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EVALUATING THE EFFECTS OF DEFICIT IRRIGATION AND MULCH TYPE ON YIELD OF ONION AND TOMATO AND WATER PRODUCTIVITY IN FOGERA, ETHIOPIA

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EVALUATING THE EFFECTS OF DEFICIT IRRIGATION AND MULCH TYPE ON YIELD OF ONION AND TOMATO AND WATER PRODUCTIVITY IN FOGERA, ETHIOPIA

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Evaluating the effects of deficit irrigation and mulch type on yield of onion and tomato and water productivity in Eogera, Ethiopia

By:

Belachew Muche Mekonen

A thesis submitted to in partial fulfillment of the requirements for the degree of Master of Science in Irrigation Engineering and Management.

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August, 2022

Bahir Dar, Ethiopia

DECLARATION

This is to certify that the Thesis entitled' 'Evaluating the effects of deficit irrigation and mulch type on yield of onion and tomato and water productivity in Fogera Ethiopia'' submitted in partial fulfillment of the requirements for the degree of Master of Science in Irrigation Engineering and management under Faculty of Civil and Water resources engineering, Bahir Dar Institute of Technology, is a record of original work carried out by me and has never been submitted to this or any other institution to get any other degree or certificates. The assistance and help I received during the course of this investigation have been duly acknowledged.

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THESIS APPROVAL SHEET

I hereby confirm that the changes required by the examiners have been carried out and incorporated in the final thesis.

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As members of the board of examiners, we examined this thesis entitled'' Evaluating the effects of deficit irrigation and mulch type on yield of onion and tomato and water productivity in Fogera Ethiopia'' by Belachew Muche. We hereby certify that the thesis is accepted for fulfillment of the thesis requirements for the award of the degree of Master of Science in Irrigation Engineering and Management

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“This work is dedicated to my family, friends, and who loved me. Special dedication goes to my mother Alemush Getnet and my father Muche Mekonen”

BIOGRAPHICAL SKETCH

I was born in 1992 in Bebekis Kebel in Fogera Woreda, South Gondar Administrative Zone, Amhara National Regional State, Ethiopia. I completed my elementary and high education at Jigna and Woreta respectively. After I completed high school, I joined Wollega University in 2011 and studied Bachelor's degree in Water Resource and Irrigation Management and graduated in June 2014. After graduation, I joined Gewane ATVET college, in the position of junior instructor for one and a half years. Then I got a chance to be employed at the Ethiopian Institute of Agricultural Research (EIAR) at Fogera National Rice Research and Training Center as a junior irrigation researcher. Then, providentially, I was sponsored by the Institute in 2020 to study master's degree in Irrigation Engineering and Management at Bahir Dar University Institute of Technology. I started my study in 2021 at the Faculty of Civil and Water Resources Engineering of Bahir Dar University.

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ABSTRACT

Water scarcity is a challenge for current irrigated agriculture. Under these circumstances, new on-farm irrigation management strategies should be established for sustainable utilization of the available scarce water resources. An experiment was conducted at Fogera Research Center (FRC) experimental site in 2021 with the objective of evaluating the effects of deficit irrigation and mulch type on the yield of onion and tomato and water productivity. A factorial combination of three levels of deficit irrigation (100%ETc, 75%ETc, and 50%ETc) based on ETc and three mulch types: No Mulch (NM), White Plastic Mulch (WPM), and Rice Straw Mulch (RSM) were evaluated in RCBD with three replications. Application of RSM at the rate of 6t/ha, while 25micron thickness was used for WPM. Monthly ETo, ETc, and irrigation scheduling were computed using CROPWAT8 model based on climate, soil, and crop data. The results of these studies showed that the yield of onion and tomato and water productivity were significantly affected by the main and the interaction effects of deficit irrigation and mulch types at (0.05%). The deficit irrigation results showed that the marketable yield of onion at 100%ETc was 12.6 % higher than 75%ETc and 59.6% higher than 50%ETc while the WP at 50%ETc was 1.0% higher than 75%ETc and 17.9% higher than 100%ETc. The marketable yield of tomatoes at 75%ETc was 4.1% higher than 100%ETc and 27.8% higher than 50%ETc while the WP at 50%ETc was 13.4% higher than 75%ETc and 53.0% higher than 100%ETc.The marketable yield of onion at RSM was 15.3 % higher than NM and 12.0% higher than PM while the WP at RSM was 17.2% higher than NM and 12.1% higher than PM. The marketable yield of tomatoes at RSM was 17.1% higher than NM and 5.1% higher than WPM. The WP of tomato in RSM was 16.3% higher than NM and 3.6% higher than in WPM. The interaction effects of deficit irrigation and mulch results showed that the yield of onion at 100%ETc with RSM was 7.5% higher than 100%ETc with NM and 15.1% higher than 100%ETc with PM. Similarly, the water productivity of onions at 75%ETc with RSM was 29.3%, higher than 100%ETc with NM, 39.4% higher than 100%ETc with PM and 20.0% higher than, 100%ETc with RSM. Similarly, the marketable yield of tomato at 75%ETc with RSM was 8.0% higher than 100%ETc with RSM and 9.7% higher than 75%ETc with WPM. Whereas, the WP of tomato in 50%ETc with WPM was 3.2% higher than 50%ETc with RSM and 8.5% higher than 75%ETc with RSM treatment combinations. These results showed that RSM with 75%ETc improves yield and water productivity by saving water without onion and tomato yield penalties.

Keywords: deficit irrigation, mulch, crop and water productivity, and conservation agriculture

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LIST OF ABBREVIATIONS

ANOVA	Analysis of Variance
ADSW	Amhara Design and Supervision Work
CEC	Electrical Conductivity of Water
CWR	Crop Water Requirements
Dw	Density of Water
Dz	Root Depth
Ea	Application Efficacy
EC	Electrical Conductivity
ET_a	Actual Crop Evapotranspiration
ET_m	Maximum Evapotranspiration
ET_c	Potential Crop Evapotranspiration
ETo	Reference Evapotranspiration
FAO	Food Agriculture Organization
FC	Field Capacity
IWR	Irrigation Water Requirement
IWUE	Irrigation Water Use Efficiency
K_y	Yield Response Factor to water stress
MAD	Manageable Depletion Level
NIR	Net irrigation Requirement in depth (mm)
PWP	Permanent Welting Point
Qm	Gravimetric Moisture Content (fraction)
Qv	Volumetric Water Content (fraction)
RAM	Readily Available Moisture
TAW	Total Available Water
TDS	Total Dissolved Salt
USDA	United State Department of Agriculture
WP	Water Productivity

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1 INTRODUCTION

1.1 Background

Increases in human populations and the emerging challenges of climate change mean that the world's agricultural systems will need to produce more food (Page et al., 2020). And food security for the globe will face great challenges (Wendimu, 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 of small-scale farmers practiced rainfed production with traditional technology (Tadesse et al., 2021). Rainfall variability and irregularity are significantly affect the productivity, and smallholder farmers are vulnerable to crop production (Yimam *et al*., 2020). Due to these, the performance, the production and productivity become very poor (Gizaw, 2020; Feleke et al., 2020),and these production is not sufficient to feed the current population (Belay et al., 2019). Therefore, improving agricultural productivity is critical to feeding its inhabitants (Tewabe et al., 2020).

To meet the food needs of the rising human population, rainfed production should be supported with irrigation (Belay et al., 2019). Irrigation is critical for reducing rainfall variability and inconsistency (Mekonen et al., 2022) .It is also 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 (Terefe, 2021). 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, 2017). However, the limited water availability is a challenge for current irrigated agriculture (Belay et al., 2019).The occurrence of drought, moisture stress and poor irrigation water management lead to a real burden on water resources (Tewabe et al., 2020). This issue causes yield reduction and substantial conflict in freshwater allocation among irrigation users (Dirirsa *et al*., 2017). A lack of available water for irrigated agricultural production is a major issue in many parts of the world (Elliott et al., 2014).

Currently irrigated agriculture take place under water scarcity and insufficient water supply for irrigation due to these the crop and the water productivity are low (Kifle and Gebretsadikan, 2016). Enhancing water productivity (WP) for sustainable crop production and water savings are a major challenge for current irrigated agricultural (Mubarak and Hamdan, 2018). Irrigation water scarcity and climate change are the challenges of the current irrigated agricultural(Wendimu, 2021). In general, in Ethiopia, crop production is dominated by traditional irrigation systems. As a result, water and crop productivity are low and stable (Hordofa et al., 2008). The lack of irrigation water management had significantly impacted the sustainability of crop production and productivity (Çolak et al., 2021). Water source is limited for vegetable production due to an expansion of irrigated land, over pumping and poor water management practices. This has led to crop failure, aggressive water competitions and caused conflict among irrigation water users. Its impact on the yield of vegetable crops and household income. Water-saving and enhancing WP technologies are most important for current irrigated agriculture (Al-ghobari & Dewidar, 2017). Those technologies practice play an important role to boost agricultural production by enhancing the efficiency of irrigation water use in small scale irrigation (Chai et al., 2016). Innovative, affordable, and easy-to-implement technologies are needed for smallholder farmers to irrigate efficiently, the available water resource (Mashnik et al., 2017). Hence, water-saving irrigation strategies need to be explored (Hashem et al., 2018). Therefore, deficit irrigation and conservation agriculture are needed to increase the efficient use of the water that is available.

Deficit irrigation (DI) is an optimization strategy whereby net returns are maximized by reducing the amount of irrigation water and increasing WP without yield penalty (Capra and Consoli, 2015). These water-saving strategies are aimed to improving WP (Nakawuka et al., 2014). DI could be an option for WP increment and increasing overall yield by expanding irrigated areas by applying the saving water (Asmamaw, et al., 2021). The potential benefits of DI are improved WP, reduced the applied irrigation water, and production costs (Hashem et al., 2018). DI is a practical technique to save large amounts of irrigation water (Ismail, 2010). Conservation practice has become one of the most effective strategies for improving water and crop productivity and reducing the cost of production.

Conservation agriculture (CA) practice is widely applied as a means to increase crop and water productivity (Erkossa et al., 2018). It is essential to increasing crop yield and WP (Adimassu et al., 2017). Adapting CA practices to vegetables is a feasible strategy to improve WP, and increase crop yield (Assefa *et al.*, 2019). CA practices increased yields, WP, and reduced irrigation water (Belay et al., 2020). Greatly increased yields and water savings under CA in smallholder plots (Belay et al., 2019). Mulching is one of the important CA strategies used to improve water and crop productivity (Rop et al., 2016). Therefore, evaluating of different water-saving techniques are most important to reduce evapotranspiration (ET) and improve WP and yield under deficit irrigation and mulch (Khan et al., 2015).

Combining mulch with optimal DI are an effective way to increase crop yield and WP in water-limited regions (Wen et al., 2017). Mulching with 20% deficit irrigation improved water and yield productivity (Razaq et al., 2019). DI with mulching gave better yield and water productivities for onion and tomato crops compared to non- mulched conditions (Biswas et al., 2017). A combination of 80%ETc with straw mulch had a high marketable bulb yield and WP of onion (Tufa, 2019). The combination of DI with mulch had pronounced effects on water and yield productivity of onion (Barakat et al., 2019a). Then, effective and economical utilization of water resources by low-cost technologies is sensible and adaptable which directly contributes to the sustainability of livelihoods of smallholder farmers. Therefore, the objective of this study was to evaluate the effects of mulch types and deficit irrigation practices on water and crop productivity on onion and tomato production.

1.2 Statement of the Problem

A lack of available water for irrigated agricultural production is a major issue in many parts of the world (Elliott et al., 2014).The limited water availability is a challenge for expanding irrigation (Belay et al., 2019). The absence of appropriate water saving technologies are also challenges of the current irrigated agriculture (Tadesse et al., 2021). The occurrence of moisture stress and poor irrigation systems lead to a real burden on current irrigated agriculture (Tewabe et al., 2020). The amount of water available for irrigation is far below the capacity (Gebre-selassie & Bekele, 2010). In general, 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 stable (Hordofa et al., 2008). The lack of irrigation water had significantly impacted the sustainability of crop production and productivity (Çolak et al., 2021).

The benefits of CA under different irrigation scheduling on smallholder irrigated farms have not been adequately investigated in the Ethiopian (Belay et al., 2019). Most of the previous studies evaluated the impacts of DI and mulch practices mainly on cereals. Individually, the effect of DI and mulch (black plastic) on onion and tomato yield and WP has been tested in the drip irrigation system. and different straw mulch by different researchers in different parts of the world. However, have not been tested in furrow irrigation, in the combination of white plastic with rice straw mulch (Yang *et al*., 2015; Hailu *et al.*, 2018; Barche *et al*., 2020). And also, experimental field measurements on vegetable production systems and the combined effect of irrigation levels with mulching practices in furrow irrigation systems have been limited. Especial the effects of white plastic and rice straw mulch with DI on onion and tomato yield and WP in furrow irrigation was not evaluated. Different mulch types had different responses in different crops and agroecology. (Mubarak & Hamdan, 2018). Though, onion and tomato are getting more popular, and farmers in the studied areas are opting to cultivate them on their farms.

Similarly, in the study area Fogera, expansion of irrigated agriculture is very high and the demand of 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 and wells, then stream flow became decreased significantly especially from February to May totally stop the flow and dry the river and the well. This has led to crop failure and total loss, fierce competition over water, and conflicts of opinion among farmers. It has been observed that severe competition and exploitation of irrigation water in the study area among smallholder farmers have been resulting in a reduction in the flow of rivers and tube wells. Moreover, inefficient utilization of irrigation water is an obstacle to vegetable production. Scarcity and growing competition for freshwater resources will also reduce its availability during all crop growth seasons; which adversely affect crop growth and yield. In this condition the expansion of vegetable farms and the possibility of extending production throughout the year become limited. Though, rising demand and competition for water need to changes in the management of irrigation to improve crop water use and save the scarcely available water for agriculture in the study area. Therefore, this research study was conducted with the overall objective to evaluate the effects of deficit irrigation and mulch type on yield of onion and tomato and water productivity in Fogera.

1.3 Objectives

1.3.1 General Objective

The overall objective of the study was to evaluate the effects of deficit irrigation and mulch type on yield of onion and tomato and water productivity

1.3.2 Specific Objectives

The specific objectives of this research are:

- To evaluate the effects of deficit irrigation on yield of onion and tomato and water productivity
- To evaluate the effects of mulch application on yield of onion and tomato and water productivity
- To evaluate the combined effects of deficit irrigation and mulch application on yield of onion and tomato and water productivity

1.4 Research questions

- What are the effects of deficit irrigation on yield of onion and tomato and water productivity?
- What are the effects of mulch application on yield of onion and tomato and water productivity?
- What are the combined effects of deficit irrigation and mulch application on yield of onion and tomato and water productivity?

1.5 Scope and Limitations of the study

Even though several mulch materials and irrigation methods were evaluated separately in different cereal crop to conserve and save water, this study focuses on evaluating the combined effects of deficit irrigation and mulch application on yield of onion and tomato and water productivity. Two main factors were considered: the first factor was mulch types (rice straw and white plastic mulch), and the second factor was irrigation deficit level based on reference evapotranspiration (ETo). In this study, the single effects of deficit irrigation level and mulch type on yield of onion and tomato and water productivity and the interaction effects of deficit irrigation with mulch types on yield of onion and tomato and water productivity were evaluated during the experiment. Onion and tomato water productivity, growth, yields, and yield components parameters data were collected and analyzed. Rice straw mulch has a significant advantage over others; the mulching process is simple, has no negative effect on the environment, used to improve water and crop productivity of onion and tomato. The experiment was conducted in 2020/21 for one irrigation season of onion and tomato crops at plot level in Fogera 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.

