WATER PRODUCTIVITY AND YIELD RESPONSE OF ONION UNDER FULL AND DEFICIT IRRIGATION IN WATER SCARCE AREA, MAREKO WOREDA, ETHIOPIA

MSc. THESIS

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HAWASSA UNIVERSITY, HAWASSA, ETHIOPIA

NOVEMBER, 2017

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A THESIS SUBMITTED TO SCHOOL OF WATER RESOURCES ENGINEERING, INSTITUTE OF TECHNOLOGY, SCHOOL OF GRADUATE STUDIES, HAWASSA UNIVERSITY,
HAWASSA, ETHIOPIA

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN IRRIGATION AND DRAINGE ENGINEERING

NOVEMBER, 2017

HAWASSA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

EXAMINERS' APPROVAL SHEET

We, the undersigned, members of the Board of Examiners of the final open defense by **Kedrala Wabela** have read and evaluated his thesis entitled **"Water Productivity and Yield Response of Onion under Full and Deficit Irrigation in Water Scarce Area, Mareko Woreda, Ethiopia ",** and examined the candidate. This is, therefore, to certify that the thesis has been accepted in partial fulfillment of the requirements for the degree

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ACKNOWLEDGMENTS

My grateful thanks to my advisors Dr. Sirak Tekleab and Dr. Moltot Zewde for their continues follow up and guidance. I have got a lot of assistances from them during my proposal preparation, experiment work and preparation of the thesis. My thanks also go to the Southern Agricultural Research Institute (SARI), for granting the scholarship and also the financial support for the research. I extend my gratitude to Worabe Agricultural Research Center (WARC) for research material supporting. I am pleased to thank the National Meteorological Agency Hawassa branch for providing me with meteorological data of the research site.

I would like to extend my deepest gratitude to my beloved father, Wabela Hussen and my mother Tibesuo Tekelo. They are always the constant source of my strength and hope in every aspect of my life. My special heartfelt gratitude also goes to my wife, Selam Surur for her encouragement, affection, and special treatment morally and psychologically. Finally, thanks also goes to my friend, Mr. Mukerem Elias, and other Worabe Agricultural Research Center staff members for their words of encouragement and material support during this study.

LIST OF ABBREVIATIONS

ANOVA	Analysis of variance
AW	Applied water
BM	Biomass
BD	Bulk density
CC	Canopy cover
CRP	Coordinate research project
CV	Coefficient of variation
CWP	Crop water productivity
CWR	Crop water requirement
DAT	Days after transplanting
DF	Degree freedom
EC	Electric conductivity
ECDSWC	Ethiopian construction design and supervision works corporation
ETc	Crop evapotranspiration
ET	Evapotranspiration
ETo	Reference evapotranspitration
EWP	Economic water productivity
FAO	Food and Agricultural Organization
FC	Field capacity
GDP	Growth and development program
GI	Gross income
GTP	Growth Transformation plan
GWC	Gravimetric water content
HI	Harvest index
IAEA	International Atomic Energy Agency
IR	Irrigation requirement
IRn	Net irrigation requirement

IW	Irrigation water
IWMI	International water management institute
Kc	Crop coefficient
LAI	Leaf area index
LSD	List significant difference
MAD	Management allowed deficit
MRR	Marginal rate of return
MS	Mean square
NI	Net income
OB	Observed yield
OM	Organic mater
Pe	Effective rain fall
PWP	Permanent wilting point
RAW	Readily available water
RMSE	Root mean square error
SNNPR	Southern Nations Nationality People Region
SS	Sum of square
TASW	Total available soil water
TAW	Total available water
TC	Total cost
Tr	Transpiration
UNDP	United Nations department of Economics and Social Affairs Population division
USDA	United State Department of Agriculture
VC	Variable cost
WP	Water productivity
WUE	Water use efficiency

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ABSTRACT

Fresh water is scarce in many parts of the world and becoming a global agenda. Agriculture is the largest among sectors which are consuming huge fresh water. The objectives of this study were to improve agricultural water productivity and investigate the yield response of onion crop to water deficit. The method employed encompasses field experiment in randomized complete block design (RCBD) with eleven treatments and three replications. The treatments were: full irrigation (0% deficit as control), 25% of CWR deficit throughout growing season,50% of CWR deficit throughout growing season, and one period deficit treatments (25% and 50% of CWR deficit at initial, development, mid and late stages). The experiment was carried out at mareko woreda southern Ethiopia. Results showed that differences in irrigation water amount significantly affect canopy cover, bulb yield and above ground biomass of onion. The maximum marketable yield was acquired from fully irrigated treatment (T1) which is 19.93 t/ha and the minimum marketable yield was obtained from T3 (50% of CWR deficit throughout growing season) which is 10.31 t/ha. T10 (50% of CWR deficit at mid stage) showed the minimum harvest index (0.68) and T4 and T7 (25% of CWR deficit at initial and late stages respectively) showed the maximum index. The lowest HI indicated that water deficit at mid stage causes high yield reduction. The maximum crop water productivity (4.98 kg/m^3) was observed at T3 (50% of CWR deficit throughout growing season) and the minimum (3.22 kg/m^3) was observed at T10 (50% of CWR deficit at mid stage). The largest water saving with significant yield reduction was obtained at T3.Yield response factor (ky) indicated that onion was sensitive (yield reduced) for water stress at development and mid growth stages. 50% of CWR deficit at one period stress treatments showed ky>1, which indicates the sensitivity of the onion crop for high water stress. The economic analysis indicated that the maximum marginal rate of return was obtained at T11 (50% of CWR deficit at the late stage) with a net income of 108,770 birr/ha and a marginal rate of return 5672.9%. Therefore, T11 (50% of CWR deficit at late stage) is economically viable system of onion production with significant water saving and if farmers at this experimental site apply this system of production they will increase their income.

Key words: Water productivity, Deficit irrigation, Yield response, Mareko Ethiopia.

1. Introduction

1.1 Background

The world population is expected to grow from 7 billion at present to 9 billion by 2050. The rate of growth is rapid in the least developed countries. The population growth combined with the rise of living standards requires a substantial increase of food production to ensure sustainable food security (UNDP, 2011). As population increases and development calls for increased allocations of ground and surface water for the domestic, agriculture and industrial sectors, as a result the need for water resources increase. The increasing stress on freshwater resources brought about by ever rising demand is of serious concern (FAO, 2008).

Although agriculture is the main stay of 85% of the Ethiopian people and accounts for 43% of the GDP of the country (IWMI, 2010), most Ethiopian farmers depend on low productive rain-fed small holder agriculture with very erratic rainfall and frequent drought. To feed the increasing population and to reduce risks caused by drought and increasing population density, continuous and extensive effort need to be made towards developing irrigated agriculture and improving agricultural production.

Irrigation agriculture plays an important role in contributing towards food security, self sufficiency, food production and exports. Increased productivity of land and labor, reduced reliance on rainfall, reduced degradation of natural resources, increased job opportunities, and promotion of a dynamic economy with rural entrepreneurship are also benefits obtained from irrigation agriculture. Ethiopia has an important opportunity in water-led development, but it needs to address critical challenges in the planning, design, delivery, and maintenance of its irrigation systems if it is to capture its full potential (IWMI, 2010). Hence, irrigated agriculture is the main concern of the food security strategy of the Ethiopian Government, which is implemented by increasing small scale irrigation and reduces dependency on rain-fed agriculture, which in turn leads to increase food production and self-sufficiency of the rapidly growth population of the country (GTP, 2010).

According to Molden et al. (2003) irrigated agriculture is the largest water consuming sector and it faces competing demands from other sectors, such as domestic and industrial sectors. Improved water management for agriculture has many potential benefits in efforts to reduce vulnerability and improve productivity. It is the act of timing and regulating irrigation water application in a way that will satisfy the water requirement of the crop without wasting water, soil, and plant nutrients and degrading the soil resource (Elwin, 1997). Nowadays, even full irrigation of CWR is considered as luxury use of water that can be reduced with minor or no effect on profitable yield (Kang and Zhang, 2004). With an increasing population and less water supply for agricultural production, the food security for future generations is impossible. Hence, the agricultural sector faces the challenge to produce more agricultural production with reduced water supply by increasing crop water productivity.

Deficit irrigation is one of the irrigation water management practices which is not necessarily based on full water required by the crops. It is an optimization strategy whereby net returns are maximized by reducing the amount of irrigation water and crops are deliberately allowed to sustain some degree of water deficit with insignificant yield reduction (Capra et al, 2008). Deficit irrigation increases the productivity of water in agriculture and plays a very important role in reducing competition for scarce water resources, minimizing environmental degradation and provision of food security. However, the amount of irrigation water reduction is based on crop characteristics and generally accompanied by no or insignificant yield loss that increases the water productivity (Ahmadi et al., 2010).

An increase in agricultural water productivity plays a vital role to sustain and increase food production so as to ensuring sustainable food security. Investigation has been placed on the concept of water productivity and defined here as the productivity of water in a given use in terms of quantity and quality of water supplied. The productivity of water refers to the amount or the value of product over volume or value of water divert. FAO (2010) and Geerts and Raes (2009) suggested that increasing crop water productivity can be an important pathway for sustainable food production and poverty reduction. This would enable to produce more food and hence feeding the ever increasing population of Ethiopia or gaining more income with minimum water amount thus improved household living standard would be attained.

Integrating local researches with modern irrigation development by creating mutual relationship between research and irrigation development is the most important for enhancing better agricultural production in the Southern region of Ethiopia (Bekele et al, 2007).The Regional Irrigation and Natural resources development office pointed out Mesken, Silti and Mareko as the most suitable districts for shallow groundwater development. In these areas, farmers use wells for irrigation purpose and a well is found almost in every compound. Irrigation practices around the area are based on two dry seasons, from October to January and from February to May. Onion, Tomato, Cabbage, Spinach, Red beets, Carrot, Chat, and Pepper are the main cultivated crops in the area. During wet seasons (June to September) Maize, Wheat and Mustard are the most common choices. In cases of short rainfalls periods, farmers have to supplement with water to their land through irrigation using wells (Mareko woreda Agricultural office, 2016).

1.2 Problem of the statement

Evaluation of irrigation production based on crop water productivity and economic water productivity per unit water used are the most important aspects of crop production in water scarce area. However, application of deficit irrigation and its economic analysis is not commonly practiced in most water scarce areas of Ethiopia. The same is true in Mareko woreda, which is one of the water scarce areas in southern region. Rainfall distribution in the woreda shows high temporal and spatial variability, with annual precipitation ranging from 500 to 800 mm. In the woreda there is hot and long dry period from October to March. Most farmers in this woreda use ground water for irrigation production by using pump system.

The farmers in study area apply much water on their farm from their limited supply that even does not correspond with the water required by the crops. Their awareness on crops yield response to water application is limited. In addition to these their knowledge on crops growth stage and associated yield reduction for water stress is not advanced. This unwise use of irrigation water causes low crop water productivity and high production cost in the area. The problems are evolved from shortage of research and awareness on irrigation water productivity based on local climate, soil type and irrigation systems. Hence, before extension of this irrigation water management system (deficit irrigation) in the study area it is a need to investigate its impact on crop yield and water productivity and providing practical recommendations to farmers and extension workers under various conditions of crop management system. Most farmers in study area produce cereals and vegetable crops as major production. Among the vegetable crops Onion is cultivated by most farmers and it is selected to evaluate deficit irrigation in the study area.

1.3 Objectives:

1.3.1 General objective:

- The main objective of this study is to investigate the effect of deficit irrigation on water productivity and yield response of onion in Mareko woreda Ethiopia.

1.3.2 Specific objectives:

- To investigate the sensitive growth stages of onion for water deficit
- To determine the water requirement of onion for deficit irrigation in the study area
- To examine crop water productivity under different deficit irrigation levels
- To make recommendations for practical application by farmers

1.4 Research questions:

In this research the following scientific questions will be answered:

- What irrigation practices and systems can significantly improve irrigation water productivity in the study area?
- In which growth stage of onion significant yield reduction observed due to water stress?
- What level of water deficit and onion growth stage combination can increase net income of the farmer in the study area?

2. Literature review

2.1 Sustainable Water Management in Agriculture

Water is considered as the most critical resource for sustainable agricultural development worldwide and the major agricultural use of water is for irrigation, which, thus, is affected by decreased supply. The sustainable use of irrigation water is a priority for agriculture in arid areas. At present and more so in the future, irrigated agriculture will take place under water scarcity and insufficient water supply for irrigation will be the norm rather than the exception (Fereres and Soriano, 2007). Agricultural water management technologies have been identified as important tools to mitigate adverse effects of climatic variability and to reduce poverty. Huge resources are being allocated to develop and promote diverse low-cost water technologies in many developing countries including Ethiopia (Hagos et al, 2012).

Sustainable water management in agriculture can be achieved by reduction of water losses, improving the efficiency of irrigation system used, adoption of innovative irrigation techniques such as deficit irrigation (Chartzoulakis and Bertaki, 2015). Well-targeted, local interventions in water can contribute to rapid improvements in livelihoods of the rural poor in Sub-Saharan Africa and help attain the Millennium Development Goals of eradicating extreme poverty and hunger (FAO, 2008). Deficit irrigation is one of agricultural water management method for improved water productivity and irrigation efficiency.

2.2 Determination of Crop Water Requirement (CWR)

According to Allen et al. (1998) 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 soil condition, soil water and fertility achieving full production potential under given growing environment. This water loss (CWR) from a given cropped plot of land can be determined from the knowledge of reference evapotranspiration (ETo) and crop coefficient (Kc). Estimates of reference evapotranspiration (ETo) are widely used in irrigation engineering to determine crop water requirements. These estimates are used in the planning process for irrigation schemes to be developed as well as to manage water distribution in existing schemes.

Numerous equations, classified as temperature-based, radiation-based, pan evaporation-based and combination-type, have been developed for estimating reference evapotranspiration (ETo). Temperature is probably the easiest, most widely available and most reliable climate parameter. The assumption that temperature is an indicator of the evaporative power of the atmosphere is the basis for temperature-based methods. The Food and Agriculture Organization (FAO) recommends the use of the FAO Penman-Monteith (FAO-PM) equation for estimating reference evapotranspiration (ETo) (Allen et al., 1998, 2006). This method is the most widely used in the world, can be considered as a sort of standard and has been proven to accurately estimate ETo in different climates (Allen et al., 1998; Walter et al., 2000).E

According to Doorenbos and Pruitt (1977) crop coefficient used for estimating CWR for specific crops by determining potential or reference (ETo) must be derived empirically for local crop based on local climatic conditions. Allen, (1998) stated that the crop coefficient(kc) for any period of the season can be derived by assuming that, during the initial and mid- season stage, Kc is constant and equal to the Kc value of the growth stage under consideration. FAO (2010) however reported that for optimum yield, onion requires 350 to 550 mm water. Experiments done in Ethiopia by Dirirsa et al. (2015) showed that for optimum yield seasonal CWR of onion was 469 mm (48, 142, 177, 102 at initial, development, mid and maturity stages respectively). Similarly Tsegaye et al. (2015) determined that for fully irrigated treatment the seasonal crop water requirement was 421.1mm.

