 was also relatively small while comparing with T5, T6 and T7 (Table 8).

Even though the maximum yield is produced by T1, its WP was lowest due to the maximum consumption of irrigation water. This implies that water productivity increase as irrigation water application level decrease. The intermediate treatment produces the WP between 12.85 kg/m^3 and 9.36 kg/m^3 (Table 7). The result is in agreement with the finding of David *et al.* (2016) who report that water productivity for onion yield was affected significantly by deficit irrigation treatments up to 80% ETc application and increase from 70% ETc application to the most deficit irrigation level treatment.

Table 7: Effect of Deficit Irrigation on Water Productivity

Treatments	Onion Yield(kg/ha)	WP(kg/m^3)
T1	38086a	9.36c
T2	36657a	9.96bc
T3	34326ab	10.43bc
T4	32490ab	11.20abc
T5	29077bc	11.58ab
T6	25213cd	11.89ab
T7	22228d	12.85a
CV%	10.4	9.6
L.S.D.	5756.1	1.885

Note: CWP- crop water productivity. Means followed by different letters in a column differ significantly and those followed by the same letter are not significantly different according to LSD at $p<0.05$ level of significance.

4.7. Effect of Deficit Irrigation on Water Saving and Yield Reduction

The result showed that the amount of irrigation water saved which can irrigate another additional area was increase as decreasing application level. The saved irrigation water from T2, T3, T4, T5, T6 and T7 were 10, 20,30,40,50 and 60 % respectively. The additional area which can be irrigated by saved water by T2, T3, T4, T5, T6 and T7 were 0.11, 0.25, 0.43, 0.66,1.00 and 1.5 ha respectively (Table 8 and Figure 9). The result shown that yield reduction was relatively increased as the amount of irrigation water application was decreased.

Table 8: Effect of Deficit Irrigation on Water Saving and Yield Reduction

Treatments	WU(m^3/ha)	TY t/ha)	WS (%)	WS(m^3/ha)	YD (%)	AIBSW	Yield to be gain (t/ha)
T1	6783.30	38.086	0	0	0	0	0
T2	6105.00	36.657	10	678.3	3.75	0.11	4.03
T3	5426.70	34.326	20	1356.6	9.87	0.25	8.58
T4	4748.30	32.49	30	2035	14.69	0.43	13.97
T5	4070.00	29.077	40	2713.3	23.65	0.66	19.20
T6	3391.60	25.213	50	3391.7	33.79	1.00	25.213
T7	2713.30	22.228	60	4070	41.64	1.50	33.34

Note: WU-water use, TY-total yield, WS-water saved, YD-yield decrease, AIBSW-area to be irrigated by saved water.

Even though there was relative yield reduction, there was the additional yield gain due to irrigating additional areas by saved water from deficit irrigation level (Table 8). Additional yield which can be irrigated by saved irrigation water from T2,T3 ,T4 ,T5 , T6 and T7 were4.03, 8.58,13.97,19.20, 25.213 and 33.34 /ha respectively (Figure 9). The results in line with Ali *et al*. (2007) who reported 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.

