EFFECT OF DEFICIT IRRIGATION LEVELS ON YIELD AND YIELD COMPONENTS OF SESAME (Sesamum indicum L.) IN BENA TSEMAY WOREDA, SOUTH OMO ZONE, ETHIOPIA

MSc. THESIS

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HAWASSA UNIVERSITY, HAWASSA, ETHIOPIA

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A THESIS SUBMITTED TO THE DEPARTMENT OF WATER RESOURCE AND IRRIGATION ENGINEERING,

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This is to certify that the thesis entitled "Effect of Deficit Irrigation Levels on Yield and Yield Components of Sesame (Sesamum indicum L.) in Bena Tsemay Woreda, South Omo Zone, Ethiopia" submitted in partial fulfillment of the requirements for the degree of **Master's** with specialization in **Irrigation and Drainage Engineering**, the Graduate Program of the **Department/School of Bio-systems and Environmental Engineering,** and has been carried out by **Medhin Madebo Mada** ID. No **GPIrDrR/013/12,** under my/our supervision. Therefore, I/we recommend that the student has fulfilled the requirements and hence hereby can submit the thesis to the department.

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We, the undersigned, members of the Board of Examiners of the final open defense by Medhin Madebo Mada have read and evaluated his/her thesis entitled "Effect of Deficit Irrigation levels on Yield and Yield Components of Sesame (Sesamum indicum L.) in Bena Tsemay Woreda, South Omo Zone, Ethiopia", and examined the candidate. This is, therefore, to certify that the thesis has been accepted in partial fulfillment of the requirements for the degree.

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DEDICATION

I dedicate this thesis manuscript to my father Madebo Mada, my mother Trunesh Dunalo and my brother Samuel Madebo for nursing me with affection and love, and for their dedicate partnership in the success of my life.

STATEMENT OF THE AUTHOR

First, I declare that this thesis is my original work and that all sources of materials used for this thesis have been duly acknowledged. I solemnly declare that this thesis is not submitted to any other institution anywhere for the award of any academic degree, diploma or certificate.

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LIST OF ABBRIVIATIONS AND ACRONYMS

ANOVA	Analysis of Variance
CSA	Central Statistical Agency
CV	Coefficient of Variation
ECe	Electrical Conductivity of soil saturated extract
ETa	Actual evapotranspiration
ETc	Crop Evapotranspiration
ETm	Maximum Evapotranspiration
ETo	Reference Evapotranspiration
FAO	Food and Agricultural Organization
FC	Field Capacity
GIR	Gross Irrigation Requirement
IAEA	International Atomic Energy Agency
IWMI	International Water Management Institute
Kc	Crop coefficient
Ky	Yield Response Factor
LSD	Least Significant Difference
MRL	Multiple Linear Regression
NIR	Net Irrigation Requirement
PWP	Permanent Wilting Point
R^2	Coefficient of determination
RAW	Readily Available Water
RCBD	Randomized Complete Block Design
TAW	Total Available Water
WP	Water Productivity
Ya	Actual Yield
Ym	Maximum Yield

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ABSTRACT

Scarcity of water is one of the major constraints for the development of agriculture in arid and semi-arid regions. Hence, the effective use of available water by deficit irrigation is an alternative means to alleviate the problem and optimize the water productivity of crop in the region. The objective of this study was to determine the effect of deficit irrigation levels applied on yield, yield components and water productivity of sesame (Sesamum indicum L.). The field experiment was carried out at Bena Tsemay Woreda, Southern Ethiopia. The experiment was laid out in randomized complete block design with six irrigation treatments and three replications. The treatments were five water deficit irrigation levels (85%ETc, 75%ETc, 65%ETc, 55%ETc and 45%ETc) and full (100%ETc) as a control treatment. The result of analysis of variance showed that the different deficit irrigation levels applied had statistically significant ($p < 0.01$) effect on yield and yield component of sesame. Significant delay in flowering and maturity was observed as the water deficit level increased. The highest plant height, number of branch per plant, number of capsules per plant, number of seed per capsule, 1000-seed weight, aboveground biomass, harvest index and straw yield were observed under control treatment (100%ETc), while the lowest observed in 45%ETc treatment respectively. The maximum grain yield (2164.56 kg/ha) was observed under control (100%ETc), while the minimum (1377.37 kg/ha) was obtained from 45%ETc treatment level. From the mean result of grain yield it was observed that control treatment (100%ETc) significantly different from all treatments except treatment under 85%ETc. The highest water productivity (0.55kg/m^3) was observed under 45%ETc, while the lowest (0.39 kg/m^3) was at control treatment. From the result of study it was observed that the obtained yield response factor (Ky) was less than unity (Ky < 1), this indicates that sesame is tolerant to water stress. From the result of study it was observed that deficit irrigation under 75%ETc resulted in significant water saving and improved water productivity with insignificant yield reduction; therefore, sesame could be irrigated at 75%ETc in region with limited water resource condition.

Keywords: Deficit irrigation, crop water requirement, sesame, water productivity

1. INTRODUCTION

1.1. Background

Water is becoming scarcer globally and every indication is that it will become even more so in the future. As cities grow and population increase, the problem worsens since needs for water increase in households, industry and agriculture (Fereres et al., 2007). Climate change has also contributed significantly to the water scarcity problem (WHO, 2009). The combination of climate change and rising population are presenting agricultural production systems with challenges that are of increasing concern for food security (Petsakos et al., 2019). It is therefore important to understand existing and future pressures on agricultural systems and to investigate available options with productivity and technological advances have contributed to more efficient resource use and improved food safety (FAO, 2017).

Agricultural interventions, such as irrigation, increase food production and availability. The use of irrigated agriculture enables crop production, which increases the number of harvests per year and leads to increased yields and crop diversification (Domenech and Ringler, 2013). In Ethiopia, farmers using irrigation systems produced crops twice, and sometimes even three times, per year (Aseyehegn et al., 2012). Nearly 40% of food and agricultural commodities are produced through irrigated agriculture on about 17% of agricultural land (FAO, 2002). Over the last 50 years, irrigated areas have almost doubled and this has been one of the factors that have contributed to growth in agricultural productivity over the years (Rosegrant and Ringler, 2000).

The scope for further irrigation development to meet food requirements in the coming years will severely constrained by decreasing water resources and growing competition for fresh water. The dependency on water has become a critical constraint on further progress and threatens to slow down development, endangering food supplies and aggravating rural poverty. As water scarcity intensifies in many regions of the world, better management of water is becoming a pressing issue (Lorite et al., 2007) because; it is the most severe constraint for development of agriculture particularly in arid and semi-arid areas. Irrigation therefore needs to be managed more efficiently and sustainably, aiming at saving water, maximizing its productivity and reducing non-point sources of pollution of the environment.

In the context of improving water productivity, there is growing interest in deficit irrigation which involves applying stress levels to plants that have minimal effects on yield in order to maximize yields per unit of water used by the crop and maximize returns. Under conditions of scarce water supply and drought, deficit irrigation can lead to greater economic retunes than maximizing yield per unit of water for a given crop; farmers are more informed to use water more efficiently and high cash crop selection helps to optimize returns (Fereres and Soriano, 2007). Therefore, there is need to recognize the potential for deficit irrigation not only to conserve scarce water resources but also increase grower profitability.