2.3 The Concept of Deficit Irrigation

2.3.1 Conceptual meaning of deficit irrigation

Water is becoming scarce, both in quantity and quality, not only in traditionally prone arid and semiarid zones, but also in regions where rainfall is abundant. Scarce water resources and growing competition for water will reduce its availability for irrigation. Many researchers gave conceptual meaning for deficit irrigation. Capra et al. (2008) define it as the application of irrigation rates below the full crop evapotranspiration (ET), is potentially able to improve efficiency and maximize profits through a reduction in capital and operating costs.

Fereres and Soriano (2007) stated that deficit irrigation, by reducing irrigation water use, can aid in coping with situations where supply is restricted. Deficit irrigation is a plan and irrigation water management strategy which allows a crop to sustain some degree of water stress in order to minimize irrigation costs without significant yield reduction and potentially increase benefits. It is one way of maximizing water use efficiency for higher yields per unit of irrigation water applied: the crop is exposed to a certain level of water stress either during a particular period or throughout the whole growing season.

According to FAO (2002), the main objective of deficit irrigation is to increase the WP of a crop by eliminating irrigations that have little impact on yield. The resulting yield reduction may be small compared with the benefits gained through diverting the saved water to irrigate other crops for which water would normally be insufficient under traditional irrigation practices. In principle, deficit irrigation is practiced to maximize profits where water costs are high or there is water shortage. In this case, crop values are associated closely with yield, and crop grade and marketability. Under these circumstances, deficit irrigation can be a practical choice for growers (English and Raja, 1996).

2.3.2 Water productivity and deficit irrigation

Water productivity is the ratio of the net benefits from crop, forestry, fishery, livestock and mixed agricultural systems to the amount of water used to produce those benefits (Molden, 2010). In its broadest sense, it reflects the objectives of producing more food, income, livelihood and ecological benefits at less social and environmental cost per unit of water consumed. According to Kijne et al. (2003), when water supplies are limiting, the ultimate goal should be to maximize net income per unit water used rather than per land unit.

Recently, investigations have been put on the concept of WP, defined here either as the yield or net income per unit of water used. Molden (2010) also defined water productivity in two ways: physical and economical. Physical water productivity is defined as the ratio of agricultural output to the amount of water consumed ‘‘more crop per drop’’ and economic water productivity is defined as the value derived per unit of water used and this has also been used to relate water use in agriculture to nutrition, jobs, welfare and the environment.

Several strategies for enhancement of WP by integrating varietal improvement and better resources management at plant level, field level and agro-climatic level. Examples of options and practices that can be taken are: increasing the harvest index, improving drought and salinity tolerance, applying deficit irrigation water reuse (Kijne et al. (2003). Water productivity is maximized under deficit irrigation, relative to its value under full irrigation. There are several reasons for the increase in water productivity under deficit irrigation. Small irrigation depths increase crop ET, more or less linearly up to a point where the relationship becomes curvilinear because part of the water applied is not used in ET and is lost. At one point yield reaches its maximum value and additional depths of irrigation do not increase it any further.

Many irrigation experiments involving different irrigation levels have also shown that deficit irrigation usually has higher WP than full irrigation. For example, two-thirds of full irrigation increased WP by 19–28% for wheat and 8% for maize (Kijne et al,2003).They also concluded that deficit irrigation leads to higher productivity of the water (rainfall and irrigation) than can be attained with full irrigation and can, therefore, be used for improving the productivity of water in semi-arid areas.

2.3.3 Yield response of crops to deficit irrigation

FAO addressed the relationship between crop yield and water use in the late seventies proposing a simple equation where relative yield reduction is related to the corresponding relative reduction in evapotranspiration (ET). Many literature reviews relate yield responses of major field crops to deficit irrigation. The yield response factor (Ky) captures the essence of the complex linkages between production and water use by a crop, where many biological, physical and chemical processes are involved (Steduto et al, 2012).

Crop yields obtained under various levels of reduced crop water requirement were fitted to linear crop yield response functions (Garcia-Vila et al., 2009). The crop yield response factor gives an indication of whether the crop is tolerant of water stress. A response factor greater than unity indicates that the expected relative yield decrease for a given evapotranspiration deficit is proportionately greater than the relative decrease in evapotranspiration (Steduto et al, 2012).

The grower must have prior knowledge of crop yield responses to deficit irrigation. Experiment was carried out on yield responses of major field crops to deficit irrigation, including cotton, maize, potato, sugar cane, soybean and wheat. Results show that cotton, maize, wheat, sunflower, sugar beet and potato are well suited to deficit irrigation practices, with reduced evapotranspiration imposed throughout the growing season (FAO, 2002). The above ground biomass of teff showed highly significant difference with the different levels of moisture. The water deficit at the initial stage and late season stage for both 75% and 50% deficit of CWR, gave non-significant different yields from the optimum application (100%). However, for all levels of water deficit at the mid season stage and 50% and 75% deficits throughout the growth stages the yields were significantly different as compared to 0% deficit (Yenesew, 2015).

Experiment on maize by Elias et al. (2014) showed that maximum grain yield was obtained due to stressing only at initial. Moisture stress at mid-season should be avoided especially when combined with moisture stress at development stage. Moreover, moisture stress at initial and late seasons enhance water use efficiency without significantly reducing the yield from the higher yielding treatments. Yield depends also on harvest index (HI) and the impact of water stresses on HI can be pronounced, depending on the timing and extent of stress during the crop cycle (Steduto et al., 2012). HI for root and tuber crops usually much higher. The range from 0.7 to 0.8 being common for high-yielding cultivars of potato, sweet potato, and sugar beet, presumably because strong stems are not required to support the harvestable product.

2.4. Deficit Irrigation Management

Deficit irrigation requires more control over the amount and timing of water application than full irrigation practice. The proper application of deficit irrigation practices can generate significant savings in irrigation water allocation. Among field crops, groundnut, soybean, common bean and sugar cane show proportionately less yield reduction than the relative evapotraspiration deficit imposed at certain growth stages (FAO, 2002). As it was argued by Kang et al. (2000) deficit irrigation practices differ from traditional water supplying practices in that the manager needs to know the level of transpiration deficiency allowable without significant reduction in crop yield.

The other way of managing deficit irrigation is developing new irrigation schedule for more effective use of the limited supplies of water. Newly developed irrigation scheduling approach, not necessarily based on full crop water requirement, but even designed to ensure the optional use of allocated water (Kirda, 2002). Research conducted by Yenesew and Tilahun , (2009) showed that the proper application of deficit irrigation practices can generate significant savings in irrigation water allocation and full water requirement during the first two stages of maize is not advisable if water shortage cannot be avoided during the remaining of the season especially during the mid season stage. English et al. (1990) stated that under deficit irrigation practices, agronomic practices may require modification, e.g. decrease plant population, apply less fertilizer, adopt flexible planting dates, and select shorter-season varieties.

2.5 Merits and Demerits of Deficit Irrigation

Reaching to higher irrigation efficiencies proportional to best yield, is one of the major challenges at near future which is impossible without using the techniques and approaches in which the consumption of water is reduced. In this respect, deficit irrigation plays an important role in increasing of water use efficiency (Malekian et al, 2009). The most important aim of deficit irrigation is reduction of water consumption by plant, so that the water deficiency stress can have the minimum effect on its yield. The main advantage of deficit irrigation is able to produce crop yield in water scarce area and increase productivity of water. In areas where water is the limiting factor for crop production, maximizing water productivity by deficit irrigation is often economically more profitable for the farmer than maximizing yield.

According to FAO (2002) deficit irrigation, where properly practiced, may increase crop quality. For example, the protein content and baking quality of wheat, the length and strength of cotton fibers, and the sucrose concentration of sugar beet and grape all increase under deficit irrigation. Moreover, irrigated yields can be stabilized at a particular level, guaranteeing a stable income for the farmer and allowing economic planning. In addition to this deficit irrigation creates a less humid environment around the crop than full irrigation, decreasing the risk of fungal diseases (Nigus, 2011).

However, deficit irrigation also causes a number of difficulties. The use of deficit irrigation requires crop yield response to drought stress should be studied carefully. Kirda and Kanber (1999) also stated that before implementing a deficit irrigation practice, it is necessary to know crop yield responses to water stress, either during defined growth stages or throughout the whole season. On the other hand according to Geerts et al. (2008) determining optimal timing of irrigation applications is particularly difficult for crops with CWP functions in which maximal water productivity is found within a small optimum range of ET; irrigators should have unrestricted access to irrigation water during sensitive growth stages.

2.6 Developing Deficit Irrigation Schedule

Irrigation schedule describes" when" and "how much amount of water" to irrigate. Precise scheduling of irrigation water applications used to resource conservation; protect the environment and increase water productivity. Irrigation scheduling also adapted for more effective use of the limited supplies of water. FAO (2002) stated that Deficit irrigation scheduling is one way of maximizing water use efficiency for higher yields per unit of irrigation water applied; the crop is exposed to a certain level of water stress either during a particular period or throughout the whole growing period. Kirda (2002) discussed that irrigation scheduling based on deficit irrigation requires careful evaluation to ensure enhanced efficiency of use of increasingly scarce supplies of irrigation water. It is necessary to develop new irrigation scheduling approaches, not necessarily based on full crop water requirement, but even designed to ensure the optional use of allocated water (FAO, 2002).

Irrigation scheduling has to be done based on the soil characteristics of the experimental site. English et al. (1990) stated that in order to ensure successful deficit irrigation, it is necessary to consider the water retention capacity of the soil. In sandy soils, plants may undergo water stress quickly under deficit irrigation, whereas plants in deep soils of fine texture may have ample time to adjust to low soil water matric pressure, and may remain unaffected by low soil water content. So, success with deficit irrigation is more probable in finely textured soils.

2.7 Yield Response of Onion to Deficit Irrigation

Onion is a cool season crop that has frost tolerant and best adapted to temperatures between 13°C and 24°C. Different levels of irrigation water application have effect on yield and water productivity of onion. Experiment by Samson and Tilahun (2007) showed water stress at two growth stages of onion have positive effect. Result of study by Ramalan et al. (2010) show that imposing irrigation deficit levels beyond 50% is not advisable as marketable bulb yield and bulb sizes decline. In addition to this combining irrigation deficit with use of mulch covers, particularly straw mulch that is in abundance with farmers, presents a sustainable strategy for onion production in the semi-arid areas of Ethiopia. According to Enciso et al. (2009) yields of onion were not affected when water applications reduced from 100% to 75% of ETc treatments probably because similar water levels were maintained during most of the season in the two years of the study. When water stress is imposed early in the growing season; high yields of onion could easily be sustained provided adequate watering conditions take place during the rest of the growing season (Samson, 2006).

On the other hand, Nigatu (2008) concluded no significant improvement in irrigation water use efficiency resulting from irrigation deficit. Under conditions of water shortage, the best growth stages at which to achieve maximum water savings in the irrigation of onion without yield reductions exceeding 31% are development (bulb formation) and maturity stages at which 50% of water requirement is applied.

3. Materials and Methods

3.1 Description of the Study Area

3.1.1 Location

The experiment was conducted at Mareko woreda (district) in Gurage zone, southern Ethiopia. Mareko woreda is one of the thirteen woredas' that located in the Gurage zone and the capital of the woreda (Koshe) is located 27 km east of Butajira and 140 km north of Hawassa, on Addis ababa Ziway Butajira road. The altitude of the woreda ranges from 1800 to 2076 m.a.s.l. The experimental site is located at 8.02° N latitude and 38.51°E longitude (Mareko woreda Agricultural department, 2016).

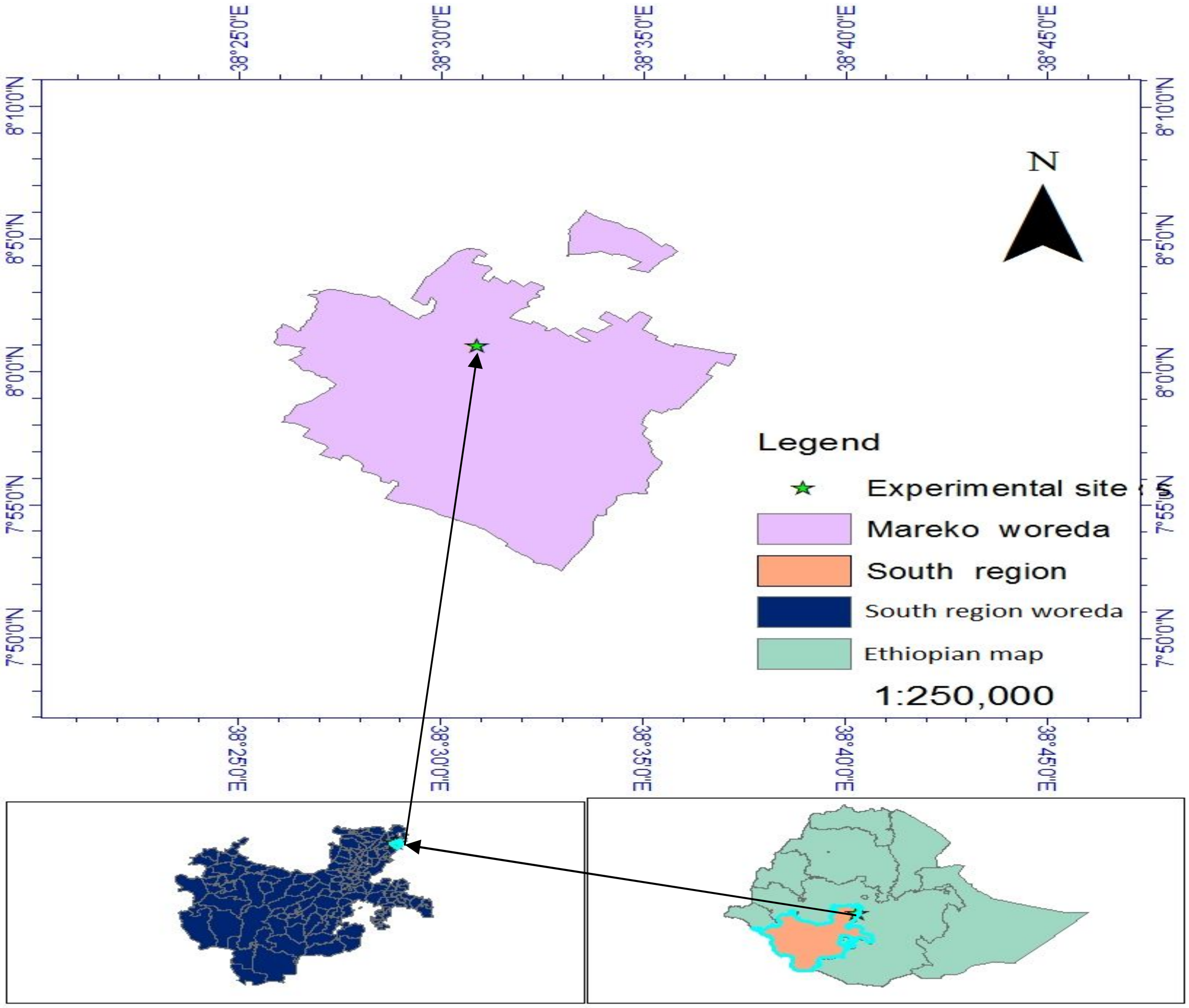

Figure 3.1: Location map of the study area

3.1.2 Climate

The data computed from 2000 to 2015 shows that the annual rainfall of the study area ranges from 500 to 800 mm and seasonal rainfall pattern at the experimental area varying in depth. There is summer rain, normally called summer, which falls between June and September and followed by the winter hot and long dry period from October to March. The mean annual temperature ranges from a minimum of 11.8°C to a maximum of 27.4°C. The experimental site is in the semiarid climate with mean relative humidity of 69% and average sunshine hour of 10.1hrs.