1.6 Significance of the study

In light of declining water resources around the globe, water restrictions are inevitable. In such a scenario, more emphasis is given to production per unit of water use rather than production per unit area. Mulch with deficit irrigation is a water conservation approach of reducing water application and conserving the moisture content and reducing evaporation loss to improve water 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. The saved water can be used to irrigate extra units of land. Mulch combined with deficit irrigation facilitates crop and water productivity by reducing the amount of water used by the plant, water-saving with a minimal impact on crop yield, and stabilizing the soil temperature. Mulches with deficits irrigation improve the water and crop productivity by conserving the soil moisture, improving photosynthesis and crop yields, reducing soil evaporation. Mulch and deficit improve agricultural productivity through moisture conservating, greatly reducing the amount of water needed by the plants, and organic mulches decompose and promote soil health and improved nutrient use efficiency. The results of these study may contribute to research institutes, water institutes, universities, and other scholars' studies on the field of deficit irrigation, conservation agriculture, agricultural water management, and irrigation. This study also contributes to the comprehensive evaluation and understanding of deficit irrigation with conservation practice for improving water and crop productivity, similarly, the result will be used as a source of information for other institutions and research.

2. LITERATURE REVIEW

2.1 Deficit Irrigation

Deficit irrigation has been widely investigated as a valuable and sustainable production strategy in dry regions. This practice aims to maximize water productivity and stabilize rather than maximize yields (Geerts & Raes, 2009). Deficit irrigation is an important tool to achieve the goal of reducing irrigation water use (Kifle and Gebretsadikan, 2016). Significant water savings can be achieved by deliberately stressing plants to a certain profitable level (Leskovar and Agehara, 2012). At present, due to the global expansion of irrigated areas and the limited availability of irrigation water, there is a need to optimize WUE to maximize crop yields under frequently occurring situations of deficit irrigation (Mubarak and Hamdan, 2018). Deficit irrigation practices could be a sustainable crop production strategy in water-scarce regions (Ararssa, 2019). Deficit irrigation will play an important role in farm-level water management strategies (Geerts & Raes, 2009). Deficit irrigation consists of deliberately applying irrigation depths smaller than those required to satisfy the crop water requirements (CWR) at certain periods in the crop season (Rodrigues, 2009).

2.1.1 Effect of deficit irrigation on crop yield and water productivity

Deficit irrigation is a tool for scheduling irrigation where a limited supply of water is available (Yang *et al*., 2015). The association between yield and irrigation amount can be described as linear in the ranges of irrigation regimes considered, and the ranges of irrigation water use efficiency (IWUE) values obtained were narrow (Ambachew et al., 2014). Deficit irrigation reduced biomass, yield, and some other traits compared to full irrigation throughout the growing season. On the contrary, WUE and IWUE values decreased when the irrigation amount increased (Sincik *et al*., 2008). DI can be used as a tactical measure to reduce irrigation water use when supplies are limited (Zhuo and Hoekstra, 2017). The deficit irrigation can improve water productivity without significantly reducing the bulb yield, considering the sensitive stage of the crop (Dirirsa et al., 2017).

2.2. Effects of mulch on water and crop productivity

Agricultural water resources have been limited over the years due to global warming and irregular rainfall and irrigation in the arid and semi-arid regions. To mitigate the water stress in agriculture, mulching has a crucial impact as a water-saving technique in irrigated crop cultivation. (Kader et al., 2019). Mulching with different irrigation practices is one of the techniques to improve water productivity and water use efficiency (Mebrahtu and Mehamed, 2019). Onion bulb diameter, total yield, dry matter, and water productivity were significantly enhanced under mulch whatever the irrigation level used (Dossou-yovo et al., 2016). Mulching applications can effectively modify the plant hydrothermal micro-environment 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).

2.2.1. Types of mulching

2.2.1.1 Organic mulches

Rice and wheat straw are the commonest mulching materials used for fruit and vegetable production. Though straw after decomposition makes the soil more fertile (Goel et al., 2019). The benefits of organic mulching are preventing evaporation, improve the condition of the soil and water productivity (Goel et al., 2019).

2.2.1.2 Inorganic mulch

Plastic mulches are the most widespread mulching materials, it is used almost everywhere due to their proven positive results in production (Haapala et al., 2014). The application of plastic mulch leads to significantly higher yield and yield components of the crop than no mulching condition and played a greater role in minimizing evapotranspiration (Mebrahtu & Mehamed, 2019). When compared to other mulches plastic mulches are impermeable to water; therefore, preventing direct evaporation of moisture from the soil and thus limiting water losses (Barche et al., 2020). Plastic mulch is the most widespread mulching material (RAY and BISWASI, 2016). Plastic mulch helps in conserving moisture, controlling weeds, and reducing outgoing radiation (Goel et al., 2019). 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 straw mulch is more effective than plastic mulch (Guan et al., 2016).

2.2.2. Effect of plastic mulch on crop yield and water use efficiency

The use of plastic mulch in agriculture is generally recommended for profitable row crops (Kader et al., 2019). Plastic mulch appears to be a feasible tool to increase crop yield and water productivity under tropical conditions (Halim, et al., 2011). Plastic Mulching is an effective practice to improve water and crop productivity in semiarid areas(Yang et al., 2018). Plastic mulch can increase water use efficiency by an average of 9.5% (Deng et al., 2019). Plastic mulch plays an increasingly important role in providing both water and crop productivity. (Ingman et al., 2015). Plastic mulching was expected to have reduced evaporation and water conserved. (Igbadun et al., 2012)**.** Plastic mulch provided a higher temperature for onion and tomato production (Sarkar et al., 2019).

2.2.3. Effect of straw mulch on crop yield and water use efficiency

Straw mulch increased soil water storage, aboveground biomass, yield and WUE increased and decreased Evapotranspiration (YAN et al., 2018). Straw mulching is widely used to conserve soil water and increase crop yields (Wang et al., 2018). Straw mulching reduced the evapotranspiration of the crop, improved the above-ground microclimate, and increase the yield and WUE but decrease soil evaporation (Quanqi Li et al., 2015). Straw mulching had a greater influence on soil water content, water consumption, and WUE than other mulch types. These results suggest that straw mulching has great potential for improving yield and WUE production (Tao et al., 2015). Straw mulches significantly increased the soil water content (SWC), increased the net photosynthetic rate of leaves, and reduced and stabilized the soil temperature during the whole growth season (Liao et al., 2021).

2.2.4. Effect of rice straw mulch on crop yield and water use efficiency

According to the reports of Mubarak and Hamdan, (2018), bulb diameter, total yield, dry matter, and water productivity were significantly enhanced under rice straw mulch whatever the irrigation level used. Crop yield significantly increased with the application of rice straw mulch (Dossou-yovo et al., 2016). The application of rice straw mulches could increase yield and improve the soil aggregates and soil organic carbon (SOC) in the conventional agricultural practice during a short-term period (Naresh et al., 2016). Yield significantly increased with the application of rice straw mulch and soil moisture was higher to improve soil quality and achieve a higher yield under rice straw mulch (Novo *et al.*, 2016). The vegetative growth i.e., leaf characteristics, and yield recorded the highest values of rice straw mulching (Gammal, 2015). Mulching with rice straw did significantly improve the crop yield and water productivity of the onion and tomato crop. To maximize irrigation water utilization under limited water supply to improve crop yield and water productivity onion and tomato crops should be mulched with rice (Igbadun et al., 2012). Rice straw is an eco-friendly source of organic mulch. It also conserves soil moisture, maintaining a favorable soil moisture regime by reducing evaporation loss from soil (Ram et al., 2019). Mulching with surplus rice straw is likely to improve onion bulb yields by 17 % and irrigation water productivity (Singh, 2018). The rice straw mulch increased all previous growth, total bulb yield, and its components of onion (Barakat et al., 2019b).

2.4. Crop yield response to the amount of water applied

The magnitude of yield response factor (Ky) value indicates the sensitivity of the crop to water deficit and subsequent yield decreases (Dirirsa et al., 2017). A standard formulation relates four parameters (Ya, Ym, ETa, and ETm) to a fifth: ky, the yield response factor, which relates relative yield decrease to relative evapotranspiration deficit (Mubarak & Hamdan, 2018). The relationship between crop yield and water supply can be determined when crop water requirements and actual crop water use, on the one hand, and maximum and actual crop yield on the other, can be quantified (FAO,1997). In the FAO 56 approach, the response of yield to the water supply is quantified by the yield response factor (K_y), which relates the relative yield decrease to relative evapotranspiration deficit. Hence, the K_y values for most crops are derived on the assumption that the relationship between relative yield and relative evapotranspiration are linear and it is valid for water deficits of up to about 50%. In field conditions, water deficit of a given magnitude, expressed in the ratio of actual crop evapotranspiration (ET_a) to potential crop evapotranspiration (ET_c), may either occur continuously over the total growing period of the crop or may occur during any stage of the individual growth periods. The Ky values are crop-specific and vary over the growing season according to growth stages with $k_y > 1$: crop response is very sensitive to water deficit with proportional larger yield reductions when water use is reduced because of stress. Ky <1: crop is more tolerant to water deficit, and recovers partially from stress, exhibiting less than proportional reductions in yield with reduced water use. Ky =1: yield reduction is directly proportional to reduced water use.

2.5 Water use efficiency

There is sufficient scope for improving water productivity in irrigated agriculture through water control. But, in most cases, it may lead to reduced net return per unit of land (Kumar *et al.*, 2003). Improving water use efficiency is one important strategy for addressing future water scarcity, which is driven particularly by the increasing human population (Dirirsa et al., 2017). Water productivity analysis combines physical accounting of water with yield or economic output to indicate how much value is obtained from the use of water (Abdullaev and Molden, 2004). Water productivity is defined as depending on many factors, such as irrigation technology and field water management. Both the increase in crop yield and improvement in water efficiency contribute to the increase in water productivity (Cai & Rosegrant, 2009). Water use efficiency (WUE) serves as a key variable in the assessment of crop responses to deficit irrigation-induced water stress because the outcome of using deficit irrigation in crop production is to assess the amount of irrigation that can be saved or the crop yield produced per unit of water supplied (Chai et al., 2016).

3 MATERIALS AND METHODS

3.1 Study Area Description

The field experiment was conducted at the Fogera National Rice Research and Training Center (FNRRTC) experimental site (11º19′ N and 37º03′ E at an altitude of 1815 m.a.s.l) during the 2020/21 irrigation season. Fogera is found in the South Gonder Zone of the Amhara regional state (figur1). It is located at 11º46ʾ to11º59′ latitude and 37º33′ to37º52′ longitude woreda capital, woreta town, which is found at a distance of 657 km from Addis Ababa and 57km from Bahir Dar. The altitude of the woreda ranges from 1774 to 2410m asl and is predominantly classified as woinadega agro-ecology (ILRI, 2005). The climatic data of Woreta town, which is situated in the middle of Fogera Plain, show that the mean annual minimum, maximum and mean temperatures of the area are 14.0ºC, 27.7ºC, and 20.8ºC, respectively. Rainfall in the area is uni-modal, usually occurring from June to October, and its mean annual rainfall is 1216.3mm and ranges from 1103 to 1336mm (Aleminew et al., 2019). According to the woreda agricultural office, Fogera borders lake tana and has an estimated water body of 23,354ha. The land in Fogera shows that 44.2% is arable or cultivable and another 20% is irrigated, 22.9% is used for pasture, 1.8% has forest or shrubland, 3.7% is covered with water, and the remaining 7.4% is considered degraded or other (System, 2006). There are two major rivers, Gumara and Ribb, which are great economic importance to the woreda. These rivers are mainly used for irrigation during the dry season for the production of horticultural crops, and vegetables (onion and tomato). Some farmers also use for the water pump to produce vegetables and cereals. Small-scale irrigation practice is intensively implemented and it plays an important role in improving household incomes in Fogera using different water sources. The total area of the woreda is 117,405ha. Flat land accounts for 76% of mountains and hills 11% and valley bottom13%. Some 490 square kilometers of land adjacent to Lake Tana is subject to regular and severe flooding (World Bank, 2008). According to the worda agricultural offices, the dominant soil type in the Fogera plain is black clay soil (ferric vertisols), while the mid and high-altitude areas are predominantly orthic Luvisols. The plain is well known for rice production in the rainy season.

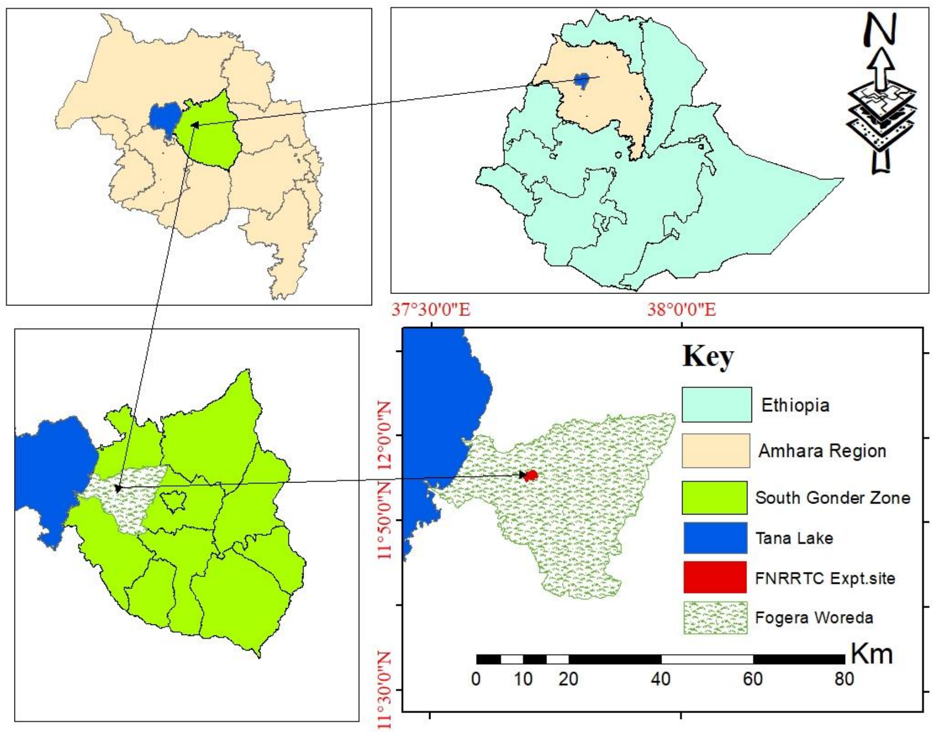

Figure 1. Map of the study area.