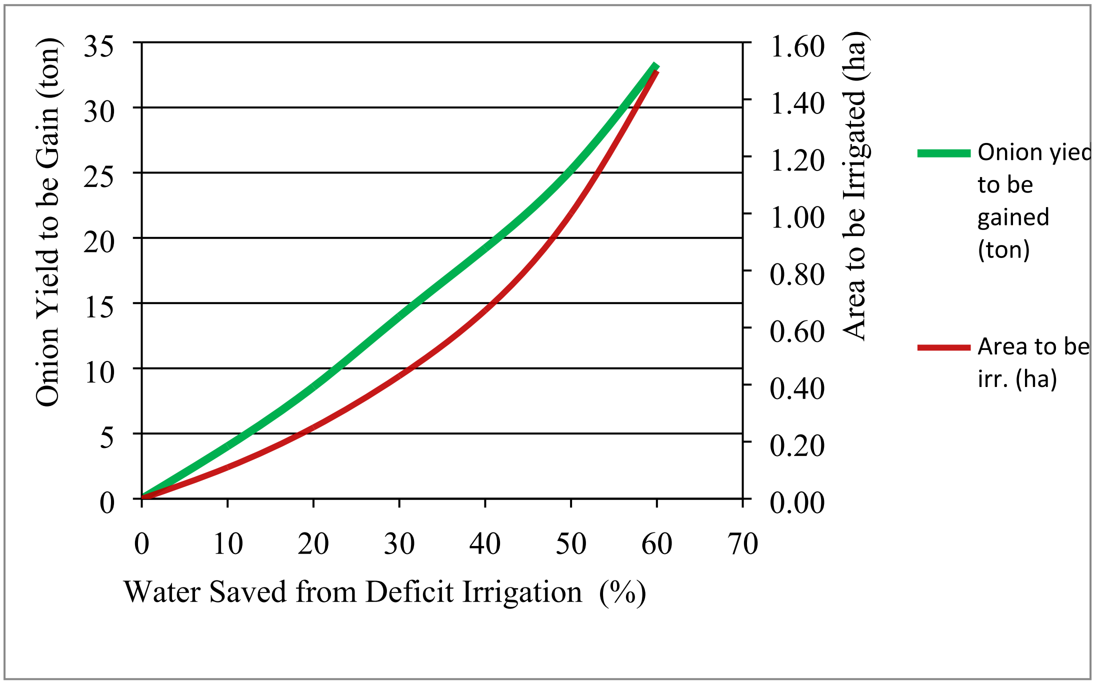

Figure 9: Effect of deficit irrigation on water saving and an additional area that to be irrigated.

The result showed that the water saved by T4 (application of 70% ETc) can irrigate additional land of 0.40 ha which can produce 13.11tonof additional onion bulb yield (Table 8) with the minimum yield reduction factor (ky) (Table 9) by saving 30% of irrigation water. So with optimum water productivity and optimum yield T4 (application of 70% ETc) was the best application deficit level during the finding.

4.8. Yield Response Factor

The yield response factor obtained from the deficit treatments T2, T3, T4, T5, T6 and T7 were 0.37, 0.48, 0.49, 0.59, 0.68 and 0.69 respectively. The study revealed that yield response factor (ky) increases with decreasing irrigation water application level. The result is in agreement with ketama (2018) who report that lower values of yield response factor associated with treatments that obtained the maximum amount of water and higher values associated treatments that obtained minimum amount of water. Different studies revealed that yield response factor varies for different crop type and deficit condition. Since the obtained Ky<1, the crop is more tolerant to water deficit, and recovers partially from a deficit, exhibiting less than proportional reductions in yield with reduced water use.

When Ky> 1, the crop response is very sensitive to water deficit with proportional larger yield reductions; Ky< 1, the crop is more tolerant to water deficit, and recovers partially from stress, exhibiting less than proportional reductions in yield with reduced water use; Ky = 1, the yield reduction is directly proportional to reduced water use (Doorenbos and Kassam, 1979). Generally, the study showedthat based on the obtained yield reduction factors onion is tolerant to water deficit and recovers partially from deficit irrigation water.

Table 9: Yield Response Factor of Onion

Treatments	ETc (mm)	Total onion bulb yield (kg/ha)	$1-\frac{Ya}{Ym}$	$1-\frac{ETa}{ETm}$	Ky
T1	423.8	38086	0	0	0
T2	381.42	36657	0.037	0.1	0.37
T3	339.04	34326	0.098	0.2	0.48
T4	296.66	32490	0.1469	0.3	0.49
T5	254.28	29077	0.236	0.4	0.59
T6	211.90	25213	0.3379	0.5	0.68
T7	169.52	22228	0.4163	0.6	0.69

Note: ETc-crop evapotranspiration (mm), Ky- yield response factor ,Eta- actual Evapotranspiration(mm) , ETm- maximum evapotranspiration(mm),Ya-actual yield(kg/ha) and Ym-maximum yield (kg/ha).

