EFFECT OF DEFICT IRRIGATION LEVELS AT DIFFERENT GROWTH STAGES ON YIELD AND WATER PRODUCTIVITY OF ONION UNDER FURROW IRRIGATION SYSTEM

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DEDICATION

I dedicate this thesis to my mother Desalech Mekonen and my brother Teshome Bekele for their affection and support in my life.

STATEMENT OF AUTHOR

I declare that this thesis is my original work and has not been presented for any other university for the award of any academic degree, diploma or certificate. All sources of material used for this thesis have been duly acknowledged.

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ABBREVIATIONS

ANOVA	Analysis of Variance
CIMMYT	Maize and Wheat Improvement Center
CV	Coefficient of Variance
EARO	Ethiopian Agricultural Research Organization
IR_g	Gross Depth of Water Applied
FAO	Food and Agricultural Organization of the United Nations
GIR	Gross Irrigation Requirement
IR_n	Net Irrigation Requirement
IWMI	International Water Management Inistitute
IWUE	Irrigation Water Use Efficiency
LSD	List Significant Difference
m.a.s.l	Meter above sea level
MS	Mean Square
MSB	Block Mean Square
MSE	Mean Squareb of Error
MST	Treatment Mean Square
IN	Net Income
ΔNI	Difference of Net income
PWP	Permanent Wilting Point
RCBD	Randomized Complete Block Design
RH	Relative Humidity
SARI	South Agricultural Research Center
SAS	Statistical Analysis System
SNNPR	South Nation Nationalies Of People Region
SS	Sum of Square
BSS	Block Sum of Square
ESS	Error Sum of Square
SSH	Sun shine Hour
TSS	Treatment Sum of Square

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ABSTRACT

Water scarcity is the most severe constraint for agricultural growth in arid and semi-arid areas. To overcome this, there is a need to use the available water efficiently and economically which is an important strategy to address present and future water need. The Studies in deficit irrigation application to improve water productivity are limited in the study area. This study was conducted in Misrak Azernet Berbere Woreda in Silte Zone from December to March / 2017 / 18 to investigate the effect of defict irrigation levels on yield and water productivity on Onion under furrow irrigation system. The experiment contained nine treatments which include: control (0 % DI); 20 % DI and 40 % DI level throughout growth stages; 0 % DI, 20 % DI, 40 % DI and 20 % DI (i.e: initial, developmental, mid and late stages) respectively; 40 % DI, 20 % DI, 0 % DI and 20 % DI (i.e: in initial, developmental, mid and late stages), respectively and 20 % DI at each growth stages (i.e: in initial, developmental, mid and late stages), respectively were laid out in RCBD replicated three times. The results obtained indicated that defict irrigation levels in different growth stages had significantly affected the yield and yield component of Onion at ($p \leq 0.05$). The highest marketable bulb yield (29.32 ton/ha) was obtained from T_1 (control) which was irrigated by 0 % DI level throughout the growth stage whereas the treatment recieved 20 % DI level at late growth stage (T_9) gave 29.14 ton/ha bulb yield. The yield result obtained from T_1 (control) had not significantly different with T_9 (20 % DI at late growth stage). The lowest bulb yield (15.23 ton/ha) was recorded from T_3 which received 40 % DI level through out the growth stages. Water productivity (WP) was found different depending on level of water application. The highest WP 9.9 kg/m^3 was obtained from T_2 (20 % DI throughout the growth stages) and it has 1.95 kg/m^3 greater WP than T_1 (8 kg/m^3) that got full irrigation. Treatment (T_9) has the highest MRR (13673.2 %) than all others treatments. This study results confirmed that with deficit irrigation practies, it is possible to increase WP by saving water and increase income from scarce irrigation water. Therefore, it can be recommended that applying irrigation water at 20 % DI of CWR at late growth stage (T_9) in 4 days irrigation interval is benificial for obtaining optimum Onion yield and incresase water productivity that brings higher economic return under scarce water condition. The farmers in scarce water resource area could also be used T_2 (20 % DI of CWR throughout growth stages) as option to save more water.

Key Words: Bulb yield, Deficit irrigation, Evapotranspiration, Growth stage and Water productivity.

1. INTRODUCTION

1.1. Background

Water scarcity is a global problem due to needs for water increase in households, industry, agriculture and climatic change (WHO, 2009). However, the limited supply of the reneweable water resources forces water managers to apply irrigation water efficiently in order to produce more food (Andarzian *et al.*, 2011). Water and food security are closely related in which irrigation enhances crop production and household income to improve the livelihood of the rural people (FAO, 2003).

Ethiopia is the second most populous country in Africa next to Nigeria. Most of its population were living in high land areas with 85% being rural and dependent on agriculture with a low level of productivity (Awulachew *et al*., 2007). Agricultural practice of the country is mostly dependent on rain-fed farming system and it accounts about 40% of the gross domestic products (GDP) (IWMI, 2010; 2007). Ethiopian government considers water as an entry point for the country development. It identified water as an important policy instrument to stimulate economic growth and ensuring food security (Fitsum *et al.,* 2009). Irrigated agriculture is the main focus for the food security strategy of the country by implementing small scale irrigation schemes which reduce dependency on rain-fed agriculture and increase food self-sufficiency of the rapidly increasing population (GTP, 2010).

Water is becoming an economically scare resource not only in arid and semi-arid areas but also in regions where rain is fall abundant. Its scarcity may be due to different natural and human-induced factors (Pereira, 1990). Agriculture under unfavorable climatic conditions and limited water resources cannot be profitable investment unless on-farm water management techniques are designed to meet the present and future growing demands of water for food production (Oad *et al.,* 2001).

Deficit irrigation (DI) is a technology to improve water productivity and reduces the irrigation water use amount by exposing crops to certain level of water stress either during a particular period or throughout the whole growing season (English and Raja, 1996). DI technology has been widely investigated as a valuable and sustainable production strategy in arid and semi-arid regions to maximize water use efficiency (WUE) for higher yields per unit of irrigation water applied (Fereres and Soriano, 2007). Numerous investigations have been conducted to produce knowledge regarding the effects of deficit irrigation on crop yield (Birhanu, 2006; Yenesew, 2007; Aklilu, 2009; Teferi, 2015; Enchalew, 2016). When water resources are scarce, deficit irrigation is one of the ways to maximize irrigation water use efficiency (Bekele and Tilahun, 2007).

Onion *(Allium cepa* L.*)* is one of a popular vegetable crops in Ethiopia and its area coverage is increasing from time to time mainly due to its high profitability per unit area, ease of production and its important in the daily diet (Lemma and Herath, 1992). Onion contributes significant value to the national economy. Ethiopia has high potential to benefit from onion production; Its higher yield potential, availability of desirable cultivars for various uses, ease of seed production, high domestic and export markets is making onion increasingly important in Ethiopia (Lemma and Shimels, 2003). Upper Awash Agro-industry Enterprise (UAAIE) alone produced 1,600 − 3,600 ton/ha in 1996 − 2001 with an overall average of 2,800 ton/year (UAAIE, 2001). The overall national average onion yield is about 10 ton/ha compared to the 15 ton/ha and 13 ton/ha of world and Africa production, respectively (FAO, 1995).

1.2. Problem of Statement

Water scarcity and continuous decreases in water resources availability coupled with an increasing demand for agricultural water has forced farmers to seek water saving technologies. To achieve sustainable irrigated agriculture by using limited water resources, different water saving technologies and guidelines are necessary for irrigation water users (Geerts *and* Raes, 2009). When water resources are scarce, DI is one of the ways to maximize irrigation water use efficiency (Bekele and Tilahun, 2007).

Onion contributes significantly to the national economy, apart from overcoming local demands. According to the World Bank report (2004), in the year 2001 the crop shared one fourth of the vegetable export quantities and stood third following green beans and peas contributing about 20% of the total vegetable export value which is about 244,000 US dollar of export earnings. This indicates that Ethiopia has high potential to benefit from Onion production. Its higher yield potential, availability of desirable cultivars for various uses, ease of propagation by seed, high domestic and export marketing were making onion increasingly important in Ethiopia (Lemma and Shimels, 2003).

The Southern Nations, Nationalities and People's Region (SNNPR), is one of the drought prone and densely populated part of Ethiopia. The region has good potential of land and water resources for irrigation development. The region has surface water resource of about 20 billion m^3 per year and ground water that is good in quality and sufficient in quantity to bring the available 648,000 ha of potential irrigable land under irrigation. The drought incidence that has affected the region since the past two three decades has forced policy makers to consider small scale irrigation as means of securing food self sufficiency(Mitiku, 2007). In line with the immediate need for increased production of food and other agricultural products the development of small scale irrigation schemes has been regarded as an attractive option as compared to medium and large-scale irrigation schemes. In order to address the need, construction of small-scale irrigation projects is being carried out in different parts of the region (Mitiku, 2007).

Goda small scale irrigation scheme at Misrak Azernet Barbere woreda is one of major sources of income to the rural communities in Silte Zone, SNNPR. The scheme can irrigate about 150 ha of land. However, the scheme is facing high water scarcity during the dry season (October to April) due to increasing of irrigation water need with unmanaged and inefficient utilization of irrigation water to the field. Irrigation applications are not based on scientific principle which result competition among the farmers. During this season, irrigation water supply was low in some parts and over-utilization in other parts while its demand was high and the irrigation water supply was not balanced. The assessment done by AGP-2 (2008), despite the significance of the problem of water scarcity and inefficient irrigation water use, studies which can improve water productivity are limited in the study area. Even though crops response to soil moisture level depends on growth stage and crop variety, there has been no investigation was identified on deficit irrigation effect on yield and water productivity based on different growth stages of crops in the study area.

However, one season exprement has been conducted by Kadirala (2009) in Mareko woreda, gurage zone, south Ethiopia on water productivity and yield response of Onion under full and deficit irrigation in water scarce condition; the study was conducted on ground water pump irrigated and bucket supplying condition. Besides, onion is very sensitive to soil moisture stress and its irrigation water requirement like any other crop is location, growth stage, variety, soil property and climate dependent which are main determining factors of the crop water requirement.

1.3. General Objective

The general objective of this study to investigate effect of defict irrigation levels on yield and water productivity of onion under furrow irrigation system.

1.3.1 Specific Objectives

- To identify the effects of deficit irrigation levels on onion yield at different growth stages under furrow irrigation system.
- To identify the most sensitive growth stages of onion to deficit irrigation levels.
- To determine the water productivity and economic benefit of onion under deficit irrigation levels.
- To detrrmine the effects of deficit irrigation levels on yield components of onion
- To investigate and recommend the best performing deficit irrigation levels which has insignificant reduction on yield.

1.4. Research Questions

This study attempts to address the following scientific research questions**:**

- What is the effect of deficit irrigation levels on Onion yield and water productivity at different growth stages under furrow irrigation system?
- Which growth stages of the onion is most water sensitive?
- What is the economic benefit of deficit irrigation levels to realize optimum Onion production and water productivity?
- Which deficit irrigation levels can significantly increase onion production and water productivity?

1.5. Hypothesis

Deficit irrigation levels at different growth stages under furrow irrigation system have significant effect on yield and water productivity of Onion.

1.6. Significance of the Study

The study was targeted on the efficient utilization of the scarce water resource on stage based water allocation technique and investigated the yield response of onion to different deficit irrigation levels in order to save scare water resources. It was also provide practical recommendations to irrigation water users about the technique to an efficient water use. This was enhanced to identifying and adopting locally feasible and socially acceptable deficit irrigation techniques to sustainable increase of agricultural water management and Onion productivity under water scarce conditions.

1.7. Scope of the Study

The scope of this study is limited to determining impact of deficit irrigation levels on yield and water Productivity of onion under furrow irrigation system in water scare condition. The study was considered only those variables which determine yield and water productivity aspect like water deficit levels, Varity, Production and Economic benefits. The research was conducted to determine effect of deficit irrigation levels at different growth stages on yield and water productivity of onion under furrow irrigation system in misrak azernet berbere woreda, silte zone, SNNPR, and Ethiopia. However, this study was subjected to the following limitations.

- Absence of meteorological stations near to the study area.
- Due to resource, Land and time limitation, the study had conducted on only one station for one season.
- Due to absence of estimated cost of irrigation water at the study area, half of tap water cost was used as base to determine irrigation water cost for economic analysis.

2. LITERATURE REVIEW

2.1. Importance of Irrigation in Ethiopia

Ethiopian agricultural practice is mostly depending on rain-fed farming system and it accounts about 40 % of the gross domestic products (IWMI, 2010; Makombe *et al*., 2007). Irrigated agriculture is the main focus of the food security strategy of the country government by implementing small scale irrigation schemes which reduce dependency on rain-fed agriculture and increase food self-sufficiency of the rapidly increasing population (GTP, 2010). Improved agricultural water management has many potential benefits in efforts to reduce food insecurity and improve productivity for increasing demand. The primary rationales for developing the irrigation sector in Ethiopia include: increased productivity of land and labor which is especial attention given for future constraints from population growth; reduced reliance on rain-fed agriculture; reduced degradation of natural resources and increased job opportunities and promotion of a dynamic economy with rural entrepreneurship (IWMI, 2010). Optimum management of available water resources at farm level is needed because of increasing demands for limited water resources, water table variation in space and time, and soil contamination (Kumar and Singh, 2003).