3.2 General framework of the research

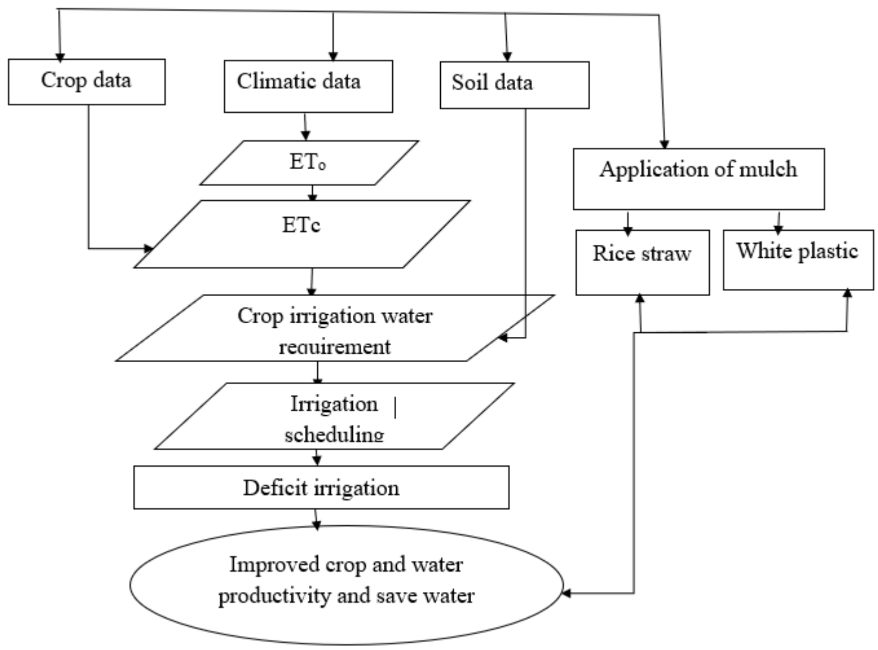

Figure 2; Flow chart of the general framework of the research

3.3 Experimental design and layout

3.3.1 Experimental design

Two main factors were considered: the first factor was mulch practices and the second factor was deficit irrigation level based on crop water requirement (ETc) and each factor had three levels. Three levels of deficit irrigation are full irrigation or 100%ETc, 75%ETc, and 50%ETc while three mulch types: No Mulch (NM), Rice Straw Mulch (SM), and White Plastic Mulch (WPM) were evaluated. The non-deficit and non-mulch treatments were used as control. Application of rice straw mulch at the rate of $6tha^{-1}$, while 25micron thickness was used for white plastic mulch. The experiment has a total of nine treatment combinations one control and the other eight treatment combinations. A factorial combination of three levels of deficit irrigation and three mulch types was evaluated in a randomized complete block design (RCBD) with three replications and treatments were randomly assigned (by chance) to the experimental block (Table 2).

Table 1. Treatment combinations

Factors			
Mulching type	deficit irrigation	Treatment combination	Trt.no.
No Mulch (NM)	100%ETc (0%DI)	100%ETc with NM	1
		75%ETc with NM	2
		50%ETc with NM	3
		100%ETc with SM	4
Rice Straw Mulch (SM)	75%ETc (25%DI)	75%ETc with SM	5
		50%ETc with SM	6
		100%ETc with PM	7
		75%ETc with PM	8
Plastic Mulch (PM)	50%ETc (50%DI)	50%ETc with PM	9

3.3.2 Experimental layout

The experimental field was divided into 27 plots. The plot size was 4.2m × 4m=16.8m^2 area. The distance between blocks and plots was 3m and 2m receptively. 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 should be sufficient. A field channel was constructed for each block to irrigate the field. The predetermined amount of irrigation water was applied to each plot using a 3-inch Parshall flume. Irrigation scheduling was done based on control treatment (100%ETc). Other’s treatments received a lower amount of irrigation water depth than the control treatment based on their level of moisture stress percentage. However, the same irrigation interval was used as that of the control treatment. 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 and apply water to the field measured by the Parshall flume.

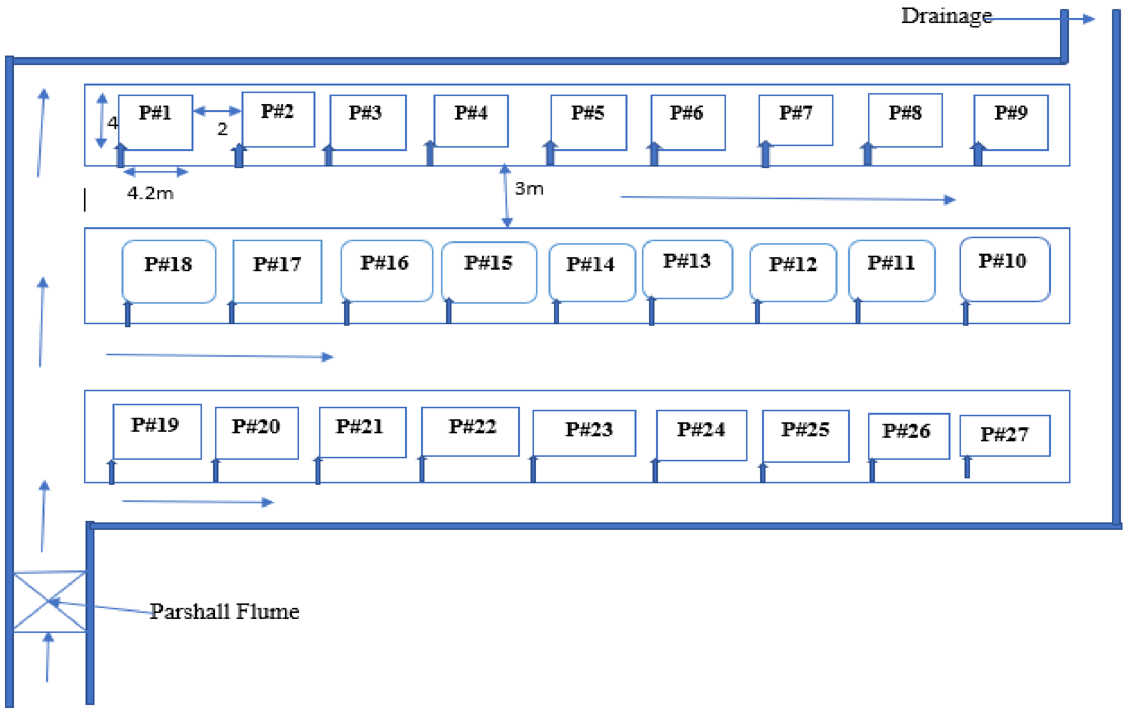

Figure 3. the experimental layout

3.3.3 Agronomic practices of the experimental

Onion (Allium cepa L) Bombay red and tomato Roma VF variety seeds was used as seed material. A nursery sed bed of 1 m X 8 m for onion and 1m X 1m for tomato was prepared. The nursery bed was prepared and the seed was sown on 10 November and 01 December 2020 for onion and tomato respectively. Watering, weeding, fertilizer, chemical spray, and other agronomic activities were applied in the nursery. The seedling was transplanted to experimental plots on 01 January 2021 both onion and tomato. Furrow irrigation method was used to grow the plant. Furrow spacing and plant space were done according to the agronomic recommendation of the area. The transplanting of onion and tomato was done with the spacing between rows being 0.6, (between ridges and furrow being 20 by 40cm), and 1m respectively while the plant spacing being 7cm and 30cm transplanting was done for onion and tomato respectively. Each plot has got seven double rows for onion and four single planting rows for tomato, each row accommodated about 60 plants for onion and 14 plant for tomato.

Each treatment was fertilized with one application of NPSB during transplanting only and a split application of urea at transplanting and 30 days after transplanting as topdressing with the agronomic recommendation rate of $336g/16.8m^2$ NPSB and $60g/16.8m^2$ urea at the time of planting and $192g/16.8m^2$ and 30 days after transplanting for onion while $386g/16.8m^2$ NPSB and $240g/16.8m^2$ urea at the time of planting and $262g/16.8m^2$ and 30 days after transplanting for tomato. Chemicals were applied to prevent the experiment from disease and pests, like Matco, Manguzab 80WP, Profit, Ajanta, and others were used according to their rate of application. Each experimental plot was equally treated with fertilizer rate, chemicals, and weed.

All treatments without treatment variation 1st and 2nd common irrigation were applied at the depth of 14.5mm and 17mm respectively before the treatment started to ensure good seedlings establishment for onion whereas one common irrigation was applied at the depth of 25.5 mm for tomato based on the irrigation scheduling. All treatments were weeded only once before mulch was applied. Fifteen days after transplanting treatments were applied, because seedings start root development and are well performed. All treatments were irrigated on the same days because the only difference was the depth of water based on deficit levels. The harvesting time of onion was April 30 and onion yield was weighed from each plot during harvest and converted to t/ha. Whereas tomato five harvesting times were done and tomato yield was weighed from each plot during harvest and converted to t/ha.

Table 2. Agronomic management of onions throughout the growing period

Crop	Management activity	Date	Methods and tools
Onion (Bombe red)	Nursery and seedling	10 November 2020	Water can manual
	1st weeding of the nursery	25 November 2020	Hand pick
	Fertilizer application for nursery	5 December 2020	Hand
	Chemical application for seedlings and 2nd weeding of nursery	10 December 2020	Knapsack, hand pick
	Chemical application and 3rd weeding of nursery	25 December 2020	Knapsack, hand pick
	Tillage	10-20 December 2020	Draught animal
	Planting and fertigation	01 January 2021	manual
	Irrigation	01January – 20 April	Furrow irrigation
	Weeding	15 January 2021	Sickle
	Mulch application	15 January 2021	Manual
	Harvesting	27-30 April 2021	Sickle

Tomato (Roma VF)	Nursery and seedling	01 December 2020	Water can
	weeding of the seedlings	15 January 2021	Hand pick
	Fertilizer application for nursey	15 January 2021	Hand
	Tillage	10-20 December 2020	Draught animal
	Planting and fertigation	01 January 2021	manual
	Irrigation	01January – 18 April	Furrow irrigation
	Weeding	15 January 2021	Sickle
	Mulch application	15 January 2021	Manual
	Harvesting	01-30 April 2021	Hand

3.4 Data source

Table 3. Different data sources were used for this study

No.	Type data	Source	Purpose
1	Climate data	Metrological stations	ETo determination
2	Crop data	FAO 56,24 and 33	Determination of crop water requirement
3	Soil data	Laboratory result	Irrigation scheduling and soil water holding capacity

3.5 Materials

The materials used for this study were presented in (Table 4)

Table 4. Different decision support tools and materials used for this study and their purposes

No.	Materials name	Purpose
1	CROPWAT8.0	ETo, ETc and irrigation scheduling determination
2	Statistix 10	Analysis of ANOVA and mean separation
3	Mendeley desktop	Citation and references
4	Rice straw and white plastic	For mulching
5	Irrigation deficit level	Amount of water applied
6	Parshall flume	Flow measurement
7	Soil auger and core sampler	Soil sample
8	Sensitive balance	Weight measurement

3.6 Determination of Soil Properties

3.6.1 Soil texture and bulk density

For soil textural class analysis, disturbed composite soil samples were collected from (0-20 cm, 20-40 cm, 40-60cm,60-90cm, and 90-120cm), depth using a soil auger at three locations of the representative site of the experiment, because of the maximum root depth of the crop. The hydrometer method was employed for analyzing particle size distribution at Amhara Design and Supervision Work (ADSW) soil laboratory and the textural class was determined based on the percent of sand, silt, and clay in the USDA textural triangle. Whereas the soil bulk density was determined from undisturbed soil samples using a core sampler of size 5 cm in diameter and 5 cm in height. The bulk density was determined by the mass of the soil per volume using equation 3.2 given by (Terzaghi et al., 1996)

$$\text{Bulk density g/cm3} = \frac{\text{Mass of oven dried soil (g)}}{\text{The total volume of soil (cm3)}} \qquad 3.1$$

3.6.2 Soil and water chemical properties

Soil pH was measured with the help of a digital pH meter. For this purpose, soil samples from 0-20 cm, 20-40 cm, and 40-60cm depths were taken by soil auger. The samples were thoroughly mixed and saturated soil paste prepared. The pH meter was standardized with 4.0 and 9.2 pH buffer solutions and accordingly, the pH of the experimental soil was measured. For soil electrical conductivity determination, an extract was obtained from the saturated soil paste with the help of a vacuum pump. Then with the help of the digital electrical conductivity meter, ECe was measured. The pH and EC of water were also measured for irrigation water quality.

3.6.3 Field capacity and permanent wilting point

A composite soil sample for the determination of moisture content at field capacity (FC) and permanent wilting point (PWP) was collected at (0-20 cm, 20-40 cm, 40-60cm,60-90cm, and 90-120cm depth), from different locations along with the representative place of the experimental site. The soil sample was saturated before keeping it in pressure plate apparatus with plastic rings. Then, the pressure plate was closed properly and the gauge from the compressor was adjusted at 1/3 and 15 bars for FC and PWP, respectively. When no more drop of water was observed, the samples were collected from the pressure plate apparatus, weighed, and oven-dried for 24 hours at 105°C. Then TAW was determined using equation 3.2.

$$TAW = (FC - PWP) * Dz * BD \quad 3.2$$

Where: TAW = Total available moisture (mm), FC = Moisture content at Field capacity (%), PWP = Moisture content at Permanent wilting point (%), BD= density of soil(g/cm^3) and Dz=root depth(mm).

However, all the available moisture was not easily available to plants. As the water suction pressure gets closer to PWP, it becomes tightly held by the soil particles (micro-pores) and the plant suffers because it needs high energy to extract. The fraction of the total available moisture that a crop can extract from the root zone without suffering water stress is the readily available moisture (RAW). Determined by using equation 3.3.

$$RAW = \rho * (FC - PWP) * Dz * BD = P * TAW \quad 3.3$$

Where RAW is the readily available moisture(mm): ρ = Allowable depletion level (%) 25% for onion and 40% for tomato according to FAO33.

3.7 Determination of crop water requirement

Monthly ETo was computed using CROPWAT model version 8.0 based on the 28-year long-term climate data (Tmax. Tmin, RH, Sh, and U) collected from West Amhara National Metrology Agency at Bahir Dar for onions and tomato during the season (Table 5). Crop water use (ETc) was determined by multiplying ETo by the crop coefficient (ETo*Kc) (Allen, 2006). The crop coefficient was used for the growth stages of the onion and tomato crop for the experimental years explained in (Table 6). Irrigation water to be applied to the onion and tomato was determined based on allowable constant soil moisture depletion fraction (p = 0.25 and 0.4 respectively) of the total available soil water (TAW).

The depth of water applied during each irrigation event was the net irrigation requirement estimated by the Penman-Monteith method using the long-term climate data. Considering conveyance and other losses for a surface furrow irrigation system, an application efficiency of 60% was assumed (Chandrasekaran *et al.*, 2010). Successive irrigation depth was applied based on the readily allowable water for the root depth on that day. The different amount of water was applied with different irrigation scheduling. Because the amount of water applied to the crop depends on the crop growth stage and the monthly weather conditions. The daily crop evapotranspiration was deducted from the net irrigation depth for the control treatment (100% ETc) until the cumulative subtraction from the net irrigation depth applied approached zero. Next irrigation was applied when the cumulative ETc approach to net irrigation depth was applied for the control treatment and applied for stress treatments based on their proportion to non-stressed treatment. The effective root depth for mid-season and the late season was taken as a constant 0.5m for onion and 1.1m for tomato.