3.1.3 Soil and agronomic practices

The data obtained from Mareko woreda agricultural department indicated that the soil of the experimental area is dominated by red and gray color. The soil laboratory result shown that the soil texture of the experimental area is loam soil and it could be described based on the texture analysis of the soil (USDA, 1999). 87.75% of people in the study area is farmers mainly cultivate tomato (Lycopersicon esculentu L.), onion (Allium cepa L.) and, pepper (piper nigrum), from vegetables and maize (Zea may) and wheat from cereals. They have long term experience especially in the production of onion and tomato by irrigation using surface and ground water. However, their knowledge on crop based optimization of irrigation water and other related water saving techniques are not satisfactory.

3.2 Methods

3.2.1 Treatments and Experimental Design

Different depth of irrigation water amount and growth stages of onion was used as experimental unit. Water productivity and yield response of onion were determined for these different depths of irrigation water application. The sensitivity of each growing stages of onion to different levels of water stress and the significance of yield reduced also investigated.

Table 3.1: Treatment setting

Trt	Growth stages S1	S2	S3	S4	Explanation: The 100% is full CWR.
T1	100%	100%	100%	100%	0%deficit throughout the growing season
T2	75%	75%	75%	75%	25%deficit throughout the growing season
T3	50%	50%	50%	50%	50%deficit throughout the growing season
T4	75%	100%	100%	100%	25% deficit at initial stage
T5	100%	75%	100%	100%	25% deficit at development stage
T6	100%	100%	75%	100%	25% deficit at mid stage
T7	100%	100%	100%	75%	25% deficit at late stage
T8	50%	100%	100%	100%	50% deficit at initial stage
T9	100%	50%	100%	100%	50% deficit at development stage
T10	100%	100%	50%	100%	50% deficit at mid stage
T11	100%	100%	100%	50%	50% deficit at late stage

NB: T1-T11= denotes 11 different treatment, S1-S4= four growth stages,

The crop growing period of onion divided into four major growth stages: initial stage (S1), development stage (S2), mid season stage (S3) and late season stage (S4). Eleven treatments: full crop water requirement (0% deficit as a control), 25% and 50% of CWR deficit throughout growing season and one growth stage deficit (25% and 50% of CWR deficit) treatments at four different growing stages of onion were used. Three levels of irrigation water depth throughout the growing season (0%, 25% and 50% of CWR deficit) plus two deficit level (25% and 50% of CWR deficit) at four different growth stages a total of 11 treatments were formed. Each treatment had three replications (blocks) made a total of 33 experimental plots that was arranged in a randomized complete block design (RCBD). Each plot had 8 m^2 (2.0 m x 4.0 m) area. The space between plots and blocks were 1 m and 1.5 m respectively. As per the recommendation of Agricultural research centers, the spacing between onion plants and rows kept at 10 cm and 20 cm respectively. Each plot had10 rows of onion plants and 40 plants in each row with a total plant population of 400 in each plot .The experimental site total area was 15 m*32 m = 480 m^2.

3.2.2 Field layout

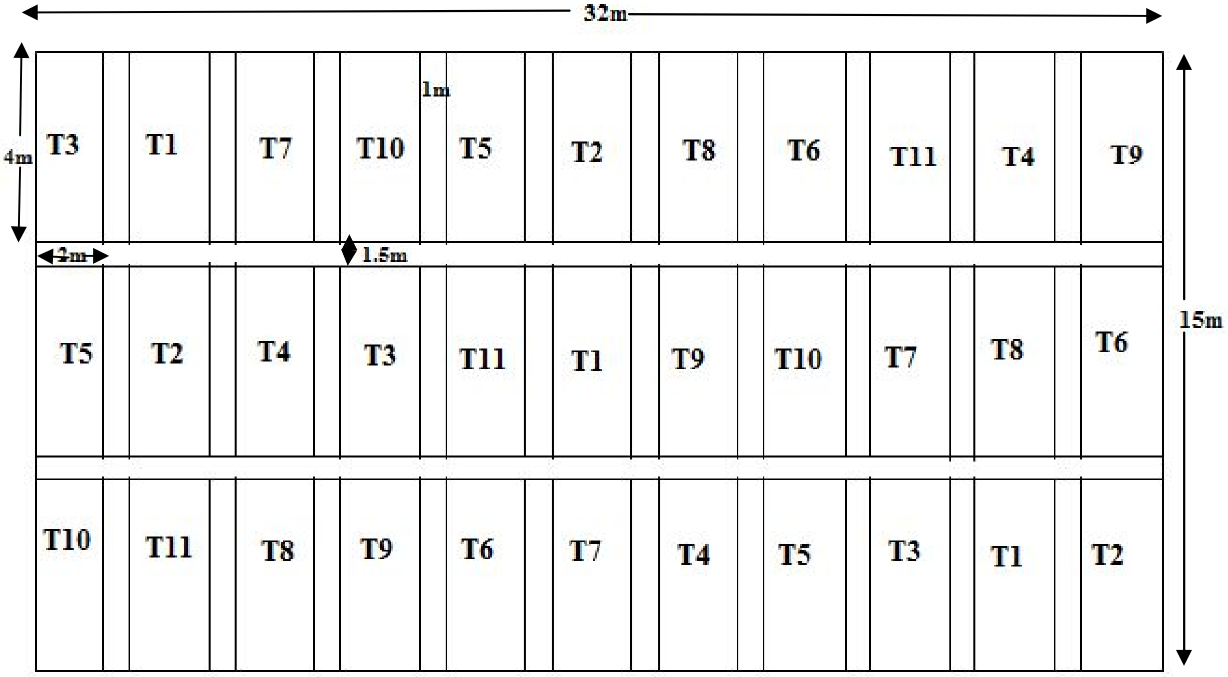

Figure 3.2: Field layout

3.3 Soil data collection

3.3.1 Soil sampling and analysis

Soil samples were taken at depths of 0-30 and 30-60 cm, since the root depth of onion grows up to 50cm (Al Naber, 2009). Soil sample was collected from experimental field diagonally to avoid bias in the sampling and it was taken just before starting of field preparation. Physical and chemical properties of the soil were analyzed. Disturbed mixture of soil samples were taken using auger for the analysis of soil moisture, texture, pH, EC and OM. The analysis was carried out at SNNPR agricultural department soil laboratory section.

Soil textural class was analyzed by using hydrometric method from collected soil samples for each depth. The weighted soil samples were sifted through screen and the soil particles that have diameter less than 2mm were used for textural class determination. The textural class was determined using USDA textural triangle procedure. A soil has acidic, neutral or basic (alkaline) character. High level of acidity and alkalinity affects plant growth. The level of acidity or alkalinity of the soil is stated by the soil pH and it was measured by pH meter. Low quality of irrigation water affects the soil property and retard plan growth. Soil to water ratio of 1:5 extract was used to determine electrical conductivity of the soil using calibrated cell electrode and expressed as dS/m based on the methods developed by the United State Salinity Laboratory Staff. The sampled soils were mixed with water and shake for one minute then left it for 30 minutes finally the resistance of the solution was recorded and converted to electrical conductivity.

The initial soil moisture content was determined before transplanting of the seedling. For determining the initial soil moisture content on a mass basis, the weight of collected sample soil was measured before and after oven dried, an. Gravimetric water content was calculated as follows:

$$GWC = \frac{weight\ of\ wet\ soil(gm) - weght\ of\ dry\ soil(gm)}{weight\ of\ dry\ soil\ (gm)} * 100 \tag{3.1}$$

Where: GWC is soil moisture content on dry weight basis (%)

Water content on volume basis was calculated as:

$$\theta v = GWC(\%) * BD(g/\text{cm}^3) \tag{3.2}$$

BD= Soil bulk density

Bulk density is an indicator of soil compaction. It is calculated as the dry weight of soil divided by its volume. This volume includes the volume of soil particles and the volume of pores among soil particles. Bulk density is typically expressed in g/cm^3. It was determined using undisturbed soil samples collected by using core sampler from 0-30 and 30-60 cm soil depths.

$$BD = \frac{Weight\ of\ dry\ soil(gm)}{Volume\ of\ the\ same\ soil(\text{cm}^3)} \tag{3.3}$$

BD= bulk density

The water content of the soil at field capacity and permanent wilting point were determined in the laboratory by using a pressure plate apparatus. The pressure plate was adjusted to 0.33bar to determine field capacity and 15bar to determine permanent wilting point to a saturated soil sample. After continues application of the pressure, water is no longer removed from the soil sample. Then the water contents were determined by gravimetric method. The soil analysis was carried out at Ethiopian Construction Design

Supervision Works Corporation (ECDSWC) Addis Ababa. Total available Water (TAW) in the root zone was computed as the difference in moisture content between FC and PWP. It is computed as follows:

$$TAW = \frac{(FC-PWP)*Dr}{100} \tag{3.4}$$

Where: TAW= total available water (cm), Fc = Water content at filed capacity (%).
pwp = Water content at permanent willing point (%) and Dr = effective depth of root zone (cm)

Readily available water is the portion of the total available water (FC – PWP) which is most easily extracted by the plant roots without creating stress. The water content approaching PWP cannot be easily extracted by the plant roots. Therefore, only part of the TASW is used before the next irrigation. The term Maximum/management Allowable Deficiency, MAD, can be used to compute the amount of water that can be used without adversely affecting the plants and can be expressed as a fraction of the TASW. This value varies with the crop type and could be obtained experimentally. Once the MAD is known, it is possible to compute the net irrigation water requirement, IRn, necessary to restore the main root-zone, Rz, to FC). The factor MAD or p is differs from crop to crop. It is about 0.30 for shallow rooted plants e.g onion (Allen et al., 1998).

3.3.2 Soil Infiltration

The infiltration rate of the soil in the experimental field was determined using double ring infiltrometer method before the staring of the experiment. The double ring infiltrometer was set up in the field surface and measured the depth of water levels infiltrated for 128 minutes continuously and the rate at which water level lowered was calculated. The observed data was fitted with two different infiltration models (L-K and Horton models) to determine the relationships.

Figure 3.3: Soil infiltration measurement

Figure 3.4: Soil sampling

3.4 Determination of Crop Water Requirement

Determinaton of water required (CWR) to compensate the amount of water lost through evapotranspiration (ETc), requires climatic and crop input data. Crop water reqiurment or ETc over the growing season was calculated from reference evapotranspiration (ETo) and crop coefficient (Kc) for that stage:

$$ETc = kc * ETo \tag{3.5}$$

Where, ETc= crop water requirement (mm), kc=crop coefficient, ETo= reference evapotranspairation (mm)

3.4.1 Climatic input data

The climatic data required for determination of ETo includes location i.e. altitude, latitude and longitude and sixteen years (2000-2015) of monthly values of maximum and minimum air temperature, were received from Ethiopia National Metrological Agency Hawassa branch. The station of the received input climatic data and the experimental area has 114m altitude difference. Hence, to get the appropriate temperature data of the experimental area, the relationship between temperature and elevation was used.

