Evaluating the Effects of Deficit Irrigation and Mulching on Yield and Water Productivity of Onion at Melkassa, Ethiopia

Tigist Worku Awulachew

A Thesis Submitted to

The Department of Water Resources Engineering

School of Civil Engineering and Architecture

Presented in Partial Fulfillment of the Requirement for the Degree of Master's in Water Resources Engineering (Specialization in Irrigation Engineering)

Office Of Graduate Studies

Adama Science and Technology University

February, 2024

Adama, Ethiopia

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DECLARATION

I hereby declare that this Master Thesis entitled "**Evaluating the Effects of Deficit Irrigation and Mulching on Yield and Water Productivity of Onion**" is my original work. That is, it has not been submitted for the award of any academic degree, diploma, or certificate in any other university. All sources of materials that are used for this thesis have been duly acknowledged through citation.

Tigist Worku Awulachew	____________________	__________________
Name of student	Signature	Date

RECOMMENDATION

I, the major advisor of this thesis, hereby certify that I have read the revised version of the thesis entitled "**Evaluating the Effects of Deficit Irrigation and Mulching on Yield and Water Productivity of Onion**" prepared under my guidance by **Tigist Worku Awulachew** submitted in partial fulfillment of the requirements for the degree of Mater's of Science in Water Resources Engineering, Specialization in Irrigation Engineering.

Therefore, I recommend the submission of the revised version of the thesis to the department following the applicable procedures.

Mekonen Ayana (Prof.)	__________________	__________________
Major Advisor	Signature	Date

APPROVAL SHEET

I, the advisor of the thesis entitled **"Evaluating the Effects of Deficit Irrigation and Mulching on Yield and Water Productivity of Onion"** and developed by **Tigist Worku Awulachew,** hereby certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

Mekonen Ayana (Prof.)	________________	________________
Major Advisor	Signature	Date

We, the undersigned, members of the Board of Examiners of the thesis by **Tigist Worku Awulachew** have read and evaluated the thesis entitled **"Evaluating the Effects of Deficit Irrigation and Mulching on Yield and Water Productivity of Onion"** and examined the candidate during the open defense. This is, therefore, to certify that the thesis is accepted for partial fulfillment of the requirement of the degree of Master of Science in Resources Engineering, Specialization in Irrigation Engineering.

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Finally, approval and acceptance of the thesis are contingent upon the submission of its final copy to the Office of Postgraduate Studies (OPGS) through the Department Graduate Council (DGC) and School Graduate Committee (SGC).

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LIST OF ACRONYMS AND ABBREVIATIONS

a.s.l	Above Sea Level
ANOVA	Analysis of Variance
CA	Conservation Agriculture
CWR	Crop Water Requirements
CV	Coefficient of Variation
DI	Deficit Irrigation
Dw	Density of Water
Dz	Root depth
Ea	Application Efficacy
ETa	Actual Crop Evapotranspiration
ETc	Potential Crop Evapotranspiration
ETm	Maximum evapotranspiration
ETo	Reference Evapotranspiration
FAO	Food and Agriculture Organization
FC	Field Capacity
GIR	Gross irrigation requirement
IWR	Irrigation Water Requirement
IWUE	Irrigation Water Use Efficiency
Kc	Crop Coefficient
Ky	Yield Response Factor
LSD	Least Significant Deference
MARC	Melkassa agricultural research center
NIR	Net irrigation Requirement
NM	No Mulch
NS	Non-Significant
P	depletion fraction
Pe	Effective Rainfall
PM	Plastic Mulch
PWP	Permanent Welting Point

Qm	Gravimetric Moisture Content
Qv	Volumetric Water Content
RH	Relative Humidity
SM	Straw Mulch
TAW	Total Available Water
Tmax	Maximum Temperature
Tmin	Minimum Temperature
TR	Total Return
WP	Water Productivity
WPM	White Plastic Mulch
Ya	Actual Yield
Ym	Maximum Yield

ABSTRACT

Water availability is becoming a critical issue in Ethiopia in arid and semiarid areas like the Rift Valley areas of the country. Therefore, enhancing the water productivity of irrigated crops through water management is a vital option in water-scarce areas. An experiment was conducted at Melkassa Agricultural Research Center (MARC) experimental site in 2022/23 under a furrow irrigation system to evaluate the effects of deficit irrigation and mulch materials on the yield and water productivity of onion. A split plot combination of three levels of deficit irrigation (100% ETc, 80% ETc, and 60% ETc) based on ETc and two mulching materials White Plastic Mulch (WPM) and Straw Mulch (SM) with no mulch as a control were evaluated with three replications. Application of SM at the rate of 6 t/ha, while 25-micron thickness was used for WPM. Daily ETo, ETc, and irrigation scheduling were computed using the CROPWAT 8.0 model based on climate, soil, and crop data. The results of these studies showed that the yield of onion and water productivity was significantly affected by the main effects of deficit irrigation and mulching materials. The deficit irrigation results showed that the highest marketable yield (37.0 t/ha) of onion was recorded under a plot irrigated with 100% ETc with no significant difference from 80% ETc (34.9 t/ha). Moreover, the highest water productivity (10.4 kg/m^3) was obtained from plots irrigated with 60% ETc but it has a non-significant difference from 80% ETc (9.9 kg/m^3). Furthermore, higher yield and yield components including water productivity were obtained from straw mulched plots than plastic mulched and no mulch. The maximum marketable yield of 36.4 t/ha and water productivity of 10.6 kg/m^3 were obtained from straw mulch. However, it has a non-significant difference from plastic mulched treatment. The partial budget analysis revealed that straw mulched treatment was more economically feasible for farmers than plastic mulch for onion production in Melkassa area. Therefore, the present study suggests that, under limited irrigation water conditions, deficit irrigation at 80% ETc or covering the soil with straw mulch application could be used to minimize evaporation loss and maximize water productivity and yield of onion at Melkassa and similar agroecology and soil types.

Keywords: deficit irrigation, mulch, onion, yield, and water productivity

1 INTRODUCTION

1.1 Background of the Study

One of the biggest problems affecting agriculture around the world is the scarcity of fresh water. Water shortage is a result of both wasteful use and inadequate management, in addition to the physical limitations of freshwater resources. Since agriculture uses more than 70% of the world's freshwater, managing the scarce water in a water-stressed region like the semiarid is a significant concern (Shanono et al., 2021). The main source of income for rural people in sub-Saharan African (SSA) countries like Ethiopia is smallholder agriculture. However, the smallholder agricultural productions predominantly depend on rainfall and drought is becoming frequent many people have been repeatedly exposed to hunger and famine (Assefa et al., 2022). Most small-scale farmers practiced rainfed production with traditional technology (Tadesse et al., 2021). Rainfall variability and irregularity are significantly affecting productivity and smallholder farmers are vulnerable to crop production (Yimam et al., 2020). Due to these, the performance, production and productivity become very poor and this production is not sufficient to feed the current population (Tewodros, 2019). Therefore, improving agricultural productivity is critical to feeding its inhabitants (Tewabe & Dessie, 2020b). To meet the food needs of the rising human population, rainfed production should be supported with irrigation (Tewodros, 2019).

Irrigation is critical for reducing rainfall variability and inconsistency (Mekonen, 2022). It is one of the leading strategies to reduce poverty and mitigate the negative impacts of erratic rainfall, ensure food security, and improve the livelihood situation in the Ethiopian community (Assefa et al., 2022). It is also one of the most valuable farming systems to increase production and productivity (Mekonen, 2022). It plays a key role in increasing production and productivity (Ahmed, 2019). It is also a viable strategy to increase production to meet the growing food demands, and improve the livelihood of rural households and incomes (Tewodros, 2019). Water-saving and enhancing WP technologies are most important for current irrigated agriculture (Al-ghobari et al., 2017). Innovative, affordable, and easy-to-implement technologies are needed for smallholder farmers to irrigate efficiently, the available water resources (Mashnik et al., 2017). Hence, water-saving irrigation strategies need to be explored

(Hashem et al., 2018). Therefore, deficit irrigation together with other on-farm management techniques like mulching are needed to increase the efficient use of the water that is available.

The concept of DI is a practice through which crops are deliberately exposed to a certain degree of water stress by irrigating below their crop water requirements. Although adopting DI practice, farmers might lose a certain proportion of yield. But there is a significant amount of water that can be saved which could be used to expand and cultivate more land, which would increase food production (Shanono et al., 2014). In arid and semi-arid areas, deficit irrigation has received much research as a valuable and sustainable production method. It is one of the strategies for increasing water use efficiency (WUE) for higher yields per unit of irrigation water applied (Mekonen et al., 2022). It provides a way to reduce water use while limiting negative effects on yield. There is no doubt that there is a growing interest in deficit irrigation to improve water productivity.

Among all other good management strategies to increase water use efficiency, mulching is another option. Its method has been applied all over the world, particularly in areas with limited water resources, to improve crop productivity and water-use efficiency. Mulching is primarily used to protect the soil surface from solar radiation, modify soil temperature, reduce evaporation, and increase soil moisture availability for crop growth resulting in improved crop water use efficiency and yields (Belachew, 2022). Mulching involves covering the surface of the soil with organic material (e.g., crop residues and grasses) or inorganic material (e.g. polyethylene sheets). When crops were planted under plastic mulch compared to no mulch conditions, Liu et al., (2014) reported a 20 to 35% increase in the yield of most types of grain crops and a 20 to 60% increase in the yield of most cash crops. Water and yield productivity were enhanced by mulching with a 20% deficit irrigation (Razaq et al., 2019). Onion showed a high marketable bulb yield and WP when grown in an environment with 80% ETc and straw mulch (Tufa et al., 2022).

In water-limited areas, increasing crop yield and WP can be achieved by combining mulching with appropriate DI (Wen et al., 2017). Razaq et al., (2019) Mulching with 20% deficit irrigation increased water and yield productivity. In comparison to non-mulched settings, DI with mulching increased yield and water productivity for onion crops (Biswas et al., 2017). Onion showed a high marketable bulb yield and WP when grown with 80% ETc and straw mulch (Tufa et al., 2022). Onion water and yield productivity were significantly affected by the addition of mulch with DI (Barakat et al., 2019). Therefore, effective and adaptable use of low-cost technology to efficiently and economically utilize water resources directly helps the sustainability of smallholder farmers' livelihoods.

One of the most widely cultivated vegetable crops in the world is onion (Allium cepa L). It is produced in various nations using irrigation as well as rainfed agriculture. The crop is one of the most significant vegetable crops grown by smallholder farmers in Ethiopia, where it is primarily grown for cash benefit and to flavor the local stew known as "wots" (Seifu et al., 2018). Therefore, the objective of this study was to evaluate the effects of deficit irrigation and mulch type applications on yield and water productivity of onion.

1.2 Statement of the Problem

In many regions of the world, there is a critical water shortage for irrigated agricultural output (Elliott et al., 2014). With the increasing population and food demand, there is a need to expand irrigation. However, the limited water availability is a challenge for expanding irrigation (Yadeta et al., 2022). Current irrigation-based agriculture is also facing difficulties due to the poor adoption of suitable water-saving technologies (Tadesse et al., 2021). Current irrigated agriculture is facing significant challenges as a result of moisture stress and poor irrigation management practices (Tewabe & Dessie, 2020a). In many areas, the amount of water that is available for irrigation is far below that is needed (Welteji, 2018). Generally, in Ethiopia, the existing irrigated agriculture has been dominated by traditional irrigation systems and suffering from various problems. As a result, water and crop productivity are low and limited (Hordofa et al., 2008). The sustainability of agricultural production and productivity have been considerably impacted by irrigation water scarcity (Goodarzi et al., 2019). Under these conditions, there is a need to adopt on-farm water-saving practices to use the limited water resources efficiently. Among many such practices, Deficit irrigation (DI) and mulch applications have been tested in the drip irrigation system (Ramalan et al., 2010). However, the practices have not been tested in furrow irrigation systems in Melkassa agroecology. More specifically the effects of DI combined with different mulching types (plastic and straw mulch) on onion yield and water productivity (WP) under furrow irrigation are not evaluated (Barakat et al., 2019). Different mulch types had different responses in different crops and agroecology

(Mubarak & Hamdan, 2018). Though onion is getting more popular, farmers in the studied areas are opting to cultivate it on their farms.

Similarly, in the study area Melkassa, the expansion of irrigated agriculture is very high and the demand for water for agricultural use has increased rapidly. Due to this, the available water is becoming insufficient for continuous vegetable production. In the dry season, there is high water abstraction for irrigation from the river, then water availability decreases significantly especially from February to May. This has led to crop failure and total loss, forced competition over water, and conflicts of opinion among farmers. Reduced crop production has been observed as a result of smallholder farmers force competition and overuse of irrigation water in the research area. Moreover, inefficient utilization of irrigation water is an obstacle to vegetable production as it causes undesirable consequences of irrigation like water-logging, soil salinity and sodicity development. Scarcity and growing competition for freshwater resources also reduce its availability during critical crop growth seasons; which adversely affects crop growth and yield. Under these circumstances, the expansion of vegetable farms and the potential for production throughout the year become limited. However, rising demand and competition for water need changes in the management of irrigation to improve crop water use and save the scarcely available water for agriculture in the study area. Irrigation management practices such as deficit irrigation and moisture conservation practices like mulching are widely practiced under water-scarce conditions. Although there are quite several researches done on the effects of such practices on yield and WP of crops, their combined effects have not been adequately studied. Therefore, this research study was conducted with the overall objective of evaluating the effects of deficit irrigation and mulch type on the yield and water productivity of onion at Melkassa.

1.3 Objectives

1.3.1 General objective

The overall objective of this study was to evaluate the effects of deficit irrigation and mulching materials application on yield and water productivity of onion.

1.3.2 Specific objectives

The specific objectives of this research are:

- To evaluate the effects of deficit irrigation levels on yield and water productivity of onion.
- To evaluate the effects of different mulching materials on yield and water productivity of onion.
- To evaluate the combined effects of deficit irrigation and application of mulching materials on yield and water productivity of onion.

1.4 Research Questions

- What level of deficit irrigation gives maximum water productivity without compromising the yield?
- Which mulching material increases the water productivity of onion crop?
- Which combination of irrigation level and mulching material gives optimal yield and water productivity of onion?

1.5 Significance of the Study

Water restrictions are unavoidable due to the global decline of water resources. In this case, production per unit of water use is prioritized over production per unit of area. Deficit irrigation with mulching is a water conservation approach of reducing water application, conserving the moisture content and reducing evaporation loss to improve yield and water productivity. It can be more profitable for a farmer to maximize crop water productivity instead of maximizing the harvest per unit of land. Additional plots of land can be irrigated using the water that was saved. Mulch combined with deficit irrigation facilitates crop and water productivity by reducing the amount of water used by the plant, water-saving with little impact on crop yield, and stabilizing the soil temperature. Mulches with deficit irrigation improve water and crop productivity by conserving soil moisture, improving photosynthesis and crop yields and reducing soil evaporation. It also improves agricultural productivity through moisture conservating, greatly reducing the amount of water needed by the plants, and organic mulches decompose and promote soil health and improve nutrient use efficiency. The findings of these studies could promote studies by universities, water institutes, research centers, and other academics in the areas of irrigation, conservation agriculture, deficit irrigation, and agricultural water management. The results of this study will also be used as a source of information for irrigation water managers and policymakers in their assessment as well as an understanding of deficit irrigation with conservation techniques to improve water and agricultural productivity.