Table 5. Long-term (from 1990 to 2017) means climate data

Month	RF (mm)	Tmin. ^{o}C	Tmax. ^{o}C	RH %	Ws (U)m/s	sunshine (hr)	ETo mm/day
Jan	0.0	11.0	27.0	49.5	0.66	9.50	3.60
Feb	0.0	12.2	28.7	44.4	0.74	9.65	4.15
Mar	0.3	13.7	29.9	42.4	0.91	9.06	4.67
Apr	3.0	14.1	30.3	42.6	1.01	9.03	4.97
May	16.2	14.3	29.4	53.6	0.94	8.31	4.64
Jun	121.7	13.7	27.5	66.7	0.93	6.99	4.08
Jul	314.2	13.7	24.3	76.1	0.76	4.65	3.25
Aug	274.4	13.8	24.6	78.1	0.72	4.58	3.22
Sep	144.0	13.2	25.7	72.8	0.72	6.45	3.65
Oct	37.9	12.8	26.7	64.3	0.73	8.55	3.93
Nov	0.9	11.4	26.9	57.0	0.68	9.45	3.72
Dec	0.0	10.9	26.7	53.8	0.62	9.81	3.50

Table 6. Onion and tomato parameters used for crop water estimation

	Growth stage				
	Initial	Development	Mid	Late	Total
		Onion			
Depletion fraction (P)	0.25	0.25	0.25	0.25	
Crop coefficient (Kc)	0.5	0.8	1.0	0.9	
Growth stage(days)	15	30	40	35	120
		Tomato			
Depletion fraction (P)	0.4	0.4	0.4	0.4	
Crop coefficient (Kc)	0.5	0.8	1.1	0.8	
Growth stage(days)	15	30	35	40	120

Source: Allen et al (1998).

3.7.1 Determination of net irrigation water requirement of the crop

The net irrigation water requirement (NIR) is defined as the water required by irrigation to satisfy crop evapotranspiration and water needs that are not provided by water stored in the soil profile or precipitation. It computed by subtracting the effective rainfall from the readily available water (RAW) then, the result was a net irrigation requirement. However, there was no rainfall during the experiment season, so, the net irrigation requirement was similar to readily available water (RAW). 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 3.4 (FRENKEN, 2002).

$$\mathrm{NIR} = \mathrm{RAW} - \mathrm{Pe} \qquad 3.4$$

Where: NIR-net irrigation water requirement (mm), Pe-Effective rainfall (mm) and RAW-readily available water (mm).

3.7.2 Determination of effective rainfall

Effective rainfall refers to that portion of rainfall that can effectively be used by plants, to sustain their growth. This is to say that not all rain is available to the crops as some are lost through runoff and deep percolation. Duning the experiment there was no rainfall, all the water required by crops has to be supplied by irrigation. Since from planting to harvesting there was no rainfall at the experimental site, due to this, the net irrigation requirement and the readily available water were equal. For different arid and sub-humid climates, an empirical formula was developed in the Water Service of FAO to estimate dependable rainfall, the combined effect of dependable rainfall (80% probability of exceedance), and estimated losses due to runoff and deep percolation using CROPWAT 8.0. Calculation according to:

$$\mathrm{Pe} = 0.6 * \mathrm{P} - 10 \qquad 3.5$$

$$\mathrm{Pe} = 0.8\mathrm{P} - 24 \qquad 3.6$$

Where p=monthly dependable rainfall (mm) and Pe = monthly effective rainfall (mm)

3.7.3. 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%. Moreover, field application efficiency varies with the type of soil and method of irrigation. The field application efficiency of heavy soil and furrow irrigation method is 60% and 57% respectively (Chandrasekaran *et al.*, 2010). 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 3.7 (FRENKEN, 2002).

$$\mathrm{GIR} = \frac{NIR}{Ea} \qquad 3.7$$

Where: GIR-gross irrigation (mm) NIR-net irrigation depth (mm) Ea.-irrigation application efficiency

3.7.4 Determination of irrigation interval

Irrigation interval is the time it takes a crop to deplete the soil moisture at a given depletion level and can be calculated using equation 3.8. Once the amount of water that needs to be given during one irrigation application is estimated and applied, the next question is when to apply irrigation again? This is known as the irrigation interval (T); T is defined as the interval in days between two consecutive irrigations for a farm.

$$T = \frac{d}{ETc} \qquad 3.8$$

Where: T = Irrigation interval (days), d = The net irrigation depth (mm) and ETc = Crop water requirement (mm/day).

3.7.5 Soil moisture mentoring

The irrigation schedule was determined by using CROWAT 8.0 model based on climate, soil, and crop data. However, monitor the soil moisture content of the experimental plots should be monitor before and after irrigation was determined by the gravimetric method. One of the most common methods of soil water content determination is the gravimetric method with oven drying. This method involves weighing a moist sample, oven drying it at 105°C for 24hr, reweighing, and calculating the mass of water lost as a percentage of the mass of the dried soil. Monitoring of soil moisture content at the time of sampling was carried out during the experimentation content at FC and PWP. Soil moisture constant was determined by the following equation:

$$\mathrm{Qm} = \frac{\mathrm{Mt-Ms}}{\mathrm{MS}} = \frac{Mw}{Ms} \qquad 3.9$$

where: Qm = Gravimetric moisture content (fraction), Mt= the total mass of the wet soil, Mw = Mass of water (g), and Ms = Mass of dry soil (g). To convert gravimetric soil moisture into volumetric moisture content, Qm was multiplied by the bulk density (BD) and divided by the density of water (γw) which can be assumed to have a value of unity.

$$Qv = \frac{BD*Qm}{\gamma w} = BD * Qm \qquad 3.10$$

$$\text{Water depth (mm)} = Dz * BD * Qm = Dz * Qv \qquad 3.11$$

Where Qv=volumetric water content (fraction), γb= bulk density, γw= density of water, and Dz=root depth. The depth of irrigation water delivered to the full irrigation treatment (FI) was determined by the equation.

$$d = \frac{(FC-MC)*Dz*BD}{100} \qquad 3.12$$

Where; d = Amount of water applied during irrigation of deficit, mm FC = Moisture content at field capacity MC = Moisture content at the time of soil sampling or in the soil before irrigation

3.7.6 Parshall flume installation

The flume was installed near the experimental field upstream of the canal based on Parshall flume standard manuals to measure irrigation water applied to experimental plots. The Parshall flume, installed carefully 10 m away from the nearest plot along the main canal in such a way that all of the flow must go through the flume there should be no bypass. The flow was effectively straightened and uniformly redistributed before it enters 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 the divergent section were checked. The base of the diverging part of the Parshall flume was slightly sloped upward. The entrance section was set 4 cm above the canal bed to avoid submergence flow and stone riprap was important 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.

3.7.7 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 measured 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 5 to 12 cm head levels. The time required to deliver the desired depth of water into each furrow was calculated using the below equation 3.13 the help 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:

$$T = \frac{A*d}{6q} \qquad 3.13$$

where A = (irrigated area) in m^2 d = irrigation depth in cm

T = (time) in min. q = (Parshall flume discharge) in l/s

3.8 Data Collection

The sampled plants were selected randomly 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. Randomly five plants were measured for growth and yield component data. Plant height, number of leaf per plant, leaf height, bulb diameter, bulb weight, bulb length, fruit diameter, fruit length, marketable, and other necessary data were recorded from the date of planting to the date on which the experiment was harvested. Sampling, harvesting, and data measurement and recording for each growth parameter, yield, and yield component are explained as follows.

3.8.1 Plant height, leaf height, and leaf number of onion

Plant height (cm) was measured from the soil surface to the top of the longest mature leaf and leaf height was measured from the start of leaf nod to the top of the longest mature leaf of the onion. The number of leaves per plant was counted by using hands. Plants were randomly selected and tagged from each plot for data measurement. Plant height, leaf height, and leaf number of onions in each experimental unit were determined from selective five samples in the central five ridges. Two ridges on the right and left side and 0.5m both alongside were not sampled taken because those areas were accounted for as border effect. This random selection of samples considers the fair distribution of the sample over an area to avoid bias among the samples. The ruler was used to measure plant height and leaf height. Mean plant height, leaf height, and leaf number of each experimental unit were calculated from the average of the collected five samples.

3.8.2 Bulb diameter and height of the crop

Onion bulb and tomato fruit diameter were measured at right angles to the longitudinal axis at the widest circumstance of the bulb of five randomly selected plants in each plot by using automatic a caliper. Onion bulb height and tomato fruit length (cm) are the vertical average length of matured bulbs of five randomly selected plants in each plot measured by a caliper.

3.8.3 Average weight of onion bulb

The average weights (gr) of five randomly selected plants from the net plot were taken and weightings the mean fresh bulb weight after harvesting and curing. Average bulb weight was determined from the total weight per number of harvested onion bulbs.

3.8.4 Marketable yield

The experimental data on the bulb yield of onion and fruit yield of tomato in each experimental plot was harvested and weighing the yield obtained after manually removing roots and stock from the onion bulb by sickle and picking the tomato fruit. Marketable yield (kg/ha) was measured for healthy and non-diseased, non- rotten, non-white (different varieties), non-split, marketable-sized, and tomato fruit recorded from the sampled plant. Marketable bulb yield was expressed as kg per plot. Finally, the bulb yield obtained from the sample area was converted to per hectare using equation 3.14 (Demisie and Tolessa, 2018).

$$\text{Bulb yield } \left(\frac{\text{kg}}{\text{ha}}\right) = \frac{\text{weight of sample yield(kg)}}{\text{Net harvested area(m2)}} * 10000\text{m2} \qquad 3.14$$

3.9 Water Productivity

Water productivity was determined based on the ratio of yield of onion and tomato (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 3.15 (Chandrasekaran *et al.*, 2010).

$$\text{WP} = \frac{Ya}{ETa} \qquad 3.15$$

Where: WP -Water productivity (kg/m^3) Ya-Actual yield (kg/ha) ETa -Seasonal applied amount of water (m^3 /ha)

3.10 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. The relative yield decrease values were the reduction of onion and tomato 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 the equation 3.16 (Smith et al., 2002)

$$\left(1-\frac{Ya}{ym}\right)=\text{ky}*(1-\frac{ETa}{ETm} \quad 3.16$$

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.

3.11 Statistical analysis

The collected data were statistically analyzed using a statistical software statistix version 10 using the procedure of a general linear for the variance analysis model. Analyses of variance (ANOVA) were used for growth, yield, and it is composed and irrigation-based data. All data collected were managed and compared with Least Square of Differences (LSD) and when the effect of the treatments was found significant, mean comparisons were tested using the Tukey test at 5% probability. Results of growth, yields, and yield component parameters were analyzed using statistix computer package version10. Simple correlation analysis was also used to see the association of onion and tomato growth parameters, yield component, yield, and water productivity.

4. RESULTS AND DISCUSSIONS

4.1 Soil and Water Properties of Experimental Site

The physical and chemical properties of the soil at the experimental site such as bulk density, texture, field capacity, permanent wilting point, pH, EC, Exchangeable Na, Exchangeable K, Exchangeable Ca, Exchangeable Mg. CEC, Exchangeable Na%(ESP) other soil nutrients are presented in (Tables 7 and 8).

4.1.1 Soil physical properties

The physical soil properties laboratory analysis results showed that the average composition of sand, silt, and clay percentages were 18.6, 17.6, and 63.8, respectively. Thus, according to the USDA soil textural classification, the soil textural class of experimental site soil is heavy clay soil. The result of soil bulk density in the experimental field has a slight variation with its depth. The BD of 1.2 g/cc may be expected for clay soil but it can vary from around 1.0-1.4 g/cc % (Hazelton & Murphy, 2019). The bulk density laboratory result shows a slight increase with depth (Table 7). The increase in BD of the experimental area might be due to the tractor plowing which could compact the lower depth. It varied from 1.22 g/cm^3 at the upper root zone (0-20 cm) to 1.33 g/cm^3 at the lower root zone layer (90-1200 cm). The average bulk density of the experimental site was 1.28 g/cm^3 (Table 7).

The soil moisture content on weight base at FC showed variation within depths of 0-20, 20-40,40-60,60-90 and 90-120 cm were 35.1, 35.6, 37.5,37.8 and 38.6 %, respectively (Table 7). Whereas the soil moisture content on weight base at PWP also showed a variation within depths of 0-20, 20-40,40-60,60-90 and 90-120 cm were 21.5, 22.3, 23.6,24.8 and 25.7%, respectively. Average moisture content on weight base at FC (1/3 bar) and PWP (15 bar) were 36.92% and 23.58%, respectively. The total available water (TAW) which was the amount of water that a crop can extract from its root zone was directly related to variations in FC and PWP. Based on the laboratory results of ADSW the experimental TAW also showed a variation within depths of 0-20, 20-40,40-60,60-90 and

90-120 cm were 33.2, 33.0, 36.4,49.9 and 51.9mm, respectively. The volumetric TAW of the experimental site was 170mm/m.

Table 7. Results of physical properties of soil of the experimental site

Soil depth (cm)	FC (%) (0.33 bar)	PWP (%) (15 bars.)	Bulk density (gm/cm^3)	Textural status (%)			Textural class	TAW (mm)
				sand	Silt	clay		
0-20	35.1	21.5	1.22	13	22	65	heavy clay	33.18
20-40	35.6	22.3	1.24	21	16	63	heavy clay	32.98
40-60	37.5	23.6	1.31	19	18	63	heavy clay	36.428
60-90	37.8	24.8	1.28	21	16	63	heavy clay	49.92
90-120	38.6	25.7	1.33	19	16	65	heavy clay	51.858
Total available water (TAW)								204mm/1.2m=170mm/m

4.1.2. Soil and water chemical properties

The analysis of applied irrigation water showed that a pH value of 7.28 and ECw value of 0.24 dS/m was obtained (Table 8).

Table 8. Analysis of chemical properties of soil and water

Soil depth (cm)	0-20cm	20-40cm	40-60cm
pH-H2O (1:2:5)	5.38	5.73	6.17
EC (mS/cm)	0.10	0.10	0.10
Exch. Na (meq. /100gm of soil)	1.25	2.23	1.07
Exch. K (meq. /100gm of soil)	0.26	0.34	0.31
Exch. Ca (meq. /100gm of soil)	30.10	37.09	26.66
Exch. Mg (meq. /100gm of soil)	9.58	15.62	7.62
CEC (meq. /100gm of soil)	42.13	55.70	48.12
Sum of cations (meq. /100gm of soil)	41.18	55.27	35.65
Exchangeable Na %(ESP)	2.96	4.00	2.22
PH of water	7.28		
EC (dS/m) of water	0.24		

4.2 Crop water requirement of onion and tomato

The total irrigation water applied to the onion and tomato crops were 413.7 and 438.5 mm for non-stressed treatment (100%ETc) respectively. The minimum amount of water for onion and tomato was 222.6 and 232.0 mm for highly stressed treatment (50%ETc) respectively (Table 9). 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 and tomato seasonal water demands of 413.7 and 438.5 mm that obtained from optimal irrigation scheduling, respectively. The result was in agreement with Doorenbos and Kassam (1986) who reported that the seasonal crop water requirement of onion and tomato ranges from 350 - 550 mm and 400-600 respectively using furrow irrigation. All treatments were irrigated on the same days because the only difference was the depth of water on deficit levels.

Table 9. Seasonal irrigation water applied for onion and tomato

Treatments	Total CWR, (mm)	Total IWR (mm)
	Onion	
100%ETc	413.7	413.7
75%ETc	318.2	318.2
50%ETc	222.6	222.6
	Tomato	
100%ETc	438.5	438.5
75%ETc	335.3	335.3
50%ETc	232.0	232.0

Note= All treatments without treatment variation 1st and 2nd common irrigation were applied at the depth of 14.5mm and 17mm respectively before the treatment started for onion and one common irrigation (25.5mm) for the tomato to ensure good seedlings establishment. *Total irrigation water requirement (IWR)= means the total amount of water that was applied in the experiment from transplanting up to harvesting, which included the amount of irrigation water that was applied for common irrigation.