4.9. Effect of Deficit Irrigation on Economic Water Productivity

Data concerning economic comparison was presented in Table 10. The detailed evaluation of the economic analysis of irrigation treatments had shown that there was an increasing trend of net income (NI) for an increase in the water application level. This was because the unit price of irrigation water of 3 birr/1000m^3, the rate of farms in the area pay for irrigation water was very low. As a result, the direct impact of water saving in generating NI was very low for a hectare of land per season which means the very small value from a hectare. Maximum total cost (42439.7 ETB) was obtained by control treatment whereas the minimum variable cost (24175.9 ETB) was obtained by T7.

Benefit-cost ratio (BCR) of each treatment was computed as the ratio of NI earned to the TC expended. Accordingly, maximum BCR (6.28) wasobtained by T4 means that treatment which receives an application level of 70% ETc. However, the lower BCR was recorded by T1 and T2. This implies that even though the maximum yield was obtained by those treatments they were economically not more attractive. From this economic analysis T4 (70% ETc application level of irrigation water) was the most economically attractive treatment with high BCR and optimum net benefit.

Table 10: Partial Budget Analysis for Deficit Irrigation

T	I. water (m^3/ha)	UMY(Kg/ha)	AMY(Kg /ha)	TR (ETB/ha)	TVC (ETB/ha)	TFC (ETB/h a)	TC(ETB /ha)	NI (ETB/ha)	BCR
T1	6783.3	37026	33323.4	266587.2	30439.7	12000	42439.7	236147.5	5.56
T2	6105.0	33390	30051.0	240408.0	27395.8	12000	39395.8	213012.3	5.41
T3	5426.7	32026	28823.4	230587.2	24351.8	12000	36351.8	206235.4	5.67
T4	4748.3	31998	28798.2	230385.6	21306.8	12000	33306.8	209078.8	6.28
T5	4070.0	27017	24315.3	194522.4	16727.6	12000	28727.6	177794.8	6.19
T6	3391.6	24313	21881.7	175053.6	15219.9	12000	27219.9	159833.7	5.87
T7	2713.3	21128	19015.2	152121.6	12175.9	12000	24175.9	139945.7	5.79

Note: T- Treatment, UMY-unadjusted marketable yield, AMY- adjusted marketable yield, TR-total revenue, TVC-total variable cost, TFC-total fixed cost, TC-total cost, NI-net income, BCR-benefit-cost ratio.

5. SUMMARY, CONCLUSION, AND RECOMMENDATION

5.1. Summary and Conclusion

Now a day, improving water productivity is a current issue in the area where irrigation water is scarce, especially in arid and semi-arid areas. The study was conducted to evaluate the effect of deficit irrigation on water productivity and yield of onion crop at Tony farm experimental station of Haramaya University in Dire Dawa.The study revealed that deficit irrigation had a significant effect on the production and Productivity ofonion. Full application of irrigation water (100% ETc) produces a high number of leaf per plant, plant height, leaf height, and leaf diameter than the others treatment.A small amount of leaf per plant, plant height, and leaf height and leaf diameter was obtained by the small application of irrigation water (40% ETc).

Application of 90% ETc, 80% ETc, and 70% ETc irrigation water level were statistically similartothe growth parameter of onion except for plant height. But start from 60% ETc to 40%ETc application of irrigation water, growth parameters of onion weresignificantly affected by deficit irrigation. The studyshowed that irrigation application-level hada significant effect on vegetative growth from 60% ETc to 40% ETc application of irrigation water which leads to reducing total bulb yield of onion. But up to a 30% deficit, no adverse effect was observed on growth parameters of onion.

Total bulb yield, marketable yield,the average weight of onion bulb yield, and bulb diameter were significantly reduced as the application level of irrigation water reduced. Up to 70%ETc application of irrigation water, statistically,no significantdifference was observed in the case of total yield except the marketable and average weight of onion. But from 60%ETc up to 40%ETc deficit of irrigation level, yield and yield components of onion was significantly reduced.