1.6 Scope of the Study

This study focuses on evaluating the effects of deficit irrigation and mulch application on the yield and water productivity of onion, even though many mulch materials and irrigation methods were studied separately in different cereal crops to conserve and save water. Two factors were considered: the main factor was mulch types (straw and white plastic mulch) and the sub-factor was deficit irrigation level based on reference evapotranspiration (ETo). In this study, the single effects of deficit irrigation level and mulch type on yield and water productivity of onion and the interaction effects of deficit irrigation with mulch type on yield and water productivity on onion were evaluated during the experiment. Onion water productivity, growth and yield component parameters, and yield data were collected and analyzed. The experiment was conducted in 2022/23 for one irrigation season (dry season) of onion crops at plot level in Melkassa Agricultural Research Center experimental site. The study does not cover the effect of mulch types on soil nutrient dynamics and moisture, soil temperature, and the occurrence of pests and diseases.

2 LITERATURE REVIEW

2.1 Food Insecurity and Water Scarcity

Increases in human populations and the emerging challenges of climate change mean that the world's agricultural systems will need to produce more food (Matthew et al., 2021). Food security for the globe faces a great challenge (Wendimu, 2021). The main source of income for rural people in Sub-Saharan African (SSA) countries like Ethiopia is small-scale agriculture. However, the small-scale agricultural productions predominantly depend on rainfall and drought is becoming frequent and many people have been repeatedly exposed to hunger and famine (Assefa et al., 2022). Most small-scale farmers practiced rainfed production with traditional technology (Tadesse et al., 2021). The worsened food insecurity can be attributed to a variety of factors, including extreme weather events, water scarcity, and violent conflicts.

2.2 On-farm Water Saving Practices

Improving the irrigation water productivity (IWP) of crops grown in areas with limited water resources is one strategy widely used in water-saving technology (Jia et al., 2017b). To reduce water stress in agriculture, conservation agriculture has a significant impact on the output of irrigated crops. Conservation agriculture is important for minimizing soil evaporation, controlling soil temperature, and retaining soil moisture all of which affect crop and water productivity (Kader et al., 2019). Adapting conservative agriculture (CA) methods in vegetables is a viable solution for increasing water efficiency and crop productivity, which directly contributes to the sustainability of smallholder farmers' livelihoods in the region (Kader et al., 2019). For rural farm households to improve their standard of living through agriculture, soil and water conservation are essential (Bashir & Bibi, 2017). Conservation agriculture (CA) techniques significantly reduced irrigation water usage by 13 - 29%, and the yield return produced under CA was 10 - 30% higher, with chances to improve water use by reducing irrigation water requirements (Mekonen et al., 2022). It increases crop output by an average of 37.4 percent when compared to conventional farming (Kader et al., 2019). Its practice resulted in a 20% increase in yields and a 21% reduction in irrigation water usage. According to Yimam et al., (2020), conservation agriculture reduces irrigation water use by 18 – 28%. The most essential water-saving techniques for increasing yield and water productivity are mulching and deficit irrigation (Iglesias, A., & Garrote, 2015).

2.2.1 Deficit irrigation

In arid and semiarid areas, deficit irrigation has received considerable study as a valuable and sustainable production method. Rather than focusing on increasing yields, this method tries to stabilize water productivity (Geerts & Raes, 2009). Currently, there is a need to enhance water use efficiency (WUE) to maximize crop yields under commonly ongoing scenarios of deficit irrigation due to the global development of irrigated areas and the limited availability of irrigation water (Mubarak & Hamdan, 2018). In areas with limited water resources, deficit irrigation techniques may be a viable crop production method. In farm-level water management methods, deficit irrigation has an important aspect (Geerts & Raes, 2009). At particular times during the crop season, deficit irrigation is the deliberate application of irrigation depths that are smaller than those necessary to meet the crop water requirements (Rodrigues & Pereira, 2009).

2.2.1.1 Effects of deficit irrigation on onion yield

According to the ranges of irrigation regimes taken into consideration and the water productivity (WP) values obtained, the relationship between yield and irrigation amount can be defined as linear (Ambachew et al., 2014). Comparing deficit irrigation to full irrigation throughout the growing season biomass, yield, and certain other attributes were decreased (Mekonen, 2022). Deficit irrigation can improve water productivity without significantly reducing the bulb yield, considering the sensitive stage of the crop.

2.2.1.2 Effects of deficit irrigation on water productivity of onion

When supplies are limited, deficit irrigation (DI) can be used as a tactical measure to reduce irrigation water use (Zhuo & Hoekstra, 2017). Considering the sensitive stage of the crop, deficit irrigation can increase water productivity without significantly reducing bulb yield (Dirirsa et al., 2017). To reduce irrigation water use, deficit irrigation is an essential technique (Kifle & Gebretsadikan, 2016). By purposefully stressing plants to a point where it is profitable, significant water savings can be made (Leskovar & Agehara, 2012). Currently, there is a need to improve WUE to maximize crop yields under frequently ongoing scenarios of deficit irrigation due to the global development of irrigated areas and the limited availability of irrigation water (Hamdan, 2016).

2.2.2 Mulching

The use of mulch reduces water losses through evaporation on the soil surface, thus leading to the net return of crops by maximizing yield and water productivity with limited available water (Kumar et al., 2021). Hence, reducing non-productive loss of irrigation water is best achieved through the integrated use of regulated deficit irrigation along with mulching material for maximum water use efficiency (WUE) in arid and semi-arid lands (Igbadun et al., 2012). Application of mulches results in additional benefits like soil conservation, moderation of temperature, reduction in soil salinity, weed control and improvement of soil structure. Covering the ground with mulch saves water by preventing surface evaporation (Yaseen et al., 2014). The advantages of plastic mulch are probably related to wider canopy air temperatures and improved periodic patterns of soil temperature. However, the choice of mulching material would be based on its compatibility, cost-effectiveness, efficiency, and ease of access.

2.2.2.1 Effects of mulch on yield and water productivity

One method to increase water productivity and efficiency in water use is mulching with different irrigation methods (Mebrahtu and Mehamed, 2019). Regardless of the irrigation level utilized, mulch significantly improved onion bulb diameter, total yield, dry matter, and water productivity (Dossou-yovo et al., 2016). Mulching applications can effectively modify the plant's hydrothermal microenvironment and water use efficiency (Li et al., 2018). Mulching has become an important practice in modern field production due to benefits such as an increase in soil temperature, reduced weed pressure, moisture conservation, reduction of certain insect pests, higher crop yields, and more efficient use of soil nutrients (Ray & Biswasi, 2016). In semi-arid regions, it is an effective method to increase crop and water productivity (Yang et al., 2018). According to Deng et al. (2019) it can improve water consumption efficiency by an average of 9.5%.

2.2.2.2 Effects of straw mulch on crop yield and water productivity

According to Yang et al. (2018) straw mulch increases soil water storage, above-ground biomass, yield, and WUE while reducing evaporation. It is frequently used to increase agricultural yields and conserve soil water (Wang et al., 2018). Straw mulching has great potential for improving yield and water productivity (Tao et al., 2015). The net photosynthetic rate of leaves, soil water content (SWC), and soil temperature are all greatly improved by straw mulches during the entire growing season (Liao et al., 2021).

2.2.2.3 Effects of plastic mulch on crop yield and water productivity

The use of plastic mulch in agriculture is generally recommended for profitable row crops (Kader et al., 2019). Under tropical climates, plastic mulch appears to be an effective method for increasing agricultural output and water productivity (Mak-Mensah et al., 2021). By Igbadun et al. (2012) plastic mulching should reduce evaporation and conserve water. For the production of onion, it provides a higher temperature (Sarkar et al.,2019). Plastic mulch aids in moisture conservation, weed control, and radiation reduction. It aids in moisture conservation, soil temperature stabilization, soil solarization, and weed control (Goel & Shankar, 2019). In terms of lowering moisture evaporation from the soil surface and enhancing soil moisture status while also improving soil nutrient status, plastic mulch is thought to be more effective than straw mulch (Mekonen et al., 2022). Ramalan et al. (2010) studied the effect of deficit irrigation and mulch on crop water use and yield of drip irrigated onion in the Central Rift Valley of Ethiopia and reported that onion bulb yield decreased with an increase in levels of water deficit, while both crop water use and irrigation water use efficiencies increased with increase in water deficit level.

2.3 Onion (Allium cepa L) Response to Water Stress

Onion is a shallow-rooted crop that needs to maintain relatively higher water potential for optimum yield and economic return (Zheng et al., 2013). Young onions develop until they completely deplete all of the water in their shallow root system if water is not supplied. This causes the plant to begin losing its root hairs, wilt in response, and finally stop growing if the drought continues. The root hairs' outermost cells are where soil water and nutrients are absorbed for plant growth. Onions need regular irrigation because they get the majority of their crop's water requirements from the top 30 cm of the soil and very little water from depths below 60 cm. As a result, it's important to maintain moisture in the upper soil to promote root growth and provide the plant with enough water. According to (Nanesa et al., 2022) Compared to 50% ETc, the marketable yield and mean bulb weight was higher at irrigation levels of 75% ETc. Mekonen (2022) demonstrated that watering plants at 75% available soil moisture (ASM) increased bulb yields more than watering them at 50%.

During the yield development period, especially during the period of rapid bulb growth and transplantation, onion is most sensitive to water deficit on the other hand, the crop seems to be less sensitive to water shortages during the vegetative and maturing stages (Dirirsa et al., 2017). Bulb yield was significantly reduced throughout the yield formation stage due to a 50–75% water shortage during the growing season (Kahlon, 2016). Furthermore, they recommended avoiding water deficiencies, particularly during yield development (bulb enlargement), to produce large bulb sizes and high bulb weights. Small water savings can be achieved during the vegetative and maturity phases when there is a limited water supply. However, an excessive lack of water at these times could lead to a greater proportion of small-sized bulbs (Dirirsa et al., 2017).

2.4 Water Productivity

The main challenge confronting both rain-fed and irrigated agriculture is to improve the water productivity of WUE for sustainable irrigated agriculture. Increasing water productivity can be an important pathway for poverty reduction, especially in developing countries, where the variability of water productivity within and between fields is very high, according to the specific condition under which the crop is grown (Tefera et al., 2021). Crop water productivity is a vital parameter to assess the performance of irrigated and rain-fed agriculture.

The physical crop water productivity (kg/m^3) is the ratio of crop yield (ton/ha) to the amount of water used (m^3/ha). The economic water productivity ($\$/m^3$) relates to the economic benefits per unit of water used.

3 MATERIALS AND METHODS

3.1 Description of the Study Area

The study was conducted at Melkassa Agricultural Research Center (MARC) experimental site which is 15 km southeast of Adama town and 107 km to the East of Addis Ababa, capital city of Ethiopia and located at 8°24' N latitude and 39°12' E longitude with an altitude of 1550 m a.s.l. The site is situated in the Central Rift Valley of Ethiopia in the Awash River Basin having a semi-arid type climate.

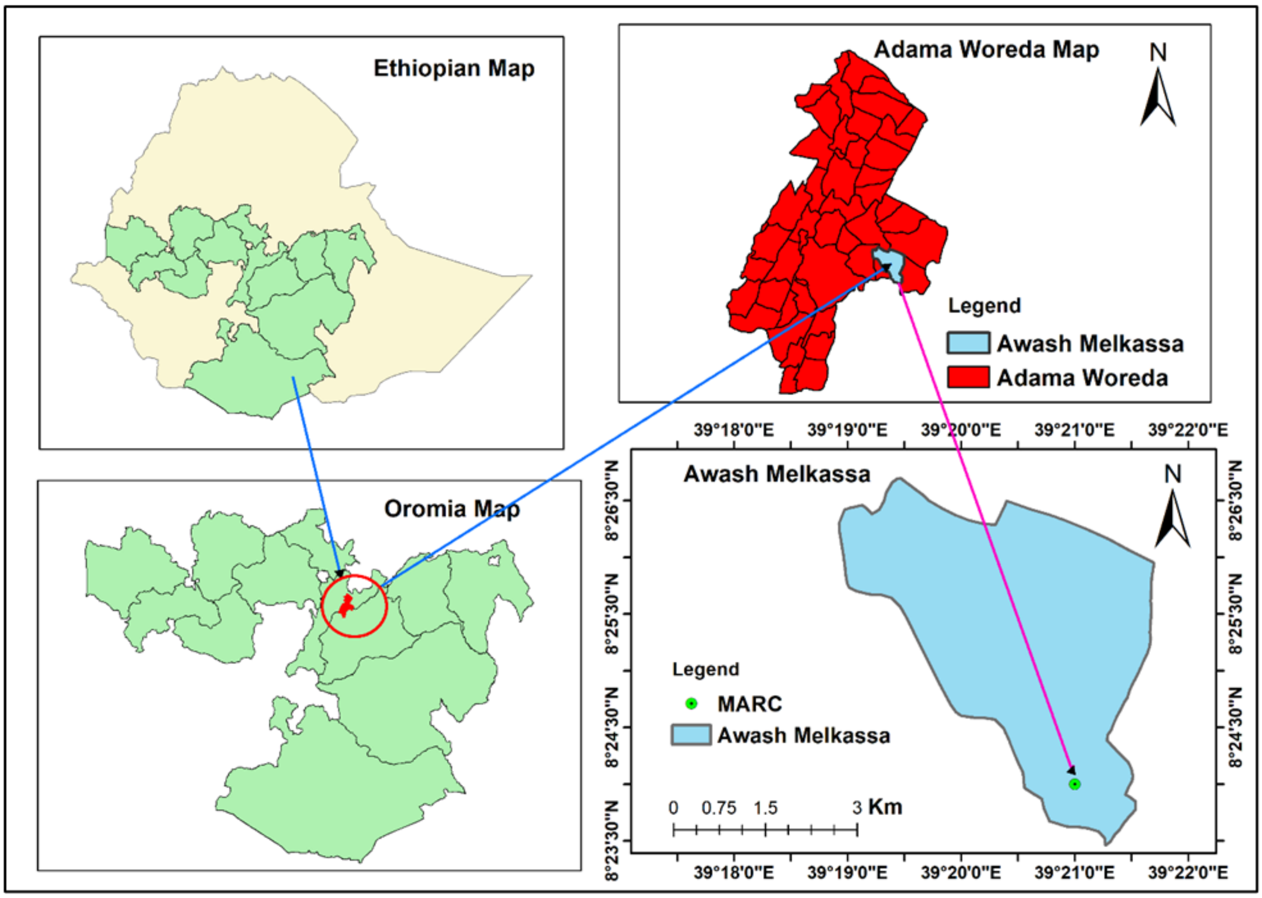

Figure 3.1. Map of the study area

3.1.1 Climate

The average annual rainfall and potential evapotranspiration in the area are 768 mm and 1994 mm, respectively, based on long-term meteorological data records. About 67% of the total rainfall of the area occurs from mid-June to mid-September, with its peak in the months of July and August. The mean maximum and minimum monthly rainfall values are 191.4 mm and 9.1

mm occurring in the month of August and January, respectively. The mean maximum temperature varies from 26.4 ^{0}C to 30.9 ^{0}C while the mean minimum temperature varies from 11.1 ^{0}C to 16.5 ^{0}C, with an average value of 20.12 ^{0}C. Loam and clay loam soil textures are the dominant soils of the area and the long-term climate data are shown (Table 3.1).