2.2. Water Resource Scarcity and Management

According to FAO (2012) water is becoming an economically scare resource even in areas of the world that have relatively plentiful water. The common understanding is that water shortage (i.e. an absolute shortage of water supply in a specified domain) is the main reason. The truth is that water scarcity (i.e: an excess of water demand over available water supply) is by far the most important global challenge. Water scarcity concerns quantity of resource available and the quality of the water because degraded water resources become available for more stringent requirements.

The major agricultural use of water for irrigation, which, thus, is affected by decreased supply (Burt and Styles, 1999). Irrigation development should be an important component of a diversification and expansion strategy to strengthen food security for the future and innovations are needed to increase the efficiency of use of the water that is available. Better management of agricultural water for increased productivity and efficiency is reduced “More crop per drop” are of vital importance. The main objective of deficit irrigation is to increase the WUE 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. Before implementing a deficit irrigation program, it is necessary to know water stress effect on crop yield by exposing crops to certain level of water stress either during defined growth stages or throughout the whole season (English and Raja, 1996).

Water for agriculture is increasingly recognized as a major constraint to improving the lives of the rural poor and is an important component of rural livelihood programs that need to be yet strongly established in Ethiopia. The best use of water must be made for efficient crop production and higher yields. Therefore, agriculture under unfavorable climatic conditions and limited water resources cannot be profitably practiced unless on-farm water management techniques are designed to meet the present growing demands of water for increased food production (Oad *et al.,* 2001). There should also be a need to identify crops and irrigation techniques which could give higher returns to scarce water and overall investment.

2.3. Irrigated Agriculture

Irrigation accounts for about 72% of globally and 90% of developing countries water withdrawals. For this reason, due to growing irrigation water demand to meet the increasing food security and increasing competition across water using sectors, the world faces a challenge to produce more food with less water (Rockstrom and Patrick, 2003). A significant challenge for agriculture is to provide the world’s growing population with a sustainable and secure supply of sufficient, safe, nutritious food that meets dietary needs and food preferences for an active and healthy life. This may probably be done using less farmland and efficient water use. For this reason, agricultural water productivity must be improved (FAO, 2002).

2.4. Furrow Irrigation

Furrow irrigation water application system is the most popular surface irrigation, as it requires a smaller initial investment compared to other surface irrigation types of water application systems. This type of irrigation method is the most widely used in Ethiopia in almost all large and small irrigation schemes. It has been reported by FAO (2001) that 97.8% of irrigation in Ethiopia is through surface methods of irrigation using furrow system in farmer's fields and majority of the commercial farms. According to Raine and Bakker (1996), furrow irrigation application efficiencies (E_a) normally vary from 45 – 60%. Application efficiency is the ratio of net amount of water needed to targeted crop to amount of water applied to yhe field.

2.5. Agricultural Drainage

Water logging and salinity have affected the productive capacity of irrigated agriculture and thus the overall target of irrigated agricultural yields and incomes (FAO, 1990). In irrigated agricultures, drainage is most important and inseparable input factors to maintain or to improve yields per unit of farmed land (Ritzema, 1994). To take full advantage of investments in agriculture, a major effort is required to modernize irrigation and drainage systems and to further develop appropriate management strategies compatible with the financial and socio-economic trends and the environment. This calls for a general approach to irrigation and drainage management and monitoring so as to increase food production, conserve water, prevent soil salinization and water logging, and to protect the environmental impact (John and Sons, 2002).

2.6. Determination of Crop Water Requirement

According to Allen *et al*. (1998), crop water requirement is defined as the depth of water needed to meet the water loss through evopotranspiration of a disease free crop growing in large fields under a non restricting soil condition, soil water and fertility achieving full production potential under a given growing environment. This water loss from a given cropped plot of land can be determined from the knowledge of reference evapotranspiration and cropcoefficient. Estimation of reference evapotranspiration is widely used in irrigation engineering to determine crop water requirements which were used in the planning of irrigation schemes and manage water distribution in existing schemes. Various classification of equations such as temperature-based, radiation-based, pan evaporation-based and combination types have been developed for estimating reference evapotranspitation. Temperature-based was probably the easiest, most widely available and reliable climatic parameter. The assumption that temperature based method is the best method to determine evapotranspiration because it is indicator of the evaporative power of the atmosphere. This method is the most widely used method in the world, can be considered as a standard method and has been proven to accurately estimate ET_o in different climate conditions (Walter *et al*., 2000).

According to Allen (1998), the crop coefficient (K_c) for any period of the season can be driven from K_c value under consideration of the growth stage. FAO (2010) reported that for optimum yield production of onion requires 350 – 550 mm water. Expriment done by Gobena *et al.* (2017) showed that for optimum yield, seasonal CWR of Onion was 469 mm.

2.7. Concept of Water Productivity

Molden (1997) mentioned that productivity takes different forms with different units but efficiency has only one form (dimensionless). Another study carriedout by Heydari (2014) indicated that WP is distinct from WUE. WP refers to crop production in relation to total water consumed while the WUE is a dimensionless ratio of total amount of water used to the total amount of water applied. WP terms are not dimensionless, i.e. cannot be categorized in efficiency terms, they are just some ratios with different units in the numerator and denominator. Similar description was given by (Michael, 2008) that water productivity with dimensions of kg m^{-3} is defined as the ratio of the mass of marketable yield (Y_a) to the volume of water applied.

2.8. Concept of Deficit Irrigation

Deficit irrigation is one of the techniques to improve water productivity and reduces the irrigation application exposed to a certain level of water stress either during a particular period or throughout the whole growing season (English and Raja, 1996). The proper application of deficit irrigation practices can save significant amount of irrigation water without high yield losses. Full irrigation water requirement application at the initial and late growth stages of maize is not advisable because no significant yield and biomass difference than applying fifty percent irrigation requirement at this stages (Yenesew, 2007).

Many investigations have been carried out worldwide regarding the effects of deficit irrigation on yield of mainly horticultural crops (Kumar *et al*., 2007; Samson and Tilahun, 2007; Sezen *et al.,* 2008). Deficit irrigation effect on water productivity and yield of onion with drip irrigation system on soil with clay textural class was done in northern parts of the Ethiopia (Teferi, 2015). The result of this investigation shows that supplying full water requirement at the 4th crop growth stage onion is not advisable because water stress during this season insignificant effect on yield. 40 % DI throughout the growing season results in the highest yield reduction per unit of water deficit. On the other hand, for the same amount of water saved through deficit irrigation, it is better to partition the stresses throughout the growing stages rather than creating stress during a critical stages of the crop growth especially during the late growth stages (Teferi, 2015).

The study result obtained by Samson and Tilahun (2007) on onion showed that deficit irrigation throughout the growing season with 50% and 75% of ET_c reduced yields from full irrigation and resulted in the highest water saving and crop water use efficiency. Similarly, Kumar *et al.,* (2007) investigated the impact of deficit irrigation strategies on onion yield and water saving reported that applying 80 and 60% of ET_c resulted in the yield decreases of 14 and 38% and saved 18 and 33% of irrigation water compared to full irrigation. A 25% decrease on irrigation water application showed no significant decrease in yield and it saved 25% of water which could be used to irrigate additional area in places where water scarcity is severe (Aklilu, 2009).

Another study has shown that deficit irrigation significantly increased grain yield, ET and WUE as compared to rainfed winter wheat (Oweis *et al.,* 2000). However, this approach requires precise knowledge of crop response to water as drought tolerance varies considerably by growth stage, species and cultivars.

2.9. Irrigation Scheduling

In sandy soils, plants may undergo water stress quickly, 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. The root zone of Onion extends up to 60 cm; 90 % of the root system is concentrated at the top 40cm of soil (Greenwood *et al.,* 1982). Irrigation scheduling (when and how much to irrigate) is one of the most important tool for developing best management practices of irrigated agriculture to supply sufficient amount of crop root need (Jamal *et al.,* 1999).

2.9.1. Deficit Irrigation Scheduling

Deficit irrigation is a new concept of irrigation scheduling which is one way to maximize water use efficiency by exposing the crop to a certain level of water stress either during a particular period or throughout the whole growing season (English *et al.,* 1990). It is necessary to know crop yield responses to water stress, either during defined growth stages or throughout the whole season before implementing deficit irrigation techniques (Kirda and Kanber, 1999). The crop yield response factor gives information about whether the crop is tolerant to water stress. If it is greater than unity indicates that the expected relative yield decrease for a given evapotranspiration deficit is proportionately greater than the relative decrease in evapotranspiration (Kirda *et al.,* 1999). Deficit irrigation can lead, in principle, to increased profits where water costs are high or where water supplies are limited. Under these circumstances, deficit irrigation can be a practical choice for growers.

2.10. Crop Yield Response to Deficit Irrigation

When water stress occurs during a specific crop growth period, the yield response can vary depending on crop sensitivity at that growth stage. The relationship formulated by Doorenbos and Kassam (1986) between the relative yield decreases produced by relative evapotranspiration deficit in a given irrigation scheduling procedures. The formulation relates four parameters such as Y_a, Y_m, ET_a and ET_m to the yield response factor (K_y).

The K_y values according to FAO data sets and from an International Atomic Energy Agency (IAEA) coordinated research project showed a wide range of variation for this parameter $0.20 < k_y < 1.15$ and $0.08 < k_y < 1.75$ (IAEA) for the crops of cotton, sugar cane, soybean, and wheat (FAO, 2002). Crop yield response factor varies depending on species, variety, irrigation method and management and growth stages when deficit evapotranspiration is carried out. The crop yield response factor gives an indication of whether the crop is tolerant of water stress or not. A yield response factor greater than unity indicates that the expected relative yield decrease for a given evapotranspiration deficit is proportionately greater than the relative decrease in evapotranspiration (Kirda *et al*., 1999).

2.10.1. Response of Onion to Deficit Irrigation

Birhanu (2006) stated that deficit irrigation level influences tomato and onion yield positively which means both crops yield decrease as water deficit level increase below 25% deficit level.

Similarly Teferi (2015) stated that results of onion trials indicated that DI at the 60% had a significant effect on yield, while the yield from DI at 80% ET_c was not much different from 100% ET_c and produced approximately equal bulb size. It was further concluded from the study that it would be possible to produce Onion by water-saving practices at 80% ET_c rate in late growth stage, as a means to target high price bulb sizes without reducing quality. Another recommendation was also made by Enchalew (2016) that showed the DI application up to 20% saved 45 to 108 mm depth of water from the gross Onion irrigation water requirement.

2.11. Agronomy of Onion

Onion is cool season crop that tolerate frost. For its optimum development, mean daily temperature varies between 15°C and 20°C before bulbing and 20°C and 25°C for bulb development is preferred. The crop is developed slowely down when the temperature rise is beyond 27°C (FAO, 1986). The roots of Onion extend beyond 50cm horizontally and reach 60 cm vertically in some cases (Jamal *et al.,* 2000). It is sensitive to low soil moisture and high water table and water logging. Onion grows on a variety of soils ranging from sand to clay loams. However, they need loamy soil that is fertile, well drained and high in organic matter, with optimum pH ranges between 6.0 − 8.0 (Olani and Fikre, 2010). Onions do not thrive in soils below pH 6.0 because of trace element deficiency such as aluminum or manganese toxicity. Onion could be produced on slightly alkaline soils, but are sensitive to soil salinity. According to the FAO (2002), a soil salinity level equal to or more than 4.3ds/m could decrease the onion yield up to 50%.

2.12. Growth Stages of Onion

The production of onion bulb depends on daylength; under normal conditions onion forms a bulb in the first season of growth and flowers in the second season. For the inial growth period cool weather and adequate water is advantegeous for proper crop establishement, where as during ripening, warm and dry weather is beneficial for high yield of good quality in FAO.33 by (Doorenbos *et al.,* 1986). The growth stages and crop coefficients used for water management of an onion crop with a growing period of 100 to 150 days in the field represented in Table 2.1 (FAO Water Development and Management Unit, 2012).

Table 2.1: Crop Coefficients (Kc) and length of growth stages values (FAO, 2012).

Crop characteristics	Development Stages				
Growth stage	initial stage	development stage	mid stage	late stage	total days
length (days)	15 – 20	25 – 35	25 – 45	35 – 45	100 – 150
crop coefficient (k_c)	0.4 – 0.6	0.7 – 0.8	0.95 – 1.1	0.85 – 1.1	

2.13. Exprimental Design and Data Analysis

According to Gomez (1983) research design is classified in to three based on the way a particular research is undertaken such as:

1. Experiments: offer the best method available to researchers to be able to investigate causality due to the high degree of control.
2. Quasi-Experiments (field methods): are often called field methods, Unlike Experiments in Quasi-experiments, the researcher usually has little control over the 'when' and 'to whom' the treatment is directed.
3. Non-Experiments: is descriptive and correlational, is only possible to investigate associations and causal links based on researcher's interpretation for direction of any correlation's if one does exist.

The experimental method is the method of searching truly test hypotheses concerning cause-and-effect relationships of experiment. It represents the most valid approach to the solution of both practical and theoretical advancement of science (Gay, 1992). According to Gomez (1983) exprimental designs are classified in to three such as completely randomized design: it is the one where the treatments are assigned completely at rabdom so that each experimental unit has the same chance of receiving any one treatments and it is appropriate for experiments for homogeneous experimental units such as laboratory experiments, where environmental effects are relatively easy to control; Randomized completely block design:it is one of the most widely used experimental design in agricultural research and the design is especially suited for field experiments where the number of treatments are not large and the experimental area has a predictable productivity gradient and latin square design: its major feature is its capacity to simultaneously handle two known sources of variation among experimental units. It treats the sources as two independent blocking (row and column blocking) criteria instead of only one as in the RCD design.