Currently, climate variability has become more threatening to food security and sustainable development of any nation. About 66% of the total areas of Ethiopia fall within arid and semi-arid climatic zone of the country (MoA, 1998). Nevertheless, agriculture, which is highly sensitive to climate variability, is the driver of county's economy as it accounts for half of GDP and 80% of employment (MoARD, 2007). The dependency of Ethiopia on agriculture makes its economy extremely vulnerable to the risks associated with climate variability. Therefore, improvement of efficient irrigation water utilization is essential to carry out irrigation in water scarce areas for different crops to determine the optimum water deficit levels and increasing yield on cultivated land per irrigation water applied.

In Ethiopia, irrigation development is increasingly implemented more than ever to supplement the rain-fed agriculture. It aims to increase agricultural productivity and diversity by production of food and raw materials for agro-industry as well as to ensure the agriculture to play a pivot for driving the economic development of the country (Mekonen, 2011). Ethiopia has planned to irrigate over 5 Mha with existing water resources, to contribute around ETB 140 billion to the economy and to ensure food security for up to six million households i.e. about 30 million direct beneficiaries (Awulachew et al., 2007).

Crops recommended for deficit irrigation application are those that are relatively drought resistant and early maturing varieties according to (Mekonnen and Sintayehu, 2020). Sesame (Sesamum indicum L.) is one of the most important oil crops in temperate and tropical regions and is grown worldwide over (Phumichai et al., 2017). Therefore sesame (Sesamum indicum L.), mehado-80 variety that has been recommended was expected to be the major strategy for increasing yield and drought tolerant crop produced in Ethiopia arid and semi-arid regions (Geremew et al., 2012).

Next to coffee, sesame seed is the second largest agricultural export earner for Ethiopia, involving a number of small-holder farmer's participation throughout the nation (CSA, 2011). According to Wijnands et al., (2007); Geremew et al., (2012) sesame mehado-80 variety was the main export types of sesame seed in Ethiopian with yield potential of (15-22 qt/ha) under irrigation. Due its moderate resistance to soil water deficit, therefore in areas like Benatsemay woreda which is low land as well as ecologically drought, therefore it is suitable for sesame production by deficit irrigation technique.

Considering the concept of improving water productivity, there is increasing interest in deficit irrigation as a practice of applying irrigation water in amounts below the optimum plant's water requirements and mild stress is allowed with minimum effect on yield. Due to this, deficit irrigation practice is a solution to minimize yield reductions with scarcity of water under irrigated agriculture (Onder et al., 2009). It is also a water management method in which water will be saved with accepting little yield reduction without any severe damage to the plant (English, 1990).

Under conditions of water stress and drought, deficit irrigation can lead greater water productivity by improving yield with unit of water applied. In all instance, improved water management practices are most effective when combined with improved agricultural practices, such as the use of drought tolerant varieties (FAO, 2020). Since water scarcity and drought were the main factor affecting agricultural production in the study area, therefore the combined effect of improved water management using deficit irrigation with drought tolerant sesame variety would cope up the water scarcity problem in study area. Therefore, the use of deficit irrigation water management practice and drought tolerant sesame variety would improve sesame production in study area.

1.2. Problem Statement

The scarcity of water is the most critical constraint for sustainable production of crops under irrigation in drought prone environment. The increasing population growth with their corresponding demand for food requires the intensification of agricultural production. The increasing competition for water in the low land areas of central rift valley of Benatsemy Woreda is currently increasing due to expansion of small holder farmers, private investors, households and municipal water demands. Thus, improved use of limited irrigation water resource to intensify the agricultural production in order to fulfill the demands of fast growing population is an important option.

The study area was characterized as arid and semi-arid climatic conditions with scarce water resource. In arid and semi-arid regions, water scarcity is the main yield limiting factor, where it is difficult to apply full crop water requirements to sustain maximum yield (Abdel-Mawgoud et al., 2009). The effective water management practice was used to alleviate the increased water demand and more production per given amount of water for the future to increase water profitability (Fereres and Soriano, 20007; Blum, 2009). Thus, increase in WP of agricultural crops and saving of water resources are becoming of strategic importance for a region with limited water resource.

The study area has focused primarily on traditional irrigation in order to maximize total production. The present aim has changed due to limiting factors in production, such as the availability of water, using all the efforts to improve water use and management in agriculture is an important consideration. With the concept, deficit irrigation is a water management practice to apply limited amount of water to crops in time and amount vital for optimum WP, but there was limited research on amount and timing of water was undertaken in the study area. Therefore, this study was aimed on identifying the amount and timing of irrigation water management practice which resulting in optimum yield and improved WP for the variety in the study area.

Since sesame grows well in hot to warm semi-arid regions and well suited to the low lands of the study area with increased production by majority of farmers. For selected drought tolerant crop, application of water below crop water requirement could improve the water productivity without significant effect on yield. Therefore, this research was aimed to determine the effect of deficit irrigation levels on yield, yield components and water productivity of sesame in the study area.

1.3. Objectives of the Study

1.3.1. General objective

The main objective of this study was to determine the effect of deficit irrigation levels applied on yield, yield components and water productivity of sesame under Bena Tsemay condition.

1.3.2. Specific objectives

The specific objectives of the study were:

- To evaluate the effect of deficit irrigation levels applied on yield and yield components of sesame.
- To determine the water productivity of sesame under different deficit irrigation levels.
- To identify the critical deficit irrigation level for optimal water saving and yield output for the variety under the study area.

1.4. Significance of the Study

The study was specifically based on the efficient utilization of the available scarce water resource by varying water deficit levels effectively. Ultimately, this would lead to a better understanding of how to improve the yield of sesame, water productivity and help to identify the optimum water deficit level where yield was not significantly affected.

1.5. Scope of the study

The study was conducted in Bena Tsemay Woreda at experimental site of Jinka Agricultural Research Center in South Omo Zone. The study focused on investigating the effect deficit irrigation levels on yield and yield components of sesame and identifying deficit irrigation level with optimum yield and WP for the variety under the study area.

1.6. Limitation of the study

The study was limited in space, resource and time. Due to these constraints, the study was not undertaken in all the irrigation schemes of South Omo Zone. To overcome this, the researcher confined to carry out the study in Benastemay Woreda of South Omo Zone.

2. LITERATURE REVIEW

2.1. The Concept and Rational for Deficit Irrigation

In the past, crop irrigation requirement did not consider the limitations of the available water supplies. However, the great challenge for the future will be the means of increasing food production with limited water resource, due to the expansion of irrigated area and the growing competition for water. Therefore, deficit irrigation is the application of irrigation rates below the full crop evapotranspiration is potentially able to improve efficiency and maximize profits through a reduction in capital and operating costs (Capra et al. 2008). In addition, deficit irrigation provides the means of reducing water consumption while minimize adverse effects on yield (Smith et al., 2002).

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

Accordingly, FAO (2002) the main objective of deficit irrigation is to increase the water productivity of a crop by eliminating irrigation that has little impact on yield. The resulting yield reduction may be small compared with the benefits obtained through diverting the saved water to irrigate other crops for which water would normally be insufficient under traditional irrigation practices. In principle, deficit irrigation is practiced to maximize profits where water costs are high or there is water shortage. In such case, crop values are associated closely with yield and crop grade and marketability. Under these circumstances, when water supplies are limiting, the farmer's goal should be to maximize net income per unit water used rather than per land unit (Fereres and Soriano, 2007).