Table 3.1 Long-term mean monthly climatic data of the study area

Month	RF (mm)	Tmin. °c	Tmax. °c	RH %	Ws (U)m/s	Sunshine (hr)	ETo mm/day
January	16	11.7	27.9	51	8.6	9	7.3
February	24.1	13.4	29.1	48.7	9.1	9.2	8.2
March	52.3	15.1	30.5	49.2	8.6	8.5	8.4
April	53.9	15.5	30.5	50.8	7.8	8.2	8.1
May	61	15.5	31	51.2	7.5	8.8	8.1
June	69	16.4	30.2	53.1	9	8.4	8.1
Jully	204.2	15.7	26.8	66.4	9.1	7	5.9
August	183.1	15.4	26.3	69.2	7	7.1	5.3
September	99.8	14.5	27.6	65.8	4.9	7.3	5.4
October	39.3	11.7	28.8	50	6.6	8.7	7.2
November	12.6	10.8	28.3	46.7	8.3	9.6	7.8
December	9.6	10.4	27.6	48.8	8.9	9.5	7.5

Source: MARC Meteorological station

3.1.2 Farming practice

Farmers in the area grow crops three times a year of which two using traditional furrow irrigation during cool (September to January) and warm (February to May) seasons and the other during the rainy season (June–September) using rainfall and irrigation as a supplementary. A variety of vegetables and crops are grown including onion, sweet potatoes, papaya, tomato, potato, wheat, maize, teff, haricot beans. The Awash River is the source of irrigation water in the area.

3.2 Experimental Design and Layout

3.2.1 Experimental design

The experiment was arranged in a split-plot design with three replications. The treatments were three levels of water application (100% ETc, 80% ETc and 60% ETc) and two mulching materials (straw mulch and white plastic mulch) with the non-deficit and non-mulch treatments used as control. The treatments were randomized both at the main and sub-plot levels. The subplots received the deficit irrigation levels, whereas the main plot received the mulch-type treatment. White plastic mulch with a 25-micron thickness and a mulching rate of 6 tons per hectare of straw was used (Belachew, 2002). Full irrigation (100% ETc) without mulch was taken to be considered as a control. The CROPWAT 8.0 model was used to calculate the irrigation amount for 100% ETc. The amount of irrigation water to be applied at each irrigation application was measured using the Parshall flume. The details of the experimental treatments are presented in Table 3.2.

Table 3.2. Experimental Treatment Combinations

Treatments			
Main plots	Subplots	Treatment combination	Treatment no
No mulch (NM)	100% ETc	100% ETc with NM	T1
	80% ETc	80% ETc with NM	T2
	60% ETc	60% ETc with NM	T3
Straw mulch (SM)	100% ETc	100% ETc with SM	T4
	80% ETc	80% ETc with SM	T5
	60% ETc	60% ETc with SM	T6
White Plastic mulch (PM)	100% ETc	100% ETc with PM	T7
	80% ETc	80% ETc with PM	T8
	60% ETc	60% ETc with PM	T9

3.2.2 Experimental layout

The experimental field was divided into 27 plots with a plot size of 5.5 m × 3.6 m=19.8 m^2 area. The distance between blocks and plots was 3 m and 1.5 m receptively (Figure 3.2). In this experiment, the furrow irrigation method was used and to minimize the influence of the lateral flow of water into the plots the block distance was sufficient. Each block has a field canal constructed to irrigate its fields. Using a 3-inch Parshall flume, the predetermined volume of irrigation water was applied to each plot. The scheduling of irrigation was done using 100% ETc as the control treatment. Depending on the proportion of moisture stress in each treatment, fewer irrigation water depths were applied compared to the control treatment. However, the irrigation interval for the treatment was similar to that of the control condition. The control treatment (optimum irrigation) was irrigated based on the allowable moisture depletion level in the effective root depth that aims to refill the soil moisture to field capacity.

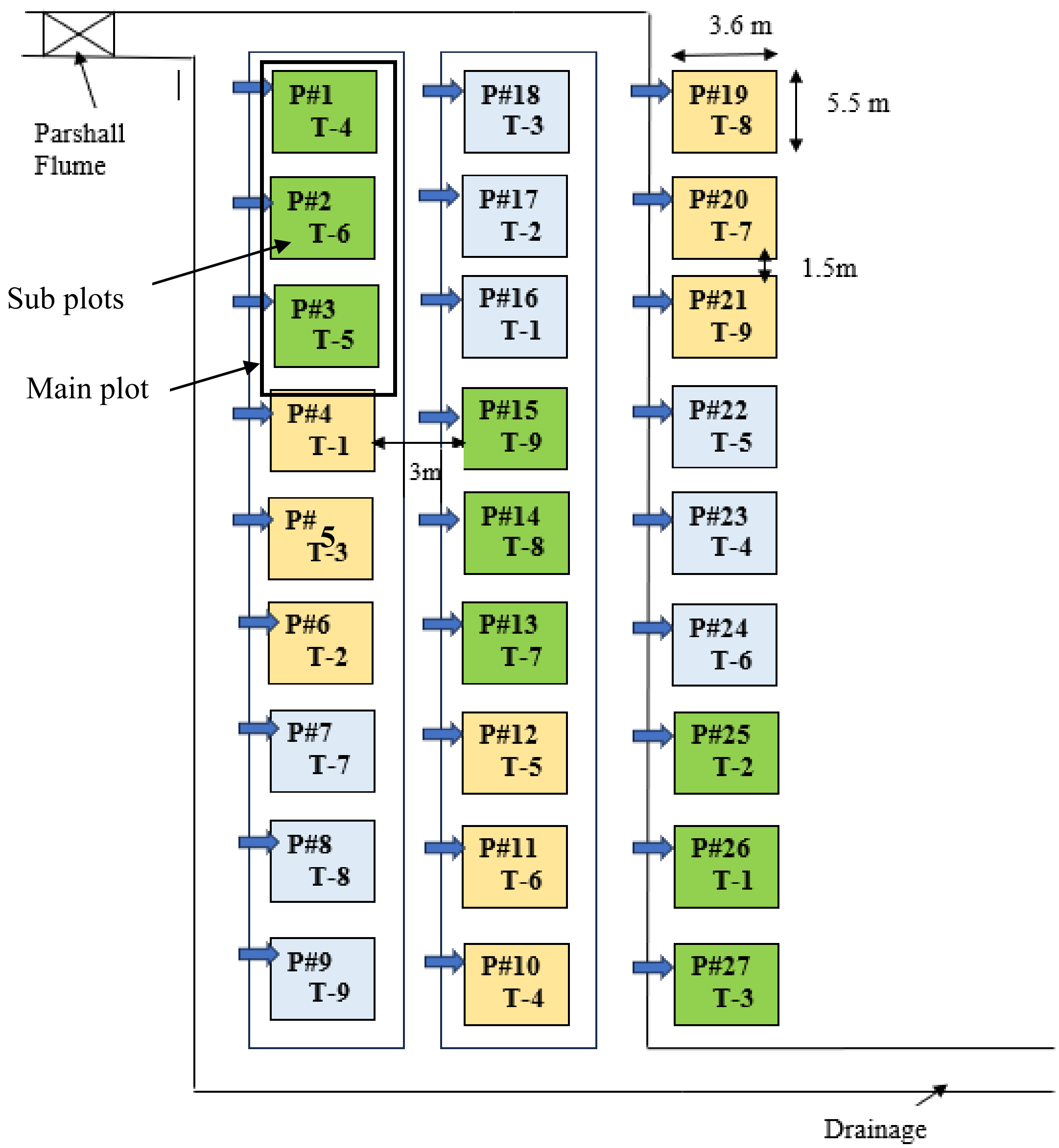

Figure 3.2 Layout of experimental field

3.3 Crop Establishment and Management Practices

Variety of onion (Allium cepa L) seed Nafis served as the seed material. About 60g of onion seed per well-prepared bed of 1 m by 5 m was planted on December 10, 2022. Nafis is a high-yielding cultivar that matures quickly. Agronomic procedures like watering, weeding, applying fertilizer, spraying pesticides, and other activities were carried out at the nursery. On February 1, 2023, after 50 days, the seedling was moved to experimental plots. Since onion are known to be a double-row crop, they were planted on both sides of the ridge with a plant spacing of 7 cm and a furrow spacing of 60 cm, respectively. Each plot received a single application of DAP during transplanting, as well as split applications of urea at 200 kg/ha and 100 kg/ha, respectively, as topdressing 15 days after transplanting (Olani and Fikr, 2010). Other than the treatment variables, all other agronomic practices (weeding, canal clearance, chemical spray and fertilizer application) were carried out following regional standards.

The crop was grown using the furrow irrigation method. Each plot has five double rows with 20 cm spacing each row holding about 142 onion plants. To protect the crop from harmful insects (thrips) and fungi, Selecron (3 liter/ha), Profit, Matco, Nativo, Tutaver and Redomil Gold (3 liter/ha) were applied.

Initially all plots were treated similarly to ensure the proper seedling establishment, first and second common irrigation was applied before the start of the treatment. All treatments were weeded once before mulch was applied. Twenty days after transplanting treatments were applied because seedings start root development and are well performed. The irrigation scheduling was done based on the optimum irrigation treatment (100% ETc) and deficit treatments received lower amounts based on their levels on the same irrigation date. Based on the daily actual weather data gathered from the Center's weather station, the CROPWAT 8.0 model was used to calculate the daily ETo. Crop coefficient, optimum depletion level and root depth were adopted from FAO Irrigation and Drainage Paper 56 (FAO, 1998). Effective rainfall for the season was calculated using the CROPWAT 8.0 model daily, considering the rainfall reported at MARC Agrometeorological Service. This amount was then subtracted from the net irrigation depth of the next irrigation. A 3-inch Parshall flume was used to measure the amount of irrigation water applied to each experimental plot. Since the only variation in the treatments was the water depth determined by deficit levels, all treatments received irrigation on the same days.

3.4 Data Sources

During the experiment climate data like (maximum and minimum temperatures, windspeed, sunshine hours, relative humidity and rainfall), crop data like root depth and crop coefficient (Kc) and soil data for different purposes was collected. Data sources used were shown in the table 3.3.

Table 3.3. Different data sources used for this study

No	Data type	Source	Data type collected	Purpose
1	Crop data	FAO 56	Effective root depth and depletion fraction	To determine crop water requirement
2	Soil data	Laboratory Result	FC and PWP	Irrigation scheduling
3	Climate data	Metrological station	Tmax, Tmin, RH, U and Sunshine hour	Determination of ETo and ETc

3.5 Materials Used

During the experiment for different purpose some materials were used and presented in table 3.4.

Table 3.4. Different materials and decision support tools used in this study

No.	Materials name	Purpose
1	Water cane	Watering the nursery
2	Tractor	Tillage and leveling
3	Meter	For layout preparation
4	Straw and white plastic	For mulching
5	Parshall flume	Flow measurement
5	Knapsack	Chemical spray
6	Pressure plate	Soil data
7	Ruler	Agronomic data collection
8	Soil auger, core sampler and oven dry	Soil sample collection and for soil moisture
9	Sensitive balance	Weight measurement
10	Sickle	Cutting leaf and root

3.6 Mulch Application

Mulching is the technique of covering of the soil surface around the plants with an organic or inorganic mulch to reduce evaporation loss of water. After 20 days from transplanting mulch was applied. Plastic mulch was done by drilling the plastic on the spacing of 7 cm (plant spacing of onion) then each plant was inserted into the hole by hand. There is space between plastics in the furrow for infiltration and lateral flow of water and also for aeration of soil. Grass straw mulch also covers the ridge and furrow with 10.8 kg per 19.8 m^2 plot area at a recommended rate of 6 t/ha. The mulching materials (straw and plastic mulch) were applied as shown figure 3.3.

Figure 3.3 Straw and plastic mulch application

3.7 Determination of Soil Physical Properties

3.7.1 Soil texture and bulk density

For the analysis of textural, disturbed soil samples were collected up to 60 cm from 0-15 cm, 15-30 cm, 30-45 cm and 45-60 cm depth using soil auger 12 samples at three locations along the diagonal of the experimental field. The soil samples were taken at these depths because the maximum root depth of onion goes up to 60 cm. The particle size distribution at the MARC soil laboratory was analyzed using the hydrometer method, and the textural class was determined based on the percent of sand, silt, and clay in the USDA textural triangle for each sample.

The soil bulk density was determined from undisturbed soil samples that were collected by using a cylindrical core sampler of size 5 cm in diameter and 5 cm in height. The samples were then dried in an oven at 105°C for 24 hours and the bulk density was then calculated using equation 3.1 given by (Hillel & Hatfield, 2005).

$$Bd = \frac{Ms}{Vt} \qquad 3.1$$

Where = Bd - bulk density (g/cm^3),

Ms - dry weight of the soil (g),

Vt - total volume of the soil (cm^3).

3.7.2 Field capacity and permanent wilting point

Samples were saturated for one day (24 hours) and water was extracted from the saturated soil using a pressure plate apparatus set at 0.33 and 15 bars, respectively at Melkassa soil laboratory. The samples were collected from the pressure plate apparatus when there was no more drop of water, weighed, and then dried in an oven for 24 hours at 105°C. The moisture contents at field capacity and permanent wilting point were then measured. Then, the total available water (TAW in mm) of the experimental field was determined using equation 3.2.

$$TAW = \frac{(FC-PWP)}{100} * BD * Dz \qquad 3.2$$

Where = TAW - total available soil water (mm/m),

FC - Moisture content at Field capacity (%),

PWP- Moisture content at Permanent wilting point (%),

BD - bulk density of the soil in g/cm^3,

Dz - maximum effective root zone depth in mm.

However, all the available moisture was not easily available to plants. The plant suffers when the water suction pressure approaches PWP because it requires more energy to extract since the water is tightly trapped by the soil particles (micro-pores). Readily available moisture (RAW) is the portion of the total available moisture that a crop can take up from the root zone without experiencing water stress. It is determined by using equation 3.3.

$$RAW = TAW * \rho \qquad 3.3$$

Where = RAW - Readily available moisture (mm)

ρ - Allowable depletion level (%) 25% for onion.

3.8 Reference Evapotranspiration (ETo) and Crop Water Requirement (CWR)

The reference evapotranspiration ETo was calculated by the FAO Penman-Monteith method, using decision support software CROPWAT 8.0 developed by FAO. FAO56 adopted the Penman-Monteith method as global standard to estimate ETo from meteorological data. Climatic parameters that were used are maximum temperature (Tmax), minimum temperature (Tmin), relative humidity (RH), wind speed (at two meters), and sunshine hour (hrs). The CROPWAT model calculates ETo based on the formula of the FAO Penman-Monteith method.

The FAO Irrigation and Drainage Paper 56 for onion provided the crop coefficient value. The initial, mid, and late stages of growth have respective crop coefficient values of 0.53, 1.05, and 0.95. The daily crop coefficient was interpolated for development and late stage based on the crop's Kc values and the duration of each growth stage. The length of growth stages of 15, 30, 40, and 25 days were considered for initial, development, mid and late stage, respectively. The ETc was calculated based on the following equation (3.4).

$$ETc = ETo * Kc \qquad 3.4$$

Where = ETc - crop evapotranspiration in (mm/day),

ETo - reference crop evapotranspiration in (mm/day).