4.3 The effects of deficit irrigation on yield of onion and tomato and water productivity

4.3.1 The effects of deficit irrigation on growth components of onion

The effects of deficit irrigation results showed there were significant differences in growth parameters when tested at the 5% level. The maximum plant and leaf heights and number of leaf per plant of 51.7 cm, 38.0cm and 10.4 respectively, were recorded from 100%ETc whereas the minimum plant and leaf heights and leaf number per plant of 39.5 cm,29.0cm and6.9 were recorded from 50%ETc treatment respectively (Table 10). The results revealed onion growth parameter was 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. These results are in agreement with the findings of Bizuneh (2019) who reported that the highest growth components of onions was 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*., (2019) 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 (50%ETc). This indicated that the growth paraments of onions was taller at maximum applied water than onions that received a minimum amount of water (Table 10). Similar results were also obtained by Singh (2018) that decreasing deficit levels (stresses) increased the plant height and leaf height and number. 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 a*l., (2017) who stated that an increasing number of leaves per plant was recorded in higher regime irrigated treatment.

Table 10. The effects of deficit irrigation on growth components of onion

Deficit level	Plant Height (cm)	Leaf Height (cm)	Leaf No. (No.)
100%ETc	51.7[a]	38.0[a]	10.4[a]
75%ETc	47.6[b]	37.8[a]	8.9[b]
50%ETc	39.5[c]	29.2[b]	6.9[c]
LSD (0.05)	2.9	2.8	0.6
P	**	**	**
C.V	5.1	6.7	5.5

Where, LSD = Least Significant Difference at 5% level; CV = Coefficient of Variation. Means in columns followed by the same letters are not significantly different at a 5% level of significance. ** =significant at $P < 0.01$.

4.3.2 The effects of deficit irrigation on yield components of onion

ANOVA of yield components of onion shows that there was significant ($P < 0.05$) influence by different levels of moisture stress (Appendix Table 5). The highest average bulb weight, bulb diameter and bulb height were 117.9gr, 6.4 and 5.7 cm recorded from full irrigation treatment respectively. Whereas the minimum average bulb weight, bulb diameter and bulb height were 79.9gr,4.8 and 5.0cm recorded from 50%ETc respectively. Results showed that onion yield components decreased with an increase in levels of water deficit. This indicated that the yield components of plots that received maximum applied water was higher than plots that received a minimum amount of applied water (Table 11). 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 is directly associated with the amount of irrigation water applied. These results were in line with the result of Rop et al., (2016) who reported that the highest mean 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 Abdelkhalik et al., (2020) who indicated that irrigation amount had an effect on plant growth and quality parameters. This finding 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 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 (Kebede, 2019a). Rop et al., (2018) also reported that the highest yield components were obtained from 100%ETc which received the maximum amount of water while 50%ETc gave the smallest diameter which received the least amount of water.

Table 11; The effects of a deficit on the yield components of onions

Deficit level	Bulb Weight (gr)	Bulb Height (cm)	Bulb Diameter (cm)
100%ETc	117.9[a]	5.7[a]	6.4[a]
75%ETc	110.3[b]	5.4[b]	5.9[b]
50%ETc	79.9[c]	5.0[c]	4.8[c]
LSD (0.05)	1.3	0.2	0.2
P	**	**	**
C.V	1.0	2.9	3.4

Where, LSD = Least Significant Difference at 5% level; CV = Coefficient of Variation. Means in columns followed by the same letters are not significantly different at 5% level of significance. ** =significant at $P < 0.01$.

4.3.3 The effects of deficit irrigation on marketable yields of onion

The analysis of variance results showed that the marketable yield of onion was significantly ($p < 0.05$) affected by deficit irrigation levels (Appendix Table 9). The yield of onion was highest in full irrigation treatments compared with other deficit treatments. The highest marketable yield 34.8 t/ha was obtained from 100%ETc and the lowest marketable yield 21.8 t/ha was obtained from 50%ETc (Table 12). The marketable yield of onion was 34.8, 30.9, and 21.8 t/ha, respectively, in 100%ETc, 75%ETc, and 50%ETc. It implies that the marketable yield of onion in 100%ETc was 12.6% higher than 75%ETc and 59.6% higher than 50%ETc. The results showed that the marketable yield of onion decreased as soil moisture levels decrease from optimum irrigation (100% ETc) to low soil moisture level (50%ETc). This indicated that the marketable yield of onion varied proportionally with the amount of irrigation water applied. There is a linear relationship between the marketable yield of onion and the amount of irrigation water applied (Table 12). These results agreed with the result of Temesgen, (2018) who stated that the minimum yield was recorded from

50%ETc. This result consistent with the finding of Piri & Naserin, (2020) reported that onion yield was reduced by reducing the amount of irrigation water. This result is in line with the result of Bizuneh, (2019) stated 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. Dirirsa *et al*., (2017) also reported that maximum and minimum onion bulb yield was obtained from100% and 50%ETc with the maximum and minimum water applications respectively. The onion yield increases with the increase in irrigation level (Kahlon, 2017).

Table 12; The effects of deficit irrigation on marketable yield of onions

Deficit level	Marketable Yield (t/ha)
100%ETc	34.8^{a}
75%ETc	30.9^{b}
50%ETc	21.8^{c}
LSD (0.05)	1.5
P	**
C.V	4.2

Where, LSD = Least Significant Difference at 5% level; CV = Coefficient of Variation. Means in columns followed by the same letters are not significantly different at 5% level of significance. ** =significant at $P < 0.01$

4.3.4 The effects of deficit irrigation on water productivity of onion

The analysis of variance showed that water productivity was significantly affected the water deficit ($p < 0.05$) (Appendix Table 11). The highest water productivity 9.9 and 9.8 kg/m^3 was obtained from 50%ETc and 75%ETc respectively, while the lowest water productivity 8.4kg/m^3 was obtained from 100%ETc (Table 13). This shows that IWUE in 50%ETc treatment was 1.0% higher than 75%ETc and 17.9 % higher than 100%ETc treatment. This shows that WUE in 100%ETc treatment was lower than 50% and 75%ETc treatment. No significant difference was observed among treatments in water productivity of 50 and 75%ETc treatments. As a result, the yield was reduced by reducing the amount of irrigation water. Whereas 100%ETc treatments had a significantly different on water productivity from all other deficit treatments. This is because the amount of water applied in the full irrigation treatment was significantly higher than the deficit treatment and reduced the yield of onion in the deficit treatment. Irrigation water use efficiency (IWUE) for onion was increased in deficit treatment compared to non-stressed treatment. Treatment 50%ETc with the smallest irrigation depth and smaller yield has the greatest IWP values, while the smallest IWP corresponds to the non-stressed treatment(100%ETc). This result was in line with Rop et al., (2016) who reported that irrigation water use efficiency 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 tends to increase water use efficiency. DI could be an option for water productivity increment by expanding irrigated areas (Asmamaw, et al., 2021). Deficit irrigation are improved water productivity, reduced irrigation, and production costs as compared to full irrigation (Hashem et al., 2018). Substantial amounts of water can be saved and improve water productivity by applying DI with no significant reduction in yields (Karrou, 2012).

Table 13. The effects of deficit irrigation on water productivity of onion

Deficit level	Water Productivity (kg/m^3)
100%ETc	8.4^{b}
75%ETc	9.8^{a}
50%ETc	9.9^{a}
LSD (0.05)	0.5
P	**
C.V	4.3

Where, LSD = Least Significant Difference at 5% level; CV = Coefficient of Variation. Means in columns followed by the same letters are not significantly different at 5% level of significance. ** =significant at $P < 0.01$.

4.3.5 The effects of deficit irrigation on yield components of tomato

Deficit irrigation had no significant effect on the fruit diameter and fruit length of tomatoes ($p < 0.05$) (Appendix Table 12 and 13). Fruit diameter and fruit length were not significantly affected by deficit level. Even with a minimal amount of water, we can get reasonable growth and yield components. However, the maximum fruit diameter and fruit length (3.63 and 5.8cm) were recorded from 75%ETc and control (100%ETc) respectively. On the other hand, the minimum fruit diameter and fruit lengths were 3.58 and 5.7cm recorded in the application of 50%ETc respectively, (Table 14). According to Berihun, (2011), amount of water applied did not have significant effect on the growth and yield components of tomatoes. This results consistent with the findings of Shahein et al., (2012) who reported that water stress for the whole growing season no significantly affect fruit length and diameters compared to fully irrigated treatment. A similar result was also reported by Selamawit Bekele, (2017) who reported that deficit levels have no significant effect on growth and yield components. No significant difference in fruit diameter was observed under full irrigation and 70%ETc (Randhe et al., 2019).

Table 14; The effects of deficit irrigation on yield components of tomato

Deficit level	Fruit diameter (cm)	Fruit length (cm)
100%ETc	3.60^{a}	5.8^{a}
75%ETc	3.63^{a}	5.78^{a}
50%ETc	3.58^{a}	5.7^{a}
LSD (0.05)	NS	NS
C.V	1.9	1.8

Where, LSD = Least Significant Difference at 5% level; CV = Coefficient of Variation. Means in columns followed by the same letters are not significantly different at a 5% level of significance. ** =significant at $P < 0.01$

4.3.6 The effects of deficit irrigation on marketable yield of tomato

The tomato yields were significantly affected by the application of different irrigation levels ($p<0.01$) (Appendix Table 11). The highest marketable yield of tomato (37.7t/ha) was obtained from the 75%ETc. In contrast, the lowest yield of tomato 29.5t/ha was obtained from the 50%ETc. This shows that the marketable yield of tomato in 75%ETc treatment was 27.8% higher than 50%ETc and 4.1 % higher than 100%ETc treatment, i.e., 75%ETc could reduce water use by 25% without affecting yield. This result was in line with Audu et al., (2020) who reported that the high mean value of tomato yield was obtained at 80%ETc than full irrigation. A similar result was also reported by Randhe et al, (2019) reported that among the deficit irrigation, the yield of tomatoes was higher under 70%ETc than full irrigation. For tomatoes applying 85% and 70% of ETc was recommended with a minimum reduction of yield (Kifle, 2018). This result is consistent with the suggestion of Biswas et al., (2015) reported that the yield of tomatoes increased with the increasing amount of irrigation water. The trend was reversed when irrigation was coupled with mulches there was a decrease in tomato yield with the increase in irrigation regime. This result was also in line with Ya-dan et al., (2017) reported that tomato yield increased with the amount of applied irrigation water at 75%ETc and then decreased at 100%ETc.

Table 15; The effects of deficit irrigation on the marketable yield of tomato

Deficit level	Marketable Yield (t/ha)
100%ETc	36.2^{b}
75%ETc	37.7^{a}
50%ETc	29.5^{c}
LSD (0.05)	1.1
P	**
C.V	2.6

Where, LSD = Least Significant Difference at 5% level; CV = Coefficient of Variation. Means in columns followed by the same letters are not significantly different at a 5% level of significance. ** =significant at $P < 0.01$

4.3.7 The effects of deficit irrigation on water productivity of tomato

The analysis of variance showed that the water productivity of tomatoes was significantly affected by the main effects of deficit irrigation ($p < 0.01$) (Appendix Table 14). The highest water productivity 12.7 and 11.2kg/m^3 was obtained from 50%ETc and 75%ETc respectively while the lowest water productivity 8.3kg/m^3 was obtained from 100%ETc (Table 16). This shows that IWUE in 50%ETc treatment was 13.4% higher than 75%ETc and 53.0 % higher than 100%ETc treatment. This shows that WUE in 100%ETc treatment was lower than 50% and 75%ETc treatment. The 100%ETc treatments had a significantly different on water productivity from all other deficit treatments. This is because the amount of water applied in the full irrigation treatment was significantly higher than the deficit treatment. Irrigation water use efficiency (IWUE) for tomato was increased in deficit treatment compared to non-stressed treatment. This result was in line with Guangcheng et al., (2017) who stated that DI significantly increased the IWUE compared to the full irrigation regime. A similar result was also reported by Ragab et al., (2019) that deficit irrigation improved irrigation water use efficiency (IWUE) for tomatoes. This result was also in line with Selamawit Bekele, (2017) reporting that the maximum WP was recorded from 50%ETc and the minimum value was recorded at full irrigation (100%ETc). The highest WP of tomato was found at 50%ETc, while 100%ETc showed the least WP (Asmamaw et al., 2021). The highest WUE and IWUE of tomatoes were obtained in 50%ETc (Ya-dan et al., 2017). The highest water productivity was observed at 60%ETc while the lowest was observed at 100%ETc (Sang et al., 2020).

Table 16; The effects of deficit irrigation on the water productivity of tomato

Deficit level	water productivity (kg/m3)
100%ETc	8.3^c
75%ETc	11.2^b
50%ETc	12.7^a
LSD (0.05)	0.3
P	**
C.V	2.7

Where, LSD = Least Significant Difference at 5% level; CV = Coefficient of Variation. Means in columns followed by the same letters are not significantly different at a 5% level of significance. ** =significant at P < 0.01

4.4 The effects of mulch types on yield of onion and tomato and water productivity

4.4.1 The Effects of mulch types on growth components of onion

Analysis of variance showed that significant all growth parameters of onion were significantly affected by mulch types ($P<0.01$) (appendix table 3&4). All growth parameters of onion were highest in rice straw mulched treatment compared to plastic and no mulch treatments. The highest plant heights, leaf height and leaf numbers of onions were 51.9cm, 40.6cm, and 10.1 respectively recorded from rice straw mulch treatments. Whereas the minimum plant height, leaf heights and leaf number of onions were 41.5cm, 31.1cm and 7.5 respectively, recorded from plastic mulch treatments (Table 17). 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 of nutrients while plastic mulch was observed that accelerated the emergence and regrowth of weeds. It, therefore, increases the competition of 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, 2019). 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 Guan et al., (2016). 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 17. The effects of mulch types on growth components of onion

Mulch types	Plant Height (cm)	Leaf Height (cm)	Leaf Number (No.)
No mulch	45.4^{b}	33.4^{b}	8.6^{b}
Rice straw mulch	51.9^{a}	40.6^{a}	10.1^{a}
Plastic mulch	41.5^{c}	31.1^{b}	7.5^{c}
C.V	5.1	6.7	5.5
P-level	**	**	**
LSD (0.05)	2.9	2.8	0.6

Where, LSD = Least Significant Difference at 5% level; CV = Coefficient of Variation. Means in columns followed by the same letters are not significantly different at 5% level of significance. ** =significant at $P < 0.01$

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 (Appendix Table 6). Greater bulb weights and size were achieved from rice straw mulch. The highest mean bulb weight, bulb height and bulb diameter 106.2gr,5.8cm and 6.0cm were obtained from the treatments mulched rice straw respectively. Whereas the lowest mean bulb weight, bulb height and bulb diameter 100.7gr,5.0cm and 5.3cm were obtained from no mulch treatments respectively. However, there was no significant difference between plastic mulch and no mulch on average bulb weight of onion (Table 18). 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 rice straw mulch increased all previous yield components (Barakat et al., 2019b). This study was in line with the result of Islam et al., (2010) who stated that plants grown with straw mulch gave higher yield components. This result agreed with the result of Singh &

Sarkar, (2020) who reported that organic mulching can improve bulb quality due to enhancing higher nutrient availability to the plants

Table 18; The effects of mulch type on yield components of onion

Mulch types	Bulb Weight(gr)	Bulb Height(cm)	Bulb Diameter (cm)
No mulch	100.7^{b}	5.0^{c}	5.3^{c}
Rice straw mulch	106.2^{a}	5.8^{a}	6.0^{a}
Plastic mulch	101.1^{b}	5.3^{b}	5.7^{b}
C.V	1.0	2.9	3.4
P-level	**	**	**
LSD (0.05)	1.3	0.2	0.2

Where, LSD = Least Significant Difference at 5% level; CV = Coefficient of Variation. Means in columns followed by the same letters are not significantly different at 5% level of significance. ** =significant at $P < 0.01$

4.4.3 The effects of mulch types on marketable yields of onion

The analysis of variance showed that the marketable yield of onion was significantly ($p < 0.01$) affected by mulch type (Appendix Table 9). The maximum marketable yield recorded at rice straw mulch was statistically superior to both plastic and no mulch. On the other hand, the lowest marketable yield of onion was observed in plastic mulch and this was statistically similar to that of no mulch. (Table 19). The marketable yield of onion was 31.7, 28.3, and 27.5 t/ha, respectively, in rice straw, plastic, and no mulch treatments. It implies that the marketable yield in rice straw treatment was 15.3 % higher than no mulch and 12.0% higher than plastic mulch treatment. The result indicated that mulching with rice straw did significantly improve the yield of onion. This result was in line with the result of Barakat *et al*., (2019b) who reported that the rice 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 rice straw is likely to improve onion bulb yields by 17%. Crop yield significantly increased with the application of rice straw mulch (Dossou-yovo et al., 2016). These results agree with the findings of Novo *et al.,* (2016) 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 (Tao et al., 2015). 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 (Guan et al., 2016).