The finding showedthat water productivity increase as water application level decrease and vice versa. This implies that water productivity reduced as more water was consumed even though the maximum yield was obtained. Statistically, water productivity of T4 (70%ETc application level) had no significance different fromthe treatment which produces maximum water productivity (40% ETc application level). By saving 30% of irrigation water, the application of 70% ETc was ingproducingoptimum yield with optimum water productivity than other treatments.

The finding also revealed that the amount of irrigation water saved which can irrigate another additional area was increased as decreasing the application level of irrigation water. Even though there was relative yield reduction there was the additional yield gain due to irrigating additional area by saved water from deficit irrigation level. The result showedthat the minimum yield reduction factor (ky) was produced by T4 (application level of 70% ETc) by saving 30% of irrigation water. From this study, thewater saved by T4 can irrigate additional land of 0.40 hector which can produce 13.97 tons of additional onion bulb yield.

Economic analysis of the study shown that BCR of treatments was affected by different application levels of irrigation water. Accordingly, BCR obtained by 70%ETc application level of irrigation water was better than other treatments. Even though the net income of control treatment (100% ETc application level) was high, the BCR obtained by this treatment was small. Generally, the study concludes that 70% ETc application level of irrigation water was the best application-level than the other treatments based on water productivity, economic visibility, total yield, percent of yield reduction, and yield response factor.

5.2. Recommendation

The following recommendations were given based on the above finding:

- ✓ The application level of 70% ETc was selected as best application level for production and productivity of onion in the study area and another similar agroecology since optimum yield, optimum water productivity and high benefit-cost ratio was obtained by this level of application
- ✓ Since the water productivity value obtained by 100% ETcapplication level was very small, a full application of irrigation water should not be used for the production of onion in water-scarce area
- ✓ The deficit irrigation strategy should be adopted by farmers and other users to save scarce water resource in water-limited area
- ✓ Even though the reduction in yield is expected when the onion is subjected to limited irrigation water, the resulting yield reduction was small when compared to the

additional area that can be irrigated by saved water. So deficit irrigation should be adopted

- ✓ In the scarce irrigation water area, the farmers should consider benefit per unit water used rather than simply wasting a huge amount of water
- ✓ Awareness should be created by the government and other stakeholders on the improvement of water productivity through deficit irrigation technology

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7. APPENDIX

Appendix Table 1: ANOVA on Water Productivity

Source	DF	Sum Square	Mean squares	F value	P value
Block	2	0.018	0.009		
Treatment	6	26.053	4.342	3.87*	0.0000
Error	12	13.466	1.122		
Total	20	39.537			

** Highly Significant (p<0.01), * significant (p<0.05), DF= degree of freedom

Appendix Table 2: ANOVA on Total Yield of Onion

Source	DF	Sum Square	Mean squares	F value	P value
Block	2	0.72	0.36		
Treatment	6	628.36	104.73	10.00**	0.0000
Error	12	125.63	10.47		
Total	20	754.71			

** Highly Significant (p<0.01), * significant (p<0.05), DF= degree of freedom

Appendix Table 3: ANOVAon Marketable Yield of onion

Source	DF	Sum Square	Mean squares	F value	P value
Block	2	0.286	0.143		
Treatment	6	562.594	93.766	47.45**	0.0000
Error	12	23.714	1.976		
Total	20	586.594			

** Highly Significant (p<0.01), * significant (p<0.05), DF= degree of freedom

Appendix Table 4: ANOVA on average bulb Yield of onion

Source	DF	Sum Square	Mean squares	F value	P value
Block	2	12.67	6.33		
Treatment	6	8098.30	1349.72	66.38**	0.0000
Error	12	244.00	20.33		
Total	20	8354.97			