In agricultural research, field collected data are subjected to statistical analysis using SAS softwares. In experimental research, the significant effects among treatment means were compared using the least significant difference (LSD) method (Steel *et al*., 1997). LSD-test is the simplest and the most commonly used procedure for making pair comparisons of treatment means. LDS procedure provides for single value at prescribed level of significance which served as the boundary between significant and non significant difference between any pair of treatment means. That is, two treatments declared significantly different at a prescribed level of significance if their difference exceeds the computed LSD value. Otherwise they are not significant. LSD must be used only when the F-test for treatment effect is significant or computed F-value must be less than tabular value at specified probability level (Gomez, (1983). Coefficient of variance (CV %) is a measure of validity of field experiment. According to Gomez (1985), coefficient of variance (CV %) is classified as low (CV % < 10 %), medium (CV % between10 % and 20 %), high (CV % between 20 % and 30 %), very high (CV % > 30 %). The upper limit of CV % value for experimental research at 95 % confidence level was 22.54 % (Patel, 2000).

2.14. Economic Analysis

According to the FAO (2003) the benefits of reduced yield with higher water productivity needs to be measured by economic analysis before recommending deficit irrigation. New irrigation technology or practice can be evaluated in terms of its effects on the productivity, profitability, acceptability and sustainability of farming systems. Partial budget analysis is a method of organizing experimental data and information about the costs and benefits of alternative treatments. It is a way of calculating the total costs that vary and the net benefits of each treatment. Partial budget analysis is a simple but effective technique for assessing the profitability of new technology. It also provides the basis for comparing the relative profitability of alternative treatments, evaluating their riskiness, and testing how robust profits are in the event of changing product or input prices (CIMMYT, 1988). The International Wheat and Maize Improvement Center approach to the economic analysis of agronomic data, which utilizes partial budgeting combined with marginal analysis, is a sound and relatively simple method for developing a recommendation from agronomic data (Duncan *et al*, 1990).

The steps presented in the CIMMYT (1988) manual and used by agricultural scientists to develop recommendations for farmers are indicated below:

1. Preparation of a partial budget to estimate the net benefits arising from alternative treatments. For each treatment in the trial, including the control, the following values must be calculated on a per hectare basis:
    a. Value of production to the farmer (called gross field benefit)
    b. Value of all inputs which differ in kind or amount used across treatments (called total costs that vary)
    c. Calculation of the net benefit, the difference between a and b.
2. Identification of inferior treatments, i.e., those that involve higher cost but do not generate higher benefits (called dominated treatments).
3. Marginal analysis is used to assess relative profitability among alternative treatments.
   Non-dominated treatments are first ranked from lowest to highest in terms of total costs that vary. The ratio of additional benefits to additional costs between each pair of treatments is calculated. This ratio, expressed in percentage form, is called the marginal rate of return (MRR).
4. Identification of a candidate recommendation among the non-dominated treatments. This is the treatment which gives the highest net return and a marginal rate of return greater than the minimum considered as acceptable to farmers. This minimum rate of return reflects the opportunity cost of resources to the farmer, i.e., the return that can be earned in alternative activities.
5. Minimum returns determination as a guideline, an MRR of below 100 % is considered low and unacceptable to farmers. This is because such a return would not offset the cost of capital (interest) and other related transaction costs while still giving an attractive profit margin to serve as an incentive.

3. MATERIALS AND METHODS

3.1. Description of the Study Area

3.1.1. Location

The study was conducted at Goda kebele in Misrak Azernet Berbere Woreda in Silte Zone, SNNPR, Ethiopia, Located 221 km from Hawassa, capital of south regional state and about 52 km from Worabe to Kilto/capital city of woreda. The geographical location of study area was 7.854 °N latitude, 38.046 °E longitude and an altitude of 2300 m above mean sea level (Own GPS measured data) Figure 3.1.

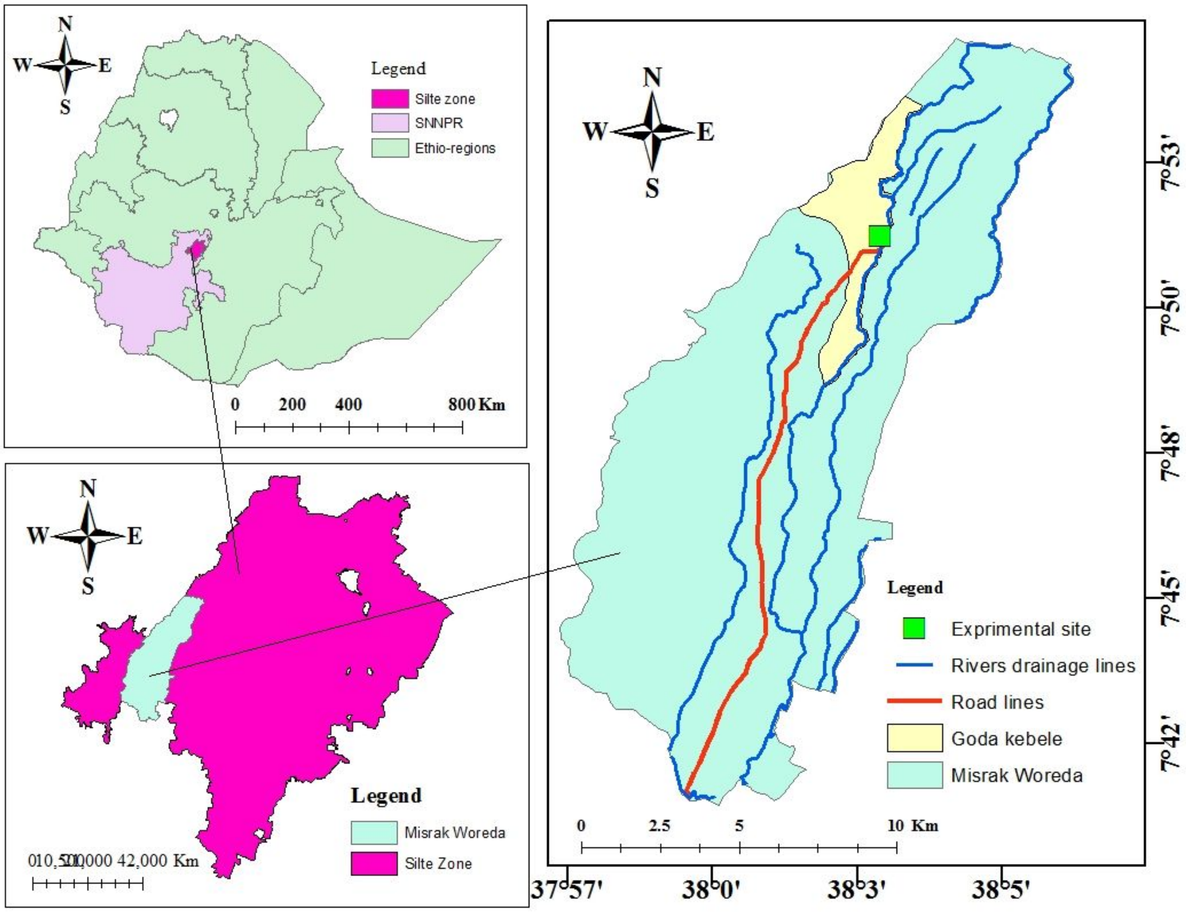
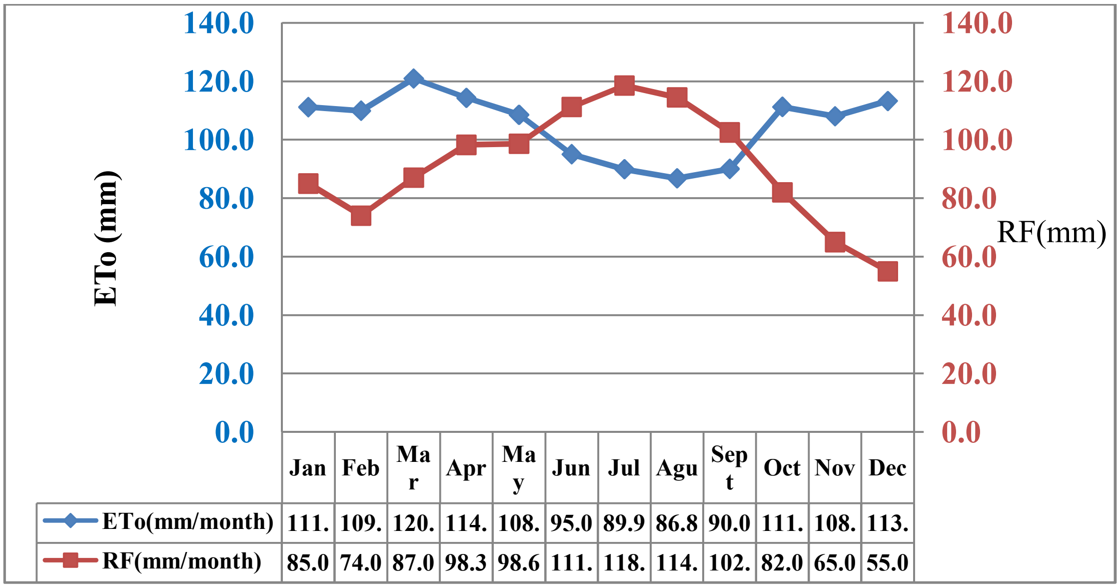


Figure 3.1: Location map of the study area

3.1.2. Climate

The average annual rainfall of the area varies from 600 to 1200 mm and seasonal rainfall pattern at the experimental area shows uni-modal distribution, which extends from half of April to early September with peaks rain fall in July. The mean annual minimum and maximum temperatures of the study area are 11 °C and 27 °C, respectively (Woreda Agricultural Office, 2010). As shown in the Figure 3.2, there is high evapotranspiration rate in the area throughout the year except from May to September.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Agu	Sept	Oct	Nov	Dec
ETo(mm/month)	111.	109.	120.	114.	108.	95.0	89.9	86.8	90.0	111.	108.	113.
RF(mm/month)	85.0	74.0	87.0	98.3	98.6	111.	118.	114.	102.	82.0	65.0	55.0

Figure 3.2 : Climatic water balance for ETo and Rainfall

3.1.3. Main Crops Grown and Agronomic Practices in the Study Area

Main Crops grown by irrigation in the study area are onion, potato, tomato, garlic and cabbage (Woreda Agricultural Office, 2010). The experimental area was kept weed free by hand digging and pulling three times throughout the cropping season starting from December to February which is being under practices in the study area. The areal recommended NPS (200 kg/ha) fertilizer was applied at transplanting and urea (200 kg /ha) was split applied during planting and 6 weeks after transplanting. Redomil Gold (3 liter/ha) and phenotrotine chemical were used, to safeguard the crop against fungus and harmful insects, respectively (Misrak Azernet Woreda Agricultural office, 2010).

3.2.Treatments Combination

The experiment was conducted from December to March 2017/18 and has 9 treatments including 20 % DI and 40 % DI throughout growth stages; 20% DI, 40% DI and 20% DI (i.e: in developmental, mid and late stages) respectively; 40% DI, 20% DI and 20% DI (i.e: in initial, developmental and late stages) respectively; 20% DI at each growth stages (i.e: in initial, developmental, mid and late stages) respectively and control (0 % DI). The treatments were arranged shown in Table 3.1 based (David *et al.,* 2016; Enchalew, 2016 and Teferi, 2015) recommendations. David *et al.* (2016) stated that 20% water stress saved 10.7% irrigation water without significantly affecting yield reduction.