Table 19; The effects of mulch type on marketable yield of onions

Mulch types	Marketable Yield (t/ha)
No mulch	27.5^{b}
Rice straw mulch	31.7^{a}
Plastic mulch	28.3^{b}
C.V	4.2
P level	**
LSD (0.05)	1.5

Where, LSD = Least Significant Difference at 5% level; CV = Coefficient of Variation. Means in columns followed by the same letters are not significantly different at 5% level of significance. ** =significant at $P < 0.01$

4.4.4 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 ($p < 0.05$) (Appendix Table 10). The highest water productivity was obtained from rice straw mulch 10.9kg/m^3, followed by plastic mulch treatments 9.94 kg/m^3. The lowest water productivity 8.9 kg/m^3 was obtained from no mulch treatment (Table 20). The WP of onion was 8.7, 10.2, and 9.1 kg m^{-3}, respectively, in no mulch, rice straw mulch, and plastic mulch treatments. It implies that IWUE in rice straw mulch treatment was 17.2% higher than no mulch treatment and 12.1% higher than plastic mulch treatment. The result indicated that mulching is one of the important water management strategies used to improve water use efficiency. This result agreed with the results of Maboko *et al*., (2017) who reported that rice 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). Straw mulching increase the yield and water productivity (Quanqi Li et al., 2015).

Table 20. The effects of mulch types on water productivity of onion

Mulch types	Water Productivity (kg/m^3)
No mulch	8.7^b
Rice straw mulch	10.2^a
Plastic mulch	9.1^b
C.V	4.3
P level	**
LSD (0.05)	0.5

Where, LSD = Least Significant Difference at 5% level; CV = Coefficient of Variation. Means in columns followed by the same letters are not significantly different at 5% level of significance. ** =significant at $P < 0.01$

4.4.5 The effects of mulch on yield components of tomato

The analysis of variance showed that the fruit diameter of tomato was significantly affected by the main effects of mulch type ($p < 0.05$), while the fruit length of tomato was not significantly affected by the mulch type (Appendix Table 12 and 13). The highest fruit diameter was obtained from rice straw mulch 3.66cm and plastic mulch 3.60cm while the lowest fruit diameter was obtained from no mulched treatment 3.56cm (Table 21). Whereas the fruit length of tomato was not significantly different among treatments. This result agreed with the results of Karaer et al., (2020) who stated fruit diameter was found to be higher in mulch applications. This result agreed with the results of Goel et al., (2020) reported that the trend of the favorable effect produced by mulches on growth parameters was rice straw mulch higher than no mulch. The application of different mulch type had no significant effect on the growth and yield parameters of tomatoes (Mn et al., 2017).

Table 21; The effects of mulch type on fruit diameter and length of tomato

Mulch types	Fruit diameter (cm)	Fruit length (cm)
No mulch	3.56[b]	5.76[a]
Rice straw mulch	3.66[a]	5.79[a]
Plastic mulch	3.60[ab]	5.77[a]
LSD (0.05)	0.08	NS
P	*	
C.V	1.9	1.8

Where, LSD = Least Significant Difference at 5% level; CV = Coefficient of Variation. Means in columns followed by the same letters are not significantly different at 5% level of significance. ** =significant at $P < 0.01$

4.4.6 The effects of mulch on marketable yield of tomato

The analysis of variance showed that the marketable yield of tomatoes was significantly ($p < 0.01$) affected by mulch types (Appendix Table 11). The maximum marketable yield of tomato recorded at rice straw mulch was statistically superior to both plastic and no mulch. On the other hand, the lowest marketable yield of tomato was observed in no mulch (Table 22). The marketable yield of tomatoes was 36.9, 35.1, and 31.1 t/ha, respectively, in rice straw, plastic, and no mulch treatments. It implies that the marketable yield in rice straw treatment was 17.1% higher than no mulch and 5.1% higher than plastic mulch treatment. The result indicated that mulch application significantly improves the yield of the tomato. This result was in line with the result of Audu et al., (2020) reported that the yields of tomatoes obtained from rice straw mulch were higher than the yield obtained from white plastic mulch treatments and it was observed that both RSM and WPM treatments have had low yield response factor. The results were also consistent with the findings reported in Goel et al., (2020) that the increase in tomato yield with mulches RSM was 25.6 % as compared to NM. Rice straw mulch increased the fruit yield of tomatoes (Pandey & Mishra, 2012). These results agree with Robel Admasu and Zelalem Tamiru, (2019) who reported that the maximum marketable yield was obtained due to plastic mulch than no mulch for tomatoes. The application of straw mulch is found to be economically and agronomically feasible (Berihun, 2011). The application of mulch types significantly influences tomato fruit yield (Tegen et al., 2016).

Table 22; The effects of mulch type on marketable yield of tomato

Mulch types	Marketable Yield (t/ha)
No mulch	31.5^{c}
Rice straw mulch	36.9^{a}
Plastic mulch	35.1^{b}
C.V	2.6
P level	**
LSD (0.05)	1.1

Where, LSD = Least Significant Difference at 5% level; CV = Coefficient of Variation. Means in columns followed by the same letters are not significantly different at 5% level of significance. ** =significant at $P < 0.01$

4.4.7 The effects of mulch on water productivity of tomato

The analysis of variance showed that the water productivity of tomatoes was significantly ($p < 0.01$) affected by mulch Types (Appendix Table 14). The maximum water productivity of tomatoes recorded at rice straw mulch was statistically superior to both plastic and no mulch. On the other hand, the lowest water productivity of tomatoes was observed in no mulch (Table 23). The water productivity of tomatoes was 11.4, 11.0, and 9.8 kg/m^3 in rice straw, plastic, and no mulch treatments, respectively. It implies that the water productivity in rice straw treatment was 16.3% higher than no mulch and 3.6% higher than plastic mulch treatment. The result indicated that mulching applications significantly improve the water productivity of the tomato crop. This result was in line with the result of Goel et al., (2020) who reported that rice straw mulch increased irrigation water use efficiency by 26.6 % over no mulch. The results were also consistent with the findings reported in tomato Robel Admasu and Zelalem Tamiru, (2019) that the maximum water use efficiency was obtained due to plastic mulch than no mulch for tomatoes.

Table 23; The effects of mulch type on water productivity of tomato

Mulch types	water productivity (kg/m3)
No mulch	9.8^{c}
Rice straw mulch	11.4^{a}
Plastic mulch	11.0^{b}
C.V	2.6
P level	**
LSD (0.05)	0.3

Where, LSD = Least Significant Difference at 5% level; CV = Coefficient of Variation. Means in columns followed by the same letters are not significantly different at 5% level of significance. ** =significant at P < 0.01

4.5 The interaction effects of deficit irrigation and mulch types on yield of onion and tomato and water productivity

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 were not significant (Appendix Table 3 and 4), while leaf number per plant was significantly affected by the interaction effects of deficit levels with mulch type. The highest leaf number 12.5 was obtained from full irrigation with rice straw mulch, while the lowest leaf number was obtained from 50%ETc with plastic mulch treatment combinations. No significant difference was observed among treatments in plant height of onion from 100%ETc with no mulch, 100%ETc with rice straw mulch, and 100%ETc with rice straw mulch. In addition, no significant effect was found in the plant height of onion treatments 100%ETc with rice straw mulch and 75%ETc with rice straw mulch. Table 24). Similarly, there is no statically significant difference between 100%ET and 75%ETc with rice straw. The result indicated that when treatments mulch with plastic plant and leaf height was lower whatever the irrigation depth was used. This may be due to the white plastic mulch reflecting the solar energy to the surface due to this reason the plant leaf was burned. 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. The results were also consistent with the findings reported in Wahed et al., (2017) plant height, was not significantly affected by an interaction between mulching materials and irrigation level. These results were in line with the result of Rachel *et al*., (2018) stated that plastic mulch significantly affected the absolute growth rate of onions.

Table 24.The interaction effects of mulch and deficit on growth components of onions

Treatments	Plant Height (cm)	Leaf Height (cm)	Leaf No. (No.)
100%ETc×NM	51.5^{ab}	36.1^{bc}	9.8^{b}
75%ETc×NM	45.9^{c}	35.5^{c}	9.1^{bc}
50%ETc×NM	39.0^{cd}	28.4^{de}	7.0^{de}
100%ETc×SM	57.9^{a}	43.6^{a}	12.5^{a}
75%ETc×SM	53.2^{a}	42.8^{ab}	9.9^{b}
50%ETc×SM	44.7^{bc}	35.4^{b}	7.9^{cd}
100%ETc×PM	45.9^{bc}	34.3^{cd}	8.9^{bc}
75%ETc×PM	43.9^{c}	35.1^{cd}	7.7^{cd}
50%ETc×PM	34.7^{d}	23.9^{e}	5.9^{e}
C.V	5.1	6.7	5.5
P level	-	-	*
LSD (0.05)	NS	NS	1.4

Where, LSD = Least Significant Difference at 5% level; CV = Coefficient of Variation. Means in columns followed by the same letters are not significantly different at 5% level of significance. ** =significant at P < 0.01

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

The analysis of variance showed that all yield components were significantly affected by the interaction of deficit irrigation and mulch types (Appendix Table 6). The highest bulb weight, bulb height and bulb diameter of the onion 121.8 gr,6.2 and 6.8 were obtained when the onions received full irrigation and mulched with rice straw while the lowest average bulb weight, bulb height and bulb diameter of the onion 77.3gr,4.6cm and 4.1cm were obtained from 50%ETc with no mulch treatment combination (Table 25). No significant difference was observed among treatments in bulb weight of onion 100%ETc with no mulch and 75%ETc with rice straw mulch treatment combinations.

Similarly, no significant difference was found in the bulb height of onion at 100%ETc and 75%ETc with rice straw mulch whereas no significant difference was observed among treatments in bulb diameter of onion 100%ETc with no mulch,100%ETc with plastic mulch, and 75%ETc with rice straw mulch treatment combinations. No significant difference was observed between treatments in bulb height of 100%ETc with plastic mulch and 75%ETc with SM treatment combinations. And also, no significant difference was observed in bulb height between the treatments of 100% and 75%ETc mulch with rice straw treatments. The result indicated that the bulb size of the onion was affected by the amount of water applied and the mulch material. Even if we use any type of mulch, the bulb size will also decrease as the irrigation water depth decreases. 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 size of the onion. This result agreed with the result of Singh and Sarkar, (2020) who reported that organic mulching can improve bulb quality due to enhancing higher nutrient availability to the plants. This result was in line with the result of Barakat *et al.*, (2019a) who stated the best quality of the onion bulb in respect of the maximum diameter of the bulb was obtained when mulching was done with rice straw.

Table 25. The interaction effects of mulch and deficit on yield components of onions

Treatments	Bulb Weight (gr)	Bulb Height (cm)	Bulb Diameter (cm)
100%ETc×NM	114.9^{bc}	5.3^{cd}	6.1^{b}
75%ETc×NM	110.0^{d}	5.0^{de}	5.5^{cd}
50%ETc×NM	77.3^{f}	4.6^{e}	4.1^{e}
100%ETc×SM	121.8^{a}	6.2^{a}	6.8^{a}
75%ETc×SM	113.6^{c}	5.9^{ab}	6.1^{b}
50%ETc×SM	83.2^{e}	5.3^{cd}	5.2^{d}
100%ETc×PM	116.9^{b}	5.6^{bc}	6.1^{b}
75%ETc×PM	107.3^{d}	5.2^{cd}	5.9^{bc}
50%ETc×PM	79.2^{f}	5.1^{d}	5.0^{d}
C.V	1.0	2.9	3.4
P level	**	*	*
LSD (0.05)	3.1	0.4	0.6

Where, LSD = Least Significant Difference at 5% level; CV = Coefficient of Variation. Means in columns followed by the same letters are not significantly different at 5% level of significance. ** =significant at $P < 0.01$

4.5.3 The effects of mulch and deficit irrigation on marketable yields of onion

The analysis of variance showed that the marketable yield of onion was significantly ($p < 0.05$) affected by the interaction effects of deficit irrigation and mulch types (Appendix Table 9). The highest marketable yield of onion (37.3t/ha) was achieved when the treatments were received full irrigation and mulched with rice straw. However, this treatment combination was no significant difference observed compared with the treatments of 100% with no mulch and 75%ETc with rice straw treatments. On the other hand, no significant difference was observed between treatments in marketable yield of onion at 100%ETc with plastic mulch**,** 75%ETc with plastic mulch, and 75%ETc with rice straw mulch treatment combinations. The lowest marketable yield (19.7t/ha) obtained from 50%ETc with no mulch treatment (Table 26). The marketable yield of onion was 37.3, 34.7,32.4, and 33.9 t/ha, respectively, in 100%ETc with rice straw mulch, no mulch, plastic mulch, and 75%ETc with rice straw mulch treatment combinations. It implies that marketable yield of onion at 100%ETc with rice straw mulch treatment combination was 7.5% higher than 100%ETc with no mulch,15.1% higher than 100%ETc with plastic mulch, and 10% higher than 75%ETc with rice straw mulch treatment combinations. However marketable yield of onion 100%ETc with no mulch treatment is only 2.5% higher than 75%ETc with rice straw mulch treatment combination. These results showed that rice straw mulch improves yield productivity for onion without yield penalty at a 25% deficit level. At this level water saving of 25% resulted in lower yield reduction (2.5%) as compared to 100%ETc with no mulch treatment combination but higher than other low moisture stressed and mulched treatments.