In areas where water resource is the limiting factor for crop production, maximizing water productivity by deficit irrigation practice is often economically more profitable for the farmer than maximizing yield. Farmers must choose crops and irrigation strategies carefully to maximize the value of their crop production activities, while ensuring the sustainability of agriculture. Deficit irrigation will play an important role in farm level water management strategies, with consequent increases in the output generated per unit of water used in agriculture (Geerts and Raes, 2009).

2.2. Water Scarcity and Deficit Irrigation

Scarcity of water is one of the major constraints for development of agriculture in arid and semi-arid regions of Ethiopia, due to inadequate, irregular and erratic nature of rainfall (Yihun et al., 2015). The study area characterized with recurrent drought and lack of effective use of scarcely available water aggravates water scarcity in agricultural production and productivity. At present and more so in the future, irrigated agriculture will take place under water scarcity and insufficient water supply for irrigation will be the norm rather than the exception (Fereres and Soriano, 2007).

To sustain the rapid growing population of Ethiopian, agricultural production will need to increase, yet the proportion of fresh water currently available for agriculture is decreasing as the allocation of water to different uses increases (IWMI, 2000). Hence, sustainable methods used to increase crop water productivity and agricultural productions are gaining importance in arid and semi-arid region of Ethiopia (Engida, 2000). Therefore, deficit irrigation is a water-saving irrigation strategy used in many parts of the world (Fernández et al., 2013) in which irrigation water is applied at lower amounts than the full crop water requirement (ET), thereby increasing water productivity.

Deficit irrigation leads to higher productivity of the water than that can be obtained with full irrigation; therefore, it could be used for improving the productivity of water in semi-arid areas (Kijne et al. 2003). With increasing scarcity and growing competition for water, there will be more wide spread adoption of deficit irrigation, especially in arid and semi-arid regions (FAO, 2002). Accordingly, Fereres and Soriano, (2007) pointed out that deficit irrigation, by reducing irrigation water use, can aid in coping with situations where supply is restricted. Water scarcity is one of the major problems facing crop production in study area and it is necessary to reduce irrigation water requirement through conducting drought tolerant cultivars (Golla, 2021).

The main focus of this study was optimizing agricultural water productivity in water scarce region by using water management practice such as deficit irrigation. Since the study area was characterized in arid and semi-arid regions with irregular and inadequate rainfall which affects the agricultural production. In order to cope with these challenges use of stress tolerant crops sustain agriculture production in these regions (Golla, 2021). Therefore, sesame is one of the stress tolerant crops according to Allen et al., (2006), was suited for this study. Therefore, the use of deficit irrigation practice due to its increased water saving and the choice of stress tolerant crop is closing the gap in agricultural production in water scarce regions.

2.3. Effect of Deficit Irrigation on Yield and Yield Components of Sesame

Previous research studies regarding effect of deficit irrigation for sesame where not under taken in the study area. Therefore, the attempt was taken to review the research findings of the effect of deficit irrigation on sesame at different study environment was undertaken. Thus most reported studies by different authors have been carried out on sesame growth and yield parameters are summarized below with their brief accounts of findings.

Accordingly, Mekonnen and Sintayehu, (2021) conducted experiment on the regulated deficit irrigation on sesame and pointed out that yield and yield components of sesame is affected by deficit irrigation application. Similarly, Hailu et al., (2018) investigated on the deficit irrigation and water application method on sesame and pointed out that sesame yield was affected by deficit irrigation application. Also according to Sarhadi, (2014) studied the effect of deficit irrigation on sesame yield and yield components resulted in significant effect on yield and yield components of sesame.

Similarly, Fazeli et al., (2006) investigated the effects of drought (different irrigation levels: 100, 75, 50, & 25 % of field capacity) on two sesame varieties revealed that drought status resulted in reduced plant growth with increasing drought stress. According to Pereira et al., (2017) conducted experiment on sesame water requirement and irrigation regime and concluded that 698mm irrigation depth resulted in highest yield whereas; 305mm resulted in best WUE. From the results of the authors, it was observed that the highest yields together with yield component achieved through full irrigation in contrast, the lowest was obtained under high water deficit levels.

Also according to Nimir, (2002) studied the effect of water stress applied at different stages of growth and found that water stress reduced plant height, number of nodes per plant, number of branches per plant, reduced time to 50% flowering, delay in maturity, reduced number of flowers, capsules per plant, decreased number of seeds per capsule, reduced 1000-seed weight, decreased seed yield per plant, final seed yield (kg/ha) and reduced harvest index. Also Vegetative growth stage characters were gradually decreased with increasing water stress according to (Elshamly et al., 2013). Also according to Mensah, (2006) demonstrated that water limitation reduced growth and yield of sesame.

Different crops and varieties have different tolerance levels for water stress. The various crop development stages possess different sensitivities to water stress where time, duration and the degree of the stress all affect yield (Elshamly et al., 2013). Sesame is one of the most drought tolerant crops in the world but will give higher yields with higher soil moisture (Langham et al., 2008). Moreover, type of soil also affects the adverse effect of water stress on crop. Water retention capacity of soil should be considered for practicing deficit irrigation to enhance crop yield in water deficit condition. Therefore, crop growth and productivity depends mainly on the proper water management. Water management that maximize yield per unit of water consumed by plant are highly desired.

The results of (Uçan and Killi, 2010 and Mensah et al. 2009) pointed out that an increase in yield per plant with increased drought stress even though the authors concluded that severe drought has reduced the sesame yield. The authors mentioned that relative water content and total chlorophyll content were increased under drought stress and hence, claimed that the sesame variety being tested was drought tolerant. Chlorophyll fluorescence, stomatal conductance and leaf temperature in 21 sesame varieties were studied against drought stress (with holding water for 16 days after 2 weeks of growth of sesame plants) by (Boureima et al. 2012) and it was reported that stomata conductance was reduced, leaf temperature was increased while the effect on chlorophyll fluorescence greatly differed among the tested varieties.

The literature review on number of days to flowering and maturity under water stress conditions. Regarding number of days to 50% of flowering and maturing, for faba bean it is noticed that plants stress condition try to escape from unfavorable condition by ending their life few days earlier than those under normal or high soil moisture conditions (Ahmed et al., 2008). Similar research reports showed that stressed treatments in wheat leads to early maturity according to (Li et al., 2011; Kilic and Yagbasanlar, 2010). Generally, plants underwater stress was commonly shorter than those gives higher amount of water supplied (Suhaibani, 2009; Simsek et al., 2011). From the result of authors it was noticed that crop under increased water defect level took earlier than that of decreased water deficit level.

2.4. Effect of Deficit Irrigation on Water Productivity of crop

In the past, the concept of productivity of water in agriculture has gained ground owing to increasing scarcity of irrigation water from physical and economic perspectives, mostly locally and often also regionally. Several studies are available from the past which deal with water productivity of crops with respect to evapotranspiration of crops (Kijne et al., 2002; Zwart and Bastiaanssen, 2004). Growing physical shortage of water on the one hand, and scarcity of economically accessible water owing to increasing cost of production and supply of the resource on the other, had preoccupied researchers with increasing productivity of water use in agriculture in order to get maximum production or value from every unit of water used (Kijne et al., 2003).