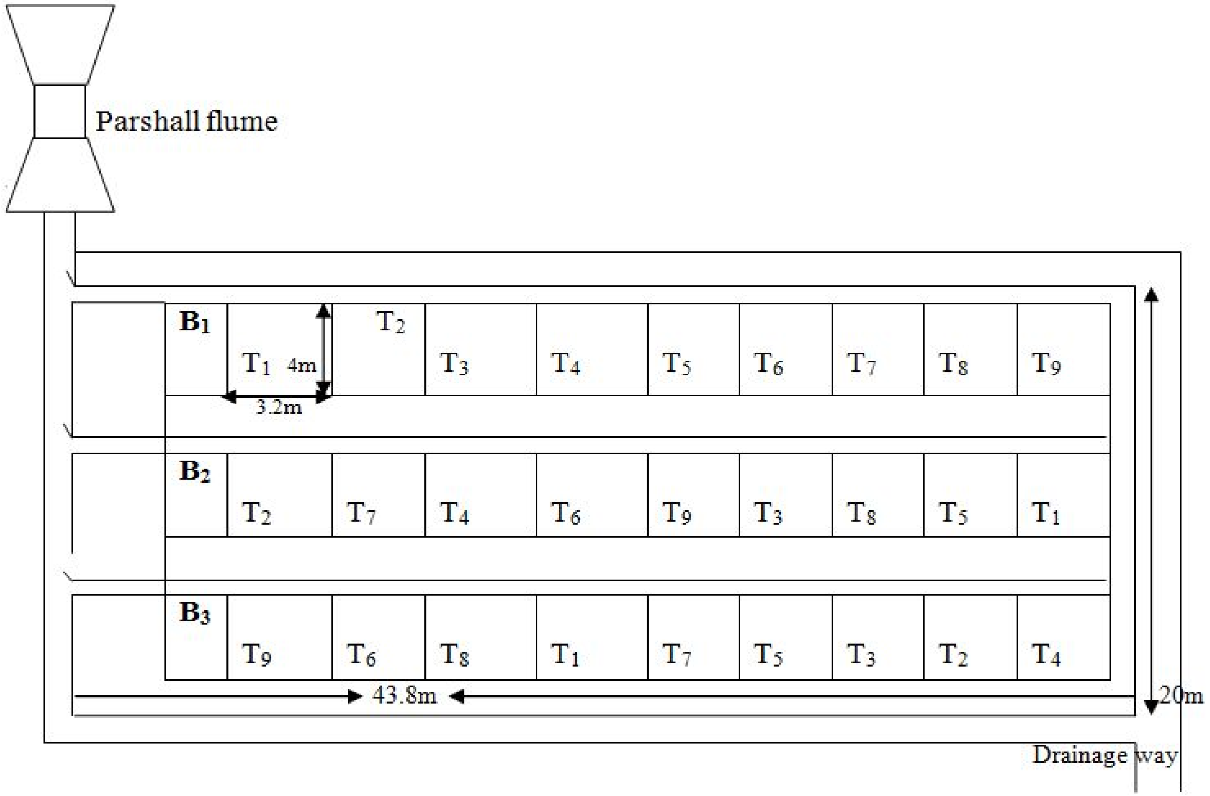
Table 3.1: Experimental Treatments Combination

Treatments	Growth stages			
	G_1	**G_2**	**G_3**	**G_4**
T_1	100% ET_c	100% ET_c	100% ET_c	100% ET_c
T_2	80% ET_c	80% ET_c	80% ET_c	80% ET_c
T_3	60% ET_c	60% ET_c	60% ET_c	60% ET_c
T_4	100% ET_c	80% ET_c	60% ET_c	80% ET_c
T_5	60% ET_c	80% ET_c	100% ET_c	80% ET_c
T_6	80% ET_c	100% ET_c	100% ET_c	100% ET_c
T_7	100% ET_c	80% ET_c	100% ET_c	100% ET_c
T_8	100% ET_c	100% ET_c	80% ET_c	100% ET_c
T_9	100% ET_c	100% ET_c	100% ET_c	80% ET_c

N.B: T_1 to $T_{9,}$ refered to treatments.

3.3. Experimental Design and Field Layout

The experiment was laidout in randomized complete block design (RCBD) with three replications in Figure 3.3.Total experimental treatments were 27 each had of 3.2 m by 4 m plot size. The spacing between plots and blocks were 1.5 m and 2 m, respectively and were used to surface draining and buffering plots and replications which protected excess flow of water to other plots field. The gross size of experimental site was 20 m by 43.8 m = 876 m^2 or 0.0876 ha. Burton (2010) stated that the lateral movement of water in the soil is significantly less than the vertical movement. Based on this recommendation the above buffer zone between plots and replications were considered satisfactory to eliminate influence of lateral water movement.



N.B: B_1, B_2 and B_3 are block numbers and each plot size was equal

Figure 3.3: Exprimental Field Layout

3.4. Onion Variety and Field Management

Bombay red Onion variety was used for this study. The variety was released by Melkassa Agricultural Research Center in 1980 (EARO, 2004). It has light red bulb skin color, dark green leaf color, flat globe bulb shape and reddish white bulb flesh color. The variety takes 110 − 120 days for bulb maturity. The seed was raised on nursery bed until transplanted on main field for 50 days and when they reached 12 − 15 cm height or 3 − 4 true leaves stage by carefully uprooting from nursery bed on December 10, 2017. One day before transplanting of seedlings, the nursery beds were irrigated for the safe uprooting of Onion. During planting only healthy, vigorous and uniform seedlings were transplanted. To ensure the plant establishment full irrigation was applied to all plots at two days interval, 7.76 mm of water for total of 8 days before beginning of the differential irrigation (EARO, 2004). As per EARO (2004) and FAO Paper No.33 by Doorenbos *et al.* (1986) onion is planted in flat ridges spacing of 40 x 20 x 10 cm (40 cm between furrow, 20cm between row on the bed of furrow and 10cm between plants respectively). Plants were grown in both ridges of furrow each plot had 8 rows and 80 plants per row.Total plants of 640 were cultivated per plot. At the end of each growth stage, 16 sample plants were used to analysis yield components:

Plant height(cm): 16 sample plants were selected from the interior rows to avoid border effect. The height of these 16 plants was measured from the soil surface to the tip of the plant using ruler and taken as an average .

Leaf numbers per plant: 16 sample plants were selected from the interior rows, the leaf number per plant of these 16 plants were measured by counting the whole health plant leaf of each from the bottom to the tip of the plant.

Bulb diameter (mm): randomly selected 16 plants sample bulbs measured at the middle portion of the mature bulb using a slide caliper.

3.5. Soil Sampling and Analysis

3.5.1. Soil Sampling

The soil samples were collected using ouger from experimental field diagonally from five points before starting of field preparation. Onion has shallow root system and its root reaches 50 cm horizontally and 60 cm vertically toward the soil (Jamal *et al*., 2000). The soil samples were collected based on the information from the field at 30 cm soil depth interval up to 60 cm (0 – 30 cm and 30 – 60 cm) and the collected samples were composite to one sample for each 30 cm interval. Undisturbed soil samples were collected for bulk density determination using core sampler of volume 98.125 cm^3.

3.5.2. Determination of Soil physical and Chemical Characteristics

Soil Texture

The soil texture of experimental site was determined by hydrometric appatus to each depth range. The textural class of the soil were determined using United States Department of Agriculture textural triangle method (USDA, 1999).

Field Capacity and Permanent Wilting Point:

The Field capacity (FC) and permanent wilting point (PWP) were determined using pressure plate and pressure membrane apparatus, respectively. Soil samples were saturated for one day (24 hrs) and a pressure of 1/3 bar and 15 bar were applied, respectively for FC and PWP, until no further change in soil moisture content is observed. Total available water (TAW) in mm was computed from the moisture content of field capacity and permanent wilting point using volumetric method in equation 3.1 below (Allen *et al.*, 1998).

$$\text{TAW} = \frac{(\Theta\text{FC} - \Theta\text{pwp})}{100} * D_r\ (\text{mm}) \qquad 3.1$$

where: Θ_{FC} and Θ_{pwp} are volumetric water content at field capacity and permanent wilting point (%) and D_r = the maximum effective root zone depth of onion (mm).

Bulk Density: It was determined from the undisturbed soil pits taken using cylindrical soil core sampler, and weighed directly after taking and oven dried at 105 ^{o}c for 24 hours. It is computed using equation 3.2 (Michael, 1997).

$$\text{BD} = \frac{\text{weight of dry soil}}{\text{volme of sample soil}} \left(\frac{\text{gm}}{\text{cm}^3}\right) \qquad 3.2$$

where: BD = the bulk density of the soil (gm/cm^3)

Soil pH: The soil pH was determined by measuring soil solution of 1:2.5, soil to water ratios with a pH meter. pH of the soil ranges (6.0 − 8.0) for Onion production (Olani and Fikre, 2010).

Organic matter: The percentage of soil organic carbon (SOC) was determined following the wet digestion method and Organic matter (OM) content was then determined by multiplying percentage SOC by 1.724 as described by (Nelson and Sommers, 1996). According to Howards (1990), the threshold value for most soils was at 2 % SOC (equivalent to 3.44 % SOM), below which most soils are laid to structural destabilization and crop yields are reduced.

Electrical conductivity (EC): The electrical conductivity (EC) of the soil was determined from the soil samples collected at the depth of 0 − 30cm and 30 − 60cm following the procedure given in Staney and Yerima (1992).

Infiltration Rate

Before the experimental work was started, soil infiltration rate was conducted using double ring infiltrometer for the total of 207 minutes (3 hours and 27 minute) continuously until the drop in water level over equal time interval remains the same and the depth of water levels infiltrated were measured at increasing time intervals starting from 1 second to 25 minute. The field test was conducted at three locations. Drop in water level in the inner ring was recorded using on the measuring rod and the level of water was brought back to approximately the original level to maintaining the water level outside the ring similar to the inside whenever the level of water drops to a level that may not be enough for next reading.

3.6. Reference Evapotranspiration and Crop Water Requirement

Periodic reference evapotranspiration (ET_o) for each day of climatic record was calculated by the modified FAO Penman-Monteith method using FAO CROPWAT 8.0 softwares. It the best method to determine CWR (crop water requirenment) because it concedered five imporatant climatic data such as: teprature, sun shine, humidity, radiation and windspeed (Allen *et al.,* 1998). The long term climatic data about four meteorological stations near to the study area (Wulbarag, Hosaina, Silti and Butajira) were collected from Ethiopian meteorological Agency Hawassa district and taken as monthly average for scheduling purposes.

Crop Water Requirement (CWR) is amount of water needed to crop to compensate the amount of water lost through evapotranspiration (ET_c) needs reference evapotranspiration (ET_o) and Onion crop coefficient (K_c) suggested by Allen *et al.* (1998), K_c for onion was 0.7 at initial stage, $0.7 < K_c < 1.05$ at development stage, 1.05 at mid-season stage and $0.95 < K_c < 1.05$ at late season stage. Crop water requirement (ET_c) was obtained using CROPWAT 8.0 software over the growing season to find ET_o and multiplied by K_c as:

$$ET_c = K_c \times ET_o \text{ (mm/day)} \qquad 3.3$$

The effective rainfall (p_e) of the area is determined using method gived by (Allen *et al*., 1998).

$$P_e = 0.6 * P - 10/3 \text{ for P monthly} \leq 70/3 \text{ mm or} \qquad 3.4$$

$$P_e = 0.8 * P - 24/3 \text{ for P month} > 70/3 \text{ mm}$$

$$IR_n = CWR - P_e$$

where: CWR = Crop water requirement (mm), P (mm) = total rain fall and IR_g = gross irrigation requirement. However ,since there was rainfall during the experimental period, p_e and IR_n values were determined using equation 3.4.

3.7. Gross Irrigation Requirement and Application Time

Gross irrigation requirement (IR_g) is the ratio of net irrigation to application efficiency of furrow irrigation (FAO, 2002). According to Raine and Bakker (1996), furrow irrigation application efficiencies normally vary from 45 – 60 %. The value of dg was computed by adopting a field application efficiency of 60 % to compensate maximum loss (FAO, 1989).

$$\mathrm{IRg} = \frac{\mathrm{IRn}}{\mathrm{E_a}} \,(\mathrm{mm}) \qquad 3.5$$

where: E_a = application efficiency (60 %)

Application Time $(\mathrm{t_a})$ **:** The scheduled amount of irrigation water applied to the plots was measured using a 3 inch throat width Parshall flume installed at the upper stream side near the experimental field. Accordingly, the time required to deliver the desired depth of water into each plot was calculated using the equation below (Kandiah, 1981).

$$\mathrm{t_a} = \frac{\mathrm{IR_g} * A}{6 * \mathrm{Q}} (\mathrm{min}) \qquad 3.6$$

Where: d_g = gross depth of irrigation water (cm), A = plot area (m^2), Q = flow rate (l/s) at 3 inch Parshall flume head and 6 is constant conversion factor.

3.8. Irrigation Scheduling

In sandy soils, plants may undergo water stress quickly, whereas plants in deep soils of fine texture may have ample time to adjust to low soil water matric potential, and may remain unaffected by low soil water content. Therefore, irrigation scheduling (when and how much to irrigate) is one of the most important tools for developing best management practices of irrigated agriculture (Jamal *et al.,* 1999; Olalla *et al.,* 1994). Proper irrigation scheduling results in high irrigation water use efficiencies necessary to conserve limited water resources.

3.9. Response of Crop to Deficit Irrigation Levels

3.9.1. Crop Water Productivity

The WUE is one of the most important indices for determining optimal water management practices. It quantifies the efficiency with which economic yield is produced as a function of water used by the crop in the field. Water productivity (WP) in this study was determined by dividing the Onion bulb yield to the net amount of irrigation water used by the crop as indicated by the following equation (Heydari, 2014; Ali *et al.,* 2007).

$$\mathrm{CWP} = \frac{\mathrm{Yield}}{\mathrm{ET_c}} \left(\frac{\mathrm{kg}}{\mathrm{m^3}}\right) \tag{3.7}$$

Where: CWP is crop water productivity (kg m^{-3}), yield (kg ha^{-1}) and ET_c is consumptive water used (m^3/ha).

3.9.2. Yield Response Factor

The yield sensitivity to water stress was quantified by relating the relative yield decrease to relative evapotranspiration deficit, an empirically derived yield response factor, calculated by equation 3.9 (FAO, 2002).

$$1 - \frac{Y_a}{Y_m} = K_y\left(1 - \frac{ET_a}{ET_m}\right) \tag{3.8}$$

where: K_y = yield response factor, Y_a = actual Onion bulb yield (kg/ha), Y_m = maximum Onion bulb yield obtained from the control (kg/ha), ET_a = actual evapotranspiration/net irrigation depth applied to each treatment (mm) and ET_m = maximum evapotranspiration/ net irrigation depth applied to the control (mm).

3.10. Onion Yield and Yield Components of Data Collection

Data recorded at the end of each growth stage were plant height and number of leaves per plant. These were collected from 12 random tagged plants of 6 centeral rows excluding 2 border rows at the end of each growth stages. Plant height was taken by measuring the main stem height from the ground level up to the tip of the leaf with the ruler expressed in centimeter (EARO, 2004). All completely developed leaflets were counted and recorded per plant. Bulb yield was collected and weighed from the 6 central rows of each plot by ignoring two border rows to avoid boarder effects. The harvested yield data from each plot was then expressed as tone per hectare (ton/ha).