These results showed that there was no yield advantage observed using 100ETc with no mulch. The yield improvement with straw mulching combination with different deficit levels could be due to the enhanced availability and release of nutrients from decomposed rice straw mulched, improved soil properties, increased soil water holding capacity leading to good aeration and better root growth, and enhanced nutrient absorption by onion plants. However, the yield decline with white plastic mulch due to increase the emergency and the regrowth of weed population, poor aeration and burned the leaf of the onion, these affect the photosynthetic activity, due to this the weed population there was higher nutrient competition the white plastic mulch treatment. This result is in line with the findings of Singh, (2018) who explained that rice straw mulch significantly improved onion bulb yields by 17% over no mulch plots. The results were also consistent with the findings reported in Nigusie *et al*., (2020) indicated that straw mulch gave a higher marketable bulb yield while plastic mulch recorded a lower marketable bulb yield. 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 100ETc with mulch. The result in agreement with the study carried out by Inusah *et al*., (2013) who reported that rice straw could contribute significantly to improved onion yields. These results also agreed with the result of Temesgen, (2018) who stated that the minimum yield was recorded from 50%ETc with no mulch. This result also agreed with the result of Biswas et al., (2017b) who reported that in terms of yield and water irrigating up to 80%ETc with rice straw mulch can be recommended for the production of onion. This result also consistence with the result of (Mubarak & Hamdan, 2018) who stated that the marketable yield of onion was significantly higher under 100%ETcwith RSM being used. Thus, bulb yields under WPM were not significantly different from a no-mulch condition (Igbadun et al., 2012). Sali et al., (2022) who stated that the lowest yield of onion was recorded from 55%ETc with no mulch. The minimum yield of onion was recorded from 50%ETc with no mulch (Temesgen, 2018).

Table 26. The interaction effects of mulch and deficit on marketable yield of onions (t/ha)

Treatments	Marketable Yield (t/ha)
100% ETc×NM	34.7^{ab}
75% ETc×NM	28.1^{d}
50% ETc×NM	19.7^{f}
100% ETc×SM	37.3^{a}
75% ETc×SM	33.9^{abc}
50% ETc×SM	24.0^{e}
100% ETc×PM	32.4^{bc}
75% ETc×PM	30.7^{cd}
50% ETc×PM	21.7^{ef}
C.V	4.2
P level	*
LSD (0.05)	3.6

Where, LSD = Least Significant Difference at 5% level; CV = Coefficient of Variation. Means in columns followed by the same letters are not significantly different at 5% level of significance. ** =significant at $P < 0.01$

4.5.4 The effects of mulch and deficit irrigation on water productivity of onion

The analysis of variance showed that water productivity was significantly affected by the combined effects of deficit irrigation and mulch type ($p < 0.05$). (Appendix Table 10). The highest water productivity of onion,10.88 and 10.73 kg/m^3, were achieved from the treatment combination of 50% and 75%ETc with rice straw mulch respectively. However, 50%ETc with rice straw mulch treatment combination was no significant difference observed compared with the treatments of 75%ETc with rice straw mulch and 50%ETc and 75%ETc with plastic mulch treatment combinations.

On the other hand, there was no significant difference was observed between treatment combinations in water productivity of 100%ETc,75%ETc, and 50%ETc without mulch and 100%ETc with rice straw mulch treatment combinations. The lowest water productivity obtained from 100%ETc with plastic mulch treatment was 7.77kg/m^3 (Table 27). However, 100%ETc with plastic mulch treatment combination was no significant difference observed compared with the treatments of 100% and 75%ETc with no mulch treatment combinations. This result indicated that water productivity in 75%ETc with rice straw mulch treatment combination was 29.3% higher than 100%ETc with no mulch,39.4% higher than 100%ETc with plastic mulch, 20.0% higher than 100%ETc with rice straw mulch, 20.3% higher than 75%ETc with no mulch and 10.2% higher than 75%ETc with straw mulch treatment combinations. However, the water productivity of 75%ETc with rice straw mulch treatment was 1.4% lower than 50%ETc with rice straw mulch treatment combination. This study confirms that limiting irrigation water could improve water productivity, by the use of deficit irrigation with mulching can increase water productivity. This result agreed with the result of Abdrabbo et al., (2021) who conclude that 50%ETc combined with rice straw and plastic mulch gave the highest WUE; while 100%ETc combined with control gave the lowest WUE. This result also agreed with the result of Biswas et al., (2017b) who reported that deficit irrigation with rice straw mulching gave better water productivity compared to non-mulched conditions. Igbadun et al., (2012) also conclude that irrigating at 50% and 75%ETc with rice straw and plastic mulch significantly improves the crop water productivity of the onion crop. This result consistence with the result of Kebede, (2019b) who conclude that deficit irrigation with straw mulch gave better water productivity compared to non-mulched condition. Mekonen et al., (2022) also stated that combination of deficit irrigation with mulching, help to improve water productivity in vegetable crops. The water productivity was higher under deficit irrigation when straw mulching was used (Mubarak & Hamdan, 2018). This result consistence with the result of Temesgen, (2018) who stated that the higher crop irrigation water use efficiency of onion was obtained from 70%ETc with mulch.

Table 27. The interaction effects of mulch and deficit on water productivity of onion

Treatments	Water Productivity (kg/m^3)
100% ETc×NM	8.3^{cd}
75% ETc×NM	8.92^{bcd}
50% ETc×NM	8.94^{bc}
100% ETc×SM	8.95^{bc}
75% ETc×SM	10.73^{a}
50% ETc×SM	10.88^{a}
100% ETc×PM	7.77^{d}
75% ETc×PM	9.74^{ab}
50% ETc×PM	9.85^{ab}
C.V	4.3
P levels	*
LSD (0.05)	1.2

Where, LSD = Least Significant Difference at 5% level; CV = Coefficient of Variation. Means in columns followed by the same letters are not significantly different at 5% level of significance. ** =significant at $P < 0.01$

4.5.5 The effects of deficit irrigation and mulch on yield components of tomato

The analysis of variance showed that the fruit diameter and fruit length of tomatoes were not significantly affected by the interaction effects of deficit irrigation and mulch types ($p < 0.01$) (Appendix Table 12 and 13). There was no significant difference was observed between treatments in fruit diameter and fruit length of tomato at all deficit irrigation and mulch types (Table 28). Even we applied minimum amount of water get the reasonable fruit size of tomato. Thise may be due to the canopy covers of tomato use as a mulch. This result agreed with the results of Kere et al., (2003) the yield attributes of tomato were not significantly affected by either irrigation amount and mulch type. According to Berihun, (2011), the interaction effect of the amount of water and mulch was not significant in fruit length and fruit diameter. According to Aliabadi et al., (2019) the interaction effect of mulch and amount of water on fruit length and diameter was not significant. A similar result was also reported by Selamawit Bekele, (2017) who reported that deficit levels have no significant effect on plant and fruit height. No significant difference in fruit diameter was observed under full irrigation and 70%ETc (Randhe et al., 2019).

Table 28.The interaction effects of mulch and deficit on yield components of tomato

Treatments	Fruit diameter (cm)	Fruit length (cm)
100% ETc×NM	3.56[a]	5.83[a]
75% ETc×NM	3.55[a]	5.75[a]
50% ETc×NM	3.55[a]	5.71[a]
100% ETc×SM	3.68[a]	5.78[a]
75% ETc×SM	3.69[a]	5.82[a]
50% ETc×SM	3.60[a]	5.76[a]
100% ETc×PM	3.57[a]	5.79[a]
75% ETc×PM	3.66[a]	5.77[a]
50% ETc×PM	3.58[a]	5.74[a]
C.V	1.9	1.8
LSD (0.05)	NS	NS

Where, LSD = Least Significant Difference at 5% level; CV = Coefficient of Variation. Means in columns followed by the same letters are not significantly different at 5% level of significance. ** =significant at P < 0.01 and NS =non-significant

4.5.6 The effects of deficit irrigation and mulch on marketable yield of tomato

The analysis of variance showed that the marketable yield of tomatoes was significantly (p < 0.01) affected by the interaction effects of deficit irrigation and mulch types (Appendix Table 11). The highest marketable yield of tomato (41.7t/ha and 38.6 t/ha) were achieved from 75%ETc and 100%ETc with rice straw mulch treatments respectively. On the other hand, no significant difference was observed between treatments in marketable yield of 75%ETc with plastic mulch, and 100%ETc with rice straw mulch treatment combinations. The lowest marketable yield obtained from 50%ETc with no mulch treatment was 26.6t/ha (Table 29). The marketable yield of tomato was 41.7, 38.6, and 38.0, t/ha, respectively, in 75% and 100%ETc with rice straw mulch, and 75%ETc with plastic mulch treatment combinations. It implies that marketable yield in 75%ETc with rice straw mulch treatment combination was 8.0% higher than 100%ETc with rice straw mulch and 9.7% higher than 75%ETc with plastic mulch treatment combinations.

Rice straw and white plastic mulch increase the marketable yield of tomatoes by 21.2% and 10.5% compared with no mulch treatment. At this level water saving of 25% resulted in yield improvement as compared to 100%ETc with no mulch treatment combination. These results showed that there was no yield advantage observed using 100ETc with no mulch. On the other hand, rice straw mulching improves the marketable yield of tomatoes more than plastic and no mulch treatments. This could be due to the enhanced availability and release of nutrients from decomposed rice straw mulched.

All the deficit treatments with mulch resulted in significantly higher yields than un-mulched irrigation level treatments. The study thus reveals that deficit irrigation with mulch has an explicit role in increasing yield of tomatoes. The yield of tomatoes increased with the increase in water supply without mulch. The effect was reversed when the irrigation level was coupled with either plastic or straw mulch; there was a decrease in tomato yield with the increase in irrigation regime. Irrigation of the same level without mulch produced the lowest yield. However, 100%ETc irrigation supply produced a lower yield than 75%ETc when mulched with polyethylene and mulched with straw. This may be due to excessive watering has been shown to increase flower drops and reduce fruit set. Also, this may cause excessive vegetative growth and a delay in ripening. Water supply during and after the fruit set must be limited to a rate that will prevent the stimulation of new growth at the expense of fruit development (Doorenbos and Kassam, 1979). This system economized 75% of irrigation water and increased about 10.5 to 21.2% of fruit yield compared to the un-mulched treatment. This result is in line with the findings of Audu et al., (2020) recommended that tomato producers should adopt water application at 80%ETc and use RSM. This result is in line with the findings of Berihun, (2011) stated that straw mulch is economically more profitable than other mulch treatments. These results were also consistent with the findings of Biswas et al., (2015) reported that with 100% water application, the polyethylene-mulched treatment produced a lower yield than the straw-mulched treatment. The tomato yield under the interactive effect of deficit irrigation and grass mulch was determined to be highest at 60%ETc with mulch (Sang et al., 2020). The maximum marketable yield of tomatoes was observed at 80%ETc with mulch (Alebachew, 2017). The maximum fruit yield was recorded from the plants receiving deficit irrigation at 80%ETc with a straw mulching treatment combination (Samui et al., 2020). The best level of irrigation for tomato crop is 80%ETc and this correspond to mulching practice of rice straw mulch (Zakari et al., 2020).

Table 29.The interaction effects of mulch and deficit on marketable yield of Tomato (t/ha)

Treatments	Marketable Yield (t/ha)
100% ETc×NM	34.4^{d}
75% ETc×NM	33.4^{de}
50% ETc×NM	26.6^{g}
100% ETc×SM	38.6^{b}
75% ETc×SM	41.7^{a}
50% ETc×SM	30.3^{f}
100% ETc×PM	35.6^{cd}
75% ETc×PM	38.0^{bc}
50% ETc×PM	31.5^{ef}
C.V	2.6
P level	**
LSD (0.05)	2.6

Where, LSD = Least Significant Difference at 5% level; CV = Coefficient of Variation. Means in columns followed by the same letters are not significantly different at 5% level of significance. ** =significant at $P < 0.01$

4.5.7 The effects of deficit irrigation and mulch on water productivity of tomato

The analysis of variance showed that the water productivity of tomatoes was significantly affected by the interaction effects of deficit irrigation and mulch type ($p < 0.01$) (Appendix Table 14). The highest water productivity of tomatoes (13.59 and 13.08 kg/m^3) were achieved from 50%ETc with plastic mulch and with rice straw mulch respectively (Table 30). There was no significant difference observed between 50%ETc with plastic and with rice straw mulch treatment combinations. The lowest water productivity was obtained from 100%ETc with no mulch. However, there were no significant difference observed between treatments in water productivity of 100%ETc with no mulch and 100%ETc with plastic mulch treatment combinations. The water productivity of tomatoes was 13.59, 13.08, and

12.44, kg/m^3, respectively, in 50%ETc with plastic, rice straw, and 75%ETc with rice straw mulch treatment combinations. It implies that water productivity in 50%ETc with plastic mulch treatment combination was 3.2% higher than 50%ETc with rice straw mulch and 8.5% higher than 75%ETc with rice straw mulch treatment combinations. These results showed that rice straw and plastic mulch combined with deficit irrigation improves tomato water productivity without yield penalty. The result indicated that the water productivity of tomatoes was affected by the amount of water applied and the mulch types. Mulch with deficit irrigation gave higher WUE over-irrigation alone under all levels of irrigation.

At an irrigation level of 50%ETc, irrigated to tomato plot mulched with polythene produced better WUE than that of rice straw mulched or un mulched treatment. The un-mulched treatment remaining always behind the mulched treatment. At a high irrigation level of 100%ETc, all mulched and un-mulched treatments performed almost similarly to produce WUE. Mulches reduced the rate of water loss through evaporation from the soil surface. So, the soil-water-plant relationship was better in a low irrigation regime than in a high irrigation regime which might help produce higher yield and thereby higher WUE. In general, the trends for the WUE related to the total water use for different irrigation level treatments showed that the lower the amount of water used, the higher the WUE. These results were consistent with the findings of, Biswas et al., (2015) reported that the higher WUEs were obtained from mulch treatments with a 50% crop water requirement. This result is in line with the findings of Goel et al., (2020) who explained that mulching increased irrigation water use efficiency by 26.6 % in rice straw mulch over no mulch. The tomato water productivity under the interactive effect of deficit irrigation and mulch was determined to be highest at 60%ETc with mulch and lowest at 100%ETc (Sang et al., 2020).

Table 30.The interaction effects of mulch and deficit on water productivity of tomato

Treatments	Water productivity (kg/m3)
100% ETc×NM	7.84[f]
75% ETc×NM	9.97[d]
50% ETc×NM	11.45[c]
100% ETc×SM	8.81[e]
75% ETc×SM	12.44[b]
50% ETc×SM	13.08[ab]
100% ETc×PM	8.12[ef]
75% ETc×PM	11.34[c]
50% ETc×PM	13.59[a]
C.V	2.6
P level	**
LSD (0.05)	0.5

Where, LSD = Least Significant Difference at 5% level; CV = Coefficient of Variation. Means in columns followed by the same letters are not significantly different at 5% level of significance. ** =significant at $P < 0.01$

4.5.8 The effects of mulch and deficit irrigation on water saving and yield penalty

Optimal irrigation treatment (100%ETc×NM) was used as the reference point 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 75%ETc and 50%ETc were 25%and 50% respectively. This implies that as water stress levels increase water savings increase. Bekele and Tilahun, (2007) reported that deficit irrigations increased the water-saving of onions and tomatoes. Similarly, Yemane *et al.*, (2018) reported that irrigation water saving was higher at lower levels of available soil moisture. Kumar *et al.*, (2021) reported that mulching is an effective water-saving technique in crop production to help mitigate water shortage in agriculture. Relative yield reduction was increased with increasing moisture stress levels for onion, but not for tomato (Table 31). These findings indicate that 75%ETc with rice straw mulch results in 25% and 2.5% water saving and yield reduction for onion. It indicated that 75%ETc mulched with rice straw obtained a comparative yield that of 100%ETc with no mulch without substantial negative effect on irrigation water and yield productivity of the onion, In the case of tomatoes, these findings indicate that 75%ETc with rice straw and plastic mulch results in 25% water saving and 17.5% and 9.5% yield increment respectively (Table 31).