Kc - crop factor in a fraction

Using the readily available water for the root depth on that particular day, successive irrigation depths were administered. For the control treatment (100% ETc), the daily crop evapotranspiration was subtracted from the net irrigation depth until the cumulative subtraction from the applied net irrigation depth approached zero. After applying the cumulative ETc technique to net irrigation depth for the control treatment and stress treatments depending on their percentage from the non-stressed treatment, irrigation was applied next. At the time of establishment, the crop's effective root depth was found to be 30 cm. The daily effective root depth value was then interpolated to account for the time interval between the first day of the initial stage and the last day of the development stage. For the mid-and late seasons, the effective root depth was assumed to be a constant 60 cm. Parameters used for crop water estimation are shown in table 3.5.

Table 3.5. Onion parameters used for crop water estimation

	Growth stage				
	Initial	Development	Mid	Late	Total
Depletion fraction (p)	0.25	0.25	0.25	0.25	
Crop coefficient (kc)	0.53		1.05	0.95	
Growth stage (days)	15	30	40	25	110
Root depth (m)	0.3		0.6	0.6	

Source: (Kassam & Smith, 2001)

3.9 Irrigation Requirements

3.9.1 Determination of net irrigation water requirement

The net irrigation water requirement (NIR) is defined as the water required by the crop to satisfy crop evapotranspiration and water needs that are not provided by water stored in the soil profile or precipitation. It was computed by subtracting the effective rainfall from the readily available water (RAW) then, the result was a net irrigation requirement. Determination of net irrigation water requirement was done based on the water holding capacity of the soil from critical depletion level to field capacity in the effective root depth for 100% ETc treatment based on equation 3.5 (Frenken, 2002).

$$NIR = RAW - Pe \qquad 3.5$$

Where = NIR - net irrigation water requirement (mm),

Pe - Effective rainfall (mm) and

RAW - readily available water (mm).

3.9.2 Determination of effective rainfall

Effective rainfall in agricultural production is the amount of rainfall that plants can effectively use to germinate or maintain their growth. This means that some rain is lost to runoff and deep percolation, meaning that not all of the rain falls on the crops. The FAO Water Service developed an empirical formula to estimate dependable rainfall, the combined effect of dependable rainfall (80% probability of exceedance), and estimated losses due to deep percolation and runoff based on analysis conducted for various arid and sub-humid climates (FAO, 2009). Using daily rainfall data, the FAO/AGLW formula's "dependable rainfall" equations 3.6 and 3.7 were used to calculate the effective rainfall.

$$Pe = 0.8\,P - 24 \quad if\ P > 75\,mm/month, \quad or \qquad 3.6$$

$$Pe = 0.6\,P - 10 \quad if\ p < 75\,mm/month \qquad 3.7$$

Where: - Pe - Effective rainfall (mm/day) and

P - Total rainfall (mm/day).

3.9.3 Field application efficiency and gross irrigation

Field irrigation application efficiency (Ea) is the ratio of water directly available in the crop root zone to water received at the field inlet. The average ranges vary from 50 to 70% However, a more common value is 60% (Belachew, 2002). Moreover, field application efficiency varies with the type of soil and method of irrigation. For this particular experiment, irrigation efficiency was taken as 60%. Gross irrigation requirement means, the total amount of water, inclusive of losses, applied through irrigation, which in other words net irrigation requirement plus application and other losses. The gross irrigation water requirement was calculated based on equation 3.8 (Frenken, 2002).

$$GIR = \frac{NIR}{Ea} * 100 \qquad 3.8$$

Where: - GIR- Gross irrigation requirement (mm),

NIR- Net irrigation requirement (mm),

Ea- Application efficiency (%).

An application efficiency of 60% was used to estimate the gross irrigation requirement using equation (3.8).

3.10 Parshall Flume Installation

Irrigation water applied to each experimental plot was measured by a 3-inch standard Parshall flume made from a metal sheet. The flume was installed near the experimental field upstream of the canal to measure irrigation water applied to each experimental plot. It is installed 10 m away from the nearest plot canal in such a way that all of the flow must go through it. The flow was effectively straightened and uniformly redistributed before it entered the flume and a stable bottom elevation was present so that the elevation does not change during irrigation seasons. It was important to get a steady constant flow of water and to avoid the turbulence flow at the Parshall flume measurement. Leveling in converging and divergent sections were checked. The entrance section was set at 4 cm above the canal bed to avoid submergence flow and a stone riprap was put on the downstream side of the canal bed to minimize downstream scouring. Flow measurement was started during the constant flow. This was the height of the water from the gauge of the Parshall flume written on the 2/3 surface wall of the entrance section.

3.11 Measuring Applied Irrigation Water and Time

The predetermined amount of irrigation water to each plot was measured using a 3-inch standard Parshall flume. Calculated gross irrigation was finally applied to each experimental plot based on the 'proportion of the treatment. The volume of water applied for all treatments was determined from the plot area and depth of gross irrigation requirement. The time required to irrigate each treatment was calculated from the ratio of the volume of applied water to the discharge-head relation of the 3-inch Parshall flume. Since discharge levels might vary under field conditions, the time required was calculated from 3 to 12 cm head levels. The time required to deliver the desired depth of water into each furrow was calculated using below equation 3.9 and irrigate the plot with the help of a stopwatch. The amount of irrigation water applied was different for each treatment based on the deficit level. According to Geremew et al. (2008) time required to irrigate a particular plot could be computed from the equation (3.9).

$$T = A * \frac{GIR}{6q} \qquad 3.9$$

Where = GIR- gross irrigation depth of water to be applied (cm), A- Area of the experimental plot (m^2),

T- application time (min),

q- flow rate of discharge (l/s).

3.12 Data Collection

The sampled onion plant was selected systematically and carefully from the middle ridges by avoiding two ridges to take care of the border effect. The crop data were collected from the experimental units. To gather information on the growth and yield components, five plants were randomly selected from the middle three ridges. The crop was harvested in May 2023. Onion can be harvested when 20 to 50 percent of the neck tissue collapses and the leaf dries and falls off, indicating that 80 percent of the bulbs have reached full maturity. Onion bulbs were manually harvested by pulling them up. after harvesting, the roots were cut and the tops removed with a sickle, and the bulbs from each plot were collected into a sample bag and properly labeled. Lastly, separate data recording and collecting for bulb yield and yield components were carried out. To get information on the growth and yield components, five plants were randomly measured. From the time of planting until the experiment's completion, information on plant height, leaf height, number of leaves per plant, bulb weight, bulb length, bulb diameter, marketable bulb yield, total bulb yield, and other relevant factors were noted. The following is an explanation of sampling, harvesting, data gathering, and recording for each growth measurement, yield, and yield component.

3.12.1 Plant height, leaf height and leaf number

To measure the data, plants from each plot were chosen at random and tagged. To prevent sample bias, this random sample selection process takes into account the sample's fair distribution over an area. Using the average of five samples that were collected, the mean plant height, leaf height, and leaf number of each experimental unit were determined. Leaf height was measured from the top of the longest mature leaf to the beginning of the leaf nod, and plant height was measured from the soil's surface to the top of the longest leaf. The number of leaves per plant was counted by hand. In each experimental plot, five randomly selected samples from the central three ridges were used to measure the height of the onion plants, the height of the leaves, and the total number of leaves. Plant and leaf height was measured by a ruler.

3.12.2 Bulb diameter, bulb height and weight of onion

Five onion bulb samples that were randomly selected and tagged from each plot harvesting area were collected in a sample bag. Then, by using a digital caliper the onion bulb diameter and bulb height were measured. Bulb diameter is the horizontal average width of the onion of selected samples and onion bulb height is the vertical average length of matured bulbs of five randomly selected plants in each plot measured by a caliper. One of the indicators of crop quality has been shown by bulb diameter. The harvested five Samples that were taken at random from each plot harvested area were measured by using sensitive balance and recording the data on the data collection sheet form.

3.12.3 Marketable yield

The experimental data on the bulb yield of onion in each experimental plot was harvested and the yield was obtained after manually removing roots and stock from the onion bulb by sickle. Marketable yield (kg/ha) was measured for healthy and non-diseased, non-rotten, non-white (different varieties), non-split, and marketable-sized. Marketable bulb yield was expressed as kg per plot. Finally, the bulb yield obtained from the sample area was converted per hectare using equation 3.10 (Demisie and Tolessa, 2018).

$$Bulb\ yield\ (kg/ha\ ) = \frac{weight\ of\ sample\ \ yield\ (kg)}{Net\ harvested\ area\ (m^2)} * 10{,}000\text{m}^2 \qquad 3.10$$

3.12.4 Total bulb yield

Is the sum of marketable and unmarketable bulb yields. The harvested onion was selected by hand as marketable, split, rotten and undersized and weighed using spring balance for each sample plot then by adding all the total yield calculated. The total yield was also expressed as kg per plot then it was converted to per hectare using the above equation (3.10).

3.13 Water Productivity

Water productivity was determined based on the ratio of the yield of onion (yield per hectare) to the amount of water used from the establishment to harvest expressed as kg of yield per m^3 of water. It was calculated based on the formula using equation (3.11).

$$WP = \frac{Ya}{ETa} \qquad 3.11$$

Where = WP -Water productivity (kg/m^3)

Ya-Actual yield (kg/ha)

ETa -Actual applied water (m^3 /ha)

3.14 General Framework of the Research

The conceptual framework of the study is presented in Figure 3.4

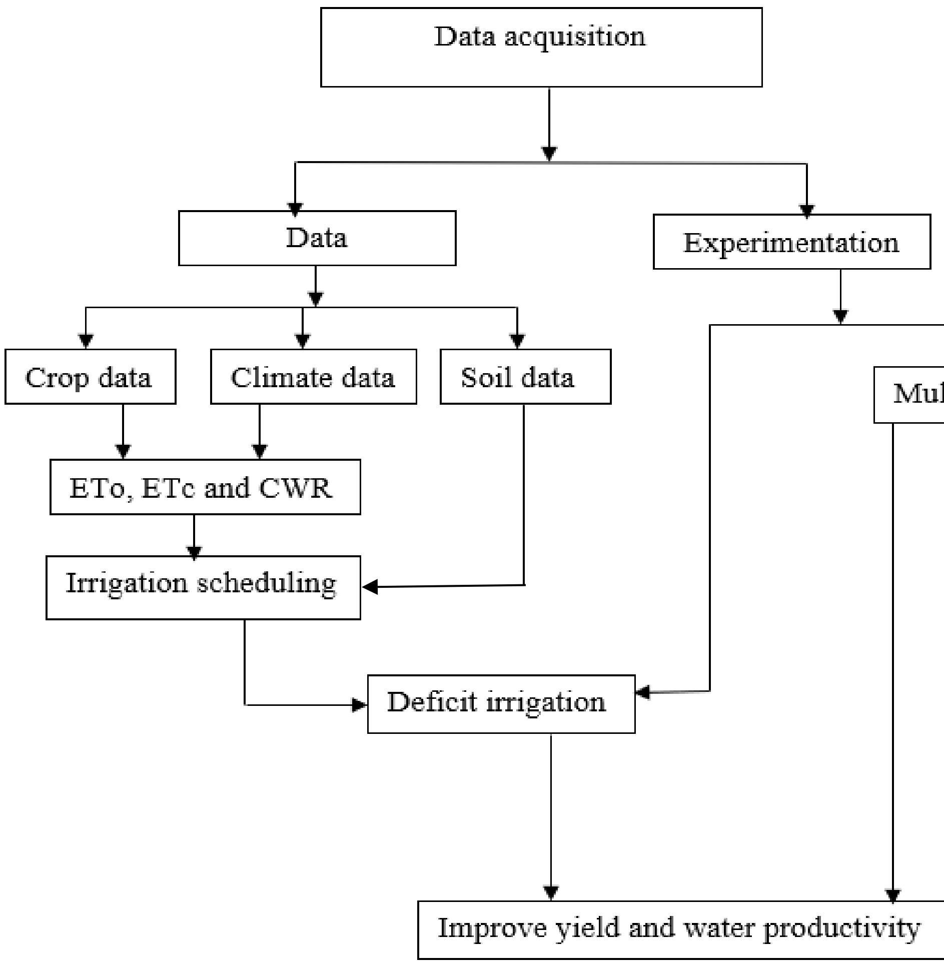

Figure 3.4 General framework of the research

3.15 Yield Response Factor

Crop yield response factor Ky was determined from the experimental data. The yield response factor (Ky) was one of the important parameters that indicate whether moisture stress due to deficit irrigation was advantageous or not in terms of enhancing water productivity. The yield response factor relates relative yield reduction to the corresponding relative deficit in evapotranspiration (ETc). It was an indication of the response of yield to water use reduction. When Ky> 1, the crop response is very sensitive to water deficit with proportional larger yield reductions; Ky< 1, the crop is more tolerant to water deficit, and recovers partially from stress, exhibiting less than proportional reductions in yield with reduced water use; Ky = 1, the yield reduction is directly proportional to reduced water use. The relative yield decrease values were the reduction of onion yield obtained from each treatment after the yield was analyzed from the (100% ETc without mulch) and the decrease in evapotranspiration was the reduction in irrigation amount due to stress level from 100% ETc without mulch treatment. The yield response factor was determined based on the ratio of relative yield decrease to relative evapotranspiration deficit expressed in decimal, using equation 3.12 (Smith et al., 2011).

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

Where: - Ya - actual harvested yield in kg/ha,

Ym - maximum harvested yield in kg/ha,

Ky - yield response factor,

ETa - actual evapotranspiration in mm/growing period and

ETm - maximum evapotranspiration in mm/growing period.

3.16 Economic Analysis

Economic analysis was done using partial budgeting and marginal return value under the prevailing market pricing of expenses and returns. According to CIMMYT, (1988), the adjusted bulb yield was computed from the average bulb yield by reducing it by 10%. The economic importance of water used should be worked out for specific situations before being expanded to the large scale for adoption. However, the application of deficit irrigation to crops used for better growth and higher yield could be economically attractive to reduce the drought-stressed conditions in water-limiting areas. The total costs considered for the economic study were the cost of the mulching materials (plastic and straw mulch) and the labor required for setting the mulch material, assuming that all other expenses were uniform for each treatment. For economic evaluation of the total return, net benefit, marginal return rate and cost-benefit ratio using the different amounts of water applied, the Partial Budget Analysis (PBA) was used following the CIMMYT procedure. It is a way of calculating the total costs that vary and the net benefits of each treatment.

The total return is the cost of returning from the adjusted bulb yield output at the market price of onions during harvesting.

$$TR = Y * P \qquad 3.13$$

Where = TR – Total return (ETbirr)

Y - Adjusted bulb yield (kg) and

P - Average market price (ETBirr/kg).

Net income (NI) was calculated by subtracting the total costs (TC) from the total return (TR) for a given treatment:

$$NI = TR - TC \qquad 3.14$$

$$TC = MC + LC \qquad 3.15$$

Where = TC - the total cost incurred

MC - The mulching material cost in ETBirr and

LC - The labor cost in ETBirr

Finally, the percent marginal rate of return (MRR) was calculated by the following formula:

$$MRR = \frac{\Delta NI}{\Delta TC} * 100\% \qquad 3.16$$

Where = ΔNI - the difference between the net income in ETBirr and

ΔTC - the additional unit of expense in ETBirr, between the two treatments.