3.11. Statistical Analysis

The collected data were subjected to statistical analysis of variance (ANOVA) appropriate to RCBD using SAS software version 9.1. Whenever treatment effects were found significant, treatment means were compared using the least significant difference (LSD) method (Steel *et al.*, 1997). LSD is sintax in SAS software which is used to identify significant difference among treatment means. Simple correlation analysis was also used to determine the relationship among yield and yield components by following accepted guidelines for interpreting the correlation coefficient (Ratner, 2001):

1. 0 indicates no linear relationship.
2. +1 indicates a perfect positive linear relationship.
3. −1 indicates a perfect negative linear relationship.
4. Values between 0 and 0.3 (0 and –0.3) indicate a weak positive (negative) linear relationship.
5. Values between 0.3 and 0.7 (0.3 and −0.7) indicate a moderate positive (negative) linear relationship
6. Values between 0.7 and 1.0 (−0.7 and −1.0) indicate a strong positive (negative) linear relationship.

3.12. Economic Analysis

For economic evaluation of the costs and benefits associated with different treatments the partial budget technique was applied by following CIMMYT (1988) procedure on the yield results. Economic analysis was done using the existing market prices during crop was harvested. All costs and benefits were calculated on hectare basis in Ethiopian Birr (Birr/ha).

The different costs among the different treatments includes cost for irrigation water and labor cost to irrigate were the variable costs (VC). The adjusted yield was obtained by reducing the obtained yield by 10% as stated in CIMMYT (1988). The average local labor cost equal to 60 Birr/day was used. The farmer get price of onion during the harvesting season was 11 birr/kg and the price of tap water was 5 birr/1m^3 (Woreda tap water prices, 2010). But for this study economic analysis, half of tap water cost was used for irrigation water because there is no recommended irrigation water cost in the area. The net income (NI) was calculated by subtracting total variable cost (TVC) from total return (TR) as follows:

$$NI = TR - TVC \tag{3.9}$$

The dominant analysis procedure as detailed in CIMMYT(1988) was used to select potentially profitable treatments from the range of the tested. The selected and discarded treatments using this technique are referred to as undominated and dominated treatments, respectively. The undominated treatments were ranked from the lowest to the highest variable cost. For each pair of ranked treatments, % of marginal rate of return (MRR) was calculated by the following formula:

$$MRR = \frac{\Delta NI}{\Delta VC} * 100 \tag{3.10}$$

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

4. RESULT AND DISCUSSION

4.1. Soil Field Investigation Results

4.1.1. Soil Physical and Chemical Properties of Exprimental Site

The soil physical and chemical properties of the experimental site are in Table 4.1.

Table 4.1: Soil Physical and Chemical Characterized Parameters Results of Study Area

Soil properties		Soil depth (cm)				
		(0 − 30)	(40 − 60)	Average	Method	Optimum ranges for Onion
Particle size distribution	Sand (%)	35.23	34.5	34.86	Hydrometer and Sieve analysis(for course soil)	Clay loam (Olani and Fikre, 2010).
	Silt (%)	28.54	26.5	27.52		
	Clay (%)	36.23	39.0	37.6		
Textural class		Clay loam	Clay Loam	Clay Loam		
Bulk density(g/cm^3)		1.05	1.2	1.13	volumetric	1− 1.4gm/m^3 (Hunt and Gilkes, 1992)
FC(vol%)		28.93	26.5	27.7	Pressure Membrane	Depends up on soil types & moisture content
PWP(vol%)		14.02	13.8	13.91		
TAW (mm/m)		156.6	152.4	154.47	formula $\frac{(\theta FC-\theta pwp)}{100} * D_r$	
pH		7.2	7.5	7.35	pH-Meter	(6.0 − 8.0) (Olani and Fikre, 2010).
EC (dS/m)(1:2.5)		0.52	0.29	0.40	conductivity meter	≤ 4.3(FAO, 2002)
OM (%)		5.08	3.75	4.4	Titration	≤ 3.48 (Howards, 1990)

The result of the soil analysis from the experimental site showed that the average composition of sand, silt and clay percentages were 34.86 %, 27.52 % and 37.6 %, respectively. Thus, according to USDA (1999) soil textural classification, the dominant textural class of the experimental site was classified as clay loam. The top soil surface had slightly lower bulk density (1.05 g/cm^3) than the subsurface (1.2 g/cm^3) this might be due to high organic matter contents in the top soil surface. In general, the average soil bulk density (1.13 g/cm^3) which is below the critical threshold level (1.4 g/cm^3) for easy movement of air and water in soil for crop root growth and it was suitable for crop root growth (Hunt and Gilkes, 1992).

Moisture content at field capacity for the experimental site soil varied between 28.93% and 26.5 % for the soil depths considered 0 – 30 cm and 40 – 60 cm, respectively. Moisture content at permanent wilting point also showed variation with depth and the values range between 14.02% and 13.8 % for the soil depths considered. The higher value of total available water (TAW) obtained was associated with the higher clay content of the soil (USDA, 1998). The average soil pH value (7.35) was found within the recommended limit of (6.0 − 8.0) for onion production (Olani and Fikre, 2010). The average value of EC at 25°c obtained was (0.4 ds/m) which was lower than the standard EC rates stated in literature (FAO, 2002). Therefore, the soil was normal and salinity was not a problem of study area. The weighted average organic matter content of the soil was 4.4 % which was above the critical value of the soil for crop production equal to 3.4 % (Howard, 1990).

4.1.2. Infiltration Rate of Exprimental Site

The field measured infiltration rate by double ring infiltrometer results were presented in Appendix Table 1. The average infiltration and cumulative infiltration rate curves of the field were generated from field collected data in Figure 4.1. The basic infiltration rate in this study was about 6.72 mm/hr which means water layer of 6.72 mm on the soil surface will take one hour to infiltrate. In dry soils, water infiltrates rapidly and as more water replaces the air in the pores, the water from the soil surface infiltrates more slowly and eventually reaches a basic infiltration rate. According to FAO (1986) the infiltration rate ranges (2.5 to 15 mm/hr) for clay loam soil. The obtained results are within the range of the FAO (1986) reccomendation.

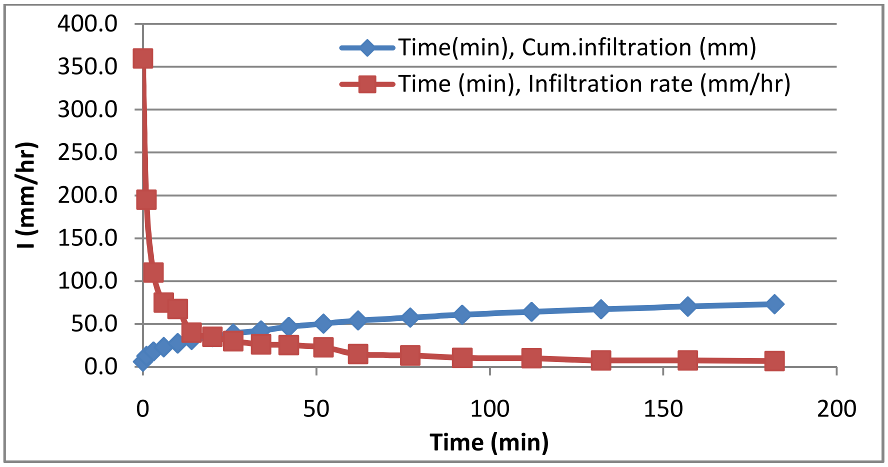


Figure 4.1: Soil infiltration rate and cumulative infiltration curves of experimental field

4.2. Determination of Reference Evapotranspiration

The long term monthly average climatic data of the experimental area was presented in Table 4.2. The result showed that reference evapotraspiration (ET_o) value of the site was minimum (2.8 mm/day) in july and maximum (4.2 mm/day) in March, respectively. Generally, if the evaporative power of the atmosphere was under (3 − 5 mm/day) range, it indicates that it is in a moderate range (Allen *et al*., 1998). The calculated IR_n value was 366 mm which is matched in range of stated by FAO (2010) for optimum onion yield production it requires 350 − 550 mm of water.

Table 4.2: Long term monthly average climatic data of the study area

	T_{min}	T_{max}	Hum	Wind	Sun	Rad	ET_o
Month	°C	°C	%	Km/hr	hr	MJ/m^2/day	mm/day
Jan	7.8	25.5	81.3	121.3	8.2	19.9	3.6
Feb	8.9	26.4	77.3	124.0	7.8	20.5	3.9
Mar	10.2	26.4	80.0	130.0	8.0	21.7	4.2
Apr	11.0	24.5	90.7	118.3	7.4	20.9	3.8
May	10.3	24.3	92.7	118.3	7.6	20.6	3.7
Jun	10.0	22.9	95.7	126.7	6.1	18.0	3.1
Jul	10.1	21.6	95.3	98.0	4.2	15.3	2.7
Agu	10.0	21.5	91.7	80.3	4.6	16.3	2.9
Sept	9.6	22.8	97.0	92.0	5.2	17.3	3.0
Oct	8.5	23.8	87.0	112.0	7.5	20.2	3.6
Nov	8.5	24.4	88.0	135.3	8.9	21.1	3.6
Dec	7.4	25.4	75.7	138.0	8.3	19.6	3.7

4.3. Irrigation water requirement and scheduling

The values of crop water requirement of onion was calculated by multiplying the referance evapotranspiration with crop coefficient. For the sake of time and labor shortage, daily ET_c value was scheduled to apply in four days irrigation interval; multiplying daily ET_c value by four. The determined ET_c values in Table 4.3 indicated that low at the beginning of the growing season, increasing gradually and attained a maximum during February and subsequently decreased. The values of IR_n, IR_g and irrigation scheduling at four days irrigation interval during the growing season were also presented in Table 4.3. There is the rainfall during experimental season in February and March which was substracted from scheduled ET_c value before applying irrigation into the field and only net irrigation requirement (IR_n) was applied to the intended treatments.

The result indicated that the maximum amount of crop water requirement was required at the mid stage of the onion.

Table 4.3: Irrigation requirement and scheduling of onion at four days interval.

Stages	Date	ETo (mm)	Kc	ETc (mm/d)	Eff.RF (mm)	IRn (mm)	IRg (mm)	IRg (cm)	t_a (min)
Initial	18-Dec	14.8	0.6	8.9	0	8.9	14.8	1.5	6
	22-Dec	14.8	0.6	8.9	0	8.9	14.8	1.5	6
	26-Dec	14.8	0.6	8.9	0	8.9	14.8	1.5	6
	30-Dec	14.8	0.6	8.9	0	8.9	14.8	1.5	6
	3-Jan	14.4	0.6	8.6	0	8.6	14.4	1.4	6
Development	7-Jan	14.4	0.8	11.5	0	11.5	19.2	1.9	8
	11-Jan	14.4	0.8	11.5	0	11.5	19.2	1.9	8
	15-Jan	14.4	0.8	11.5	0	11.5	19.2	1.9	8
	19-Jan	14.4	0.8	11.5	0	11.5	19.2	1.9	8
	23-Jan	14.4	0.8	11.5	0	11.5	19.2	1.9	8
	27-Jan	14.4	0.8	11.5	0	11.5	19.2	1.9	8
	31-Jan	14.4	1.1	15.8	0	15.8	26.4	2.6	11
Mid	4-Feb	15.6	1.1	17.2	0	17.2	28.6	2.9	12
	8-Feb	15.6	1.1	17.2	0	17.2	28.6	2.9	12
	12-Feb	15.6	1.1	17.2	0	17.2	28.6	2.9	12
	16-Feb	15.6	1.1	17.2	7	10.2	17.0	1.7	7
	20-Feb	15.6	1.1	17.2	0	17.2	28.6	2.9	12
	24-Feb	15.6	1.1	17.2	8	9.1	15.2	1.5	6
	28-Feb	15.6	1.1	17.2	0	17.2	28.6	2.9	12
	4-Mar	16.8	1.1	18.5	11.5	7.0	11.7	1.2	5
	8-Mar	16.8	1.1	18.5	8	10.4	17.4	1.7	7
Late	12-Mar	16.8	0.9	15.1	6	9.1	15.15	1.5	6
	16-Mar	16.8	0.9	15.1	0	15.1	25.2	2.5	10
	20-Mar	16.8	0.9	15.1	0	15.1	25.2	2.5	10
	24-Mar	16.8	0.9	15.1	0	15.1	25.2	2.5	10
	28-Mar	16.8	0.9	15.1	0	15.1	25.2	2.5	10
	1-Apr	4.2	0.9	3.8	0	3.8	6.3	0.6	3
	Total			366	40.65	324.9	541.55	54.2	220

t_a = time of application (min) based on schedule

4.4. Irrigation Water Applied For Each Treatment in Different Groth Stages

The net depth of irrigation water applied to the different treatments during the experimental period is shown in Table 4.4. The total net crop water requirement applied varied from the lowest 219.9 mm (T_3) to the highest 366 mm (T_1) without including common irrigation given during establishment period. The maximum total net depth of water was applied to the control treatment, which received 100 % ET_c at all growth stages, while the lowest was applied to the treatment which received 60 % ET_c all stages.