** Highly Significant (p<0.01), * significant (p<0.05), DF= degree of freedom

Appendix Table 5: ANOVA on leaf diameter of onion

Source	DF	Sum Square	Mean squares	F value	P value
Block	2	0.89075	0.44538		
Treatment	6	4.22493	0.70416	29.73**	0.0000
Error	12	0.28418	0.02368		
Total	20	5.39987			

** Highly Significant (p<0.01), * significant (p<0.05), DF= degree of freedom

Appendix Table 6: ANOVA on leaf height of onion

Source	DF	Sum Square	Mean squares	F value	P value
Block	2	67.52	33.76		
Treatment	6	1018.29	169.71	15.07**	0.0000
Error	12	135.14	11.26		
Total	20	1220.95			

** Highly Significant (p<0.01), * significant (p<0.05), DF= degree of freedom

Appendix Table 7: ANOVA on number of leaf per plant

Source	DF	Sum Square	Mean squares	F value	P value
Block	2	1.2381	0.6190		
Treatment	6	103.9048	17.3175	34.09**	0.0000
Error	12	6.0952	0.5079		
Total	20	111.2381			

** Highly Significant (p<0.01), * significant (p<0.05), DF= degree of freedom

Appendix Table 8: ANOVA on number of leaf per plant

Source	DF	Sum Square	Mean squares	F value	P value
Block	2	1.2381	0.6190		
Treatment	6	103.9048	17.3175	34.09**	0.0000
Error	12	6.0952	0.5079		
Total	20	111.2381			

** Highly Significant (p<0.01), * significant (p<0.05), DF= degree of freedom

Appendix Table 9: ANOVA on plant height

Source	DF	Sum Square	Mean squares	F value	P value
Block	2	0.095	0.048		
Treatment	6	1273.238	212.206	183.14**	0.0000
Error	12	13.905	1.159		
Total	20	1287.238			

** Highly Significant (p<0.01), * significant (p<0.05), DF= degree of freedom

Appendix Table 10: Soil Infiltration Characteristics of Study Area

Elapsed Time (min)	Time difference (min)	Cumulative time (min)	Water level reading (mm)		Infiltration (mm)	Infiltration rate (mm/hr)	Cumulative infiltration(mm)
			Before	After			
-	-	-	-	100	-	-	-
1	1	1	85	100	15	450	15
3	2	3	95	100	5	300	20
5	2	5	94	100	6	180	26
15	10	15	80	100	20	120	46
25	10	25	85	100	15	90	61
35	10	35	87	100	13	78	74
50	15	50	84	100	16	64	90
65	15	65	87	100	13	52	103
85	20	85	89	100	11	44	114
100	15	100	90	100	9	36	123
120	20	120	90	100	9	27	132
140	20	140	94	100	6	18	138
165	25	165	97	100	3	7.2	141
190	25	190	97	100	3	7.2	144
215	25	215	97	100	3	7.2	147

Appendix Table 11: Parshallflume discharge rate calibration at experimental field

Parshall flume head (cm)	Discharge (l/sec)
1	0.16
2	0.45
3	0.84
4	1.31
5	1.85
6	2.45
7	3.10
8	3.81
9	4.57
10	5.37
11	6.22
12	7.12
13	8.05
14	9.02
15	10.03
16	11.08
17	12.17
18	13.29
19	14.44
20	15.63
21	16.85
22	18.10
23	19.38
24	20.69
25	22.04
26	23.41
27	24.81
28	26.24
29	27.70
30	29.18

Appendix Table 12: Determination of Soil Field Capacity

Depth (cm)	Wet weight (gm)	Dry weight (gm)	Can weight (gm)	FC(% by W/W)	Bulk density (g/cm3)	FC(% by V/V)
0-15	304	256	98	30.40	1.21	36.78
15-30	285	241	97	30.00	1.02	30.60
30-45	308	255	96	33.30	1.12	37.29
45-60	283	231	96	38.51	1.16	44.67