3.17 Statistical Analysis

The collected data were statistically analyzed using the R software using the procedure of a general linear for the variance analysis model. Analyses of variance (ANOVA) were used for growth and yield components, yield and water productivity. When the effect of the treatments was found significant, mean comparisons were tested using least significant difference (LSD) test at 5% probability. Simple correlation analysis was also used to see the association of onion growth parameters, yield component, yield, and water productivity.

4 RESULTS AND DISCUSSIONS

4.1 Soil Characterization of the Experimental Site

The physical and chemical parameters of the soil were examined in Melkassa Agricultural Research Center laboratory and the results are shown in tables 4.1 and 4.2.

4.1.1 Soil physical properties

The average composition of clay, silt, and sand percentages, according to an investigation of the physical characteristics of the soil were 26.5, 40 and 33.5 respectively. Thus, the particle size distribution of the experimental site indicated that the soil textural class is loam soil, which is suitable for onion based on the USDA's classification of soil textural class. The result regarding bulk density indicates a small increase in depth. The experimental site's average weighted bulk density was 1.16 g/cm^3. This could be because of a slight decrease in organic matter with depth and compaction due to the weight of the overlying soil layer (Brady and Weil, 2002). The total volumetric TAW was 103.4 mm with the onion root depth of 60 cm and readily available water, with an optimum depletion level of 25%, was calculated as 25.85 mm.

Table 4.1. Analysis of physical properties of soil of experimental site

Depth (cm)	Texture				Bulk Density (g/cc)	FC (%wt bases)	PWP (%wt bases)	TAW (mm)
	%Clay	% Silt	%Sand	Class				
0 – 15	26.5	45	28.5	Loam	1.06	33.8	20.8	20.7
15 – 30	24	42.5	33.5	Loam	1.15	36.5	21.1	26.6
30 – 45	29	35	36	Clay loam	1.19	39.3	23.5	28.2
45 – 60	26.5	37.5	36	Loam	1.26	37.7	22.9	28
Average	26.5	40	33.5	Loam	1.16	36.83	22.08	25.85

4.1.2 Chemical properties

Based on the analysis of the soil profile, the average pH value at the experimental site was found to be 7.02 almost neutral (Table 4.2). Onion can grow best in soils with a pH value range from 6.0 to 8.0 (Olani and Fikre, 2010). According to Smith et al. (2011) the average electrical conductivity of the soil through a 60 cm profile was 0.262 dS/m, which is less than the onion threshold value of 1.2 dS/m. The average values of the soil's OM, OC, and TN contents were 3.3%, 5.29%, and 5.68%, respectively.

Table 4.2. Average chemical soil properties of the experimental site

Depth (cm)	pH	Ece (ds/m) at 25°c	Total Organic matter (%OM)	Total Nitrogen (%TN)	Total organic carbon (%TOM)
0 – 15	6.74	0.215	7.4	0.37	4.29
15 – 30	7.07	0.229	6.72	0.34	3.9
30 – 45	7.08	0.299	5.24	0.26	3.04
45 – 60	7.18	0.305	3.36	0.17	1.95
Average	7.02	0.262	5.68	0.29	3.3

4.2 Crop Water Requirement of Onion

The total irrigation water applied was 422.1 mm for the control treatment (100% ETc). For highly stressful treatment (60% ETc), the lowest volume of water applied was 273.32 mm (Table 4.3). Irrigation in all treatments was managed by replacing the water lost in crop evapotranspiration (ETc) based on a deficit level assuming a 60% irrigation efficiency. The result of onion seasonal water demands of 422.1 mm that obtained from optimal irrigation scheduling. There was rainfall during the experiment, and the effective rainfall was computed (see Appendix Table 10). The total result of calculated effective rainfall was reduced from the net irrigation depth during the next irrigation treatment application. From the time of transplanting (February 1) until the harvesting day (May 21) a total of 174.1 mm of effective rainfall fell. Because depth of water on deficit levels was the only factor, all treatments received irrigation on the same days. By subtracting the total effective rainfall from the total crop water requirement (CWR), the total irrigation water requirement (IWR) was also determined.

Table 4.3. Seasonal irrigation water applied

Treatments	Total CWR, (mm)	Total IWR (mm)
100%	422.1	247.9
80%	347.7	173.6
60%	273.3	99.2

4.3 The Effects of Deficit Irrigation on Yield and Water Productivity of Onion

4.3.1 The effects of deficit irrigation on growth components of onion

Field experiment of analysis result showed that the effects of deficit irrigation showed there were highly significant ($p<0.001$) differences in growth parameters as shown table below (Table 4.4) and (Appendix Table 1,2 & 3). The maximum plant and leaf heights and number of leaves per plant of 60.2 cm, 54.1 cm and 10.1 respectively, were recorded from the control treatment (100% ETc) whereas the minimum plant and leaf heights and leaf number per plant of 54 cm, 47.2 cm and 7.5 were recorded from highly deficit irrigation treatment (60% ETc) respectively. The results revealed onion growth parameters were directly associated with the amount of irrigation water applied. This result showed that onion growth components decreased with an increase in levels of water deficit. The primary reason for the increase in plant and leaf heights observed with increased irrigation water could be attributed to improved soil moisture availability, which enhances plant vegetative development by promoting cell division and elongation. These results are agreed with the result of Mebrahtu (2019) who reported that the higher leaf length was recorded by 100% ETc of irrigation level. These results are in agreement with the findings of Tezera (2022) who reported that the highest growth components of onion were recorded from full irrigation and the lowest heights were recorded from high stressed treatment. The current result was also in line with Abdelkhalik et al. (2020) who stated that 100% ETc resulted in the highest values of growth parameters, while 50% ETc led to the lowest, with intermediate values recorded at 75 % ETc. Nurga et al. (2020) also reported the lowest plant heights obtained from treatments receiving a low amount of water of 50% ETc.

In general, the results indicated growth components of onion decreased as irrigation depth decreased from optimum irrigation (100% ETc) to low soil moisture level (60% ETc). This indicated that the growth parameters of onion were taller at maximum applied water than onion that received a minimum amount of water (Table 4.4). This might be because plants respond to water stress by closing their stomata to slow down water loss by transpiration, gas exchange within the leaf is limited, consequently, photosynthesis and growth slow down. Similar results were also obtained by Singh (2018) that decreasing deficit levels (stresses) increased the plant height and leaf height and number of leaves. Metwally (2011) also indicated that the higher water supply resulted in higher vegetative parameters. These results were in line with the result of Biswas et al. (2017a) who stated that an increasing number of leaves per plant was recorded in higher regime irrigated treatment. The present result was also in agreement with the work of Al-Moshileh (2007) who reported that with increasing soil water supply, plant growth parameters (plant height) were significantly increased. Mebrahtu (2019) stated that Leaf length increased with increasing irrigation depth, as the plant does not experience moisture stress during any growth and development. This result seems closely related to that of Biswas et al. (2003), who reported that onion bulbs of irrigated treatments gave the highest leaves number per plant than the non-irrigated one, whereas onion grown without supplemental irrigation gave a lower number of leaves.

Table 4.4. The effects of deficit irrigation on growth components of onion

Deficit level	Plant Height (cm)	Leaf Height (cm)	Leaf No. (No.)
100% ETc	60.2^{a}	54.1^{a}	10.1^{a}
80% ETc	57.0^{b}	50.8^{b}	8.4^{b}
60% ETc	54.0^{c}	47.2^{c}	7.5^{c}
LSD (0.05)	1.24	0.92	0.59
CV (%)	2.12	1.77	6.69

Means with the same letter (s) are not significantly different at $P \leq 0.05$; LSD= least significant difference; CV = Coefficient of variation.

4.3.2 The effects of deficit irrigation on yield components of onion

Statistical analysis made on yield components indicated that there was highly significant ($p<0.001$) (Appendix Table 4,5 & 6) influence by different levels of deficit irrigation as shown in the table below (Table 4.5). The highest average bulb weight, bulb diameter and bulb height were 110.9 g, 5.9 and 5.4 cm recorded from the control treatment (100% ETc) respectively. Whereas the minimum average bulb weight, bulb diameter and bulb height were 88.2 g, 5.4 and 5.1 cm recorded from 60% ETc respectively. This result showed that onion yield components decreased with an increase in water deficit levels. This indicated that the yield components of plots that received maximum applied water were higher than plots that received a minimum amount of applied water (Table 4.5). The result shows that there was a linear relationship between bulb size and the quantity of irrigation water applied. This means that water stress affects negatively the weight of individual bulbs. The results revealed yield components are directly associated with the amount of irrigation water applied. This is an indication that larger onion sizes can be produced when the applied water is optimum and the moisture stress affects the size of the onion negatively. The result indicated that the lower irrigation depth might have reduced transpiration and photosynthesis and assimilate available for growth of the crop, which thus caused to produce small bulbs.

These results were in line with the result of Rop et al. (2016) who reported that the highest yield components were obtained from treatment with the highest supply of water while the treatment with the lowest quantity produced the least mean yield components. The results are in agreement with Olalla et al., (2004) who observed smaller-sized bulbs in mild water-stressed onion plants. This finding is also consistence with the result of Bizuneh (2019) who reported that the highest yield components were obtained from treatment that received the highest supply of water while that received the lowest quantity produced the minimum average bulb weight of onion. In general, yield components were reduced significantly with decreasing applied irrigation, which might be due to water shortage. This shows the response of the crop to deficit irrigation and as applied water increased the average weight of onion bulbs increased.

Table 4.5. The effects of a deficit on the yield components of onion

Deficit level	Bulb Weight (g)	Bulb Height (cm)	Bulb Diameter (cm)
100%ETc	110.9^{a}	5.4^{a}	5.9^{a}
80% ETc	105.1^{a}	5.2^{b}	5.8^{a}
60%ETc	88.2^{b}	5.1^{c}	5.4^{b}
LSD (0.05)	7.54	0.1	0.17
CV (%)	7.24	1.9	2.95

Where, means with the same letter (s) are not significantly different at $P \leq 0.05$; LSD= least significant difference; CV = Coefficient of variation.

4.3.3 The effects of deficit irrigation on marketable yields of onion

The results of the analysis of variance indicated that different deficit irrigation levels had a highly significant ($p< 0.001$) (Appendix Table 7) impact on the marketable yield of onion (Table 4.6). In comparison to other deficit irrigation treatments, the full irrigation treatment was the maximum yield of onion but this treatment is not statistically significant from 80% ETc. The highest marketable yield 37 t/ha was obtained from full irrigation treatment (100% ETc) and the lowest marketable yield 28.1 t/ha was obtained from 60% ETc (Table 4.6). It implies that the marketable yield of onion in 100% ETc was 31.7% higher than 60% ETc. The results indicated that as soil moisture levels decreased from optimal irrigation (100% ETc) to low soil moisture levels (60% ETc), the marketable yield of onion decreased. This indicated that the amount of irrigation water applied has a proportional effect on the marketable yield of onion. The amount of irrigation water supplied and the marketable yield of onion relate linearly (Table 4.6). These results agreed with Temesgen (2018) finding that the minimum yield was obtained at 50% ETc. This result is in line with the finding obtained by Piri et al. (2020) who found that reducing irrigation water usage decreased onion output. This finding is consistent with that of Tezera & Woldemichael (2022) who concluded that the marketable bulb yield from non-stressed treatments was the highest while the most stressed treatment had the lowest marketable bulb yield of onion. According to Dirirsa et al. (2017), the highest and lowest onion bulb yields were attained at 100% and 50% ETc, respectively, with the highest and lowest water applications. According to Kahlon (2016), the yield of onion rises as the irrigation level increases.

Table 4.6. The effects of deficit irrigation on the marketable yield of onion

Deficit level	Marketable Yield (t/ha)
100% ETc	37.0[a]
80% ETc	34.9[a]
60% ETc	28.1[b]
LSD (0.05)	2.98
CV (%)	8.71

Where, means with the same letter (s) are not significantly different at $P \leq 0.05$; LSD= least significant difference; CV = Coefficient of variation.

4.3.4 The effects of deficit irrigation on total yield of onion

Analysis of variance showed that there was a highly significant difference ($P<0.001$) (Appendix Table 8) in total yield of onion due to the effects of deficit irrigation (Table 4.7). Accordingly, the maximum total yield (38.4 t/ha) was obtained from the experimental plots that received 100% ETc, followed (36.7 t/ha) by plots that were grown with 80% ETc. In contrast, the minimum total bulb yield (29.2 t/ha) was recorded from the treatment that received 60% ETc. Plots with 100% ETc received the maximum yield, both marketable and unmarketable yield, and contributed to the overall yield. Increased full irrigation may have a positive effect on vegetative growth, including plant height, number of leaves, and leaf length. These factors raise the plant's ability to compete for photosynthetic energy, which can enhance bulb weight and increase overall bulb production. The overall bulb yields increased as the irrigation level increased from 60% ETc to 100% ETc. This result is in line with Mubarak, I., & Hamdan (2018) who indicated that the relationship between the total bulb yield and irrigation level (as a percentage of ETc) was linear.

Table 4.7. The effects of deficit irrigation on total yield of onion

Deficit level	Total Yield (t/ha)
100% ETc	38.4[a]
80% ETc	36.7[a]
60% ETc	29.2[b]
LSD (0.05)	3.59
CV (%)	10.04

Where, means with the same letter (s) are not significantly different at $P \leq 0.05$; LSD= least significant difference; CV = Coefficient of variation.

4.3.5 The effects of deficit irrigation on the water productivity of onion

The analysis of variance indicated that the water productivity was significantly affected by the water deficit level ($p < 0.05$) (Appendix Table 9) (Table 4.8). The highest water productivity 10.4 and 9.9 kg/m^3 was obtained from 60% ETc and 80% ETc respectively, while the lowest water productivity 8.8 kg/m^3 was obtained from 100% ETc. This shows that water productivity in 60% ETc treatment was 5.1% higher than 80% ETc and 18.2% higher than 100% ETc treatment. This demonstrates that compared to 60% and 80% ETc treatment, water productivity was lower in 100% ETc treatment. In terms of water productivity, there was not a significant difference between the 60 and 80% ETc treatments. As a result, the yield was reduced by reducing the amount of irrigation water. In contrast, the water productivity of the 100% ETc treatments differed significantly from that of the other deficit treatments. This is because the deficit treatment's onion results were decreased and the full irrigation treatment's water application was much higher than the deficit treatments. Irrigation water use efficiency (IWUE) for onion was increased in deficit treatment compared to non-stressed treatment. Treatment with the smallest irrigation depth (60% ETc) and smaller yield has the greatest WP values, while the smallest WP corresponds to the non-stressed treatment (100% ETc). This result was in line with Rop et al., (2016) who reported that IWUE values decreased with increasing water application levels with the highest at 50% ETc and the lowest at 100% ETc. This result was also in line with Ismail (2010) who reported that deficit irrigation often results in more water being used efficiently. Expanding irrigated areas could be one way to increase water productivity through the use of DI (Asmamaw et al., 2021). Compared to full irrigation, deficit irrigation results in higher water productivity, lower irrigation costs, and lower production costs (Hashem et al., 2018). Applying DI can save a large quantity of water and increase water productivity without significantly lowering yields (Mekonen et al., 2022). This result shows that a deficit irrigation application level of 80% ETc results in high water saving (20%) without compromising significant yield reduction.