In broader sense, water productivity is the net return for a unit of water used. Recent investigations have been put on the concept of WP, defined here as the yield or net income per unit of water used. According to Molden, (2010) water productivity is defined as the ratio of agricultural output to the amount of water consumed “more crops per drop” and this has also been used to relate water use in agriculture. Water productivity reflects the goal of producing more food, income, livelihoods and ecological benefits at less social and environmental cost per unit of water. When water supplies are limiting, the farmer’s goal should be to maximize net income per unit water used rather than per land unit (Fereres and Soriano, 2007).

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

The increased water productivity can be attributed to the following reasons: water loss through evaporation is reduced; the negative effect of drought stress during specific phonological stages on biomass partitioning between reproductive and vegetative biomass is avoided, which stabilizes or increases the number of reproductive organs and the individual mass of reproductive organs (Karam et al., 2007).

Increasing WP is particularly appropriate where water is scarce, for instance more productive use of water in such area was the means of better nutrition for families, more income and productive employment. Targeting high water productivity can reduce investment costs by reducing the amount of water that has to be withdrawn. The higher water productivity reduces the need for additional water and land resources in irrigated and rain fed systems (Molden, 2010). Enhancing water productivity is thus critical responses to growing water scarcity, including the need to leave enough water in rivers to sustain ecosystem to meet the growing demands of cities and industries (Hengsdijk et al., 2006).

According to Geerts and Raes (2009), by reviewing selected research works around the world confirms that deficit irrigation successfully increased water productivity for various crops. Also according to Zwart and Bastiaanssen, (2004) reviewed that obtained crop water productivity for several crops around the world and concluded that the crop water productivity could be significantly increased if irrigation was reduced and crop water deficit was intentionally induced.

2.5. Determination of Crop Water Requirement

According to Allen et al., (1998) the amount of water required to meet the water loss through evapotranspiration (ETc) of a disease-free crop, growing in large fields under non restricting soil conditions including soil water and fertility achieving full production potential under the given growing environment is defined as crop water requirement. It is also the quantity of water required by the crop in a given period to meet its normal growth under a given set of environmental and field conditions. The computation of crop water requirement requires the effect of climate on crop, which is the reference crop evapotranspiration (ETo) and the effect of crop characteristics (Kc) (Allen et al, 1998). Estimates of reference evapotranspiration (ETo) are widely used in irrigation engineering to determine crop water requirements.

The reference evapotranspiration is both the combined effect of water loses through evaporation and transpiration. FAO Penman-Monteinth equation was used for estimating reference evapotranspiration (Allen et al, 1998). The method recommended as the sole standard method with strong likelihood of correctly predicting ETo in a wide range of locations and climates and it has provision for application in data-short situations (Walter et al., 2000).

According to Allen et al, (1998) crop coefficient used for estimating CWR for specific growth stages using derived numerically for each growth stages. The crop coefficient for any period of growing season can be derived by considering that, during the initial and mid-season stage Kc is constant and equal to the Kc value of the growth stage under consideration (Allen et al. 1998). During the crop development and late season stage, Kc varies linearly between the Kc at the end of the previous stage (Kc prev) and the Kc at the beginning of the next stage (Kcnext), which is Kcend in the late season stage (Allen et al. 1998).

2.6. Water Requirement of Sesame

The water requirement of sesame was obtained from the reference evapotranspiration for the study and crop coefficient factor FAO (Savva and Frenken, 2002). The water requirement of sesame was the part of water requirement of the crop that should be fulfilled by irrigation. In other words, it is the water requirements of sesame excluding effective rain fall. If irrigation is the only source of water supply for the plant, the irrigation requirement will always be greater than the crop water requirement to allow for inefficiencies in the irrigation system. If the crop receives some of its water from other sources (rainfall, water stored in the ground, underground seepage. etc.), then the irrigation requirement can be considerably less than the CWR (Yonas, 2012).

2.7. Deficit Irrigation Management

Deficit irrigation management is commonly used in regions with inadequate water supplies to meet the full crop seasonal consumptive use or to conserve irrigation water. According to Howell et al., (2010) it requires careful attention to both strategic and logistical decisions for successful implementation. It is a practice which requires more control over the amount and timing of water application than full irrigation practice.

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

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

2.8. Developing Irrigation Scheduling

Irrigation scheduling is the process of determining when to irrigate and how much water to apply based upon measurements or estimates of water used by plant. Irrigation schedules are based on current crop water requirements and predict irrigation needs in immediate future. Irrigators practicing deficit irrigation need to predict irrigation schedules in advance of the growing season and make appropriate adjustments based on potential crop yields and economic returns (Klocke et al., 2009). Irrigation scheduling is also adapted for more effective use of the limited supplies of water.

According to FAO, (2002) stated that deficit irrigation scheduling is one way of maximizing water use efficiency for higher yields per unit of irrigation water applied; the crop is exposed to certain level of water stress either during a particular period or throughout the whole growing period. Also according to Kirda, (2002) pointed out that irrigation scheduling based on deficit irrigation requires careful evaluation to ensure enhanced efficiency of use of scarce supplies of irrigation water. It is necessary to develop new irrigation scheduling approaches, not necessarily based on full crop water requirement, but even designed to ensure the optional use of allocated water (FAO, 2002).

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

2.9. Yield Response of Crop to Deficit Irrigation

Yield responses to irrigation and to ET deficits have been studied empirically for decades (Howell, 2001). It turned out that is not only biomass production that is linearly related to transpiration, but the yield of many crops is also linearly related to ET. The design of a DI program must be based on knowledge of this response but the exact characteristics of the response function are not known in advance. Also, the response varies with location, stress patterns, cultivar, planting dates and other factors.

In particular, many crops have different sensitive to water stress at various stages of development and the DI program must be designed to manage the stress so that yield decline is minimized (FAO, 2002). However, when the yield decline in relative terms is less than the ET decrease, WP under DI increases relative to that under full irrigation. Nevertheless, from the standpoint of farmer, the objective is not WP per second, but net income, low risk and other issues related to the sustainability of irrigation are more important (Fereres and Soriano, 2007). Knowledge of the crop response to DI is essential to achieve such objectives when water is limited.

Crop yield under varies levels of reduced crop water requirements were fitted to linear crop yield response functions (Garcia-Vila et al. , 2009). The crop yield response factor gives an indication of whether the crop is tolerant of water stress. The response factor greater than unity indicates the expected relative yield decrease for a given ET deficit is proportionately greater than the relative decrease in evapotranspiration (Steduto et al., 2007).

The response of a crop to its soil moisture environment is quantified through Ky. Thus, the Ky-approach provides an efficient, time effective and reliable means of simulating crop yield in response to water stress for a specific region (Shrestha et al., 2010). Doorenbos and Kassam(1979) reported Ky values for several crops. As values of Ky represent a crop sensitivity factor to drought, existing crop water productivity function's and Ky values for specific crops are non-transferable since they are influenced by localized climatic conditions (Ferreira & Goncalves, 2007; lgbadun et al., 2007).