During the initial stage, lower depth of irrigation water of 37.6 mm was applied for the control treatment. As the crop canopy grew, the depth of water applied increased from 87.5 mm at development stage and reached its highest value of 160 mm. Irrigation water depth of 79.4 mm was applied during maturity stage for the control treatment. The irrigation water depth applied to each deficit treatments were in accordance with their percentage proportion set in this study. The result was agreed with range stated in FAO (2010) for optimum onion yield production it required 350 − 550 mm water.

Table 4.4: Net irrigation depth (IR_n) applied at each growth stage

	Growth stages				
Treatments	initial	development	mid	late	IR_n(mm)
T_1	37.6	87.5	162.0	79.4	366.4
T_2	30.0	70.0	129.6	63.5	293.1
T_3	22.5	52.5	97.22	47.6	219.9
T_4	37.6	70.0	97.22	63.5	268.2
T_5	22.5	70.0	162.0	63.5	318.0
T_6	30.0	87.5	162.0	79.4	358.9
T_7	37.6	70.0	162.0	79.4	348.9
T_8	37.6	87.5	129.6	79.4	334.0
T_9	37.6	87.5	162.0	63.5	350.5

4.5. Deficit Irrigation Effects on Plant Height and Leaves Number at Different Stages

The average plants height in various irrigation levels were different during all the four growth stages. The analysis in Table 4.5 generally indicated that plant height measured at the end of each growth stages, i.e. at 17, 46, 83 and 104 days after scheduling were significantly affected at ($P \leq 0.05$) whereas number of leave at these stages were slightly affected by varying irrigation levels.

In initial growth stage plant height measured was not significantly influenced in all treatments at ($P \leq 0.05$) except T_3 and T_5 in Table 4.5. During this stage, only T_5 and T_3 were resulted a significantly shorter plant height with (20.33cm and 21.66 cm), respectively than the others. Such results indicated that the trend of onion growth within each treatment was showed consistency except T_3 and T_5. Thus, the effect of soil moisture on plant height for T_2, T_4, T_6, T_6, T_7, T_8 and T_9 treatments should be ignored though they were statistically non significant as compared to T_1. The number of leaves per plant with different irrigation levels at initial stage were significantly affected T_3 and T_5 when compared with T_9 in Table 4.5. The highest leaf number per plant was observed in treatments T_9 (3.44). This variability may be resulted due to the lower initial moisture content in the field in T_3 and T_5.

In the Development growth stages, the statistical analysis of the data revealed that the different amounts of irrigation applications did not significantly affect the growth of the plant height except treatments T_3 and T_5 which had plant height of 29 cm and 35.88 cm, respectively. While the number of leaves per plant were significantly affected for this two treatments (T_3 and T_5) which had 4 cm and 4.47 cm respectively when compared with other treatments. The significant difference also occour between treatments T_3 and T_5. This difference was due to the highly diffiiciency of irrigation water in T_3.

In the mid growth stages, statistical analysis of the data show that the irrigation treatments significantly affected the growth of onion at ($P \leq 0.05$). At the end of this growth stage, 83 days after scheduling, the significant difference were observed in treatments (T_3, T_4 and T_5) with all other treatments but not with each other. The minimu and maximum plant height were recorded in T_1 and T_3, 67 cm and 49.67 cm, respectively. Statically significant difference in number of leaves per plant was also observed for treatments which has minimum and maximum value at T_3 and T_1 were 5 and 8, respectively.

At the end of the late season, analysis of the data revealed that the irrigation treatments at ($P \leq 0.05$) affected the growth of onion height in Table 4.5. The trend of growth of plants in all treatments at this stage has similar to the preceding growth stages. Statistically significant differences were observed in treatments T_3, T_5 and T_4 when compared with all other treatments but not with each other. At this stage, highest mean plant height (71.33 cm) was observed on plots that received full irrigation in T_1, while the lowest (53.67cm) was obtained at T_3.

Maximum number of leaves per plant was observed in treatments (T_1 and T_9) which had 9.67 cm and 8.833 cm respectively while minimum number (6.67) of leaves per plant was recorded in T_3. The result indicated that at the late growth stage, reduction of irrigation water levels did not significantly affected leaf number, since the crop was in maturity stage and did not use much water. But due to the difference in amount of irrigation level applied to T_3, cumulative effect of the moisture throughout the growing seasons, significant differences in plant growth were recorded.

In general, ph and lnpp increase when the amount of irrigation water increases. The results obtained were in agreement with observation of other irrigation studies on onion by different researchers. El-Oksh *et al.* (1993) reported that ph, leaf number, bulb weight increased with increasing of soil moisture level. Thabet *et al.* (1994) indicated that the number of leaves and bulb dry matter were increased by increasing irrigation. Similar recommendation was given by El-Haris and Razek (1997) revealed that growth characteristics, yield and yield components generally improved with the increased in total water applied during growing period. Metwally, (2011) indicated that the higher water supply resulted in higher vegetative parameters: Plant height, number of leaves per plant. Another result reported by Moshileh (2007) that with increasing soil water supply plant height, number of green leaves and bulb diameter were significantly increased in the tested growing stages.

Table 4.5: Effects of DI levels on ph and Lnpp at different growth stages of onion.

Treatments	**Growth Stages**							
	initial		**development**		**Mid**		**Late**	
	ph(cm)	Lnpp	ph(cm)	Lnpp	ph(cm)	Lnpp	ph(cm)	Lnpp
T_1	27.3^{a}	3.0^{ab}	39.7^{a}	5.2^{a}	67.0^{a}	8.0^{a}	71.3^{a}	9.7^{a}
T_2	27.3_{a}	3.1^{ab}	36.7^{ab}	4.7^{ab}	64.0^{ab}	7.0^{abc}	68.7^{a}	8.3^{bc}
T_3	21.7^{b}	2.8^{b}	29.0^{c}	4.1^{c}	49.7^{c}	5.3^{e}	53.7^{b}	6.7^{e}
T_4	27.7^{a}	3.3^{ab}	37.3^{ab}	4.7^{ab}	52.3^{c}	6.0^{cde}	56.3^{b}	7.7^{bcde}
T_5	20.3^{c}	2.8^{b}	35.9^{b}	4.5^{bc}	51.3^{c}	5.8^{de}	55.7^{b}	7.0^{de}
T_6	27.3^{a}	3.3^{ab}	37.3^{ab}	5.2^{a}	63.3^{b}	7.2^{ab}	68.0^{a}	7.4^{cde}
T_7	28.3^{a}	3.3^{ab}	37.4^{ab}	5.1^{a}	63.7^{ab}	6.8^{abc}	68.7^{a}	8.3^{bc}
T_8	27.0^{a}	3.3^{ab}	39.4^{a}	5.1^{a}	65.3^{ab}	7.5^{ab}	69.3^{a}	8.0^{bcd}
T_9	27.8^{a}	3.4^{a}	39.3^{a}	5.1^{a}	65.0^{ab}	7.5^{ab}	69.3^{a}	8.8^{ab}
Mean	25.1	3.1	36.9	4.8	67.5	7.5	64.6	8.0
LSD (5%)	3	0.7	3.3	0.5	3.4	1.1	4.0	1.3
CV	6.9	12.8	5.14	6.4	3.2	8.9	3.6	9.5

In Table 4.5, ph = plants height, lnpp = leaves number per plant, letters a, b, c, d and e indicates significance level at ($P \leq 0.05$). Means followed by the same letter in a column are non-significantly different with each other at a 5% probability level in (SAS 9.1).

4.6. Effects of Deficit Irrigation on Yield and Bulb Diameter of Onion

4.6.1. Deficit Irrigation Effects on Yield of Onion

The statistical analysis results in Table 4.6 indicated that bulb yield was significantly affected by the deficit irrigation levels at different growth stages at ($p \leq 0.05$). The highest bulb yield of 29.32 ton/ha was obtained was from the control treatment T_1 (0 % DI) which had significant difference with all other treatments except with treatment(T_9) that has 29.14 ton/ha in Table 4.6. While the lowest bulb yield 15.22 ton/ha was recorded from treatment T_3 which received 40% DI at all growh stages. This revealed that decreasing of irrigation levels at specific stage or throughout growth stages significantly effected yield of onion when compared with control treatment (T_1) which received full irrigation throughout growth stages but treatment T_9 which recieved 20 % DI at late growth stage has similar yield result to control treatment (T_1). This indicated that when onion approach to maturity it did not need much water because of 20% DI at late stage for T_9 and full irrigation for T_1 had insignificant yield difference. Samson and Ketema (2007) found that applying deficit irrigation in some growth stages of Onion did not significantly reduce bulb yield. Similar result was reported by Jamal *et al.* (2000) that Onion can grow to maturity under different soil moisture deficit condition but higher yields are generally associated with high irrigation depth that avoid any water stress particularly at bulb formation stage. The yield reduction were occurred in T_4 (17.35 ton/ha) which received maximum deficit at mid stage and T_5 (17.52 ton/ha) which received maximum deficit at initial stage when compared to full irrigation (T_1) which has 29.32 ton/ha. Kadayifci *et al.* (2005) confirmed that in order to obtain a high yield, water deficits should be avoided especially during initial and mid growth stages.

4.6.2. Deficit Irrigation Effects On Bulb Diameter of Onion

The different deficit irrigation levels had significantly affected onion bulb diameter at ($P \leq 0.05$). As shown in Table 4.6, the bulb diameter of T_3 had significantly different with all treatments except T_4 and T_5 whereas T_4 and T_5 had significantly different with all treatments except T_3, T_6, T_7 and T_9. Treatments T_1, T_2, T_6, T_7, T_8 and T_9 were not significantly different with each other. The hieghest and lowest bulb diameter 6.1 cm and 5.1 cm were recorded from T_1 and T_3, respectively. This implies that application of 40% DI throughout all growth stages had significantetly reduced bulb diameter. This result were agreement with conclusion made by David *et al.* (2016) that bulb size varied proportionally with the quantity of irrigation water applied (maximum bulb size from the 100 % of ET_c and minimum bulb size from 50 % of ET_c).

Table 4.6 : Effects of DI on Yield and Bulb Diameter

Treatments	Yield (ton/ha)	Bulb Diameter (cm)
T1	29.32^{a}	6.10^{a}
T2	28.56^{b}	5.98^{ab}
T3	15.22^{d}	5.10^{d}
T4	17.35^{c}	5.34^{cd}
T5	17.53^{c}	5.47^{bcd}
T6	28.63^{b}	5.67^{abc}
T7	28.58^{b}	5.77^{abc}
T8	28.62^{b}	6.05^{a}
T9	29.14^{ab}	5.85^{abc}
CV	1.370	5.490
LCD(0.05)	0.60	0.54

The letters a, b, c and d indicates means significant level at ($P \leq 0.05$). Treatments having similar letter in a column refered as non-significant different with each other at a 5 % probability level while treatment having different letter in a column refered as significant different with each other at a 5 % probability level in (SAS 9.1).

4.7. Water Productivity

The analysis shown in Table 4.7 indicated that there is significant difference at ($P \leq 0.05$) on WP of the various deficit irrigation levels. Applying 80% of ET_c (T_2) throughout the whole growth season resulted highest water productivity (9.9 kg/m^3). While the lowest WP (6.14 kg/m^3) was obtained from T_5 which received water deficit levels of 60%, 80%, 100% and 80% of ET_c at initial, development, mid and late stages, respectively. Besides this higher WP was obtained from treatments supplied 20% of ET_c than full irrigation ($T`_1$). This shows that the onion was more efficient in using 20% of ET_c than full irrigation to save water and obtain optimum yield.

The analysed result presented in Table 4.7 show that the WP increment for treatments T_2, T_8 and T_9 indicated 24.53, 5.05 and 3.03% higher WP value than T_1 respectively. In treatment T_2, 20% water was saved with 3.9% yield reduction in comparison with full irrigation. This shows that increasing the areas irrigated with the saved water could compensate for any yield loss due to deficit irrigation. For instance, in T_2 the water saved could compensate the yield reduction due to 20% DI throughout growth stages and produced 7.10 ton more yield by cultivating additional 0.25 ha of land. In addition, treatments T_6, T_7, T_8 and T_9 could produce additional yield (6, 0.57, 1.61 and 0.93 ton) than full with the saved water, respectively. Inspite of the fact that there were other treatments with greater percent of saved water but only treatments with higher WP than the control could compensate for the yield reduction. Therefore, it was observed that there is not only the difference in deficit irrigation levels which resulted in higher WP but also the irrigation application on growth stage was observed to be the main determinant factor.

The result is in agreement with the study by David *et al.,* (2016) who concluded that DI at vegetative and late growth stages influence yields in a positively. Thus 20% of ET_c water stress throughout growth stages saved 10.7% irrigation water and onion bulb production at this level of water insignificant effect on yields. Similar results was observed by Mandal *et al*. (2005) who found higher water productivity values obtained under deficit irrigation condition than full irrigation, especially when irrigation is applied in the critical growth stages. The letters a, b, c, d e and f in Table 4.7 analysed indicated significance level at $P \leq 0.05$. Means followed by the same letter in a column are not significantly different from each other at a 5% probability level.