Appendix Table 13: Determination of Soil Permanent Wilting Point

Depth (cm)	Wet weight (gm)	Dry weight (gm)	PWP (% by W/W)	Bulk density(g/cm3)	PWP (% by V/V)
0-15	24	21	19.05	1.21	23.05
15-30	23	20	15.00	1.02	15.3
30-45	24	21	14.28	1.12	15.99
45-60	22	19	15.78	1.16	19.09

Appendix Table 14: Total available water in the soil

Depth (cm)	FC(% by W/W)	PWP (% by W/W)	TAW (mm)
0-15	38.51	19.05	20.60
15-30	30.00	15.00	22.95
30-45	30.40	14.28	31.95
45-60	33.30	15.78	39.55
Total available water in effective root zone of 60cm			115.05

FC- Field Capacity, PWP – Permanent Wilting Point, TAW- Total Available Water

Appendix Table 15: ETo Determination from Long Term Meteorological Data of Study Area

Months	Avg. Min.Temp	Avg. Max.Temp	Avg.RH (%)	Avg. WS(m/sec)	Avg.Sun shine(hr)	Dependable Rainfall	ETo(mm/day)
Jan	15.09	30.4	43	0.517	8.37	0	3.59
Feb	16.26	30.9	42	0.666	8.51	0	4.10
Mar	18.8	32.4	38	0.804	7.40	11	4.07
Apr	20.5	33.6	41	1.070	7.72	101	4.49
May	22	35.2	49	1.129	7.74	21	4.83
Jun	23	35.6	35	1.878	7.77	11	5.93
July	21	35.4	38	2.260	6.96	51	4.70
Aug	19.5	33.9	42	1.855	7.14	111	5.39
Sep	22	33.1	39	1.342	6.75	51	5.66
Oct	18	33.3	35	0.697	6.92	31	4.46
Nov	15.5	32.8	35	0.542	8.37	11	4.54
Dec	14.5	29.8	36	0.448	8.67	0	4.00

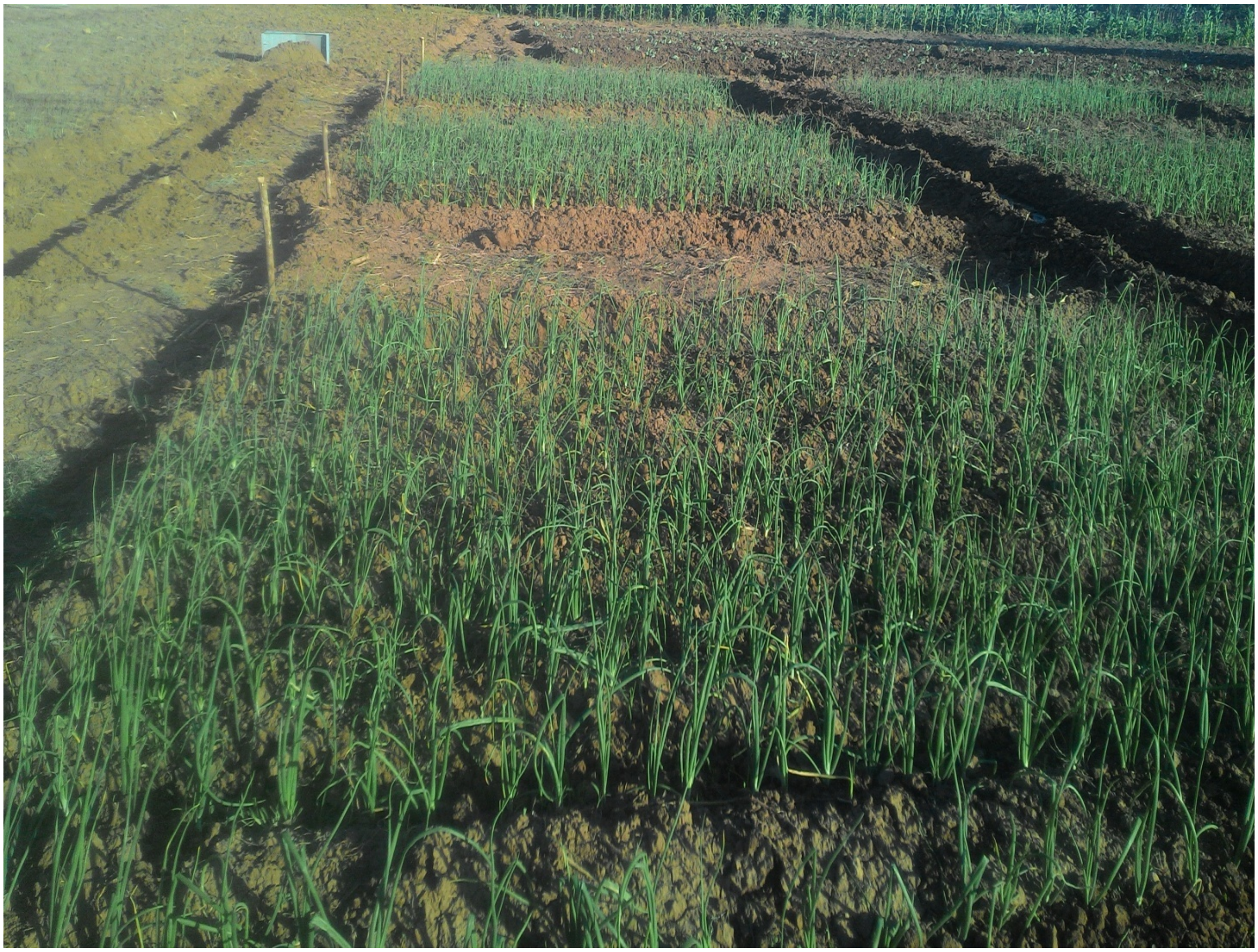
Source: Dire Dawa Meteorological Station