FAO and International Atomic Energy Agency (IAEA) research coordinated group studied yield responses of major field crops to deficit irrigation, including cotton, maize, potato, sugar cane, soybean and wheat (FAO, 2002). The key values obtained from FAO data sets and from an IAEA coordinated research project(CRP) showed a wide range of variation for this parameter $0.20 < Ky < 1.15$(FAO,2002) and $0.08 < Ky < 1.75$(IAEA). However, for many other crops FAO recommendation of Ky values are more reliable and practical. Accordingly, the yield response factor (Ky) value of 0.95 for sesame under deficit irrigation during the whole growing season (Thazin, 2019).

However, stress applied during reproductive growth stages can affect fruit or grain set, resulting in decreased yields. The effects of stress on yields are complex and may differ with species, cultivar, and growth stage; they have been the subject of many studies. Extensive field research is required to better understand the physical and biological processes that control crop responses to moisture stress. Therefore, crop response to water deficit is mainly influenced by inherent crop trait, phonological stage, climatic condition and edaphic effects of an environment (Zwart and Bastiaanssen, 2004).

2.9.1. Sesame crop response to deficit irrigation

According to Bahrami et al., (2012) pointed out that water stress have adverse effect on plant growth and productivity. However, sesame is one of the most drought tolerant crops in the world but will give higher yields with higher soil moisture (Langham et al., 2008). Despite having an optimal range of between 500 and 650 mm of water during its production cycle (Grild et al., 2013) sesame is considered as resistant to drought. Similarly, Allen et al., (2006) pointed out that sesame is tolerant to water stress.

In general, water deficiency is caused by the transpiration of water exceeding the rate of absorption, thereby acting directly on the water balance in plants (Costa et al., 2008). Damage to the plants, which can be more or less severe, depends on the intensity of the stress, exposure time and stage of development of crop (Rufino et al. 2013). The early maturing and low-crop water requirement nature of sesame, assessing the critical growth stages where sesame is most sensitive to water stress could help with improving crop water productivity and water-related managements (E.K. Hailu, et al., 2018 and Tewelde, 2019).

3. MATERIALS AND METHODS

3.1. Description of the Study Area

3.1.1. Location

The experiment was conducted at Woito experimental site of Jinka Agricultural Research Center during the 2020/2021 season. The site is located in Bena Tsemay Woreda in South Omo Zone, Southern Ethiopia. Geographically the experimental site is located at 5˚18′0″ to 5˚31′33″ N latitude and 36˚52′30″ to 37˚5′0″ E longitude and an altitude of 660 meters above sea level. The area is situated in the eastern part of Bena Tsemay Woreda with a distance of 82 km away from Jinka, 438 km south of Hawassa and 668 km south west of Addis Abeba.

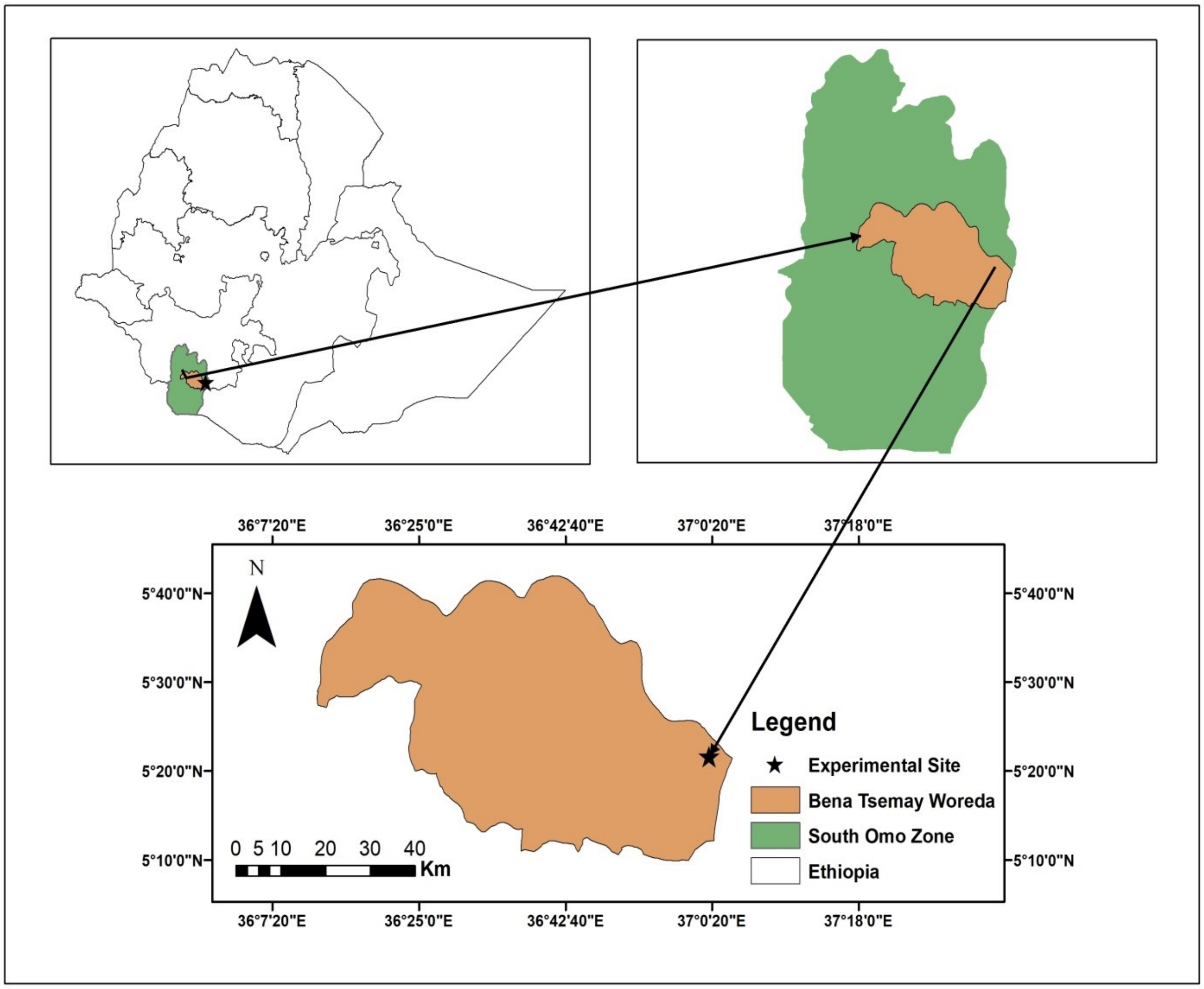

Figure 1. Map of the Study Area

3.1.2. Climate characteristics of experimental site

According to the long-term (1998-2020) record of meteorological data, the mean annual reference evapotranspiration of the study area was 2364mm. The mean monthly minimum and maximum temperature of the study area were 26℃ and 40℃ respectively. The rainfall distribution of the experimental site is erratic and uneven with mean annual rain fall ranges from 200mm to 578mm. Agro-ecologically, the area is classified as hot arid and semi-arid climate, and it is characterized by recurrent water shortage, intermittent famine, overgrazing and dry-land cultivation (BOFED, 2015). The climatic characteristics of the study area show high evapotranspiration throughout the year except August and September.