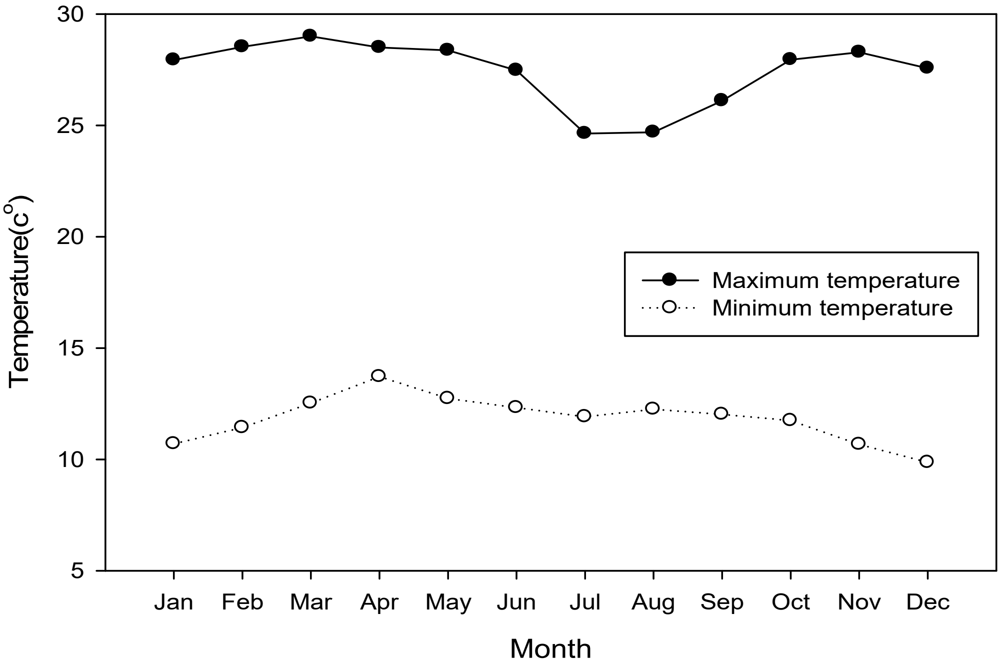

Figure 3.5: Average monthly temperature of experimental site

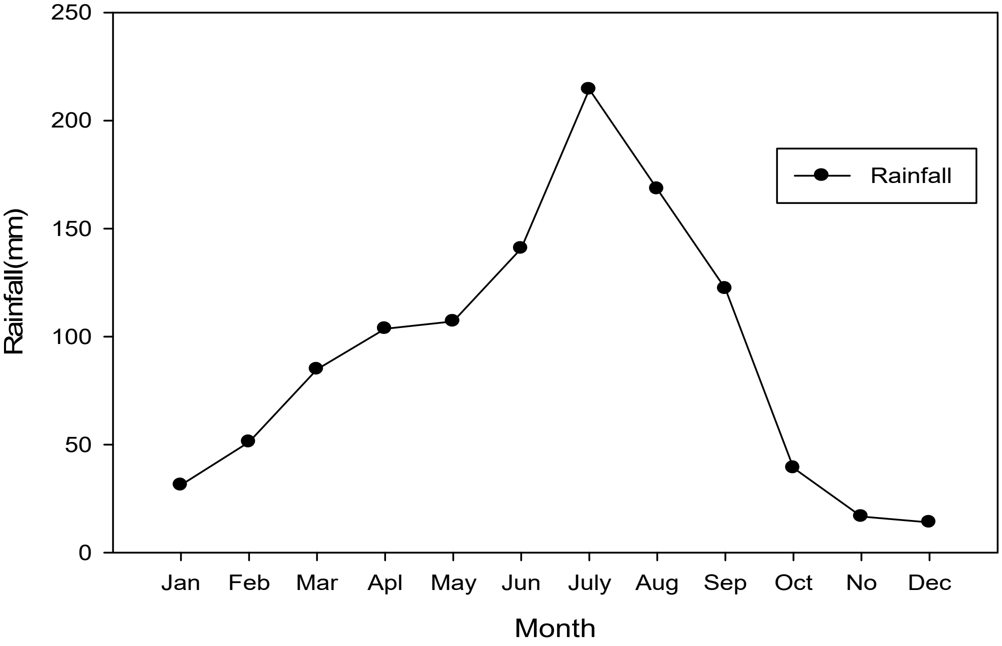

Figure 3.6 : Monthly rainfall of butajira(near by) station

3.4.2 Determination of ETo

Since the climatic data obtained was from third class station, humidity, wind speed and sun shine hours were not available and ETo was calculated based on temperature based method (reduced Penman –Monteith) by using CROPWAT soft ware. Reference evapotranspiration calculated by reduced FAO Penman-Monteith method is standard and used for determination of CWR (Allen et al., 1998).

The reduced Penman-Monteith methodology has provisions for application in data-short situations (Allen et al. 1998), including the use of temperature data alone. The reduced set of Penman-Monteith equation requiring only the measured maximum and minimum temperatures uses estimates of solar radiation, relative humidity, and wind speed. Solar radiation can be estimated using averages from nearby stations. Relative humidity can be estimated by assuming that the dew point temperature is approximately equal to Tmin (Allen1996; Allen et al. 1998) which is usually experienced at sunrise. In this case, ea can be calculated as:

$$ea = e^{o}(T\min) = 0.611\exp\left(\frac{17.27T\min}{T\min + 237.3}\right) \tag{3.6}$$

Where: e^{o} (Tmin) is the vapour pressure at the minimum temperature. For wind speed, Allen et al. (1998) recommend using average wind speed data from nearby locations or using a wind speed of 2 m/s, since the impact of wind speed on the ETo result is relatively small, except in windy areas.

3.4.3 Crop input data

Crop coefficient given by Allen et al. (1998) for onion was 0.7 for the initial stage, $0.7<Kc<1.05$ for the crop development stage, 1.05 for the mid-season stage and $0.75<Kc<1.05$ for the late season stage. Crop data required for determination of crop water requirement are presented in table 3.2.

Table 3.2: Crop data required for CWR determination.

	Growth stage				
Crop data	Initial	Dev.t	Mid	Late	Total
Length of growing season(days)	20	30	30	15	95
Crop coefficient(kc)	0.7		1.05	0.95	
Rooting depth(m)	0.3		0.6	0.6	
Depletion level(p)	0.3		0.45	0.5	
Yield response(ky)	0.8	0.4	1.2	1	

Source: FAO 56(Allen et.al, 1998)

3.4.4 Irrigation Requirement

The net irrigation requirement was calculated using the CROPWAT computer program based on Allen et al. (1998) as follows:

$$IR = ETc - pe \qquad (3.7)$$

Where, IR =Irrigation requirement (mm), ETc in mm and Pe = effective rainfall (mm) which is part of the rainfall that enters into the soil and makes available for crop production. The effective rainfall (pe) is estimated using the method given by (Allen et al., 1998) as.

$Pe = (P\,(125 - 0.2*P))/125$ for $P <= 250$ mm

$Pe = 125 + 0.1*P$ for $P > 250$ mm

Where: Pe (mm) = effective rainfall and P (mm) = total rainfall.

However, since there was no rainfall during the experimental period, pe is equal to zero and net irrigation requirement was taken as equal to the crop water requirement.

3.5 Irrigation Scheduling

Irrigation scheduling is the most important means for application of best management practices in irrigated agriculture. In this experiment irrigation scheduling for onion was developed based on collected climatic data, soil data and FAO publications by using CROPWAT software. The textural class of the soil at experimental site was loam soil. Loam soil has medium water infiltration characteristics. The calculated crop water requirement was irrigated in five days interval based on the crop need. Water was applied in known volume of watering can by converting the crop water requirement in depth to volume. Volume of applied water calculated as follows:

$$V = 1000 * A * d \tag{3.8}$$

Where: d = depth of application (m), V = volume of water (lit), A = plot area (m^2)

3.6 Field Data Collection and Analysis

3.6.1 Crop parameters and measurements

The Field data such as, onion yield, above ground biomass, leaf length and width and population density per plot were recorded. Above ground biomass, leaf length and width were taken from each plot at the end of each growth stages. The data were taken by random selection of fifteen (15) plants from six central rows on each plot by excluding the border rows and border plants. At the end of the season the amount of bulb yield produced was harvested and weighted from each plot. The harvested yield was grouped based on its quality for market according to the size and degree of damage. Lemma and Shimels (2003) stated that onion bulb with less than 2 cm diameter was categorized under nonmarketable yield.

3.6.2 Canopy cover

Leaf length (L) and leaf width (W) in cm of plants from each plot was measured manually using ruler at the end of each growing stages. The total leaf area index (LAI) in cm^2 for onion leaves were therefore obtained with the relationship given by Kang et al. (2003).

$$LAI = 0.75 * \rho * \left(\frac{\sum_{i=1}^{m}\sum_{i=1}^{n}(Lij * Wij)}{m}\right) \tag{3.9}$$

Where, ρ is plant density, m is the number of measured plants, L_{ij} is leaf length, W_{ij} is the maximum leaf width and n is the number of leaves of the n^{th} plant. Canopy cover was estimated from leaf area index based on the formula given by Hsiao et al. (2009).

$$CC = 1 - \mathrm{EXP}^{(-0.65 * LAI)} \tag{3.10}$$

where, CC is canopy cover (%), and LAI is the leaf area index

3.6.3 Harvest index (HI)

Yield depends on harvest index (HI) and the impact of water stresses on HI can be pronounced, depending on the timing and extent of stress during the crop cycle (Steduto et al., 2012). HI for root and tuber crops usually much higher. The range from 0.7 to 0.8 being common for high-yielding cultivars of potato, sweet potato, and sugar beet, presumably because strong stems are not required to support the harvestable product. In this experiment yield was measured by harvesting onion on each plot distinctively and weighing them separately. Effects of water stress on HI can be negative or positive (Steduto et al., 2012). The harvest index was estimated using the equation;

$$HI = \frac{\text{Yield(t/ha)}}{\text{Biomass(t/ha)}} \qquad (3.11)$$

3.6.4 Yield response factor

Fereres and Soriano (2007) stated that when water deficit occurs during a specific crop development period, the yield response can vary depending on crop sensitivity at that growth stage. The degree of sensitivity also varies with amount of water deficit and with crop type. Therefore, knowledge of crop response factor for water deficit and time of irrigation is a tool for scheduling irrigation where a scarce supply of water is available. Although it is difficult to measure the actual evapotranspiration values during the experimental season, water applied in the total growing season for full irrigated treatment (T1), was taken as the maximum evapotranspiration (ETm), and the deficit water applications values were taken as actual evapotranspiration(ETa). A standard formulation relates four parameters (Ya, Ym, ETa and ETm) to a fifth: Ky, the yield response factor as follows.

$$ky = \frac{(1 - \frac{ya}{ym})}{(1 - \frac{ETa}{ETM})} \qquad (3.12)$$

where:Ya = actual yield (kg/ha),Ym = maximum yield (kg/ha),ETa = actual evapotranspiration (mm),ETm = maximum evapotranspiration (mm),Ky = yield response factor.

Ky relates relative yield decrease to relative evapotranspiration deficit. Two series of Ky values obtained from FAO data sets and from (IAEA) and (CRP) showed a wide range of variation for this parameter. $0.20 < Ky < 1.15$ (FAO, 2002), and $0.08 < Ky < 1.75$ (IAEA) (Moutonnet, 2002; Kipkorir et al., 2002). According to (Steduto et al., 2012), the Ky values are crop specific and vary over the growing season. For Ky >1, crop response is very sensitive to water deficit with proportional larger yield reductions when water use is reduced. For Ky <1, crop is more tolerant to water deficit, and recovers partially from stress, exhibiting less than proportional reductions in yield with reduced water use. For Ky =1, yield reduction is directly proportional to reduced water use.

From above equation it could be calculate Ya where the available water supply does not meet the full moisture requirements of the crop. The response of crops for water deficit is differ from crop to crop and with growing stages. Therefore, the timing of the deficit is important for scheduling the use of scarce water available.

3.7 Crop Water Productivity

Water productivity has broad interrelated and cascading definitions useful for different purposes. In crop production water productivity is defined as the ratio of the yield produced from crops to the volume of water required to produce those yield. Definitions of water productivity are varies with the background of the researcher. Kijne et al. (2003) give a number of strategies for enhancement of agricultural water productivity by integrating varietal improvement and better resource management at plant level, field level and agro climatic level.

$$CWP = \frac{Yield(kg)}{ETc(m3)} \tag{3.13}$$

ETc= Seasonal crop water requirement, CWP= Crop water productivity

Mid Stage

Late Stage

Figure 3.7: Field data collection

3.8 Economic analysis

Economic evaluation of deficit irrigation is analyzing the cost that invested during growing season and benefit gained from yield produced by application of water. Marginal Rate of Return (MRR) was used for analysis following the CYMMYT method (CIMMYT, 1988). Economic water productivity was calculated based on the information obtained at the study site: the size of irrigable area, the price of water applied and the income gained from the sale of onion yield by considering the local market price. Yield and economic data was collected to evaluate the benefits of application of different levels of water in deficit irrigation treatments. Economic data includes input cost like cost for water (water pricing), seeds, fertilizers, fuel and labor. However, cost of water pricing and yield sale price were the only cost that varies between treatments. The net income (NI) treatments were calculated by subtracting total cost (TC) from gross income (GI) and were computed as:

$$NI = GI - TC \tag{3.14}$$

The difference between net income of a treatment and its next higher variable cost treatment termed as change in net income (ΔNI). Higher net benefits may not be attractive if they require very much higher costs (CIMMYT, 1988). Hence, it is required to calculate marginal costs with the extra marginal net income. The marginal rate of return (MRR) indicates the increase of the net income, which is produced by each additional unit of expenditures and it is computed as follows:

$$MRR = \frac{\Delta NI}{\Delta VC} \tag{3.15}$$

Where, MRR= marginal rate of return

ΔNI= change in net income

ΔVC= change in variable cost

3.9 Statistical Analysis

Data was subjected to ANOVA using R statistical soft ware based on randomized complete block design. Least Significant Difference (LSD at P = 0.05) was employed to identify water depth with growth stage that were significantly different from other treatment.

Table 3.3: ANOVA

Source of variation	DF	SS	MS	F	F tab
Treatment(t)	t-1	$(\Sigma ti^2/r)$-CF	SSt/t-1	MSt/MSe	
Replication(r)	r-1	$(\Sigma ri^2/t)$-CF	SSr/r-1	MSr/MSe	
Error(e)	(t-1)(r-1)	SST-(SSt+SSr)	SSe/((t-1)(r-1))		
Total(T)	n-1	Σxi^2-CF			

NB: DF= degree freedom, SSt= sum square of treatment SSr= sum square of replication, SSe= sum square of error, MSt =mean square of treatment, MSr = mean square of replication, MSe= mean square of error, SST= sum square of total

$$LSD = t_a * \sqrt{\frac{2 * meansquareerror}{r}} \tag{3.16}$$

LSD= List significant difference, r= replication, t_a= tabulated value from table

$$CV= \frac{\sqrt{Mean\ square\ error}}{Grand\ mean} *100 \tag{3.17}$$

CV= coefficient of variation

4. Results and Discussions

4.1. Soil physical and chemical properties

4.1.1 Soil sample analysis

The experimental area soil physical and chemical properties (texture, bulk density, FC, PWP, EC, OM and pH) were analyzed. Soil samples were collected depending on the root depth of the experimental crop onion before field preparation. The analyzed soil result indicated that the average composition of sand, clay and silt percentages were 27%, 24% and 49%, respectively. Based on soil textural classification of USDA, the average percent of particle size distribution for experimental site laid under loam soil. According to USDA (2011) loam soils have medium size and moderate air and water permeability character. The average soil bulk density is 1.16g/cm^3 which is lower than the critical threshold level for medium texture soil (1.4 g/cm^3). This might be due to high organic matter contents in the experimental site. In general, the average soil bulk density (1.16 g/cm^3) was suitable for crop root growth.