Table 31. The effects of mulch and deficit irrigation on water saving and yield penalty

Treatment	Marketable Yield t/ha	Water saved (%)	Yield reduction (%)	An additional area to be cultivated (ha) by saved water
		Onion		
100%ETc ×NM	34.7	0.0	0.0	0.0
75%ETc × NM	28.1	25.0	19.0	0.25
50%ETc × NM	19.7	50.0	43.3	0.5
100%ETc× SM	37.3	0.0	+7.4	0.0
75%ETc × SM	33.9	25.0	2.5	0.25
50%ETc× SM	24.0	50.0	31.0	0.5
100%ETc× PM	32.4	0.0	6.8	0.0
75%ETc × PM	30.7	25.0	11.0	0.25
50%ETc× PM	21.7	50.0	37.5	0.5
		Tomato		
100%ETc×NM	34.4	0.0	0.0	0.0
75%ETc×NM	29.1	25.0	18.2	0.25
50%ETc×NM	26.6	50.0	29.3	0.5
100%ETc×SM	38.6	0.0	+10.9	0.0
75%ETc×SM	41.7	25.0	+17.5	0.25
50%ETc×SM	30.3	50.0	13.5	0.5
100%ETc×PM	35.6	0.0	+3.4	0.0
75%ETc×PM	38.0	25.0	+9.5	0.25
50%ETc×PM	31.5	50.0	9.2	0.5

4.6. Correlation between growth, yield and yield components

The correlation analysis of onion in table 32 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 0.81, 0.75, 0.82, 0.93, 0.91 and 0.77 respectively. The results indicate that the application of deficit irrigation with mulch treatments positively 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 had a response negative effect on WP for onion. This reveals that growth, yield, and yield components reduced while WP improved due to the reduction of irrigation water amount for onion.

Table 32.Pearson's correlation coefficient (r) of growth and yield parameters of onions as influenced by different mulch and levels of moisture stress

	PH	LH	LN	BW	BD	BH	MY	WP
PH	1							
LH	0.94	1						
LN	0.92	0.84	1					
BW	0.78	0.73	0.8	1				
BD	0.78	0.73	0.76	0.9	1			
BH	0.72	0.67	0.75	0.69	0.82	1		
MY	0.81	0.75	0.82	0.93	0.91	0.77	1	
WUE	-0.13	0.05	-0.23	-0.38	-0.19	0.06	-0.17	1

*MY = Marketable yield, UMY=Un Marketable yield, WP = Water productivity, BD = bulb diameter (cm), BH= bulb height, BW = Average bulb weight, PH = plant height (cm), LH=Leaf height (cm), LN = leaf number per plants.

Whereas the correlation analysis of tomatoes in table 33 showed that there was a weak association between marketable yield with yield components and water productivity, such as fruit diameter, and fruit length of tomato with the Pearson Coefficient of 0.48, and 0.25 respectively. On the other hand, water productivity affect marketable yield of tomato in which water use maximization could not be achieved without tomato yield reduction. The result reveals that WP was correlated negatively with the yield of tomatoes.

Table 33.Pearson's correlation coefficient (r) of growth and yield parameters of tomato as influenced by different mulch and levels of moisture stress

	MY	FD	FL	WP
MY	1			
FD	0.48	1		
FL	0.25	0.33	1	
WUE	-0.2	0.09	-0.19	1

*MY = Marketable yield, WP = Water productivity, FD = fruit diameter (cm), fruit length (cm),

4.7 The effect of mulch and deficit irrigation on yield response factor

The study reveals that a lower yield response factor of 0.5 and 0.0 was achieved from75%ETc with rice straw mulch for both onion and tomato respectively. The result indicated that the yield response factor was associated with deficit level and mulch types. At 100%ETc were no recorded yield response factors (Table 34). Because the actual amount of water applied at 100%ETc was similar to ETm, the result was one. In this study the Ky of the onion crop under no mulch condition was higher(1.0), this result agreed with Igbadun, (2012) reported that Ky of the onion crop under no mulch condition was 1.1. In this study, the Ky of the tomato crop under no mulch condition was 1.0. The Ky values of the no mulch treatment were higher than the mulched treatment which implies that the proportional decrease in yield under the no mulch condition was much higher than in the mulched condition.

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. This reveals a greater tolerance of this mulched treatment to water shortage. In this respect, Ky may be a valuable tool for water deficit tolerance and, thus, for deficit irrigation adaptability evaluation in tomato and onion production. It also suggests that mulching helped to improve the impact of the deficit irrigation on yield, these results agreed with Igbadun, (2012). Different studies revealed that yield response factor varies for different crop types and stress conditions. However, yield response factors are dependent on locations. The result of the experimental site indicated that the effect of mulch and deficit treatments influence onion and tomato yield. When Ky> 1, the crop response is very sensitive to water deficit with proportional larger yield reductions; Ky< 1, the crop is more tolerant to water deficit, and recovers partially from stress, exhibiting less than proportional reductions in yield with reduced water use; Ky = 1, the yield reduction is directly proportional to reduced water use (Doorenbos and Kassam, 1979). The result among the treatments showed as the deficit increased the sensitivity of yield increased. The yield response factor (Ky) indicates a linear relationship between the decrease in relative water consumption and the decrease in relative yield.

Table 34. Effect of mulch type and deficit irrigation levels on onion yield response factor

Treatment	Yield kg/ha	ETa	ETa/ETm	Ya/Ym	$1-Y_a/Y_m$	$1-ET_a/ET_m$	$K_Y = \frac{1-(Y_a/Y_m)}{1-(ET_a/ET_m)}$
100%ETC× NM	34722	413.7	1.0	0.9	0.1	0.0	-
75%ETC × NM	28125	318.2	0.8	0.8	0.2	0.2	1.0
50%ETC × NM	19688	222.6	0.5	0.5	0.5	0.5	1.0
100%ETC × SM	37292	413.7	1.0	1.0	0.0	0.0	-
75%ETC × SM	33854	318.2	0.8	0.9	0.1	0.2	0.5
50%ETC × SM	23958	222.6	0.5	0.6	0.4	0.5	0.8
100%ETC × PM	32361	413.7	1.0	0.9	0.1	0.0	-
75%ETC × PM	30729	318.2	0.8	0.8	0.2	0.2	1.0
50%ETC × PM	21701	222.6	0.5	0.6	0.4	0.5	0.8

Table 35. Effect of mulch type and deficit irrigation levels on tomato yield response factor

Treatment	Yield (kg/ha)	ETa	ETa/ETm	Ya/Ym	$1-Y_a/Y_m$	$1-ET_a/ET_m$	$K_Y = \frac{1-(Y_a/Y_m)}{1-(ET_a/ET_m)}$
100%ETC× NM	34375	438.5	1.0	0.8	0.2	0.0	-
75%ETC × NM	32097	335.3	0.8	0.8	0.2	0.2	1.0
50%ETC × NM	26563	232.0	0.5	0.6	0.4	0.5	0.7
100%ETC × SM	38646	438.5	1.0	0.9	0.1	0.0	-
75%ETC × SM	41701	335.3	0.8	1.0	0.0	0.2	0
50%ETC × SM	30347	232.0	0.5	0.7	0.3	0.5	0.5
100%ETC × PM	35625	438.5	1.0	0.9	0.1	0.0	-
75%ETC × PM	38021	335.3	0.8	0.9	0.1	0.2	0.4
50%ETC × PM	31528	232.0	0.5	0.8	0.2	0.5	0.5

5. CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

An experiment on deficit irrigation and mulch types was conducted on onion and tomato at Fogera NRRTC research station. The treatments were composed of three deficit levels (100, 75 and 50% of ETc) and three mulch types (NM, WPM and RSM). The amount of water added was determined based on the stress level and compared with conventional practice (100%ETc with NM).

In the main effects of deficit irrigation, the marketable yield of onion in 75%ETc was 12.6% lower than 100%ETc, while the IWP in 75%ETc was 17.9% higher than 100%ETc treatment. Whereas the marketable yield of tomato in 75%ETc was 27.8% higher than 50%ETc and 4.1% higher than 100%ETc treatment. While the IWUE in 50%ETc treatment was 13.4% higher than 75%ETc and 53.0% higher than 100%ETc treatment. Whereas, the marketable yield of onion in RSM was 15.3% higher than NM and 12.0% higher than WPM while the IWUE of onion in RSM was 17.2% higher than NM and 12.1% higher than WPM. The marketable yield of tomato in RSM was 17.1% higher than NM and 5.1% higher than WPM treatment while the IWUE of tomato in RSM was 16.3% higher than NM and 3.6% higher than in the WPM treatment.

In the combination effects of mulch and deficit irrigation, the marketable yield of onion in 100%ETc with RSM was 7.5% higher than 100%ETc with NM,15.1% higher than 100%ETc with WPM, and 10% higher than 75%ETc with RSM treatment combinations. On the other hand, the marketable yield of tomatoes in 75%ETc with RSM was 8.0% higher than 100%ETc with RSM and 9.7% higher than 75%ETc with WPM treatment combinations. Similarly, the water productivity of onion in the interaction effects of 75%ETc with RSM was 29.3% higher than 100%ETc with NM,3 9.4% higher than 100%ETc with WPM, 20.0% higher than 100%ETc with RSM, 20.3% higher than 75%ETc with NM and 10.2% higher than 75%ETc with RSM treatment combinations. While The water productivity of tomatoes in 50%ETc with WPM was 3.2% higher than 50%ETc with RSM and 8.5% higher than 75%ETc with RSM treatment combinations.

5.2 Recommendation

Based on the present study result the following recommendations have been suggested.

- Deficit irrigation strategies are recommended for use by farmers and extension workers to achieve optimum onion and tomato yield and maximize crop water productivity by applying at 75%ETc through growth phases with saving water 25% of the water requirement.
- Smallholder farmers should apply rice straw mulch practices to increased onion and tomato yields and savings water under conservation agriculture.
- Onion and tomato growers are highly advised to cover their crop with rice straw mulch and apply 25%deficit irrigation instead of full irrigation to achieve higher onion yields and better water use efficiency.
- Adoption of water-saving strategies by smallholder farmers during the water scarcity time has economic benefits because less production cost was required for diesel, and labor for irrigation water application, and the saved water can potentially increase farm income to be used for bringing new areas under irrigation
- Additional research is needed on the effect of mulch types on soil nutrient dynamics, soil temperature, and the occurrence of pests and disease while different irrigation levels of moisture stress to determine conclusively the influence of the same study on yields and water productivity. Such studies may result in a further improvement of the yield of onion and tomato in water shortage areas of the country.

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APPENDIX

Table 36. Factorial Analysis of variance for onion plant height

Source	DF	SS	MS	F	P
Rep.	2	45.88	22.938		
Mulch	2	500.52	250.258	44.73	0.0000
Deficit	2	699.48	349.738	62.52	0.0000
Mulch * Deficit	4	11.77	2.942	0.53	0.7183
Error	16	89.51	5.594		
Total	26	1347.15			

Table 37. Factorial Analysis of variance for onion Leaf height

Source	DF	SS	MS	F	P
Rep	2	33.11	16.553		
Mulch	2	444.24	222.121	40.91	0.0000
Deficit	2	453.20	226.601	41.74	0.0000
Mulch*Deficit	4	16.01	4.004	0.74	0.5800
Error	16	86.87	5.429		
Total	26	1033.43			

Table 38. Factorial Analysis of variance for onion Leaf number per plant

Source	DF	SS	MS	F	P
Rep	2	1.8341	0.9170		
Mulch	2	30.0474	15.0237	66.17	0.0000
Deficit	2	54.4385	27.2193	119.89	0.0000
Mulch*Deficit	4	3.8993	0.9748	4.29	0.0151
Error	16	3.6326	0.2270		
Total	26	93.8519			

Table 39. Factorial Analysis of variance for onion average bulb weight

Source	DF	SS	MS	F	P
Rep	2	0.05	0.03		
Mulch	2	167.82	83.91	73.77	0.0000
Deficit	2	7259.17	3629.59	3190.95	0.0000
Mulch*Deficit	4	22.38	5.60	4.92	0.0089
Error	16	18.20	1.14		
Total	26	7467.62			

Table 40. Factorial Analysis of variance for onion bulb diameter

Source	DF	SS	MS	F	P
Rep	2	0.1279	0.06395		
Mulch	2	2.5536	1.27680	35.08	0.0000
Deficit	2	11.6587	5.82936	160.15	0.0000
Mulch*Deficit	4	0.6696	0.16740	4.60	0.0116
Error	16	0.5824	0.03640		
Total	26	15.5922			

Table 41. Factorial Analysis of variance for onion bulb height

Source	DF	SS	MS	F	P
Rep	2	0.00393	0.00197		
Mulch	2	3.04684	1.52342	65.08	0.0000
Deficit	2	2.30558	1.15279	49.25	0.0000
Mulch*Deficit	4	0.31256	0.07814	3.34	0.0362
Error	16	0.37451	0.02341		
Total	26	6.04342			

Table 42. Factorial Analysis of variance for onion marketable bulb yield

Source	DF	SS	MS	F	P
Rep	2	1.901E+07	9505610		
Mulch	2	8.981E+07	4.491E+07	29.61	0.0000
Deficit	2	8.026E+08	4.013E+08	264.66	0.0000
Mulch*Deficit	4	2.344E+07	5859174	3.86	0.0221
Error	16	2.426E+07	1516334		
Total	26	9.592E+08			

Table 43. Factorial Analysis of variance for onion water productivity

Source	DF	SS	MS	F	P
Rep	2	2.0860	1.04300		
Mulch	2	10.2405	5.12024	32.16	0.0000
Deficit	2	13.4146	6.70731	42.12	0.0000
Mulch*Deficit	4	2.4686	0.61715	3.88	0.0219
Error	16	2.5478	0.15923		
Total	26	30.7574			

Table 44. Factorial Analysis of variance for tomato marketable yield

Source	DF	SS	MS	F	P
Rep	2	4153003	2076501		
Mulch	2	1.378E+08	6.890E+07	88.10	0.0000
Deficit	2	3.466E+08	1.733E+08	221.61	0.0000
Mulch*Deficit	4	3.434E+07	8585110	10.98	0.0002
Error	16	1.251E+07	782104		
Total	26	5.355E+08			

Table 45. Factorial Analysis of variance for tomato fruit diameter

Source	DF	SS	MS	F	P
Rep	2	0.00479	0.00239		
Mulch	2	0.04511	0.02255	4.84	0.0227
Deficit	2	0.01280	0.00640	1.37	0.2812
Mulch*Deficit	4	0.01305	0.00326	0.70	0.6028
Error	16	0.07452	0.00466		
Total	26	0.15027			

Table 46. Factorial Analysis of variance for tomato fruit length

Source	DF	SS	MS	F	P
Rep	2	0.05122	0.02561		
Mulch	2	0.00346	0.00173	0.16	0.8530
Deficit	2	0.01994	0.00997	0.92	0.4168
Mulch*Deficit	4	0.01227	0.00307	0.28	0.8837
Error	16	0.17255	0.01078		
Total	26	0.25945			

Table 47. Factorial Analysis of variance for tomato water productivity

Source	DF	SS	MS	F	P
Rep	2	0.590	0.2951		
Mulch	2	13.940	6.9699	87.00	0.0000
Deficit	2	92.528	46.2638	577.45	0.0000
Mulch*Deficit	4	4.257	1.0643	13.28	0.0001
Error	16	1.282	0.0801		
Total	26	112.597