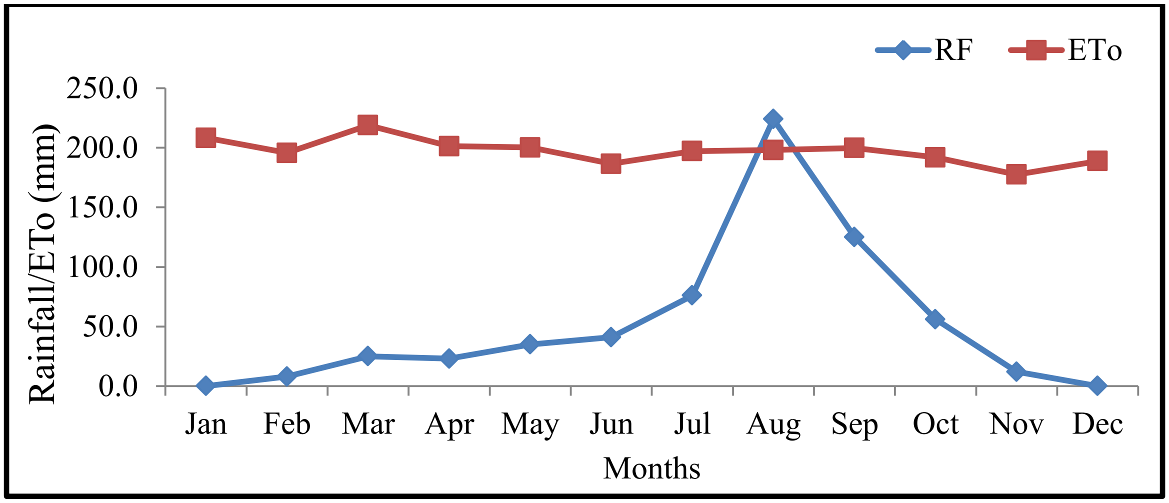

Figure 2. Climatic-water balance of the study area

3.1.3. Soil characteristics

According to the data obtained from Bena Tsemay woreda agricultural department showed that the experimental area soil is dominated by loam soil, this makes the soil of the area suitable for crop production. The low land of the experimental site is agro-ecologically hot to warm semi-arid therefore it is suitable for sesame production under irrigation. Farmers of the study area produce crops twice a year, one during the dry season (March-July) by irrigation the other during the partial rainy season (August-October) by using supplementary irrigation (Mugoro et al, 2020). The source of irrigation water in the study area is diverted from Woito River. The major crops produced in the study area include cotton, maize, sesame, onion, tomato and banana by using surface irrigation (AGP-II, 2015).

3.2. Methods

3.2.1. Treatments and Experimental Design

The depth of irrigation water applied for the different deficit irrigation treatments throughout the growth stages of sesame was used as the experimental factor. The yield and yield component response of sesame was determined for the different depths of irrigation water applied. The sensitivity of growth stages to different levels of water deficit was investigated. The experiment was conducted with having of five levels of deficit irrigation and full crop water requirement (0% deficit as control) by considering the allowable depletion fraction of (0.6) for sesame (FAO, 1998). Treatments were arranged in each of experimental plots within the three blocks randomly based on randomization using R (Statistical software) version 4.1.3 for windows.

Table 1. Treatment setting of the experiment

Treatments	Crop water deficit levels and one control irrigation
T1	Irrigation water application at 100%ETc
T2	Irrigation water application at 85%ETc
T3	Irrigation water application at 75%ETc
T4	Irrigation water application at 65%ETc
T5	Irrigation water application at 55%ETc
T6	Irrigation water application at 45%ETc

Where: ETc- crop evapotranspiration, T- Treatment,

The field experiment was laid out in RCBD with six irrigation treatments and replicated three times. Each experimental plot had 15m^2 (3 m x 5 m) net area was used. Fertilizer application of 46kg/ha P_2O_5 was used at time of planting and split application of 64kg/ha urea; half at planting and half at 45 days of planting (Mekonnen and Sintayehu, 2020). Sesame seed was sown manually on furrows having the recommended row spacing of 40cm and plant spacing of 10cm was used (Geremew et al., 2012). The gross size of experimental site was 30 m x 22.2 m. The plots and replications had a buffer zone of 2.40 m from water supplying canal and 2.40 m between plots to eliminate the influence of lateral water movement; the lateral movement of water in the soil is significantly less than the vertical movement (Burton, 2010).