Table 4.1: Characteristics of the soil in experimental area

Parameters	Soil depth(cm)		
	0-30	30-60	Average
FC (%)	32.6	31.5	32.05
PWP (%)	15.8	15.8	15.8
TAW(mm/m)	168	157	162.25
Initial soil water content (%)	4.66	6.76	5.71
EC(dS/m)	0.0947	0.0943	0.0945
OM (%)	2.9	3.64	3.27
PH	7.19	7.02	7.10
BD(gm/cm^3)	1.18	1.13	1.16
Particle size distribution			
-sand (%)	24	30	27
-clay (%)	24	24	24
-silt (%)	52	46	49
Textural class	Silt loam	Loam	Loam

Soil moisture content of the soil at field capacity showed variation with depth (32.6 % for depth of 0-30 cm and 31.5 % for depth of 30-60 cm). On the other hand moisture content of the soil at permanent wilting point showed no variation with depth and it is 15.8% for the two sampling depth .The total available water (TAW) that is the amount of water that a crop can extract from its root zone is directly related to variation in Field capacity and Permanent Wilting Point. The average value of TAW in the experimental site soil was found to be 162.25 mm/m. The average root depth of onion was 0.5m. So, for this depth TAW was equal to 81.125mm.

The average result of soil pH was 7.1 which is optimum value for crop production. The amount of soil salinity was measured by electrical conductivity of the soil (EC).The average value of the soil EC was 0.0945dS/m which is smaller than the threshold level for onion. Onion is under moderate salt tolerate crops and the moderately salt tolerant crops can withstand salt up to 4.5 dS/m (FAO, 1985). Generally USDA soil classification stated that a soil with electrical conductivity of less than 2 dS/m at 25°C and pH less than 8.5 are classified as normal soil. Hence, the soils of the experimental site are normal soil for crop production. The average organic matter content of the soil was about 3.27%.

4.1.2 Infiltration characteristics of the soil

The basic infiltration rate in this experiment was found to be 28.5mm/h. This means that a water layer of 28.5 mm on the soil surface will take one hour to infiltrate. At first, water infiltrates rapidly and as more water replaces the air in the pores, the water from the soil surface infiltrates more slowly and finally reaches basic infiltration rate. Based on USDA soil infiltration rate group, 28.5mm/hr was under moderate infiltration rate. Statistical indicators showed there is good relationship between the field observed infiltration data and simulated data with soil infiltration models (Lewis-kostiakov and Horton models). Among the two models, L-K model gave the better representation of the infiltration rate with observed data with coefficient of determination 0.98. At the start of the process, infiltration rates by the two models were smaller than the observed. As we have seen in figure 4.2, infiltration rate by Horton model attained its basic infiltration rate earlier than the observed data and L-K model. As a result the final cumulative infiltrated depth was smaller than the observed data. In this model reduction in infiltration rate with time was largely controlled by factors operating at the soil surface. The basic infiltration rate by L-K model was smaller than observed data. Experiment conducted by Girei et al. (2016) showed L-K model was best predictor than other infiltration rate models.

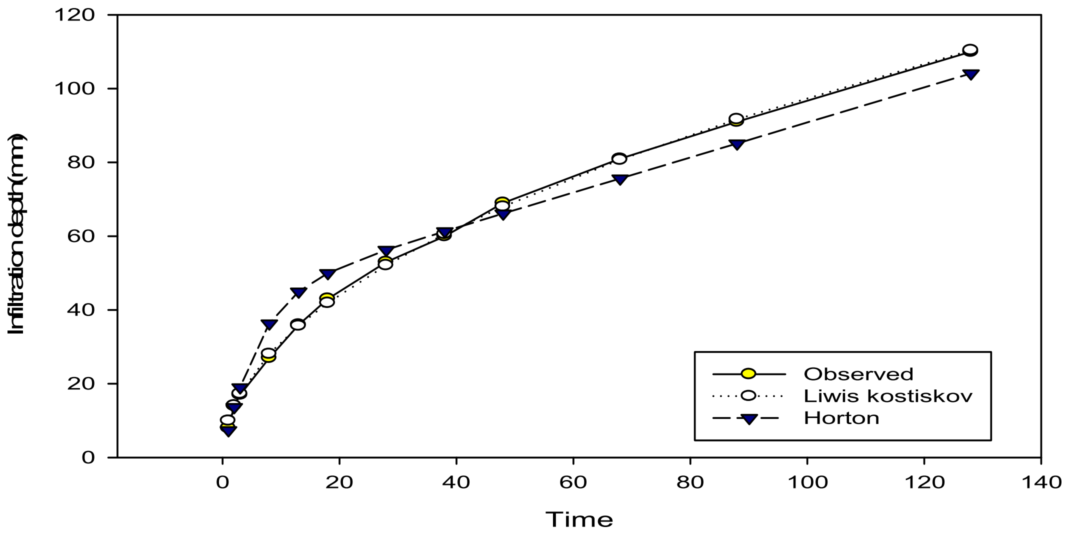

Figure 4.1: Infiltration depth

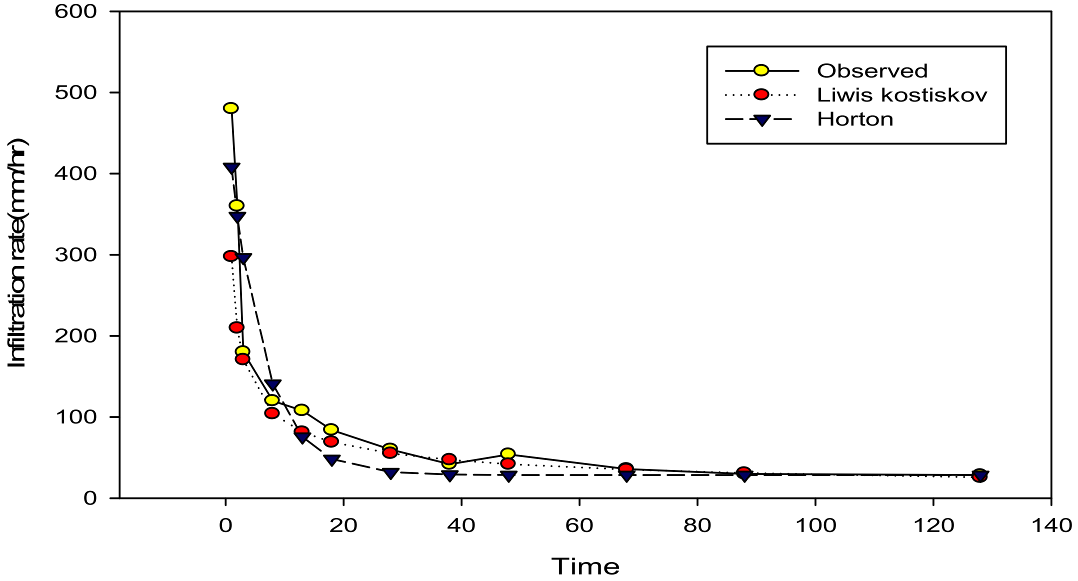

Figure 4.2: Infiltration rate

4.2 Crop Water Requirement

Reference evapotranspairation (ETo) was calculated by FAO reduced Penman-Monteith method. It was relatively high in the months from Fabruary to May and it was low in July and August at the experimental site. The maximum reference evapotranspairation was observed at March with daily average of 5.24 mm/day. The minimum ETo was observed at July and daily average was 4.29 mm/day. July is high rainfall month in experimental site. According to Itensifu et al. (2003) most of the reduced-set equations (temperature- based methods) do not explicitly account for wind speed, it is natural for the calibration slope to be influenced by this parameter.

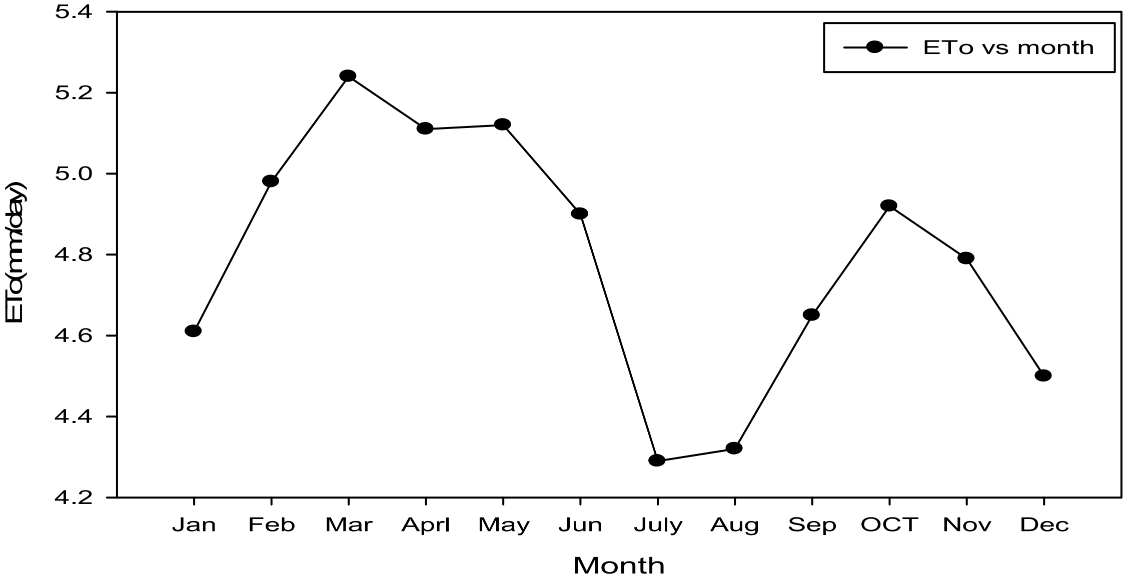

Figure 4.3: ETo of experimental site

Reference evapotranspiration of the growing season per five days (the irrigation interval) was presented in figure 4.4. It was used to calculate the crop water requirement for the days of the interval. The reference evapotransipration was increasing from the initial period to the last period. This is due to the increasing of temperature from the transplanting month (January) to April at experimental site.

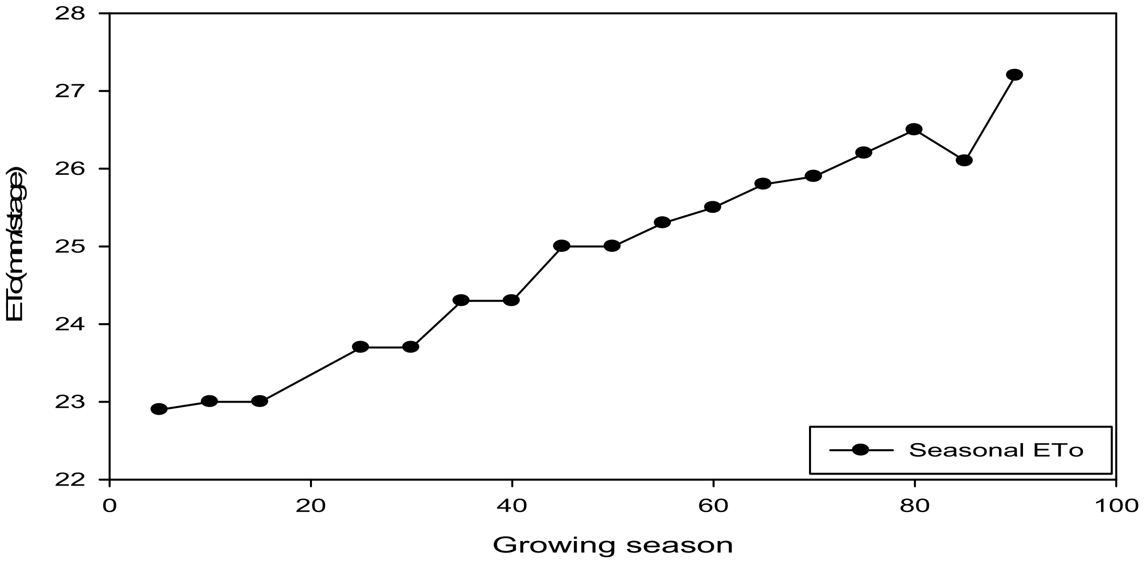

Figure 4.4: Seasonal ETo value of experimental site

Crop coefficient (kc) value was constant at initial period (0.7) and it was started to increase at development period. At mid stage it attained its maximum value (1.07) and constant until the start of the late period. At the beginning of late period the kc value started to decrease.

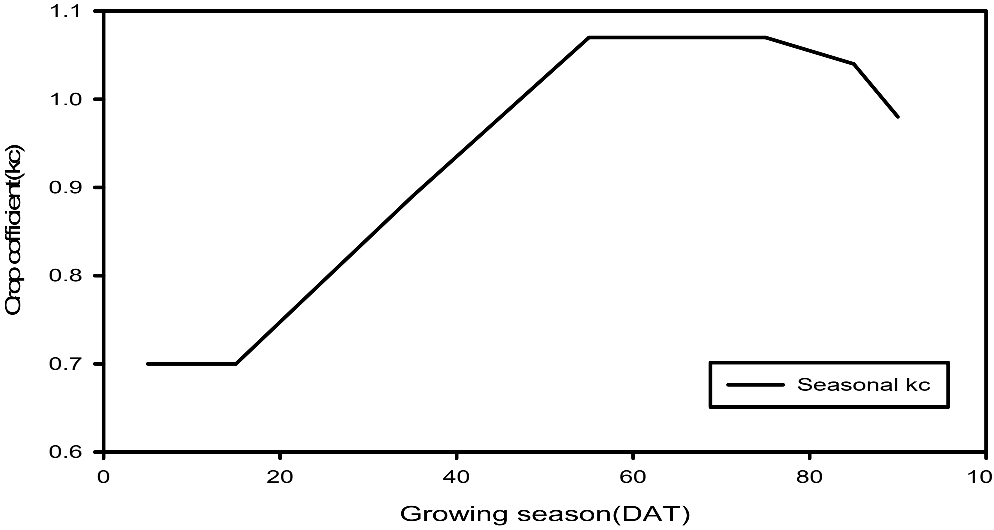

Figure 4.5: Seasonal crop cofficient value of onion

Crop water requirement was calculated for each growth stage from reference evapotranspiration and crop coefficient of that stage. Onion was planted on 02/01/2017 and the growing months were (January, February, March and April) with increasing daily reference evapotranspairation. The amount of water required by onion was increasing from the initial period to mid period. The maximum irrigation water (28mm) was required at mid March of mid stage. In this stage onion was attained its maximum crop coefficient and there was high reference evapotranspiration. At late period the water required was reduced due to reduction in crop coefficient value.