Table 4.8. The effects of deficit irrigation on the water productivity of onion

Deficit level	Water Productivity (kg/m^3)
100% ETc	8.8^{b}
80% ETc	9.9^{a}
60% ETc	10.4^{a}
LSD (0.05)	0.83
CV (%)	8.36

Where, means with the same letter (s) are not significantly different at $P \leq 0.05$; LSD= least significant difference; CV = Coefficient of variation.

4.4 The Effects of Mulch Types on Yield and Water Productivity of Onion

4.4.1 The effects of mulch types on growth components of onion

Analysis of variance showed that all growth parameters of onion were significantly affected by mulch types (P<0.05) (Appendix Table 1,2 & 3) (Table 4.9). All growth parameters of onion were highest in straw mulched treatment compared to plastic and no mulch treatments. Statistically straw mulch was significantly different from plastic and no mulch treatments. Both plastic and no mulch treatments were non-significant differences in all growth parameters of onion. The highest plant height, leaf height and leaf numbers of onion were 59.1 cm, 53.6 cm, and 10.0 respectively recorded from straw mulch treatments. Whereas the minimum plant height and leaf height of onion were 55.5 and 48.8 cm respectively, recorded from no mulch treatments, and the minimum leaf number was 7.6 recorded from plastic mulch treatments (Table 4.9). It could be the white plastic mulch increase the surface temperature and reflect solar energy above the optimal level. Due to this the plant leaf was burned and dry. It was observed that straw mulch prevented the emergence and regrowth of weeds. It, therefore, reduced the competition for nutrients while plastic mulch was observed to accelerated the emergence and regrowth of weeds. It, therefore, increases the competition for nutrients. This result agreed with the result of Ranjan et al. (2017) who reported that maximum plant height and maximum leaf height are observed in plots mulched with straw. Treatments mulch with straw plants received more soil moisture and good aeration which might promote vegetative growth resulting in the maximum growth components (Tufa et al., 2022). This result was in line with the result of Ramalan et al. (2010) who reported that the use of plastic mulches did not show any superiority over straw mulches. This result agreed with the results of (Amare & Desta, 2021) which indicates that the negative impacts of plastic mulch decrease growth components and reduce the activity of soil microorganisms. In improving the soil nutrient status straw mulch is more effective than plastic mulch (Guangcheng & Carlos, 2017). This result agreed with the results of (Anisuzzaman et al., 2009) stated that white plastic mulch gave the minimum number of leaves compared with other mulch types. Straw mulches significantly increased the net photosynthetic rate of leaves more than other mulch types during the whole growth season (Liao et al., 2021).

Table 4.9. The effects of mulch types on growth components of onion

Mulch Types	Plant Height (cm)	Leaf Height (cm)	Leaf No. (No.)
No mulch	55.5[b]	48.8[b]	8.4[b]
Straw mulch	59.1[a]	53.6[a]	10.0[a]
Plastic mulch	56.6[b]	49.6[b]	7.6[b]
LSD (0.05)	2.33	3.82	1.12
CV (%)	3.12	5.76	9.87

Where, means with the same letter (s) are not significantly different at $P \leq 0.05$; LSD= least significant difference; CV = Coefficient of variation.

4.4.2 The effects of mulch types on yield components of onion

The analysis of variance showed that the yield components of onion were significantly affected by mulch type (Table 4.10) (Appendix Table 4, 5 & 6). The highest mean bulb weight, bulb height and bulb diameters 108.8 g, 5.5 cm and 5.9 cm respectively were obtained from the treatments mulched with straw. Whereas the lowest mean bulb weight, bulb height and bulb diameter 87.1 g, 4.9 cm and 5.4 cm respectively were obtained from no mulch treatments. However, there was no significant difference between straw and plastic mulch on yield component of onion. This result is in line with Amil et al. (2005) who reported maximum bulb weight in straw mulch followed by plastic mulch and no mulch treatment. The straw mulch increased all previous yield components (Barakat et al., 2019). This study was in line with the result of Ismail (2010) who stated that plants grown with straw mulch gave higher yield components. This result is in agreement with the result of Singh, A., & Sarkar (2020) who reported that organic mulching can improve bulb quality due to enhancing higher nutrient availability to the plants.

Table 4.10. The effects of mulch type on yield components of onion

Mulch type	Bulb Weight (g)	Bulb Height (cm)	Bulb Diameter (cm)
No mulch	87.1^{b}	4.9^{b}	5.4^{b}
Straw mulch	108.8^{a}	5.5^{a}	5.9^{a}
Plastic mulch	108.3^{a}	5.3^{a}	5.8^{a}
LSD (0.05)	16.4	0.39	0.22
CV (%)	12.35	4.67	2.88

Where Means with the same letter (s) are not significantly different at $P \leq 0.05$; LSD= least significant difference; CV = Coefficient of variation.

4.4.3 The effects of mulch types on marketable yield of onion

The analysis of variance showed that the marketable yield of onion was significantly affected at ($p < 0.05$) by mulch type applications (Table 4.11 and Appendix Table 7). The maximum marketable yield recorded under straw mulch showed a statistically non-significant difference from plastic mulched plots. On the other hand, the lowest marketable yield of onion was observed in no mulch treatment and this was statistically significant different from straw and plastic mulch treatments. The marketable yield of onion was 36.4, 35.8, and 27.7 t/ha, respectively in straw, plastic and no mulch treatments. It implies that the marketable yield in straw mulch treatment was 31.4% higher than no mulch treatment. The result indicated that mulching with straw did significantly improve the yield of onion. This result was in line with the result of Barakat et al. (2019) who reported that straw mulch increased the bulb yield of onion and its components. The results were also consistent with the findings reported by Singh (2018) who stated that mulching with straw is likely to improve onion bulb yields by 17%. Crop yield significantly increased with the application of straw mulch (Dossou-yovo et al., 2016). These results agree with the findings of Novo et al. (2016) who reported that the onion yields significantly increased with the application of rice straw mulch. This result agreed with the result of Igbadun et al. (2012) who stated that mulching with plastic material gave an onion yield increase of about 12–15% compared to a no-mulch condition. These results suggest that straw mulching has great potential for improving onion yield. Plastic mulch is considered more effective than straw mulch in reducing the moisture evaporation from the soil surface and improving the soil moisture status while in improving the soil nutrient status and bulb yield, straw mulch is more effective than plastic mulch (Guangcheng & Carlos, 2017).

Table 4.11. The effects of mulch type on marketable yield of onion

Mulch type	Marketable Yield (t/ha)
No mulch	27.7^{b}
Straw mulch	36.4^{a}
Plastic mulch	35.8^{a}
LSD (0.05)	7.04
CV (%)	16.16

Where, means with the same letter (s) are not significantly different at $P \leq 0.05$; LSD= least significant difference; CV = Coefficient of variation.

4.4.4 The effects of mulch types on total yield of onion

The analysis of variance showed that the total yield of onion was significantly ($p < 0.05$) affected by mulch types (Table 4.12) (Appendix Table 8). The maximum total yield of onion recorded at plastic mulch was statistically similar with straw but it was significantly different from no mulch treatment. On the other hand, the lowest total yield of onion was observed in no mulch. The total yield of onion was 37.6, 37.5, and 29.2 t/ha, respectively, in plastic, straw, and no mulch treatments. It implies that the total yield in straw mulch treatment was 28.8% higher than no mulch. The result indicated that mulch application significantly improves the yield of the onion. These results agree with Tefera et al. (2021) who reported that the maximum total yield was obtained due to plastic mulch rather than no mulch.

Table 4.12. The effects of mulch type on the total yield of onion

Mulch type	Total Yield (t/ha)
No mulch	29.2^{b}
Straw mulch	37.5^{a}
Plastic mulch	37.6^{a}
LSD (0.05)	6.45
CV (%)	14.17

Where, means with the same letter (s) are not significantly different at $P \leq 0.05$; LSD= least significant difference; CV = Coefficient of variation.

4.4.5 The effects of mulch types on water productivity of onion

The analysis of variance showed that water productivity was significantly affected by the mulch Types ($p < 0.01$) (Table 4.13 and Appendix Table 9). The highest water productivity was obtained from straw mulch 10.6 kg/m^3, followed by plastic mulch treatments 10.4 kg/m^3. The lowest water productivity 8.1 kg/m^3 was obtained from no mulch treatment. The maximum water productivity (10.6 & 10.4 kg/m^3) obtained at straw & plastic mulching was statistically no different with each other but both are superior to no mulch conditions. Hence, there was 30.9 % and 28.4% increment of water productivity of onion by applying straw and plastic mulching respectively over the non-mulching condition. The result indicated that mulching is one of the important water management strategies used to improve water productivity. This result agreed with the results of Maboko et al., (2017) who reported that straw mulch increased water productivity. This result was in agreement with the finding of Amil et al., (2005) who reported that straw mulches gave maximum water productivity of onion as compared to other mulch types. Straw mulch increased water productivity, and decreased evapotranspiration (Yan et al., 2018). This research shows that Straw mulching increase yield and water productivity.

Table 4.13. The effects of mulch types on water productivity of onion

Mulch type	Water Productivity (kg/m^3)
No mulch	8.1^b
Straw mulch	10.6^a
Plastic mulch	10.4^a
LSD (0.05)	2.18
CV (%)	17.1

Where, means with the same letter (s) are not significantly different at $P \leq 0.05$; LSD= least significant difference; CV = Coefficient of variation.

4.5 The Interaction Effects of Deficit Irrigation and Mulch Types on Yield and Water Productivity of Onion

4.5.1 The effects of deficit irrigation and mulch on growth components of onion

The interaction effect of mulch type with deficit level on plant and leaf height was not significant (Table 4.14 and Appendix Table 1 & 2), while leaf number per plant was significantly affected (Appendix Table 3) by the interaction effects of deficit levels with mulch type. The highest leaf number 12.7 was obtained from full irrigation with straw mulch, while the lowest leaf number was obtained from 60% ETc with plastic mulch treatment combinations. This result was in agreement with the finding of El-wahed et al., (2017) reported that the leaf height was not significantly affected by the interaction between mulching materials with deficit irrigation treatments. These results are in line with the result of Rachel et al., (2018) who stated that plastic mulch significantly affected the onion leaf number.

Table 4.14. The interaction effects of deficit and mulch on growth components of onion

Treatments	Plant Height (cm)	Leaf Height (cm)	Leaf No. (No.)
100% ETc with NM	57.7 ^{ns}	52.4 ^{ns}	9.2^{b}
80% ETc with NM	56.0 ^{ns}	48.9 ^{ns}	8.3^{bc}
60% ETc with NM	52.9 ^{ns}	45.0 ^{ns}	7.6^{cd}
100% ETc with SM	62.8 ^{ns}	57.2 ^{ns}	12.7^{a}
80% ETc with SM	58.5 ^{ns}	53.8 ^{ns}	9.3^{b}
60% ETc with SM	56.0 ^{ns}	49.8 ^{ns}	8.1^{c}
100% ETc with PM	60.2 ^{ns}	52.6 ^{ns}	8.5^{bc}
80% ETc with PM	56.7 ^{ns}	49.5 ^{ns}	7.5^{cd}
60% ETc with PM	53.0 ^{ns}	46.7 ^{ns}	6.7^{d}
LSD (0.05)	2.15	1.59	1.02
CV (%)	2.1	1.8	6.7

Where, means with the same letter (s) are not significantly different at $P \leq 0.05$; LSD= least significant difference; CV = Coefficient of variation.

4.5.2 The effects of deficit irrigation and mulch on yield components of onion

The analysis of variance showed that one yield component (bulb height) was significantly affected by the interaction of deficit irrigation and mulch types (Table 4.15 and Appendix Table 6) but the other yield components (bulb weight and bulb diameter) were not significantly affected by the interaction effect (Appendix Table 4 & 5). The highest bulb height of the onion 5.8 cm was obtained when the onion received full irrigation and mulched with straw it was a significant difference from the other treatment, while the lowest bulb height of the onion was 5.0 cm obtained from 60% ETc and 80% ETc with no mulch treatment combination.

The result indicated that the bulb height of the onion was affected by the amount of water applied and mulch material used. Even if we use any type of mulch, the bulb size also decrease as the irrigation water depth decreases. The result is agreed with Nanesa et al. (2022) who stated that the effects of deficit irrigation and straw mulching levels had a highly significant effect on onion leaf length. This result is in line with Amil et al. (2005) who reported maximum bulb size in straw mulch while minimum bulb was at 50% ETc with plastic mulch and no mulch treatment combinations. This result also agreed with the result of Tolossa (2020) who stated that the interaction effects of deficit irrigation with mulch significantly influenced bulb height of the onion.

Table 4.15. The interaction effects of deficit and mulch on yield components of onion

Treatments	Bulb Weight (g)	Bulb Height (cm)	Bulb Diameter (cm)
100% ETc with NM	94.8 ^{ns}	5.0^{d}	5.5 ^{ns}
80% ETc with NM	90.9 ^{ns}	5.0^{d}	5.6 ^{ns}
60% ETc with NM	75.6 ^{ns}	4.7^{e}	5.1 ^{ns}
100% ETc with SM	119.4 ^{ns}	5.8^{a}	6.2 ^{ns}
80% ETc with SM	110.5 ^{ns}	5.5^{b}	6.0 ^{ns}
60% ETc with SM	96.4 ^{ns}	5.3^{c}	5.7 ^{ns}
100% ETc with PM	118.4 ^{ns}	5.3^{c}	6.0 ^{ns}
80% ETc with PM	114.0 ^{ns}	5.2^{c}	5.9 ^{ns}
60% ETc with PM	92.4 ^{ns}	5.2^{c}	5.5 ^{ns}
LSD (0.05)	13.05	0.18	0.3
CV (%)	7.2	1.9	2.6

Where, means with the same letter (s) are not significantly different at $P \leq 0.05$; LSD= least significant difference; CV = Coefficient of variation.

4.5.3 The effects of DI and mulch on marketable yield, total yield and WP

The analysis of variance showed that the marketable yield, total yield and water productivity of onion was not significantly ($p < 0.05$) affected by the interaction effects of deficit irrigation and mulch types (Table 4.16 and Appendix Tables 7, 8 & 9). The results were also consistent with the results of Igbadun et al., (2012) stated that the bulb yields of the treatments irrigated at 75% ETc with mulch were not statistically significantly different from those that were fully irrigated 100% ETc with mulch. Thus, bulb yields under WPM were not significantly different from a no-mulch condition (Igbadun et al., 2012).

Table 4.16. The interaction effects of deficit and mulch on MY, TY and WP of onion

Treatments	Marketable Yield (t/ha)	Total yield (t/ha)	Water Productivity (kg/m^3)
100% ETc with NM	30.7 ns	31.5 ns	8.8 ns
80% ETc with NM	29.3 ns	31.4 ns	8.2 ns
60% ETc with NM	23.0 ns	24.8 ns	7.4 ns
100% ETc with SM	39.7 ns	42.2 ns	9.4 ns
80% ETc with SM	38.1 ns	38.5 ns	11.0 ns
60% ETc with SM	31.5 ns	31.9 ns	11.5 ns
100% ETc with PM	40.6 ns	41.6 ns	9.6 ns
80% ETc with PM	37.2 ns	40.3 ns	10.7 ns
60% ETc with PM	29.7 ns	31.0 ns	10.9 ns
LSD (0.05)	5.16	6.22	1.45
CV (%)	8.7	10.0	8.4

Where, means with the same letter (s) are not significantly different at $P \leq 0.05$; LSD= least significant difference; CV = Coefficient of variation.