* ETo-reference Evapotranspiration, Avg. - average, WS-wind speed, RH-relative humudity

Appendix Table 16: Irrigation Scheduling of Onion crop at Study Area

Date	Stage	Kc	ETo(mm/period)	ETc (mm/period)	Pe	NIR(mm/period)	GIR (mm/period)
5-Jan	Init	0.7	14.36	10.052	0	10.052	16.753
9-Jan	Init	0.7	14.36	10.052	0	10.052	16.753
13-Jan	Init	0.7	14.36	10.052	0	10.052	16.753
18-Jan	Init	0.7	17.94	12.558	0	12.558	20.930
23-Jan	Dev	0.7	17.94	12.558	0	12.558	20.930
29-Jan	Dev	0.89	21.54	19.1706	0	19.1706	31.951
5-Feb	Dev	0.99	28.7	28.413	0	28.413	47.355
14-Feb	Dev	1.05	36.97	38.8185	0	38.8185	64.698
23-Feb	Mid	1.05	37.63	39.511	0	39.511	65.852
4-Mar	Mid	1.05	44.87	47.113	0	47.113	78.522
13-Mar	Mid	1.05	37.63	39.511	0	39.511	65.852
21-Mar	Mid	1.05	32.56	34.188	0	34.188	56.980
30-Mar	End	1.05	36.66	38.493	6.40	32.093	53.488
8-Apr	End	1.12	35.92	40.230	0	40.230	67.050
18-Apr	End	0.96	44.9	43.104	10.40	32.704	54.507
25-Apr	End						
Total				423.80	16.80	407.00	678.33

ETo - Reference evapotranspiration, Kc - Crop coefficient, ETc- Crop evapotranspiration, Pe- Effective rainfall, NIR - Net irrigation requirement, GIR - Gross irrigation requirement.



Appendix Figure 1: Status of Experiment at Initial Stage

Appendix Figure 2: Watering of Onion and Disease Control

Appendix Figure 3: Soil Infiltration Capacity Test of Study Area

Appendix Figure 4: FC and PWP analysis by pressure plate