Seasonal water requirement for fully irrigated treatment was found to be 413.4 mm. This amount of irrigation water was required for full irrigation level treatment. The 310.05 and 206.7 mm seasonal irrigation water depths were determined for treatments that have 25% and 50% of CWR deficit throughout the season respectively. Water depths for one period stress treatments were the percent of the deficit from the period's full irrigation.

Since there was no rainfall in the experimental season, full crop water requirement was supplied by irrigation. As the plots were sufficiently leveled, water was applied only to refill the soil water to required level while the groundwater table was far below the root zone; deep percolation and upward flow were neglected. Surface runoff was assumed to be zero as the irrigation water was protected by constructed soil bunds around each plot. The depths of applied water for treatments other than fully irrigated treatment were taken simply as percentage of the full irrigation.

Table 4.2: Seasonal CWR for fully irrigated treatment

Date	Day	Stage	ETo/period(mm)	kc	IRn(mm)
6 Jan	5	Init	22.9	0.7	16.0
11Jan	10	Init	23	0.7	16.1
16Jan	15	Init	23	0.7	16.1
21Jan	20	Init	21.7	0.76	16.5
26Jan	25	Dev	23.7	0.76	18
31Jan	30	Dev	23.7	0.76	18
5-Feb	35	Dev	24.3	0.89	21.6
10Feb	40	Dev	24.3	0.89	21.6
15Feb	45	Dev	25	1.01	25.2
20Feb	50	Dev	25	1.01	25.2
25Feb	55	Mid	25.3	1.07	27.1
2-Mar	60	Mid	25.5	1.07	27.3
7-Mar	65	Mid	25.8	1.07	27.6
12Mar	70	Mid	25.9	1.07	27.7
17Mar	75	Mid	26.2	1.07	28
22Mar	80	Mid	26.5	1.04	27.6
27Mar	85	End	26.1	1.04	27.1
1-Apr	90	End	27.2	0.98	26.7
Total					413.4

NB: ETo = reference evapotranspiration, IRn = net irrigation requirement and kc = crop coefficient.

Table 4.3: Seasonal depth of applied water in mm for each treatment

Date	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11
6-Jan	16.0	12.0	8.0	12.0	16.0	16.0	16	8.0	16	16.0	16
11-Jan	16.1	12.1	8.1	12.1	16.1	16.1	16.1	8.1	16.1	16.1	16.1
16-Jan	16.1	12.1	8.1	12.1	16.1	16.1	16.1	8.1	16.1	16.1	16.1
21-Jan	16.5	12.4	8.3	12.4	16.5	16.5	16.5	8.3	16.5	16.5	16.5
26-Jan	18	13.5	9.0	18.0	13.5	18.0	18	18.0	9.0	18.0	18
31-Jan	18	13.5	9.0	18.0	13.5	18.0	18	18.0	9	18.0	18
5-Feb	21.6	16.2	10.8	21.6	16.2	21.6	21.6	21.6	10.8	21.6	21.6
10-Feb	21.6	16.2	10.8	21.6	16.2	21.6	21.6	21.6	10.8	21.6	21.6
15-Feb	25.2	18.9	12.6	25.2	18.9	25.2	25.2	25.2	12.6	25.2	25.2
20-Feb	25.2	18.9	12.6	25.2	18.9	25.2	25.2	25.2	12.6	25.2	25.2
25-Feb	27.1	20.3	13.6	27.1	27.1	20.3	27.1	27.1	27.1	13.6	27.1
2-Mar	27.3	20.5	13.7	27.3	27.3	20.5	27.3	27.3	27.3	13.7	27.3
7-Mar	27.6	20.7	13.8	27.6	27.6	20.7	27.6	27.6	27.6	13.8	27.6
12-Mar	27.7	20.8	13.9	27.7	27.7	20.8	27.7	27.7	27.7	13.9	27.7
17-Mar	28	21.0	14.0	28.0	28.0	21.0	28	28.0	28	14.0	28
22-Mar	27.6	20.7	13.8	27.6	27.6	20.7	27.6	27.6	27.6	13.8	27.6
27-Mar	27.1	20.3	13.6	27.1	27.1	27.1	20.3	27.1	27.1	27.1	13.6
1-Apr	26.7	20.0	13.4	26.7	26.7	26.7	20.0	26.7	26.7	26.7	13.4
Total	413.4	310.1	206.7	397.2	381.0	372.1	400.0	381.1	348.6	330.8	386.5

Table 4.4: Irrigation water depth at four growth stages in mm

Period	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11
Initial	64.7	48.5	32.4	48.5	64.7	64.7	64.7	32.4	64.7	64.7	64.7
Dev.t	129.6	97.2	64.8	129.6	97.2	129.6	129.6	129.6	64.8	129.6	129.6
Mid	165.3	124	82.7	165.3	165.3	124	165.3	165.3	165.3	82.7	165.3
Late	53.8	40.4	26.9	53.8	53.8	53.8	40.4	53.8	53.8	53.8	26.9

4.3 Response of crop parameters to water deficit

4.3.1 Canopy cover

The measured values of canopy cover calculated from leaf area index were analyzed and it indicated that differences in irrigation water depth were significantly affected canopy cover. Canopy cover measured at the end of initial growth stage (20 days after transplanting) was not significantly influenced by all treatments. T5 (25% of CWR deficit at development stage) and T9 (50% of CWR deficit at development stage) showed relatively higher canopy cover than treatments that had reduced level of water at this stage (see table 4.5). During this stage, T5 and T9 which produced 6.63% and 6.34% canopy cover respectively were received 100% of CWR. T8 (50% of CWR deficit at initial stage) and T3 (50% of CWR deficit throughout growing season) produced the smallest canopy cover which is 5.40% and 3.69% respectively. T2 (25% of CWR deficit throughout growing season) and T4 (25% of CWR deficit at initial stage) produced 5.07% and 5.69% canopy cover respectively.

Canopy cover measured at the end of development growth stage (50 days after transplanting) showed significant variation between fully irrigated treatment and half irrigated treatment. T1 received 100% of CWR and canopy cover produced was 71.0% and T3 received 50% of CWR deficit and canopy cover produced was 35.7%. Similarly canopy cover observed at mid growth stage indicated similar trend of the above stages. Treatments that received reduced water level developed low canopy cover. Generally the data obtained in different growth stages showed canopy cover was affected by water stress.

Table 4.5 Effects of water deficit on canopy cover

Initial stage			Development stage		Mid stage	
R	trt	(CC %)	trt	(CC%)	trt	(CC%)
1	T5	6.630^{a}	T1	71.099^{a}	T1	83.383^{a}
2	T9	6.342^{b}	T7	67.007^{ab}	T5	81.578^{a}
3	T1	5.947^{c}	T5	65.269^{abc}	T7	80.653^{a}
4	T10	5.849^{c}	T10	61.966^{abcd}	T9	78.294^{a}
5	T11	5.772^{c}	T4	61.054^{abcd}	T6	78.047^{a}
6	T6	5.733^{c}	T6	59.514^{abcd}	T2	74.596^{ab}
7	T7	5.723^{c}	T8	57.403^{abcd}	T11	73.634^{ab}
8	T4	5.690^{c}	T11	56.388^{bcd}	T4	72.747^{ab}
9	T8	5.400^{d}	T9	52.303^{cd}	T8	67.654^{ab}
10	T2	5.070^{e}	T2	50.382^{d}	T10	59.463^{bc}
11	T3	3.690^{f}	T3	35.736^{e}	T3	48.185^{c}
CV		2.902		14.324		14.772
MS error		0.026		69.203		114.3
$LSD_{(0.05)}$		0.277		14.168		18.257

NB: R=Rank, trt=Treatment, CC= canopy cover, T1 to T11 refers to eleven treatments

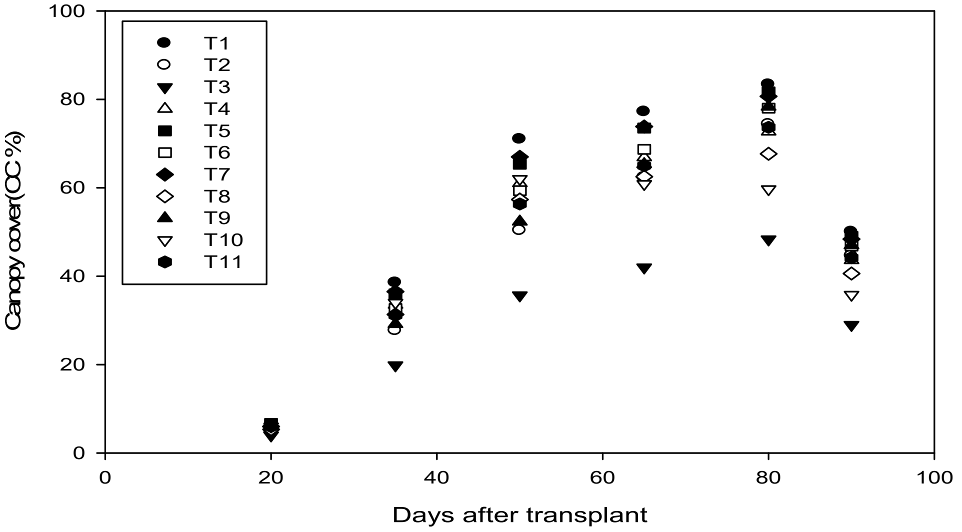

Figure 4.6: Canopy cover development

Figure 4.6 shows seasonal canopy cover status of all treatments. At the end of initial period almost all treatments had the same canopy cover status and there was small list significant difference level. T3 showed low coverage of canopy throughout the season. This is due to small number of stand count (dried because of stress) and narrow leaf area, since it received 50% of CWR deficit throughout the season. T10 (50% of CWR deficit at mid stage) came to low canopy cover at mid stage. In this period this treatment was received 50% of CWR deficit. This result in agreement with Yayra (2015) who discussed that decreasing irrigation water significantly decreases canopy cover of onion. Table 4.6 compare mean canopy cover of a control treatment (0 % deficit) and each of 10 treatments using LSD test.

Table 4.6: Comparison of canopy covers (CC %) using LSD test

Initial stage			Development stage			Mid stage		
Trt	CC	difference	Trt	CC	difference	Trt	CC	difference
T5	6.630	0.682**	T1	71.099	-	T1	83.383	-
T9	6.342	0.394**	T7	67.007	4.092^{ns}	T5	81.578	1.804^{ns}
T1	5.947	-	T5	65.269	5.830^{ns}	T7	80.653	2.729^{ns}
T10	5.849	0.097^{ns}	T10	61.966	9.132^{ns}	T9	78.294	5.089^{ns}
T11	5.772	0.174^{ns}	T4	61.054	10.045^{ns}	T6	78.047	5.336^{ns}
T6	5.733	0.214^{ns}	T6	59.514	11.585^{ns}	T2	74.596	8.787^{ns}
T7	5.723	0.223^{ns}	T8	57.403	13.695^{ns}	T11	73.634	9.749^{ns}
T4	5.690	0.256^{ns}	T11	56.388	14.711*	T4	72.747	10.636^{ns}
T8	5.400	0.546**	T9	52.303	18.795*	T8	67.654	15.728^{ns}
T2	5.070	0.876**	T2	50.382	20.716**	T10	59.463	23.919*
T3	3.690	2.256**	T3	35.736	35.363**	T3	48.185	35.197**
LSD,5%=0.278, 1%=0.379			LSD,5%=14.16, 1%=19.32			LSD,5%=18.25, 1%=24.83		

NB: Trt= treatment, ns= non significant, **= highly significant, *=significant

4.3.2 Above ground biomass

Crop biomass is responsible for yield production. Any positive or negative effect on biomass may also affect yield. The result in table 4.7 indicated that above ground biomass of onion was significantly affected by water stress at different growth stages. At the initial stage the highest above ground biomass was obtained at T7 (25% of CWR deficit at late stage) which is 0.68 t/ha and the second highest was obtained at T1 (0% deficit) which is 0.65 t/ha). Both of them were subjected to full irrigation water at this stage. In this stage the smallest biomass were observed at T8 (50% of CWR deficit at initial stage) and T3 (50% of CWR deficit throughout growing season) which are 0.53 and 0.38 t/ha respectively.

Table 4.7: Effects of water deficit on above ground biomass

Initial stage			Development stage		Mid stage		Late stage	
R	trt	(BM t/ha)	trt	(BM t/ha)	trt	(BM t/ha)	trt	BM t/ha)
1	T7	0.680^{a}	T7	6.161^{a}	T1	7.254^{a}	T1	4.857^{a}
2	T1	0.656^{ab}	T10	5.806^{a}	T7	6.482^{b}	T4	4.650^{ab}
3	T11	0.629^{ab}	T8	5.321^{b}	T4	6.109^{c}	T5	4.589^{ab}
4	T5	0.606^{ab}	T1	5.173^{bc}	T2	5.727^{cd}	T7	4.538^{ab}
5	T10	0.602^{ab}	T11	5.089^{bcd}	T11	5.713^{cd}	T11	4.506^{ab}
6	T9	0.593^{ab}	T6	4.789^{cd}	T5	5.602^{cde}	T2	4.500^{ab}
7	T2	0.581^{ab}	T5	4.712^{d}	T6	5.398^{def}	T8	4.469^{ab}
8	T4	0.558^{ab}	T2	4.218^{e}	T8	4.981^{efg}	T6	4.410^{b}
9	T6	0.545^{b}	T4	4.167^{e}	T10	4.781^{fg}	T9	3.957^{c}
10	T8	0.535^{b}	T9	3.235^{f}	T9	4.678^{g}	T10	3.630^{c}
11	T3	0.386^{c}	T3	2.786^{g}	T3	3.211^{h}	T3	2.654^{d}
CV		12.569		5.436		7.336		5.637
MS error		0.005		0.064		0.159		0.057
$LSD_{(0.05)}$		0.124		0.433		0.680		0.408

NB: R=Rank, trt=Treatment, BM= Biomass, t/ha= ton per hectare, T1 to T11 refers to eleven treatments.

There were significant different between above ground biomass obtained at development stage. At the end of this stage T7 and T10 developed 6.16 and 5.8 t/ha biomasses respectively. In this stage these two treatments received 100% of CWR. These are the highest above ground biomass compared with other treatments. According to the result obtained application of 50% of CWR deficit at development stage affect the above ground biomass of onion. In the mid growth stage, statistical analysis of the data revealed that the irrigation treatments significantly affected the above ground biomass of onion. At the end of this growth stage (80 days after transplanting) the maximum and minimum above ground biomass (statistically significant) were observed at treatments T1 (7.25 t/ha) and T3 (3.21 t/ha) respectively. Shock et al. (2000) reported similar result that the dry matter production of onion is highly dependent on appropriate water supply.