Table 4.7 : Influence of DI levels on water productivity

Treatments	WP (kg/m^3)	Relative water saved (%)	Relative yield reduction (%)	Additional area cultivated by saved water (ha)	Additional yield obtained by saved water (ton)	WP increment (%)
T_1	8.00^c	0	0	0	0	0
T_2	9.90^a	20.0	3.90	0.25	7.10	24.53
T_3	7.00^e	40.00	48.24	0.67	10.20	-12.44
T_4	6.20^f	27.0	40.41	0.37	5.81	-22.52
T_5	6.14^f	13.00	32.23	0.15	2.43	-32.04
T_6	7.60^d	2.00	2.61	0.02	0.60	-0.5
T_7	7.90^{cd}	5.00	3.15	0.05	1.50	-0.90
T_8	8.40^b	9.00	2.40	0.10	2.80	5.03
T_9	8.20^{bc}	4.00	0.98	0.04	1.22	3.03

The letters a, b, c, d, e and f indicated means significant level at ($P \leq 0.05$). Treatments having similar letter in a column refered as non-significant different with each other at a 5% probability level while treatment having different letter in a column refered as significant different with each other at a 5% probability level in (SAS 9.1).

4.8. Net Crop Water Requirement, Yield and Water Productivity Relationship

The result of Net Crop Water Requirement (IRn), Yield and Water Productivity (WP) relationship presented in Figure 4.2 shows that the amount of irrigation water has positive effect on yiled and WP. Specially, in T_2 has higher WP than all other treatments. Low amount of WP was obtained from treatment T_5. Therefore, result indicated that onion is not tolerate to maximum deficit irrigation at initial and development stages to produce optimum yield.

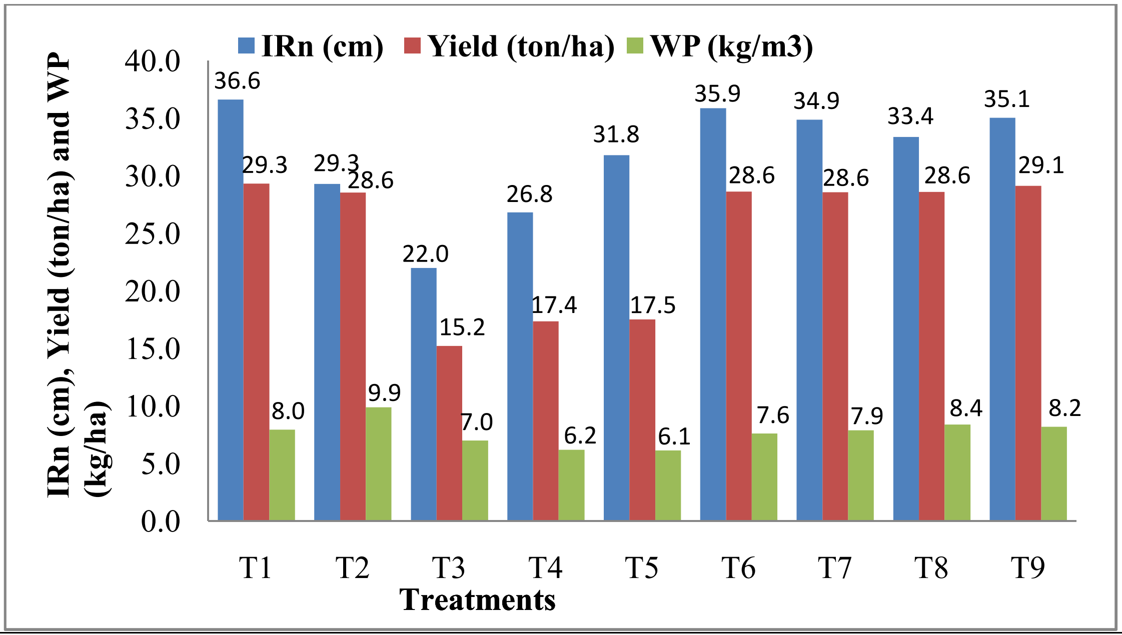


Figure 4.2 : Net crop water requirements, yield and water productivity relationship

4.9. Yield Response Factor

The analysis of yield response factor (K_y) presented in Table 4.8 has highest K_y equal to 2.44 obtained from trearment T_5 and the lowest K_y was 0.13 recorded at T_2, followed by 0.14, 0.30 and 0.53 obtained from T_9, T_8 and $T_{7,}$ respectively. The result indicated that water stress at initial and development stage resulted in very noticeable decrease in yield compared to the other stages with the similar deficit level. At 20% DI throughout growth stages did not resulted in significant yield reduction. This shows that deficit irrigation levels distributed at different growth stages could tolerate yield reduction. The K_y value greater than one indicated that the relative yield decrease was higher than the water deficit levels (Smith *et al*., 2002). According to this limitation, the result obtained in this study indicated that there is the risk when the water deficit level above 20% DI throughout growth stages or one of the growth stages. But there is no significant effect on yield when applying 20% DI level ethier in all stages or one of growth stages.

Table 4.8: Relationship Relative Water use, Decrease in Relative yield and K_y values

Treatmentsts	Relative Yield reduction (%)	Relative water deficit (%)	K_y
T_1	0	0	0*
T_2	2.60	20.00	0.23*
T_3	48.08	40.00	1.20
T_4	40.83	26.80	1.52
T_5	32.23	13.20	2.44
T_6	2.36	2.00	1.15
T_7	3.15	4.85	0.53*
T_8	2.39	8.80	0.30*
T_9	0.98	4.10	0.14*

* = indicates K_y value less than one

4.10. Correlation Between Yield and Bulb Diameter of Onion

The result in Table 4.9 showed that there is a visible relationship of the yield and bulb diameter with each other. Accordingly, bulb diameter (r = 0.68*), plant height at initial stage (r = 0.67*) and plant height at development stage (r = 0.58*) had moderate positively linear relationship at ($p \leq 0.05$) with bulb yield. Plant height at mid stage (r = 0.82**) and late stage (r = 0.82**) had strong positively linear relationship at ($p \leq 0.05$) with yield whereas ET_a had strong positively linear relationship at ($p \leq 0.05$) with yield and bulb diameter. This indicated that various DI levels at different growth stages had an effect on yield and bulb dimeter of onion. This result was in agreement with study result of Teferi (2015) he concluded that all yield parameters such as plant height, leaf number per plant and irrigation water level in all stages were positively correlated at ($p \leq 0.05$) with onion yield. A similar study by Metwally (2011) stated that plant height and bulb diameter had positive and significant correlated with yield of onion. Abdel El-Hady *et al*. (2015) found that there is a significant and positive correlation between bulb diameter and bulb yield of onion.

Table 4.9 : The correlation matrix of onion yield and yield components

	PH_1	PH_2	PH_3	PH_4	BY	BD	ET_a
PH_1	1.00						
PH_2	0.58*	1.00					
PH_3	0.67*	0.55*	1.00				
PH_4	0.67*	0.53*	0.99**	1.00			
BY	0.67*	0.58*	0.82**	0.82**	1.00		
BD	0.29w	0.28w	0.34*	0.32*	0.68*	1.00	
ET_a	0.45*	0.71**	0.77**	0.77**	0.75**	0.72**	1.00

* = moderate positively linear relationship at ($P \leq 0.05$), ** = strong positively linear relationship at ($P \leq 0.05$), w = weak positively linear relationship ($P \leq 0.05$), PH_1, PH_2, PH_3 and PH_4 are Plant height at initial, development, mid and late stages, respectively, BY = bulb yield, BD = Bulb diameter and ET_a = actual irrigation water level.

4.11. Economic Analysis of Stage Based Deficit Irrigation

As per the procedure needed for economic analysis and the result presented in Table 4.10, the highest and lowest variable cost 18,321 and 10,992.5 ETB were invested for treatments T_1 and T_3, respectively. All the remaining treatments were included between these two treatment ranges. The highest MRR of 13674% was obtained from treatment T_9. The highest NI was obtained from T_1 which had maximum MRR (3554%) next to T_9 (13674%) and T_2 (5783%). This indicates that for every one Birr invested in using treatments T_9, T_2 and T_1 farmers can expect to recover their one birr and obtain an additional 136.74, 57.83 and 35.53 ETB respectively. This shows that T_9 was the most economically attractive treatment with lower cost of production and higher benefit. This could be because of that T_9 had experienced with 20% DI water stressed at late growth stage of onion, thus resulted with better bulb yield and benefit-cost ratio compared to treatment T_1.

On the other hand, the lowest benefit-cost ratio and MRR of 23.3 and 304% were obtained from T_5. While treatments T_6, T_7 and T_8 were dominated and signed as "D" and finally they were not considered for further analysis of MRR.

Based on results in Table 4.10, T_1 consumed highest water (366.42 mm) and produced maximum yield (26388 kg/ha) while the lowest water applied (219.85 mm) for treatment T_3 has yield

(13701 kg/ha). The applied water difference between treatments (T_1) and (T_3) was (1465.7 m^3). If it is considered to produce additional yield by this saved water, the produced yield could be (10.18 ton). Even though, we have obtained a higher yield from T_1 and maximum water saved from T_3, they both are not economically feasible. To improve farmers' income, it is important to pay attention on net benefits and WP rather than yields because higher yield does not necessarily mean that it has high net benefit and WP.

Table 4.10 : Economic Analysis of Bulb Yield for Different Irrigation Treatments

Treatment	AW/ha m^3	Yield Kg	Adjusted Yield (kg)	TR birr/ha	VC birr/ha	NI birr/ha	B/C constant	MRR %
T_3	2199	15223	13701	150708	5496	145212	26.40	2642
T_4	2682	17350	15615	171765	6706	165059	24.60	1641
T_5	2856	17527	15774	173517	7140	166377	23.30	304
T_2	2931	28557	25701	282714	7329	275386	37.60	5783
T_8	3340	28620	25758	283338	8350	274988	32.90	D
T_7	3489	28583	25725	282972	8723	274248	31.44	D
T_9	3505	29143	26229	288516	8764	279752	31.90	13674*
T_6	3589	28627	25764	283407	8973	274435	30.60	D
T_1	3664	29320	26388	290268	9161	281108	30.70	3554

* = treatment having high MRR, AW = Applied water, ha = Hectare, and D = Dominated treatment; the onion bulb yield was adjusted by 10% adjustment coefficient. During the field harvesting season, the market price of onion and tap water of the area were 11 birr/kg and 2.5 birr/m^3 respectively (assuming half of tap water cost as irrigation water cost).

Therefore, the result obtained from T_9 in hectare based consumed 3505 m^3/ha had produced 279752 birr/ha net benefit and MRR (136.74) found to be economically feasible. Treatment T_2 had highest cost benefit ratio (37.6) and has MRR (57.83) next to T_9. This result is agreed with the research result obtained by Teferi (2015) who reported that 20% DI at late stage has highest net benefit and MRR.

5. SUMMARY, CONCLUSIONS AND RECOMMANDATIONS

5.1. Summary and Conclusions

Water is becoming an economically scarce resource not only in arid and semi-arid areas but also in regions where rainfall is abundant. Its scarcity may be due to different natural and human-induced factors. Agriculture under unfavorable climatic conditions and limited water resources cannot be profitable investment unless on-farm water management techniques could be designed to meet present and future growing demands of water for food production. DI is a technology introduced mainly to improve water productivity by exposing crops to certain levels of water stress either during specific growth stage or throughout the whole growing seasons. It enabled farmers to use their scarce water resources effectively. DI technology needs to be tested under different crop type, crop variety and local environment. In this study, onion was test crop for deficit irrigation practice for one growing season because it was potentioally grown crop in Misrak Azernet Berbere Woreda, Silte Zone, SNNPR, Ethiopia.

The experiment contained combination of nine treatments including: control (0% DI); 20% DI and 40% DI levels throughout the growth stages; 0% DI, 20% DI, 40% DI and 20% DI (i.e: in initial, developmental, mid and late stages) respectively; 40% DI, 20% DI, 0% DI and 20% DI (i.e: in initial, developmental, mid and late stages), respectively and 20% DI at each growth stages (i.e: in initial, developmental, mid and late stages), respectively were laid out in RCBD replicated three times.

The field study result revealed that the variation of irrigation levels significantly affected onion yield and yield components. When water stress was imposed at T_2 and T_9 had higher bulb yield were obtained. High water stress during the initial and development growth stages could be avoided since it was critical period of irrigation for onion bulb formation. During these periods the onion water need was high and it cannot resist water stress without significant reduction on yield. Supplying full water requirement T_1 could not advisable because it has low water productive, MRR and benefit cost ratio than T_2 and T_9, respectively. 40 % DI throughout the season results in highest yield reduction per water deficit.

This study also showed that 20% DI applications throughout the growing season (T_2) gave maximum WP (9.9 kg/m^3) than all other treatments including control and T_9 also had maximum WP (8.40 kg/m^3) next to T_2 . This indicated that increasing the areas irrigated with the saved water would compensate for any yield loss due to 20% DI thoughout season (T_2) and 20% DI at lategrowth stage (T_9). While the minimum WP (6.1 kg/m^3) was obtained at (T_5) which was deficited (40% DI at initial, 20% DI at development, 0% DI at mid and 20% DI at late) stages. In the case of partial stress in different growth stages especially for treatments T_4 (6.20 kg/m^3) and T_5 (6.14 kg/m^3) had low water WP which showed that the amount of the saved water did not compensate the amount of the yield reduced due to deficit irrigation. Applying 40% DI level throughout the growing season resulted in 48% yeld reduction and 2.9 kg/m^3 lower WP than the full irrigation. This suggested that increasing the areas irrigated with the saved water would not compensate for any yield loss due to 40% DI throughout season compared to full irrifation and 20% DI at late growth stage. Therefore, it was not applicable to use deficit irrigation level at 40% DI and below it.