4.6 The Effects of Deficit Irrigation and Mulching Water Saving and Yield Reduction

Optimal irrigation treatment (100% ETc with NM) was used as the control treatment for the comparison of deficit irrigation level and mulch type treatment combinations in saving water and yield reduction. The net saving in irrigation water from 80% ETc and 60% ETc were 20% and 40% respectively. This implies that as deficit level increase water savings also increase. This suggests that increasing the area irrigated with the water saved would compensate for the yield loss due to deficit irrigation for these treatments. This result shows relative yield reduction was increased with increasing moisture stress levels but mulch treatments reduce water losses by evaporation and absorb soil moisture. These findings indicate that the highest yield increment of 32.08% was obtained from 100% ETc with straw mulch compared with the control treatment (Table 4.17).

Table 4.17. Marketable bulb yield, WP and relative water saved influenced by treatments

Treatments	Marketable yield ton/ha	Relative water saved (%)	Relative yield reduction (%)
100% ETc with NM	30.74	0	0
80% ETc with NM	29.26	20	4.81
60% ETc with NM	23.14	40	24.72
100% ETc with SM	40.6	0	+32.08
80% ETc with SM	37.23	20	+21.11
60% ETc with SM	29.7	40	3.38
100% ETc with PM	39.7	0	+29.15
80% ETc with PM	38.13	20	+24.04
60% ETc with PM	31.49	40	+2.44

4.7 The Effect of Deficit Irrigation and Mulch Types on Yield Response Factor

The result indicated that the yield response factor was associated with deficit level and mulch types. The study also reveals that a lower yield response factor of 0.3 was achieved from 80% ETc with straw mulch. At 100% ETc there were no recorded yield response factors (Table 4.18), because the actual amount of water applied at 100% ETc was similar to ETm. Based on the result obtained the Ky values of the no mulch treatment were higher than the mulched treatment. It is because the mulched experimental plot was resisting water stress by reducing water lost by evaporation accordingly it increases yield and Ky but in no mulch treatment the soil was exposed to sun which causes evaporation loss. This result agreed with Igbadun et al., (2012) reported that the Ky of onion crop under no mulch condition was higher.

The yield response factor Ky, which indicates the level of tolerance of a crop to water stress, approaching unity when yield declines proportionally to ET deficit (the greater Ky the lower the tolerance), was higher in no mulch compared to mulched treatment. It also suggests that mulching helped to improve the impact of the deficit irrigation on yield, these results agreed with Igbadun et al., (2012). Different studies revealed that yield response factor varies for different crop types and stress condition.

Table 4.18. Effect of deficit irrigation levels and mulch type on yield response factor

Treatment	Yield (Kg/ha)	Eta (mm)	ETa/ETm	Ya/Ym	1-Ya/Ym	1-Eta/Etm	Ky
100% ETc with NM	30740	4221	1.0	0.8	0.2	0.0	
80% ETc with NM	29260	3477	0.8	0.7	0.3	0.2	1.6
60% ETc with NM	23140	2733	0.6	0.6	0.4	0.4	1.2
100% ETc with SM	40600	4221	1.0	1.0	0.0	0.0	
80% ETc with SM	38130	3477	0.8	0.9	0.1	0.2	0.3
60% ETc with SM	31490	2733	0.6	0.8	0.2	0.4	0.6
100% ETc with PM	39700	4221	1.0	1.0	0.0	0.0	
80% ETc with PM	37230	3477	0.8	0.9	0.1	0.2	0.5
60% ETc with PM	29700	2733	0.6	0.7	0.3	0.4	0.8

4.8 Comparison of Onion Yield with Water Productivity

As shown in the figure below, if insufficient water is applied the crop is not fully developed resulting in low yield and high-water productivity. Crop yield and water productivity can be increased if a considerable amount of water is added. The result shows full irrigation (100% ETc) had the highest yield and low water productivity. As the amount of water applied increased the yield also increased but water productivity decreased. From mulch types straw mulch was high yield and water productivity. Treatment effects on onion yield and water productivity has shown in figure below (Figure 4.1).

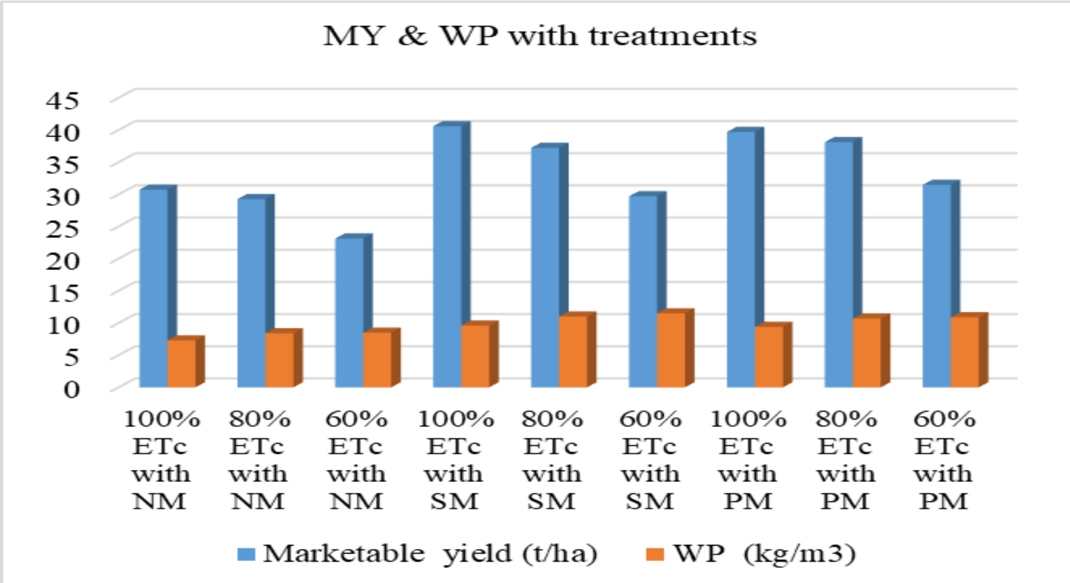

Figure 4.1. Effects of treatments on yield and WP

4.9 Correlation Between Growth, Yield and Yield Components

The result reveals that marketable yield was associated positively with all parameters recorded (Table 4.19). The correlation analysis of onion showed that there was a strong association between marketable yield with growth and yield components, such as plant height, leaf height, leaf number, bulb diameter, bulb height, and average bulb weight of onion with the Pearson Coefficient of 0.71, 0.64, 0.39, 0.67, 0.77 and 0.79 respectively. The results indicate that the application of deficit irrigation with mulch treatments had positive effects on the important growth parameters and yield components of the onion crop. The positive and significant correlation observed among the yield and growth parameters indicates that the yield was directly associated with the values of these parameters. The results were also consistent with the findings reported by Metwally, (2011) that growth and yield components had a positive and significant correlation with bulb yield. Furthermore, all the studied parameters except bulb diameter and bulb weight had a negative response on WP for onion.

Table 4.19. Correlation coefficient (r) of growth and yield parameters of onion

	PH	LH	LN	BH	BD	Bwt	MY	TY	WP
PH	1								
LH	0.81	1							
LN	0.78	0.74	1						
BH	0.70	0.67	0.68	1					
BD	0.80	0.68	0.58	0.69	1				
Bwt	0.76	0.65	0.44	0.65	0.82	1			
MY	0.71	0.64	0.39	0.67	0.77	0.79	1		
TY	0.72	0.69	0.38	0.61	0.81	0.89	0.80	1	
WP	-0.04	-0.06	-0.22	-0.36	0.24	0.23	-0.50	-0.24	1

*MY = Marketable yield, TY= Total yield, WP = Water productivity, BD = bulb diameter (cm), BH= bulb height (cm), Bwt= Bulb weight (g), PH = plant height (cm), LH=Leaf height (cm), LN = leaf number per plants.

4.10 **Economic Analysis**

The partial budgeting analysis was done by arranging the total variable cost in an increasing order as described by the procedure (CIMMYT, 1988). 11220 m^2/ha plastic mulch and 6 tons/ha straw mulch material were used for this experiment with a cost of 15.00 ETbirr/m^2 and 25.00 ETbirr/10kg respectively. The average daily labor cost was 60.00 ETbirr, whereas the farm gate price of onion during harvesting was 50 ETbirr per kg taken for analysis. Dressing a single plot with straw and plastic mulch takes 10 minutes and 40 min per person respectively. The partial budgeting analysis on mulch material described in (Table 4.20) showed that the application of plastic mulch gave higher total revenue with a high variable cost of plastic mulch material that reduced the net income with a minimum benefit-to-cost ratio. Also, the change in total variable cost of the plastic treatment with straw mulch gives a negative result and it becomes dominant for calculating the marginal return. In the case of straw mulch, the total revenue results in a higher value with minimum total variable cost as compared to having a high net return value and benefit-to-cost ratio as compared to plastic mulch as well as no mulch treatments. According to the international maize and wheat improvement center (CIMMYT), the minimum acceptable marginal rate of return (MRR %) should be between 50 and 100% and above (CIMMYT, 1988). As shown in the table below (Table 4.20) application of straw mulch is economically important as the MRR value of 650.7 % which is greater than 100%.

Table 4.20. Economic analysis of onion yield production under different treatments

Trt	TY (kg/ha)	AY (kg/ha)	TR (ETB/ha)	TC (ETB/ha)	NI (ETB/ha)	ΔNI	ΔVC	MRR (%)	B /C ratio
NM	27666	24899.4	1244970	0	1244970	-	-	-	-
SM	36440	32796	1639800	52605.8	1587194	342224	52605.8	650.5	30.2
PM	35844	32259.6	1612980	451128	1161852	-425342	398522	D	2.6

Trt- treatment, TY- Total yield, AY- Actual yield, TR- Total return, TC – Total cost, NI- Net income, VC- Variable cost, MRR- Marginal rate of return, B/C- Benefit to cost ratio

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

This experiment was undertaken to study the effects of deficit irrigation and mulch-type application on yield and water productivity of onion. The results of the study show that the effects of deficit irrigation and mulch type applications are significantly important in obtaining higher onion yield and water productivity. According to the result of this study, the highest marketable yield was obtained from 100% ETc has no significant difference from 80% ETc but it was a 31.7% yield improvement from 60% ETc. While the highest water productivity of onion was obtained from 60% ETc and it has insignificant difference from 80% ETc but 18.2% higher than 100% ETc treatment, however, higher yield reduction (31.7%) was obtained corresponding to this treatment (60% ETc). From deficit irrigation treatments 80% ETc saves 20% of water compared to the control treatment (100% ETc) and the water saved could be used to cultivate additional land in areas where there is water scarcity and it could increase the cultivated land area. This treatment also has a non-significant difference in terms of MY and WP from 100% ETc treatment. This research concludes that, irrigation with 80% ETc has great importance.

Whereas, the marketable yield of onion in SM was 31.4% higher than NM and but statistically similar with WPM while the water productivity of onion in SM was 30.9% higher than NM and there was not significant difference from WPM. The partial budget analysis revealed that the highest benefit-cost ratio of about 30.2 was obtained from straw mulching. However, the lowest benefit-cost ratio of about 2.6 obtained from plastic mulching. Regards to this result straw mulch for onion production was economical and better overall performance than the others and also for being cheaper and organic in nature.

The combined effect of deficit irrigation and mulching materials application has a significant impact on one growth parameter (leaf number per plant) and one yield parameter (bulb height) but did not significant effect on the other growth and yield parameters, marketable yield and water productivity of onion. Therefore, in terms of marketable yield, water productivity and economic importance, deficit irrigation with 80% ETc or by covering the soil with straw mulch can be suggested for production of onion in the study area and similar agro-ecology and soil type.

5.2 Recommendations

Based on the results obtained and discussed in this thesis the following recommendations have been suggested.

- The major limiting factor to improve production and productivity is a shortage of water. In the Central Rift Valley of Ethiopia, water is a scarce resource that greatly limits crop productivity. Moreover, onion is one of the most significant and economical (profitable) vegetable crops farmed in this area. Therefore, deficit irrigation (DI) practice is a suitable and most efficient practice for sustainable production in water scarce area like Central Rift Valley of Ethiopia.
- Farmers and extension workers are advised to adopt deficit irrigation practice at 80% ETc in order to achieve optimum onion yield, water productivity and to cultivate additional land by saving water.
- In DI practice crops are deliberately exposed to a certain degree of water stress by irrigating below their crop water requirement (80% ETc), but mulch type application (straw mulch) reduce water stress by reducing water loss through evaporation that means crops are use the applied water effectively because of this to increase production and water productivity smallholder farmers (onion growers) are strongly encouraged to cover their crops with straw mulch.
- This research was conducted at one location in one season (dry season) of the year. Therefore, conducting the same experiment for different seasons, and in different location (agroecology) is recommended for the validity of this research.
- It is advised that every effort be made to create awareness for farmers about water saving practice (deficit irrigation) to save an adequate quantity of water and mulching by easily available material (straw mulch) to reduce evaporation and maintain moisture levels on their farms.

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APPENDICES

Appendix Table 1. Analysis of variance for onion plant height

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Block	2	11.547	5.773	1.8232	0.27366
Main. Plot	2	60.047	30.023	9.4811	0.03035*
Ea	4	12.667	3.167		
Sub. plot	2	176.109	88.054	60.2654	5.51e-07 ***
Main. plot: sub. plot	4	7.924	1.981	1.3559	0.30605
Eb	12	17.533	1.461		

***Highly Significant (p<0.001), * significant (p<0.05), DF= degree of freedom

Appendix Table 2. Analysis of variance for onion Leaf height

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Block	2	11.685	5.843	0.6853	0.55473
Main. Plot	2	121.347	60.674	7.1164	0.04813 *
Ea	4	34.104	8.526		
Sub. plot	2	214.361	107.18	133.543	6.319e-09 ***
Main. plot: sub. plot	4	2.275	0.569	0.7086	0.60144
Eb	12	9.631	0.803		

*** Highly Significant (p<0.001), * significant (p<0.05), DF= degree of freedom

Appendix Table 3. Analysis of variance for onion Leaf number per plant

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Block	2	1.349	0.6744	0.9232	0.468107
Main. Plot	2	28.016	14.0078	19.1741	0.008922 **
Ea	4	2.922	0.7306		
Sub. plot	2	32.087	16.0433	47.8641	1.91e-06 ***
Main. plot: sub. plot	4	9.991	2.4978	7.4519	0.002951 **
Eb	12	4.022	0.3352		

*** Highly Significant (p<0.001), * significant (p<0.05), DF= degree of freedom

Appendix Table 4. Analysis of variance for onion average bulb weight

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Block	2	630.25	315.12	2.0081	0.24899
Main. Plot	2	2754.45	1377.22	8.7762	0.03445 *
Ea	4	627.71	156.93		
Sub. plot	2	2508.84	1254.42	23.2977	7.377e-05 ***
Main. plot: sub. plot	4	70.94	17.74	0.3294	0.85294
Eb	12	646.12	53.84		

*** Highly Significant (p<0.001), * significant (p<0.05), DF= degree of freedom

Appendix Table 5. Analysis of variance for onion bulb diameter

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Block	2	0.24981	0.1249	4.6197	0.091281
Main. Plot	2	1.46003	0.73001	27.0005	0.004756 **
Ea	4	0.10815	0.02704		
Sub. plot	2	1.30954	0.65477	23.0975	7.687e-05 ***
Main. plot: sub. plot	4	0.07881	0.0197	0.6951	0.609675
Eb	12	0.34018	0.02835		