Similarly, at the end of the late season, statistical analysis of the data showed that the irrigation treatments significantly affected the biomass of onion. The trend of growth of onion crop in all treatments at this stage (95 days after transplanting) similar to the preceding growth stages, but the growth was at a decreasing rate. Maximum mean above ground biomass (4.85 t/ha) was observed at treatments that received the higher level of water (0% deficit). The lowest (2.65 t/ha) was recorded at T3 which received 50% of CWR deficit throughout the growing season. The reduction of biomass for response of irrigation water stress was determined by Araya et al. (2010) for barely crop.

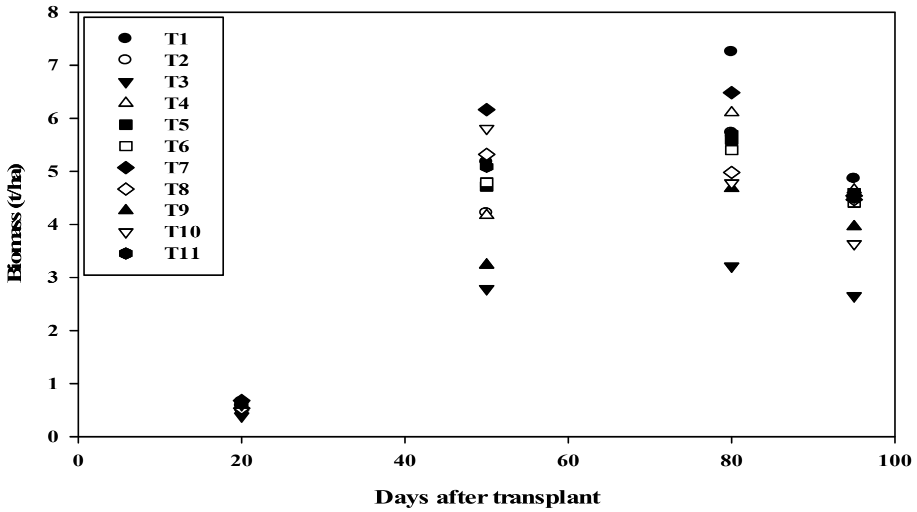

Figure 4.7: Biomass development

Seasonal development of biomass in all treatments was shown in figure 4.7. Treatments that received high and low irrigation water depth produced maximum and minimum biomass respectively. This confirms the statement of reduced irrigation water reduces total yield components of crops. Table 4.8 compare mean biomass of a control treatment (0 % deficit) and each of 10 treatments using LSD test.

Table 4.8: Comparison of biomass (t/ha) using LSD test

Initial stage			Development stage			Mid stage		
Trt	BM	difference	Trt	BM	difference	Trt	BM	difference
T7	0.689	0.024^{ns}	T7	6.161	0.987**	T1	7.254	-
T1	0.656	-	T10	5.806	0.632**	T7	6.482	0.771*
T11	0.629	0.026^{ns}	T8	5.321	0.147^{ns}	T4	6.109	1.145**
T5	0.606	0.049^{ns}	T1	5.173	-	T2	5.727	1.526**
T10	0.602	0.053^{ns}	T11	5.089	0.084^{ns}	T11	5.713	1.540**
T9	0.593	0.062^{ns}	T6	4.789	0.384^{ns}	T5	5.602	1.652**
T2	0.581	0.074^{ns}	T5	4.712	0.461*	T6	5.398	1.856**
T4	0.558	0.097^{ns}	T2	4.218	0.955**	T8	4.981	2.272**
T6	0.545	0.110^{ns}	T4	4.167	1.006**	T10	4.781	2.473**
T8	0.535	0.120^{ns}	T9	3.235	1.938**	T9	4.678	2.576**
T3	0.387	0.269*	T3	2.786	2.387**	T3	3.211	4.042**
LSD (5%=0.124, 1%=0.169)			LSD(5%=0.433,1%= 0.592)			LSD(5%=0.680, 1%= 0.928)		

NB: Trt= treatment, ns= non significant, **= highly significant, *=significant, BM= biomass

4.3.3 Bulb yield

In this experiment bulb yield was measured by harvesting onion yield on each plot distinctively and weighing them separately. The responses of onion bulb yield to different depth of irrigation water and at different growth stages were varied. The analysis of variance (in appendix table 13) shown that the yield showed statistically significant difference. It affected by the amount of irrigation water stress and time of application (see table 4.9).

The highest mean marketable bulb yield of 19.93 t/ha was observed at T1 (0% deficit) and the lowest mean bulb yield of 10.31 t/ha was observed at T3 (50% of CWR deficit throughout the growing season). The yield was reduced to 14.83 t/ha in T2 (25 % of CWR deficit throughout the growing season) from the maximum. The result showed that irrigation water stress throughout the season significantly reduced onion yield. The result obtained in this experiment was in agreement with Teferi (2015) who observed that irrigation water stress throughout the season significantly decreased onion bulb yield. Nazeer and Ali (2012) also discussed that different irrigation water depth affects onion yield and biomass.

The yield of T2 which received 310.5mm seasonal irrigation depth better than yields of T10 (50% of CWR deficit at mid stage) and T9 (50% of CWR deficit at development stage) which received 330.7mm and 348.6mm seasonal irrigation depth respectively. This result indicated that partitioning of the stress is better than one period stress for yield increment. Kumar et al. (2014) concluded that depending on the quantity and timing of irrigation, the applied irrigation imparted different degrees of influence on the various components of growth and yield parameters of onion.

There were no statistically significant yield difference between control treatment (0% deficit) and T4 (25% of CWR deficit at initial stage), T7 (25% of CWR deficit at late stage) and T11 (50% of CWR deficit at late stage). This indicated that reducing the irrigation water during the initial stage by 25% and during late stage by 50% did not brought significant yield reduction compared with full irrigation.

As it shown in table 4.9, 50% and 25% of CWR deficit throughout the whole growth season and water deficit during the development and mid growth stages resulted in a significant yield reduction compared with control treatment. Related results were also obtained for onion by Samson and Tilahun (2007), where 25% and 50% water deficit throughout the growing season resulted in 15 and 45% reduction in yield, respectively.

Table 4.9: Effects of water deficit on onion yield

R	Trt	Seasonal irrigation depth (mm)	yield t/ha
1	T1	413.4	19.936^{a}
2	T7	399.95	19.713^{a}
3	T4	397.225	19.446^{ab}
4	T11	386.5	17.856^{abc}
5	T5	381.0	15.200^{bc}
6	T8	381.05	15.060^{c}
7	T6	372.05	15.030^{c}
8	T2	310.05	14.833^{cd}
9	T9	348.6	13.656^{cde}
10	T10	330.75	10.656^{de}
11	T3	206.7	10.310^{e}
	CV	-	16.33
	MS error	-	6.50
	$LSD_{(0.05)}$	-	4.34

NB: R=Rank, trt=Treatment, T1 to T11 refers to different treatments

Generally water deficit at the initial and late growing stages had limited effect on onion yield, whereas water deficit at the development and mid stages had significant yield reduction effect. Experimental results carried out on cereals crops such as on maize by Gebreselassie et al. (2015) and on wheat by Salemi et al. (2011) were in line with this experimental observation. Yenesew and Tilahun (2009) also concluded that soil moisture stress during vegetative and reproductive stages of maize results in the reduction of above ground dry weight and yield.

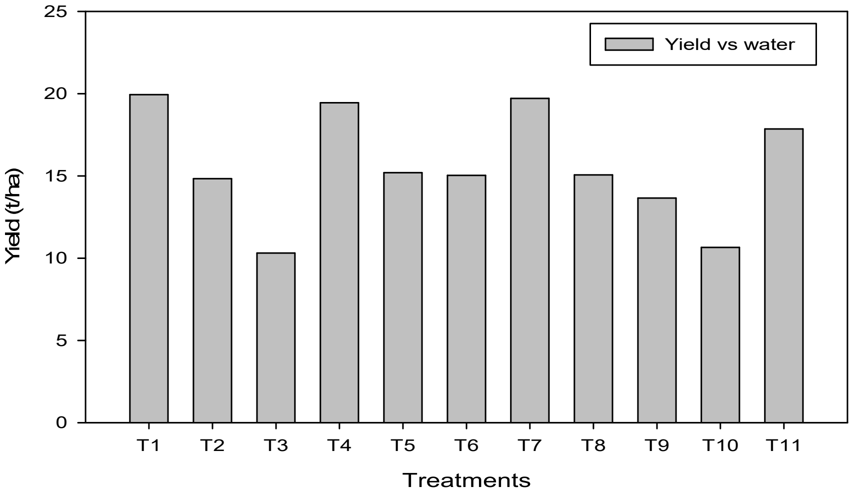

Figure 4.8: Yield response for water stress

The onion yield acquired in this experiment by varying irrigation water depth was used to develop the response function required for the optimization procedure. In this experiment the relationship of onion yield in t/ha and seasonal irrigation water depth in mm with coefficient of determination 0.65 can be expressed by a linear equation. The relationship of seasonal irrigation water depth and onion yield was positive and linear.

Table 4.10: Comparison of bulb yield using LSD test

Trt	mean yield (t/ha)	Difference: LSD=(5%=4.34, 1%= 5.92)
T1	19.936	-
T7	19.713	0.23^{ns}
T4	19.446	0.49^{ns}
T11	17.856	2.08^{ns}
T5	15.200	4.73*
T8	15.060	4.87*
T6	15.030	4.90*
T2	14.833	5.10*
T9	13.656	6.28**
T10	10.656	9.28**
T3	10.310	9.63**

NB: ns= non significant, **= highly significant, *=significant

4.4 Crop Water Productivity

Table 4.11 shows the crop water productivity of onion under different deficit levels and timings of irrigation water. Irrigating 50% of CWR deficit throughout the whole growing season (T3) and irrigating 50% of CWR deficit at mid growing stage (T10) resulted the maximum(4.98 kg/m^3) and minimum(3.22kg/m^3) crop water productivity respectively. Crop water productivities of other treatments were in between these two extremes values.

This study revealed that the water productivity of onion was maximized when water deficit occur throughout growing season due to minimum water applied. These results are in a close agreement with Kebede (2003), Samson and Tilahun (2007) who reported that when irrigation water becomes a limiting factor, yield losses due to scarce soil moisture could be compensated for by water productivity. In this study the highest and the lowest water saving was observed at T3 and T7 respectively. Production of more yields with reduced water, more water will be saved to irrigate more land in a water scarce area.

In this experiment higher water productivity was associated with reduced water application showing water deficit at different growth stage enhance water productivity. This is also in agreement with reports of FAO (2002) on wheat and cotton and Elias et al. (2014) on maize. Better water productivity without significant yield reduction was obtained on treatments in which water deficit happen only at initial and late stages.

Water stress at mid growth stage resulted low crop water productivity. This was due to high yield reduction during mid period (yield formation period) water stress. Water deficit at initial and late growth stages had limited effect on crop water productivity. English et al. (1990) concluded that it is important to decide on the deficit level and the time of its application to achieve the highest water productivity at minimum cost. The report of experimental result carried out by Samson and Tilahun (2007) indicated that water stress occurred at initial stage increased the water productivity of onion by 6%. They also report that 75% of CWR water stress throughout the growing season increased water productivity by 13%.

Table 4.11: Yield (crop) water productivity

Treatments	Applied water (m^3/ha)	Observed yield (kg/ha)	Water Productivity (kg/m^3)	Water saved (m^3/ha)	Water productivity rank
T1	4134	19936.70	4.82	0	4
T2	3100.5	14833.33	4.78	1033.5	5
T3	2067	10310.00	4.98	2067	1
T4	3972.25	19446.70	4.89	161.75	3
T5	3810	15200.00	3.98	324	8
T6	3720.75	15030.00	4.03	413.25	7
T7	3999.5	19713.30	4.93	134.5	2
T8	3810.5	15060.00	3.95	323.5	9
T9	3486	13656.70	3.92	648	10
T10	3307.5	10656.70	3.22	826.5	11
T11	3865	17856.70	4.62	269	6

The water productivity of treatments that received deficit water throughout the season was high. However, in these treatments the yield reduced due to water deficit was significant. The water productivity result showed that decreasing irrigation water increases the yield per cubic meter of applied water. Higher dosage of water applied meant lower water productivity. The lower water productivity at high dosage of irrigation water could be due to lack of proportional increase in yield with increasing water depth further. The lower water productivity also associated with period of water stress. In this experiment high water productivity reduction was observed at treatment that received 50% of CWR stress at mid growth period.

4.5 Harvest index (HI)

Harvest index has been shown to be a variable factor in crop production and in many situations it is closely associated with crop water productivity. Shortage of water reduces canopy cover of the crops which is responsible for photosynthesis process and indirectly affects harvest index. In this experiment harvest index for different treatments were affected by the period of deficit water application. Water deficit at development and mid period decreased the harvest index of onion.

T10 (50% of CWR deficit at mid period) showed the lowest harvest index and T9 (50% of CWR deficit at development stage) showed the next lowest harvest index. This was due to water stress at mid and development stage causes high yield reduction. This result in line with reported by Steduto et al. (2012) who observed that water deficit at yield formation stage reduces HI. T7 (25% of CWR deficit at late stage) gave the highest harvest index. T1 (full irrigation) acquired medium harvest index which indicated that full irrigation throughout the growing season might not be responsible for higher harvest index.

Table 4.12: Harvest index of each treatment

Treatments	Harvest index(HI)
T1	0.87
T2	0.87
T3	0.80
T4	0.90
T5	0.80
T6	0.76
T7	0.91
T8	0.76
T9	0.73
T10	0.68
T11	0.87

4.6 Yield response factor (ky)

Table 4.13 indicated that the yield of onion was not sensitive for water deficit that happen at initial and late stages (25% of CWR deficit at initial and late stages) since yield response factor (ky) is less than one. i.e onion tolerate some degree of water stress at initial and late stage without significant yield reduction. T8 and T11 (50% of CWR deficit at initial and late stage respectively) showed the sensitivity of onion for high water stress since the value of yield response factor greater than one (ky>1).