A maximum bulb yield of 29.32 ton/ha was obtained under full irrigation when onion was not subjected to any water stress throughout growing seasons. Similar yield production were observed in T_9 and T_2. Stressing the onion by 40% DI throughout results in minimum yield (15.22 ton/ha). While stressing onion by 40% DI at mid growth stage (T_4) and 40% DI at initial growth satge (T_5), repectively had higher yield reduction following 40% DI throughout season. This indicates that onion was very sensitive to water stress during the initial and mid stages than other stages. Even though, the yield and water productivity differences are significant between T_1 and T_2 distributed throughout the growing seasons, adopting the 20% DI throughout the growing season saved 732.8 m^3 amount of water per hectare which is sufficient to produce 7.14 ton yield from additional 0.25 ha land. By producing more yields with less water, saved water could be available to irrigate additional land in water scarce area.

The highest bulb yield was obtained from full irrigation (T_1). The highest WP was obtained from 20% DI of CWR throughout growth stages (T_2). Based on the partial budget analysis, the highest MRR was obtained from T_9 (13674%) which received 20% DI at late growth stage with net income of 279752 birr/ha. Therefore, it can be recommended that 20% DI of CWR at late growth stage in 4 days irrigation interval is benifical for obtaining optimum Onion yield, incresase water productivity and brings higher economic return under scarce water condition. The farmers in scarce water resource area could also be used 20% DI of CWR throughout growth stages as option to increase water productivity and cultivate additional land with save water.

5.2. Recommandations

Based on the results obtained from one cropping season, the following recommendations could be made:

- Applying 20% DI of CWR at late growth stages (T_9) has insignificant yield difference and WP compared to full irrigation (T_1) and it gave high MRR (13673.2%). Therefore, adopting 20% DI level in late growth stage is recommended for the farmers in the study area to save scarce water and increase WP.
- The WP (9.9 kg/m^3) and MRR (5783%) obtained from T_2 (20% DI of CWR throughout growth stages) has higher than full irrigation (T_1) having WP (8.0 kg/m^3) and MRR (3554%). The farmers in water scarce area could also be advised to used T_2 (20% DI of CWR throughout growth stages) as option.
- The test crop considered here was onion for one year in one station, repeated study over locations and years is necessary to confirm this study result.
- Nonethless, further study should be made to crops like potato, tomato and maize because they are also widely growing at the study area.

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7. APPENDICES

List of Appendix Tables

Table 1. Soil infiltration rate measured value (mm/hr)

No.	Time (min)	Time Difference (min)	Com Time (min)	Reading After filling (cm)	Reading (cm)	Difference (cm)	Cum Infiltration (mm)	Infiltration Rate (mm/hr)
1	4:46		1	14			0	
2	4:48	1	2		13.4	0.60	6.0	360
3	4:50	2	4		12.75	0.65	12.5	195
4	4:54	3	7		12.2	0.55	18.0	110
5	4:58	4	11		11.70	0.50	23.0	75
6	5:06	4	15	14.0	13.55	0.45	27.5	67.5
7	5:14	6	21		13.15	0.40	31.5	40
8	5:22	6	27		12.8	0.35	35.0	35.0
9	5:32	8	35		12.40	0.40	39.0	30.0
10	5:42	8	43		12.05	0.35	42.5	26.25
11	5:52	10	53		11.63	0.42	46.7	25.2
12	6:07	10	63	14	13.62	0.38	50.5	22.8
13	6:22	15	78		13.25	0.37	54.2	14.8
14	6:42	15	93		12.92	0.33	57.5	13.2
15	7:02	20	113		12.57	0.35	61.0	10.5
16	7:22	20	133		12.24	0.33	64.3	9.9
17	7:47	25	158		11.93	0.31	67.4	7.44
17	8:07	25	183		11.65	0.28	70.2	6.72
18	8:32	25	208		11.37	0.28	73.0	6.72

Table 2. Discharge values for different head values of 3 inch Parshall flumes

Head (cm)	Thought width (inches)				
	1	2	3	6	9
	Discharge (l/s)				
2	0.140	0.281			
3	0.263	0.772	**0.526**	1.496	2.504
4	0.411	0.822	1.206	2.357	3.889
5	0.581	1.162	1.705	3.354	5.471
6	0.771	1.541	2.261	4.473	7.232
7	0.979	1.957	2.872	5.707	9.155
8	1.205	2.407	3.532	7.047	11.231
9	1.446	2.889	4.239	8.489	13.448
10	1.702	3.402	4.991	10.027	15.801
11	1.973	3.943	5.786	11.656	18.281
12	2.258	4.513	6.621	13.374	20.885
13	2.557	5.109	7.496	15.177	23.605
14	2.868	5.731	8.408	17.062	26.440
15	3.191	6.377	9.358	19.027	29.383
16	3.527	7.048	10.342	21.070	32.433
17	3.875	7.743	11.361	23.188	35.585
18	4.234	8.460	12.413	25.38	38.837
19	4.604	9.200	13.499	27.643	42.186
20	4.985	9.961	14.616	29.976	45.630

Table 3. Analysis of variance for plant height (cm) at initial stage

Source	DF	TSS	MS	F_{cal}	F_{crit}	$F_{cal} > F_{crit}$
REP	2	5.019	2.5093			
TRT	8	206.185	25.77	27.84*	2.64	SD
Error	16	14.815	0.926			
Total	26	226.019				

*Significant ($p \leq 0.05$), SD = significant difference among Treatment mean, F_{cal} = calculated Fvalue and F_{crit} = critical value read from table.

Table 4. Analysis of variance for number of leaves per plant at initial stage

Source	DF	SS	MS	F_{cal}	F_{crit}	$F_{cal} > F_{crit}$
REP	2	0.166	0.083			
TRT	8	1.23127	0.1539	1.82	2.64	NSD
Error	16	1.35637	0.0847			
Total	26	2.75347				

NSD = Non significant difference among Treatment mean ($p \leq 0.05$)

Table 5. Analysis of variance for plant height (cm) at developmental stage

Source	DF	SS	MS	F_{cal}	F_{crit}	$F_{cal} > F_{crit}$
REP	2	3.799	1.899			
TRT	8	251.58	31.454	8.76*	2.64	SD
Error	16	57.466	3.5917			
Total	26	312.851				

* Significant ($p \leq 0.05$) and SD = significant difference among Treatment mean

Table 6. Analysis of variance for number of leaves per plant at developmental stage

Source	DF	SS	MS	F_{cal}	F_{crit}	$F_{cal} > F_{crit}$
REP	2	0.07916	0.03958			
TRT	8	3.08692	0.38586	4.08*	2.64	SD
Error	16	1.51357	0.09460			
Total	26	4.67965				

* Significant ($p \leq 0.05$) and SD = significant difference among Treatment mean

Table 7. Analysis of variance for plant height (cm) at mid stage

Source	DF	SS	MS	F_{cal}	F_{crit}	$F_{cal} > F_{crit}$
REP	2	53.4074	26.703			
TRT	8	1150.074	143.759	37.96*	2.64	SD
Error	16	60.5925	3.787			
Total	26	1264.074				

* Significant ($p \leq 0.05$) and SD = significant difference among Treatment mean

Table 8. Analysis of variance for number of leaves per plant at mid stage

Source	DF	SS	MS	F_{cal}	F_{crit}	$F_{cal} > F_{crit}$
REP	2	0.2962	0.14814			
TRT	8	18.9629	2.37037	6.46*	2.64	SD
Error	16	5.87037	0.36689			
Total	26	25.1296				

* Significant ($p \leq 0.05$) and SD = significant difference among Treatment mean

Table 9. Analysis of variance for plant height (cm) at late stage

Source	DF	SS	MS	F_{cal}	F_{crit}	$F_{cal} > F_{crit}$
REP	2	34.89	17.444			
TRT	8	1207.33	150.917	27.93*	2.64	SD
Error	16	86.44	5.403			
Total	26	1328.67				

* Significant ($p \leq 0.05$) and SD = significant difference among Treatment mean

Table 10. Analysis of variance for number of leaves per plant at late stage

Source	DF	TSS	MS	F_{cal}	F_{crit}	$F_{cal} > F_{crit}$
REP	2	2.296	1.148			
TRT	8	21.129	2.641	4.43*	2.64	SD
Error	16	9.537	0.5960			
Total	26	32.96				

* Significant ($p \leq 0.05$) and SD = significant difference among Treatment mean

Table 11. Analysis of variance for bulb diameter(cm)

Source	DF	SS	MS	F_{cal}	F_{crit}	$F_{cal} > F_{crit}$
REP	2	0.07209	0.03604			
TRT	8	2.97247	0.37156	3.80*	2.64	SD
Error	16	1.56604	0.09788			
Total	26	4.61060				

*Significant ($p \leq 0.05$) and SD = significant difference among Treatment mean

Table 12. Analysis of variance for bulb yield (ton/ha)

Source	DF	SS	MS	F_{cal}	F_{crit}	$F_{cal} > F_{crit}$
REP	2	0.997	0.499			
TRT	8	891.19	111.40	965.35**	2.64	SD
Error	16	1.846	0.115			
Total	26	894.04				

**Highly Significant ($p \leq 0.05$) and SD = Significant difference among Treatment mean

Table 13. Analysis of variance for water productivity

Source	DF	SS	MS	F	F_{crit}	$F_{cal} > F_{crit}$
REP	2	0.0741	0.03704			
TRT	8	32.8841	4.11051	110.98**	2.64	SD
Error	16	0.5926	0.03704			
Total	26	33.5507				

**Highly Significant ($p \leq 0.05$), SD = Significant difference among Trt mean

List of Appendix Figures

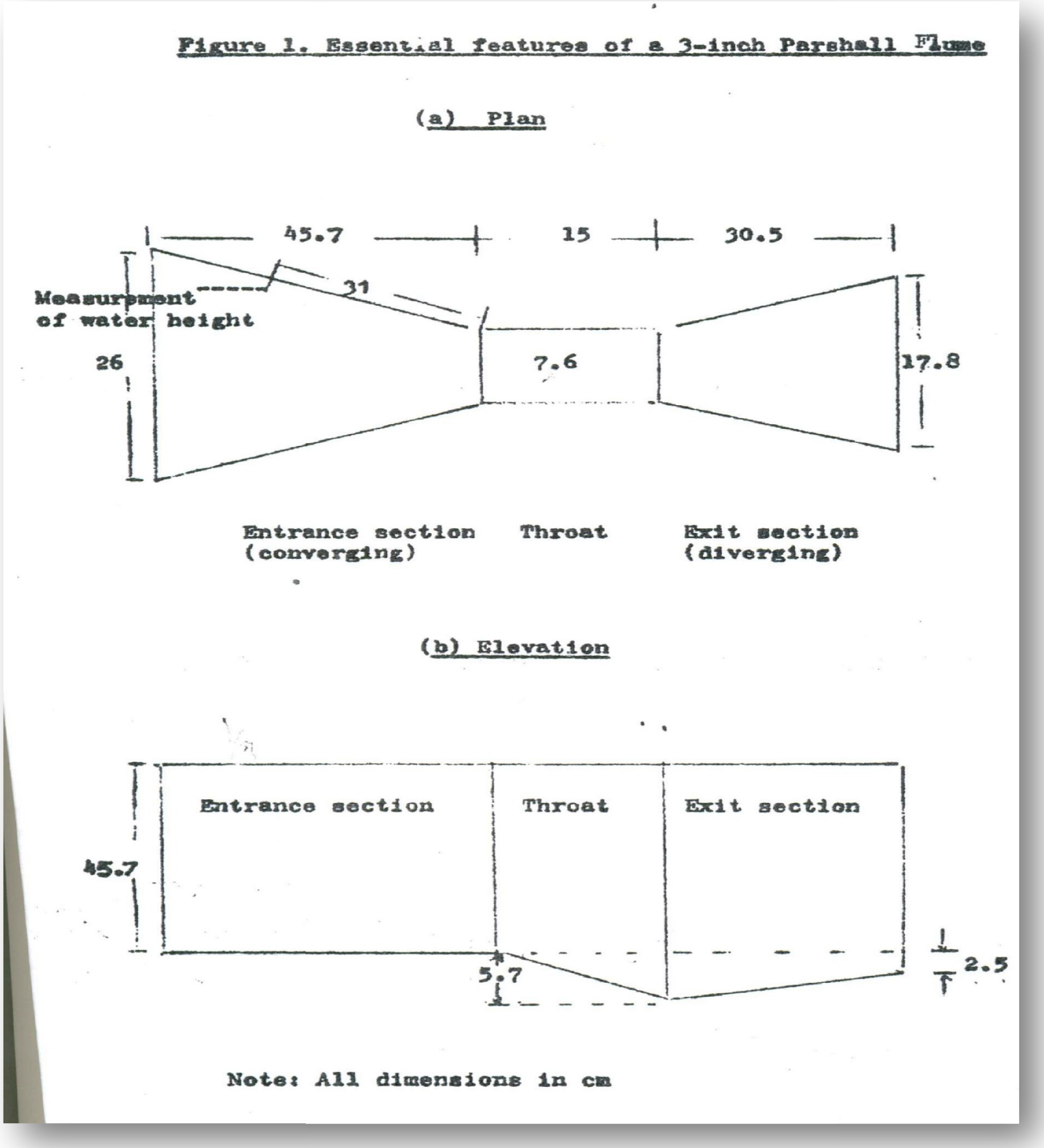

Figure 1. Dimensions of 3 inch parshall flume (Fitsum, 2014)

Figure 2. Field infiltration rate measurement and transplanting

1st –stage

2nd -stage

3rd-stage

4th-stage

Figure 3. Growth stages

Figure 4. Field data collection and illustration