*** Highly Significant (p<0.001), * significant (p<0.05), DF= degree of freedom

Appendix Table 6. Analysis of variance for onion bulb height

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Block	2	0.0613	0.03065	0.5134	0.6331773
Main. Plot	2	1.80179	0.90089	15.0922	0.0136919 *
Ea	4	0.23877	0.05969		
Sub. plot	2	0.41721	0.2086	21.1423	0.000117 ***
Main. plot: sub. plot	4	0.23819	0.05955	6.0353	0.0067100 **
Eb	12	0.1184	0.00987		

*** Highly Significant (p<0.001), * significant (p<0.05), DF= degree of freedom

Appendix Table 7. Analysis of variance for onion marketable yield

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Block	2	36.96	18.481	0.6377	0.57494
Main. Plot	2	432.61	216.303	7.4631	0.04467*
Ea	4	115.93	28.938		
Sub. Plot	2	393.29	196.646	23.3751	7.262e-05 ***
Main. plot: sub. plot	4	8.96	2.241	0.2664	0.89396
Eb	12	100.95	8.413		

*** Highly Significant (p<0.001), * significant (p<0.05), DF= degree of freedom

Appendix Table 8. Analysis of variance for onion total bulb yield

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Block	2	19.77	9.884	0.4068	0.690536
Main. Plot	2	418.22	209.11	8.6057	0.03556*
Ea	4	97.2	24.299		
Sub. plot	2	433.56	216.781	17.7485	0.00026***
Main. plot: sub. plot	4	21.41	5.351	0.4381	0.07788
Eb	12	146.57	12.214		

*** Highly Significant (p<0.001), * significant (p<0.05), DF= degree of freedom

Appendix Table 9. Analysis of variance for onion water productivity

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Block	2	3.469	1.7344	0.6222	0.581757
Main. Plot	2	34.327	17.1633	6.1566	0.060123
Ea	4	11.151	2.7878		
Sub. plot	2	11.869	5.9344	8.984	0.004122**
Main. plot: sub. plot	4	0.784	0.1961	0.2969	0.8744
Eb	12	7.927	0.6606		

*** Highly Significant (p<0.001), * significant (p<0.05), DF= degree of freedom

Appendix Table 10. Effective rainfall during the growing season of Onion

Month	Date	Rainfall (mm)	Effective rainfall (mm)
March	1	2.3	0
	2	5	0
	12	55.5	36.4
	13	7.5	1.2
	14	25.5	12.4
	15	7.4	1.1
	18	27.5	14
	22	14.3	5.2
	23	13.2	4.6
	29	7.5	1.2
April	1	17.5	7.2
	20	63.5	42.8
	26	2.5	0
	27	36.5	21.2
	29	18.3	7.6
	30	14.3	5.2
May	1	27.5	14
	2	2.5	0
	5	10.5	3
	8	7.3	1
	21	5.4	0
	24	2.3	0
	30	7.7	1.3
	31	2.3	0

Source: Melkassa Meteorological Station, 2023

Appendix Table 11. February daily meteorological data and estimated ETo value

Day	Rainfall mm	Min Temp °C	Max Temp °C	RH %	wspeed m/s	sunshine hour	ETo mm/day
1	0.0	4.0	31.0	84.8	1.8	10.0	4.61
2	0.0	7.0	29.5	83.6	2.7	10.0	4.63
3	0.0	8.0	30.0	84.8	2.4	10.0	4.59
4	0.0	9.0	30.5	80.4	2.7	10.0	4.85
5	0.0	11.0	29.5	82.4	2.2	10.0	4.56
6	0.0	7.0	29.5	83.0	2.6	10.0	4.66
7	0.0	6.0	30.0	88.0	2.5	10.2	4.64
8	0.0	5.0	30.0	82.0	2.8	10.2	4.91
9	0.0	14.0	28.0	86.0	3.1	10.0	4.38
10	0.0	12.0	31.0	82.8	3.1	10.2	4.97
11	0.0	8.0	30.0	84.8	3.2	10.0	4.81
12	0.0	6.0	30.0	84.0	2.3	10.0	4.71
13	0.0	5.0	30.5	83.6	2.0	10.0	4.74
14	0.0	5.0	31.0	77.8	2.1	10.3	5.02
15	0.0	8.0	30.5	82.2	2.1	9.5	4.68
16	0.0	9.0	29.5	77.8	3.7	9.8	5.09
17	0.0	13.5	29.0	81.2	3.8	10.8	5.00
18	0.0	14.0	27.5	84.6	3.6	10.8	4.63
19	0.0	14.0	27.0	84.4	2.8	10.0	4.41
20	0.0	11.0	28.0	84.2	3.3	10.1	4.60
21	0.0	6.0	30.0	81.0	1.9	10.0	4.77
22	0.0	4.0	31.0	79.2	1.9	9.9	4.94
23	0.0	10.0	31.5	85.2	1.6	8.9	4.57
24	0.0	11.0	32.0	87.0	1.5	8.3	4.45
25	0.0	15.0	29.0	81.2	1.6	1.7	2.88
26	0.0	13.0	29.0	82.6	2.4	6.4	4.01
27	0.0	15.0	30.0	83.8	2.7	10.0	4.86
28	0.0	12.0	31.0	73.6	2.1	10.0	5.16

Source: Melkassa Meteorological Station, 2023

Appendix Table 12. March daily meteorological data and estimated ETo value

Day	Rainfall mm	Min Temp °C	Max Temp °C	RH %	wspeed m/s	sunshine hour	ETo mm/day
1	2.3	11	33	83.6	1.8	9.3	4.96
2	5	15	30	74.2	1.9	6.8	4.35
3	0	15	30	82.8	1.3	6.4	3.95
4	0	14	29.5	79	2.3	7.6	4.44
5	0	14	31.5	81.8	3.0	9.8	5.18
6	0	14	31	81.8	4.4	9.7	5.28
7	0	12	32	85	1.0	10.0	5.14
8	0	15	32	80.8	1.6	9.6	5
9	0	12	33	83.4	1.7	8.6	4.84
10	0	14.5	30	81.4	5.7	6.8	4.77
11	0	14	29	76	2.5	3.2	3.67
12	55.5	14	25	74.2	1.5	1.5	2.8
13	7.5	15	25	70	1.8	2.3	3.17
14	25.5	14	27.5	73.2	2.1	2.3	3.35
15	7.4	14	27	71.8	2.1	5.0	3.89
16	0	14	26	75.6	1.3	3.3	3.16
17	0	14	26.5	76.8	2.0	3.1	3.31
18	27.5	15	26	64	1.3	5.5	3.85
19	0	14	27.5	66.4	1.5	4.8	3.84
20	0	15	27.5	71	1.0	5.7	3.78
21	0	14	30	65.6	1.5	0.5	3.13
22	14.3	15	29.5	66	1.6	6.1	4.34
23	13.2	13	26.5	70.4	0.7	1.3	2.64
24	0	14	29.5	63.4	1.2	9.3	4.88
25	0	14	29.5	63.6	1.9	8.3	4.98
26	0	15	26	68	1.1	0.0	2.57
27	0	14	29	61.4	1.9	10.0	5.32
28	0	16	27	79.2	3.6	4.2	3.8
29	7.5	15	26.5	75.6	1.2	1.0	2.7
30	0	13	28.5	72.8	1.3	6.7	4.14
31	0	14	28.5	65.2	1.8	10.3	5.22

Source: Melkassa Meteorological Station, 2023

Appendix Table 13. April daily meteorological data and estimated ETo value

Day	Rainfall mm	Min Temp °C	Max Temp °C	RH %	wspeed m/s	sunshine hour	ETo mm/day
1	17.5	14.0	29.0	63.4	1.57	6.3	4.39
2	0.0	14.0	28.5	71.4	1.21	8.2	4.48
3	0.0	14.0	27.0	74.2	1.70	6.7	4.12
4	0.0	15.0	29.5	67	2.21	8.6	5.1
5	0.0	15.0	28.0	65	2.23	7.3	4.75
6	0.0	15.0	31.0	61.6	1.45	10.0	5.35
7	0.0	15.0	31.0	61.8	1.81	7.5	4.99
8	0.0	14.0	31.0	60.6	2.15	8.9	5.46
9	0.0	14.0	29.5	59.4	2.20	10.8	5.72
10	0.0	13.0	31.0	53.2	2.13	10.8	5.99
11	0.0	14.0	31.0	53.6	2	9.0	5.57
12	0.0	14.0	32.0	54.2	1.91	10.5	5.91
13	0.0	15.0	31.0	58.6	2.27	10.3	5.87
14	0.0	14.0	30.0	67.2	3.01	11.5	5.97
15	0.0	14.0	31.0	51.8	2.38	10.5	6.12
16	0.0	14.0	31.0	54.4	2.26	11.0	6.08
17	0.0	14.0	30.0	53.6	2.03	9.1	5.49
18	0.0	14.0	32.0	51.6	1.92	11.0	6.05
19	0.0	13.0	32.0	60.8	1.85	11.3	5.89
20	63.5	15.0	32.0	46.4	1.61	10.3	5.79
21	0.0	14.0	27.5	62.6	0.98	9.3	4.62
22	0.0	16.0	22.0	79.6	1.77	2.3	2.78
23	0.0	14.0	28.0	70	1.04	8.9	4.53
24	0.0	16.0	31.5	67.4	1.41	9.5	5.17
25	0.0	14.0	29.0	70.6	1.34	9.4	4.8
26	2.5	14.0	30.0	70	2.08	6.2	4.48
27	36.5	15.0	23.0	86.8	1.23	2.6	2.66
28	0.0	14.0	28.0	74.6	0.50	4.0	3.2
29	18.3	15.0	27.0	74	0.85	3.8	3.25
30	14.3	14.0	25.0	74	1.27	7.0	3.89

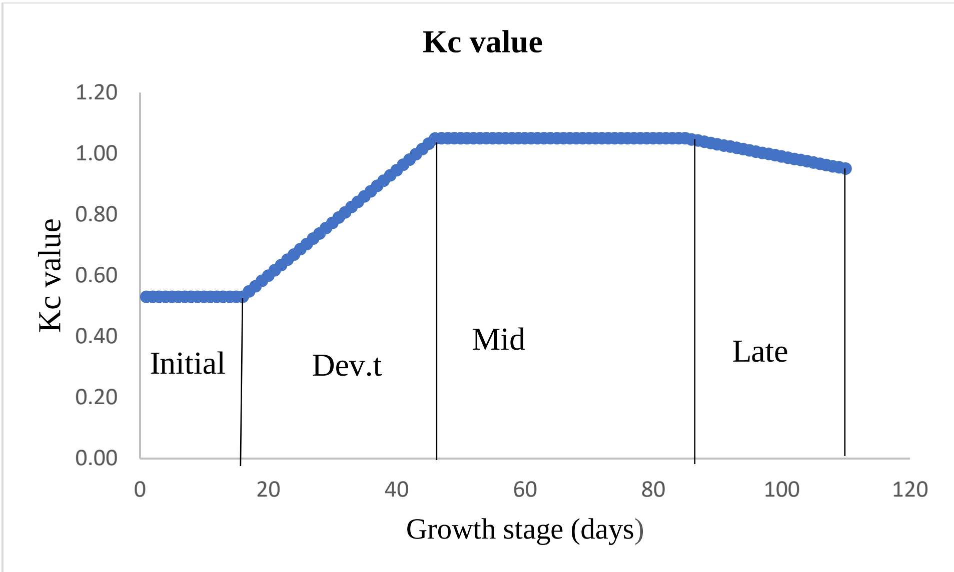
Source: Melkassa Meteorological Station, 2023

Appendix Table 14. May daily meteorological data and estimated ETo value

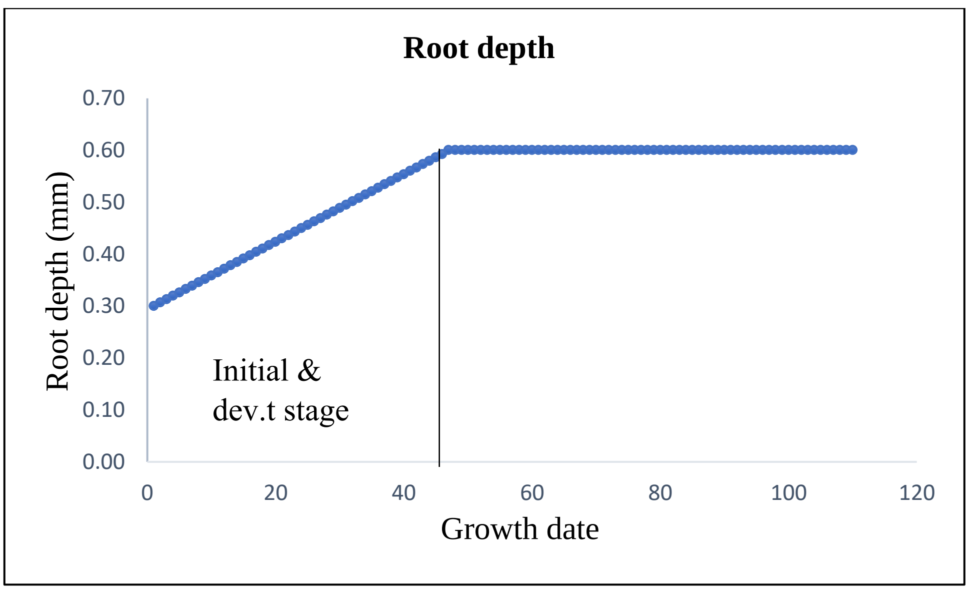
Day	Rainfall mm	Min Temp °C	Max Temp °C	RH %	wspeed m/s	sunshine hour	ETo mm/day
1	27.5	14	26	73.2	1.18	6.5	3.85
2	2.5	14	27	73.2	1.13	5.3	3.64
3	0	16	26	71.4	1.32	1.0	2.79
4	0	14	28	69	1.44	8.2	4.47
5	10.5	14	26	72.2	1.15	5.1	3.56
6	0	13	29	70.2	1.84	10.8	5.17
7	0	17	30	66.4	1.66	1.9	3.5
8	7.3	14	29.5	66.8	1.61	8.9	4.84
9	0	13.5	29.5	72.6	1.44	10.5	5
10	0	15	31	73	1.75	9.7	5.08
11	0	12.5	31	60.6	1.75	10.0	5.38
12	0	16	32	69.4	2.14	8.0	5.05
13	0	15	31	67.8	1.91	11.0	5.52
14	0	14	31	64.6	1.55	10.3	5.28
15	0	12	32	65.8	1.80	8.5	5.06
16	0	15	31	67.8	2.51	8.5	5.21
17	0	15	32	63.4	1.77	9.7	5.38
18	0	15	31	65.8	2.36	9.3	5.38
19	0	17	29	74.6	2.13	7.0	4.37
20	0	14	31	70.2	2.43	10.0	5.37

Appendix table 15. Discharge measurement using 3’ Parshall flume

Head (cm)	Throat width (inches)				
	1	2	3	6	9
	Discharge (l/s)				
2	0.14	0.281			
3	0.263	0.526	0.772	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



Appendix Figure 1. Crop coefficient for different growth stage of onion



Appendix Figure 2. Root depth of onion through growth stage






PRATA

Appendix Figure 3. Pictures captured during experimental season