Similarly, T9 and T10 (50% of CWR deficit at development and mid stage respectively) and T5 and T6 (25% of CWR deficit at development and mid stage respectively) shown the sensitivity of onion for water stress (ky>1). This might be due to higher water need for development and yield formation at these stages. This variability in response of crops for water deficit at different growth stages were illustrated by Steduto et al. (2012). They also concluded that flowering and yield formation stages of crops are sensitive to water stress, while stress occurring during the late stages has limited effect.

Table 4.13: Yield response factor of onion for different water stress level

Trt	Actual yield in kg/ha	Maximum yield in kg/ha	Actual Eta (mm)	Maximum ETm (mm)	Yield response factor (ky)
		19936.67		413.40	
T2	14833.33		310.05		1.02
T3	10310.00		206.70		0.97
T4	19446.70		397.23		0.63
T5	15200.00		381.00		3.03
T6	15030.00		372.08		2.46
T7	19713.30		399.95		0.34
T8	15060.00		381.05		3.12
T9	13656.70		348.60		2.01
T10	10656.70		330.75		2.33
T11	17856.70		386.50		1.60

ETa=actual evapotranspiration, ETm=maximum evapotranspiration,

Table 4.14: Yield response factor (ky) for two deficit levels on each stage (biomass as a yield)

Treatment	Initial	Development	Mid	Late
T2(25% deficit whole season)	0.446011	0.739691	0.842421	0.297402
T3(50% deficit whole season)	0.823608	0.92268	1.114645	0.908093

4.7 Economic analysis of deficit irrigation with onion

The application of deficit irrigation for improved growth and higher yield could be economically attractive to minimize drought hazards in water shortage areas. Cost benefit ratio for each treatments were analyzed and income was computed based on the current local market price of onion at Mareko. At the time of harvest the market price of onion was 9 birr per kg and the cost of irrigation water was 8 birr/m^3 (by considering cost of drink water as the cost irrigation water).

To analyze by the producer of dominance analysis, the treatments were set in their sort of increasing variable cost and their equivalent benefits were put aside. T3 and T1 showed the minimum and maximum variable cost respectively. In table 4.15 shown that T5, T6, T8, T9 and T10 have higher variable cost and lower net income than T2. Hence T5, T6, T8, T9 and T10 are dominated (D).The remain treatment were transferred to MRR analysis.

Based on the current prices of onion yield produced and input costs required for production, the economic analysis was carried out. The highest net income (125338 birr/ha) was obtained at T1 (full CWR throughout growing season) that received 413.4mm seasonal irrigation water depth and the least net income (48430 birr/ha) was obtained at T10 (50% of CWR deficit at mid stage) that received 330.75 mm depth of irrigation water. However, as it is indicated in table 4.14, the largest MRR (5672.9%) was acquired at T11 and the smallest MRR (86.8%) was obtained at T1.

Table 4.15: Economic analysis of deficit irrigation on onion

Trt	AW (m^3/ha)	OY (kg/ha)	GI (birr/ha)	FC (birr/ha)	VC (birr/ha)	TC (birr/ha)	NI (birr/ha)	MRR (%)
T3	2067	10310.00	92790	21020	16536	37556	55234	-
T2	3100.5	14833.33	133500	21020	24804	45824	87676	392.4
T10	3307.5	10656.70	95910	21020	26460	47480	48430	D
T9	3486	13656.70	122910	21020	27888	48908	74002	D
T6	3720.7	15030.00	135270	21020	29766	50786	84484	D
T5	3810	15200.00	136800	21020	30480	51500	85300	D
T8	3810.5	15060.00	135540	21020	30484	51504	84036	D
T11	3865	17856.70	160710	21020	30920	51940	108770	5672.9
T4	3972.2	19446.70	175020	21020	31778	52798	122222	1567.8
T7	3999.5	19713.30	177420	21020	31996	53016	124404	1000.9
T1	4134	19936.70	179430	21020	33072	54092	125338	86.8

AW= Applied water, OY=Observed yield, GI=Gross income, FC= Fixed cost, Trt= treatment, VC=Variable cost, TC=Total cost, NI=Net income, MRR=Marginal rate of return, D=Domination

Therefore, the highest economic return was observed at T11 (50% of CWR deficit at late stage of growing season) with net income of 108770 birr/ha and MRR of 5672.9%. The MRR tell us that the amount of additional income obtained for every 1 birr spent. Hence, T11 (50% of CWR deficit at late stage of growing season) acquired additional 56.729 birr for every 1birr spent. The minimum acceptable marginal rate of return (MRR) should be between 50 and 100% (CIMMYT, 1988).

5. Conclusions and Recommendations

5.1 Conclusion

Drought, fast growth of population, improved living standard and shortage of rainfall increases competition for water resources. To feed the growing population agricultural production must be increase. Due to these competitions for water, agricultural production will reduce and big challenge will face this sector. Strategies such as deficit irrigation have to apply in order to reduce the problem and improving agricultural production. The importance of deficit irrigation is not only for water saving, but also it is effective in yield enhancement, economic and social benefits to the society. It is practiced by keeping the soil moisture content below the optimum level at specific growth stages of the season or throughout the growing season and it is used to identify the stage at which water stress would have a limited effect on crop production.

This research was conducted to find out the effects of deficit irrigation on water productivity and yield response of onion (Allium Cepa) in Southern Ethiopia at Mareko woreda. Eleven treatment combinations that include 0%, 25% and 50% of CWR deficit throughout growing season and one period stress (25% and 50% of CWR deficit) at four growth stages (initial, development, mid and late) were laid with three replications in randomized complete block design.

The field observed data showed that when water deficit is happened at initial and late stages in the growing season; the yield reduced is not significant by talking reference of yield obtained from fully irrigated treatment. However, water stress at development and mid growth stages not advisable since above ground biomass and yield reduction are significant. Continuous water stress of 25% and 50% of CWR throughout growing season is also not recommended for the reason that of its significant yields reduction. The most sensitive growth stage of onion for water stress is the mid stage and the next high sensitive stage is development stage. These sensitive stages are the stage of the crop with the maximum water requirement and the crop cannot resist water stress at these stages without significant yield reduction.

The result acquired from this field experiment indicated that when water stress happened throughout the growing season, water productivity is maximized. The water productivity of deficit irrigation throughout the season is higher than the water productivity of deficit at specific stage. In addition to this, water deficit at initial and late growth stages have higher water productivity. Water deficit at development and mid growth stages have high yield reduction and low water productivity. The saved water from deficit irrigation in these stages does not compensate the yield loss due to water stress.

The maximum onion bulb yield was obtained at 0% deficit irrigation and the maximum water productivity was obtained at 50% of CWR deficit throughout the growing season. The cost benefit analysis result showed that the maximum marginal rate of return was obtained from deficit at late growth stage. This result tells us that maximum yield and maximum water productivity does not mean economically feasible system of production.

General conclusions acquired from this experiment are:-

- ✓ Applications of 50% and 25% of CWR deficit at development and mid growth stages resulted significant yield reduction. Therefore, any water stress at these stages is not advisable.
- ✓ There was no significant yield difference between onion yield obtained from full irrigation and yield obtained from 50% of CWR deficit at late stage and 25% of CWR deficit at initial growth stages. Therefore, full irrigation in these stages is not recommended.
- ✓ Stressing the onion crop throughout the growing season is not advisable since significant yield reduction was observed.
- ✓ The maximum onion yield was obtained at T1 (full irrigation) and maximum crop water productivity was acquired at T3 (50% of CWR deficit throughout the growing season). However the maximum marginal rate of return was obtained from 50% of CWR deficit at late stage of growing season.

5.2 Recommendations

- ✓ Irrigating 50% of CWR deficit at late growth stage was gave high marginal rate of return and save significant water. So, farmers in this experimental location should use this result to increase their income.
- ✓ Irrigating 25% of CWR deficit at initial and late stages do not reduce significant yield. Using these system as one method of production also increase income of the farmers with water savings.
- ✓ This experimental data was obtained from only one season, to get better insight in these directions additional and repeated experiments will be need for onion and other crops in the study area.
- ✓ However, future studies in the study area will also have to consider other production factors.

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7. Appendices

Appendices tables

Appendix Table 1. Meteorological data of the study area

Month	Min °C	Max °C	Hum %	Wind km/day	Sun hours	Rain mm
Jan	10.7	27.9	67	173	10.5	31.3
Feb	11.4	28.5	67	173	10.6	51.2
Mar	12.5	29.0	68	173	10.4	84.8
April	13.7	28.5	70	173	9.8	103.6
May	12.7	28.4	69	173	10.4	107.1
June	12.3	27.5	70	173	10.3	140.8
July	11.9	24.6	73	173	8.9	214.4
Aug	12.2	24.7	73	173	8.7	168.3
Sep	12.0	26.1	71	173	9.4	122.1
Oct	11.7	27.9	68	173	10.4	39.2
Nov	10.7	28.3	67	173	10.8	16.7
Dec	9.9	27.6	67	173	10.7	13.9
Average	11.8	27.4	69	173	10.1	

Source: National meteorological agency Hawassa branch

Appendix Table 2. Infiltration characteristics of the soil at the study area

Elapsed time(min)	Com.time(min)	Infil depth(mm)	Com.Infil(mm)	rate(mm/min)	rate(mm/hr)
0	0	0	0	0	0
1	1	8	8	8	480
1	2	6	14	6	360
1	3	3	17	3	180
5	8	10	27	2	120
5	13	9	36	1.8	108
5	18	7	43	1.4	84
10	28	10	53	1	60
10	38	7	60	0.7	42
10	48	9	69	0.9	54
20	68	12	81	0.6	36
20	88	10	91	0.5	30
40	128	19	110	0.475	28.5

NB: Infil=Infiltration, Com=Cumulative

Appendix Table 3. ETo of experimental site by temperature based methods.

Month	HG	TW	BC	PME
JAN	11.6	3.84	4.46	4.61
FAB	13.1	4.21	4.64	4.98
MAR	13.38	4.74	4.74	5.24
APR	13.16	4.96	4.96	5.11
MAY	12.89	4.55	4.89	5.12
JUN	12.39	4.16	4.9	4.9
JUL	10.78	3.19	4.69	4.29
AGU	10.95	3.3	4.62	4.32
SEP	11.96	3.62	4.69	4.65
OCT	12.39	4.15	4.62	4.92
NOV	12.1	3.97	4.48	4.79

NB: HG=Hargreaves, TW=Thornwaite, BC= Blanney Criddle, PME= peman monteith

Appendix Table 4. Comparison of observed infiltration data with infiltration models.

Cumulative time	Observed data		Predicted by L-K model with k=10.04110023 a=0.494040501 cumulative =kt^{a} rate=akt$^{(a-1)}$		Predicted by Horton model: cumul=$i_f t + \frac{i_o - i_f}{\delta}(1 - e^{-\delta t})$ rate=$i_f + (i_o - i_f)e^{-\delta t}$	
min	Cumulative infiltration depth(mm)	Infiltration rate(mm/hr)	Cumulative infiltration depth(mm)	Infiltration rate(mm/hr)	Cumulative infiltration depth(mm)	Infiltration rate(mm/hr)
1	8	480	10	297.6	7.38	408.02
2	14	360	14.1	209.6	13.68	347.51
3	17	180	17.3	170.7	19.02	296.65
8	27	120	28.1	103.9	36.33	141.03
13	36	108	35.7	81.3	44.97	75.72
18	43	84	41.9	69	49.97	48.32
28	53	60	52.1	55.1	56.29	31.99
38	60	42	60.6	47.2	61.32	29.11
48	69	54	68	42	66.11	28.61
68	81	36	80.7	35.2	75.62	28.5
88	91	30	91.7	30.9	85.12	28.5
128	110	28.5	110.4	25.6	104.12	28.5
			R^2=0.99	R^2=0.98	R^2=0.98	R^2=0.95

Appendix Table 5. Analysis of Variance for CC at initial stage

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
rep	2	0.1818	0.09091	3.4125	0.2308
as.factor(trt)	10	15.2121	1.52121	57.102	2.289e-09 ***
Residuals	20	1.1515	0.02664		

Appendix Table 6. Analysis of Variance for CC at development stage

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
rep	2	214.61	107.303	1.5506	0.236577
as.factor(trt)	10	2770.30	277.030	4.0032	0.004022 **
Residuals	20	1384.06	69.203		

Appendix Table 7. Analysis of Variance for CC at mid stage

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
rep	2	308.6	154.30	1.3499	0.28188
as.factor(trt)	10	3327.4	332.74	2.9110	0.02012 *
Residuals	20	2286.1	114.30		

Appendix Table 8. Analysis of Variance for CC at late stage

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
rep	2	111.10	55.549	1.3499	0.28188
as.factor(trt)	10	1197.86	119.786	2.9110	0.02012 *
Residuals	20	822.98	41.149		

Appendix Table 9. Analysis of Variance for BM at initial stage

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
rep	2	0.001024	0.0005121	0.0967	0.908242
as.factor(trt)	10	0.182455	0.0182455	3.4455	0.008917 **
Residuals	20	0.105909	0.005309		

Appendix Table 10. Analysis of Variance for BM at development stage

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
rep	2	0.4036	0.20179	3.1091	0.06672 .
as.factor(trt)	10	31.3406	3.13406	48.2875	8.555e-12 ***
Residuals	20	1.2981	0.06490		

Appendix Table 11. Analysis of Variance for BM at mid stage

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
rep	2	0.676	0.3380	2.1159	0.1467
as.factor(trt)	10	33.562	3.3562	21.0112	1.772e-08 ***
Residuals	20	3.195	0.1597		

Appendix Table 12. Analysis of Variance for BM at late stage

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
rep	2	0.2753	0.13765	2.3679	0.1194
as.factor(trt)	10	11.8392	1.18392	20.3672	2.331e-08 ***
Residuals	20	1.1626	0.05813		

Appendix Table 13. Analysis of Variance for yield

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
rep	2	11.35	5.676	0.8734	0.4328775
as.factor(trt)	10	339.53	33.953	5.2245	0.0008348 ***
Residuals	20	129.98	6.499		

Appendix Table 14 . Total costs of items and labor in birr per hectare

Item/activities	Units	Types of cost
1. Field activity and labor cost	Birr	fixed
Ploughing		2500
Bed preparation		1000
Planting		2000
Watering		6000
Weeding and cultivation		2000
Harvesting		2000
Transporting		2000
Sub-total		17500
2. Inputs cost	Birr	
Seeds		1000
Urea		1200
DAP		1200
Malation		120
Sub-total Birr		9520
Grand total		21020

Appendices figures

Figure1:at the time of planting

Figure 2: at development stage

Figure 4: Yield harvestin