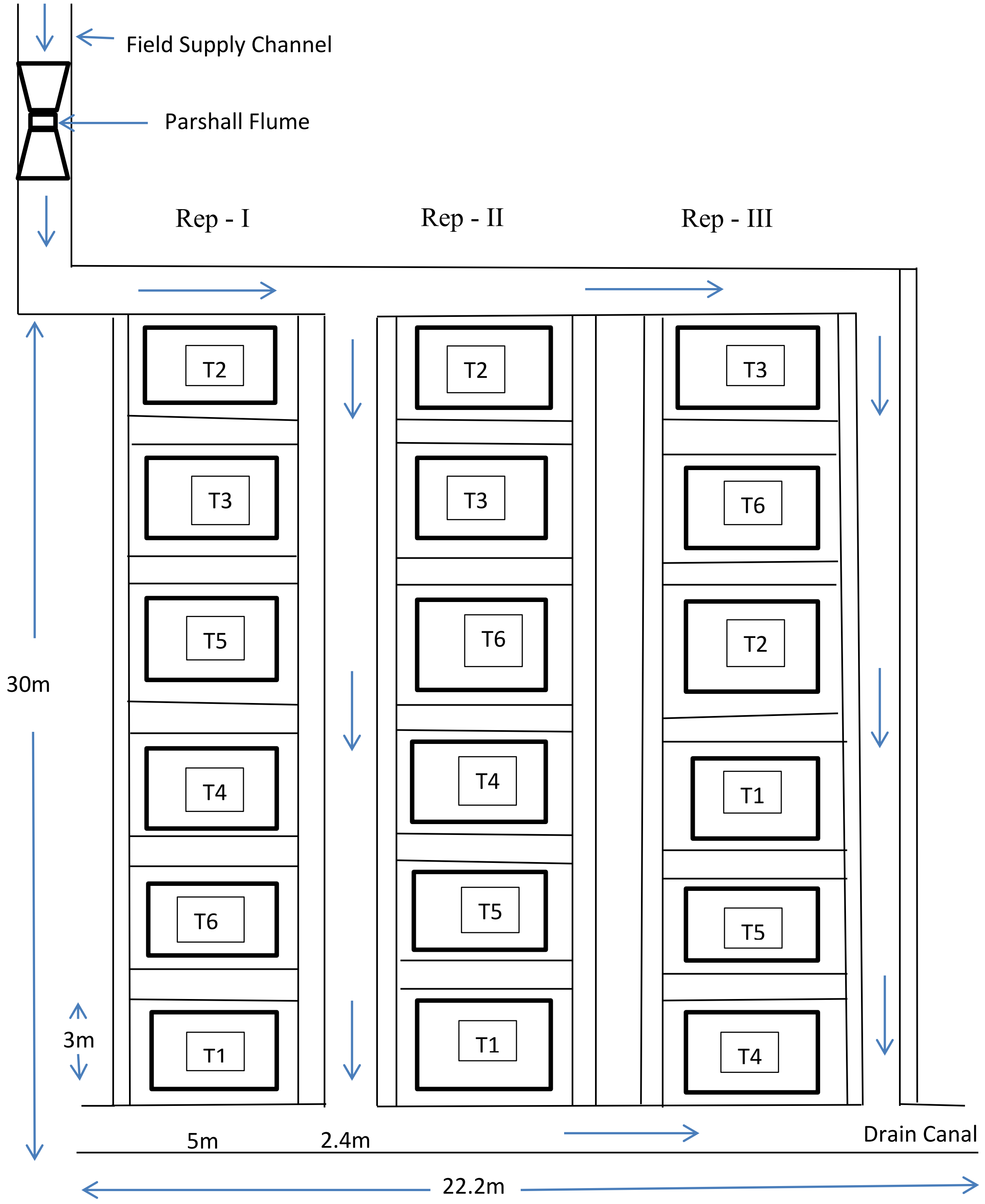

Figure 3. Experimental Field Layout

3.3. Irrigation Management

As described in the objective, one of the aims of the study was to determine the water productivity of sesame crop under different deficit irrigation levels. The irrigation treatments were the only variable whose effect is expected from the experimental unit. The irrigation depth was converted to volume of water by multiplying it with plot area. Based on the volume of water and the discharge capacity of Parshall flume at different head, the time required to irrigate each treatment was calculated. Each treatment was irrigated with the duration of time computed for different head of water in the Parshall flume. Then the water was applied to the experimental field by small earthen canal and was distributed to each experimental plot based depths' of each treatment. The source of irrigation water used was from the nearby water channel which was diverted from Woito River to the irrigated field.

3.4. Soil sampling and analysis

Soil samples were taken at depths of 0-30, 30-60, 60-90 and 90-120 cm from the experimental field. The soil samples were taken from the experimental field diagonally to avoid bias in the sampling and it was taken before of field preparation. The physical and chemical properties of the soil sample were carried out at Jinka Agricultural research center soil laboratory. Soil textural class and moisture contents at field capacity and permanent wilting point analysis were done in Debre Zeit Agricultural Research Center soil laboratory using pressure plate apparatus.

3.5. Determination of Soil Physical Characteristics

3.5.1. Soil texture

Soil textural class was analyzed by using hydrometer method for undisturbed soil samples for each depth. The weighted soil samples were sifted through screen and the soil particles that have diameter less than 2mm was used for textural class determination. The amounts of sand, silt and clay fractions were then calculated. The textural class was designated based on the mass ratio of the three particles (clay, silt and sand) with the help of soil textural triangle (Hillel, 2004).

3.5.2. Bulk density

Soil bulky density is an indicator of soil compaction. It was determined by using undisturbed soil samples collected by metallic core sampler of known volume (98.125cm^3) through the soil depth. The collected soil samples were oven dried for 24 hours at a temperature of 105°C to remove the soil moisture and to get the dry weight of soil sample. Then the bulky density was calculated as the ratio of the dry weight of the soil to known cylindrical core sampler volume (Hillel, 2004).

$$\mathrm{BD} = \frac{\mathrm{Wtsc}}{\mathrm{V}} \qquad (3.1)$$

Where: BD = bulk density of soil (g/cm^3)

Wtsc = weight of oven-dry soil core (g)

V= volume of soil in core (cm^3)

3.5.3. Soil moisture determination

Determination of moisture content of the soil was carried out by collecting soil samples. The collected soil sample was weighted before an oven dry. Then the sample was placed in an oven at a temperature of 105°C for 24 hours. The soil was taken out of the oven; cooled and weighted again. The gravimetric moisture content (θm) was determined (DeAnglis, 2007).

$$\theta\mathrm{m} = \frac{(\mathrm{Ww}-\mathrm{Wd})}{\mathrm{Wd}} * 100 \qquad (3.2)$$

Where: Ww = weight of wet soil sample (g)

Wd = weight of dry soil sample (g)

θm = soil moisture on mass base (%)

Water content on volumetric base was calculated as:

$$\theta\mathrm{v} = \theta\mathrm{m} * \mathrm{BD} \qquad (3.3)$$

Where: θv = Volumetric moisture content (%) and BD = bulky density of soil (g/cm^3)

3.5.4. Field capacity and permanent wilting point

The water content of soil at field capacity and permanent wilting point were determined for undisturbed soil samples in the laboratory with the help of pressure plate apparatus. The pressure plate was adjusted to a suction of 0.33bar to determine field capacity and 15bars to determine permanent wilting point to a saturated soil sample (Richards, 1954). The samples placed on plates were allowed to stand overnight with an excess of water maintained in the tray. After putting the tray containing the samples in the pressure plate chamber, the required pressured was maintained by the air compressor fitted with suitable pressure regulator so as to equilibrate the sample for required suctions. After attaining the equilibrium, the samples were immediately transferred to the moisture box and the moisture content at a particular suction was determined by drying the samples in an oven at 105 ℃ till constant weight was achieved.

3.5.5. Soil infiltration rate

The infiltration rate of the soil in the experimental field was measured by using double ring infiltrometer (Reynolds et al, 2002). The infiltrometer were installed with the help of specially designed crossed bar hammer with a circular driving cap resting on the top of the infiltrometer. Water was added slowly to avoid disturbance of soil at the surface in between outer and inner rings. The observations were taken from the inner ring till steady rate was achieved. The scale readings were recorded at time intervals in minute. The difference in water level in mm recorded at three replicated rings at an elapsed period of time divided by the time interval was expressed as infiltration rate.

3.6. Determination of Soil Chemical Characteristics

The soil chemical properties such as pH, electrical conductivity of soil saturated paste extract (ECe), organic matter content (OM) and organic carbon were analyzed in laboratory. The ECe for the soil sample was determined by ECe method by allowing soil saturated paste to stand for 24hrs (Londra et al., 2020). Subsequently, the vacuum extracts were collected and ECe was measured by a conductivity meter. The soil pH was determined by saturated soil paste method (Singh et al., 2019). The Organic carbon (%) was determined following the wet digestion method as described by (Walkley and Black 1934). Organic matter content was then determined by multiplying OC by 1.724 (Nelson and Sommers, 1996). Electrical conductivity of the irrigation water and the soil was determined using electrical conductivity meter (EC meter).

3.7. Determination of Crop Water Requirement

The depth of water needed by crop to meet the amount of water loss through evapotranspiration of a crop requires climatic and crop input data. Crop water requirement refers to the water used by crops for cell construction and transpiration (FAO, 2002). According to FAO, (1998) the crop water requirement (ETc) for the growing season of sesame was calculated from reference evapotranspiration (ETo) and crop coefficient (kc) values for each growth stages.

$$ETc = ETo * Kc \tag{3.4}$$

Where: ETc = crop water requirement (mm/day)

ETo = reference evapotranspiration (mm/day)

Kc = crop coefficient

3.7.1. Determination of reference evapotranspiration

The reference evapotranspiration (ETo) for the experimental site was computed based on the modified FAO Penman-Monteith equation (Allen et al., 1998) by using FAO CROPWAT software version 8.0. Penman Monteith equation as the sole standard method with strong likelihood of correctly predicting ETo in a wide range of locations and climates (Walter et al., 2000). The input data used compute ETo, includes altitude, latitude, longitude and 23 years (1998-2020) climatic data for Woito experimental site include monthly values of maximum and minimum temperatures, relative humidity, sunshine hours and wind speed were acquired from National Meteorological Agency Hawassa Branch, was used.

The crop coefficient (Kc) values used to determine the ETc for sesame crop was 0.35 at initial stage, $0.35 < Kc < 1.1$ for development stage, 1.1 for the mid-season stage and $1.1 < Kc < 0.35$ for the late season stage according FAO (Savva and Frenken, 2002). Based on the Kc values and length of each growth stages of sesame, daily crop coefficient value was calculated for the corresponding stages. The length of growth stages used were 20, 30, 40 and 20 days for initial, development, mid-season and late season stages respectively (FAO,1998).

3.7.2. Determination of irrigation requirement

The irrigation requirement was computed using the CROPWAT computer based on Allen et al, (1998) as follows:

$$IR = ETc - Pe \tag{3.5}$$

Where: IR = irrigation requirement (mm)

ETc = crop evapotranspiration (mm)

Pe = effective rainfall (mm).

3.7.3. Determination of effective rainfall

Effective rainfall (Pe) is a part of the rainfall which entered into the soil and being available for crop. The empirical formula developed by (FAO) to estimate defendable rainfall, was used to calculate the effective rainfall.

$$Peff = 0.6P - 3.33 \quad \text{for P month <= than 23.33mm} \tag{3.6}$$

$$Peff = 0.8P - 8 \quad \text{for P month > than 23.33 mm} \tag{3.7}$$

Where: Peff = effective rainfall in mm, P = total rain fall in mm

3.7.4. Determination of soil available water

According to Allen et al., (1998) the amount of water that a crop can extract from its root zone and its magnitude depends on the type of soil and the rooting depth. Not all of the water found in the root zone was actually be taken by plant root. Therefore, the water that plants can easily take from the soil is in the readily available form.

The total available water (TAW), in the root zone was computed as the difference between soil moisture content at field capacity (FC) and permanent wilting point (PWP) and computed by using equation (Jaiswal, 2003).

$$TAW = 10(\theta vfc - \theta vpwp) * D \tag{3.8}$$

Where: TAW = the total available soil water in the root zone (mm)

$\theta vfc =$ the volumetric water content at field capacity (%)

$\theta vpwp =$ the volumetric water content at permanent wilting point (%)

D = the root depth of the sesame in (mm/m)

Readily available water is the fraction of TAW that a crop can extract from the root zone without tending water stress, determined as:

$$RAW = p*TAW \tag{3.9}$$

Where: RAW = the readily available soil water in the root zone (mm)

TAW = the total available soil water in the root zone (mm)

p = allowable soil water depletion fraction and taken as 0.6 for sesame based on recommendation of (FAO, 1998). The allowable soil water depletion (RAW) was considered as 100%ETc as full and the defect irrigation treatments were set with their corresponding deficit level.

3.7.5. Gross irrigation Requirement

The gross irrigation requirement was computed by using a field application efficiency of 60% (FAO, 1989). According to Raine and Bakker (1996), furrow irrigation application efficiencies vary from 45-60%. However, according to Brouwer and Prins, (1986), the application efficiency for a short, end diked furrow is taken as 60%. Since this particular study was carried out in furrow irrigation with application efficiency of 60%. Gross irrigation usually requires more amount of water than net irrigation requirement and it is applied during irrigation to compensate for unavoidable losses and satisfy ET. Based on the net irrigation depth and irrigation application efficiency the gross irrigation water requirement was calculated in the equation given as:

$$Ig = \frac{In}{Ea}*100 \tag{3.10}$$

Where: Ig = gross irrigation requirement (mm)

In = net irrigation requirement (mm)

Ea = application efficiency (%)

3.7.6. Determination of irrigation application time

The gross irrigation depth determined was applied to the experimental plots based on the treatment. The volume of water applied for each treatment was the product of area of the plot and gross irrigation depth. The determined amount of irrigation water applied to the experimental plot by using a 3-inch throat width Parshall flume with discharge rate and its corresponding head. The time required to irrigate each plot was based on the discharge head relationships. Accordingly, the time required to deliver the desired depth of water into each plot was calculated using the equation by (Kandiah, 1981).

$$t = \frac{l * w * Ig}{60 * q} \tag{3.11}$$

Where: t = application time (min)

l = furrow length (m)

w = plot width (m)

Ig = gross irrigation depth (mm)

q = flow rate (l/s) at specific parshall flume head and 60: is unit conversion factor.

3.8. Response of Sesame to Irrigation

3.8.1. Water productivity

The crop water productivity was determined based on the ratio of grain yield produced (kg/ha) to the seasonal amount of water (m^3/ha) used by sesame. Water productivity in agriculture WP (kg/m^3) also known as water use efficiency, generally expressed as the ratio between the actual crop yields produced and the corresponding total water use (Pereira, et al., 2020) expressed as:

$$WP = \frac{\text{Grain yield}(\frac{kg}{ha})}{ETc(\frac{m3}{ha})} \tag{3.12}$$

Where: WP = water productivity (kg/m^3)

Y = grain yield of sesame (kg/ha)

ETc = Seasonal crop water need (m^3/ha)

3.8.2. Yield response factor

The relationship between crop yield and water supplied can be determined when crop water requirements and crop water deficits, on the one hand and maximum and actual crop yield on the other can be determined. Yield response factor (ky) was determined from the relationship between relative yield decrease and relative evapotranspiration deficit empirically (Doorenbos and Kassam, 1979).

$$\left(1-\frac{\mathrm{Ya}}{\mathrm{Ym}}\right) = \mathrm{Ky}\left(1-\frac{\mathrm{ETa}}{\mathrm{ETm}}\right) \tag{3.13}$$

Where: ky = yield response factor

Ya = actual marketable yield (t/ha)

Ym = maximum marketable yield (t/ha)

ETa = actual evapotranspiration (mm)

ETm = Maximum evapotranspiration (mm)

3.9. Data on Yield and Yield Components

A sample of ten plants was selected randomly from each experimental plot and continued to measure the following agronomic parameters (Ahmed et al., 2010). Data on plant phonological stages such as days to 50% flowering and maturity was recorded. Parameters such as plant height, number of capsule per plant and number of seed per capsule and number of branch per plant were recorded on plant base.

For grain yield and above-ground biomass harvesting was done manually by cutting, bundling and stacking upright. Each bundle had to be pegged to protect wind damage by tightening strings around it and trashed after two weeks. Thousand seed weight (g), grain yield (kg/ha), Harvest index, straw yield (kg/ha) were recorded and finally crop water productivity (kg/m^3)

was calculated from grain yield obtained with seasonal water applied. These parameters were determined in the following ways:

Plant height: Plant height was recorded at maturity of crop using measurement tape from bottom to tip of the randomly selected plants in each plot and was averaged (cm).

Number of branches: Branches in randomly selected ten plants were counted and accordingly average number of branch per plant was worked out for each treatment.

Number of Capsules per plant: The numbers of capsules per pant were counted for randomly selected ten plants and averaged.

Number of Seed per Capsules: At maturity, number of seed per capsule was counted from randomly selected ten plants and averaged.

Aboveground biomass: At maturity, the sesame crop in each plot was harvested; weighted and biological yield was converted to kg/ha.

Grain yield (kg/ha): At maturity, sesame crop in each plot was harvested and threshed and yield per ha was calculated by the following formula:

$$\text{Grain yield (kg/ha)} = \frac{\text{Grain yield}(\frac{\text{kg}}{\text{plot}})}{\text{Plot size(m2)}} \text{ X } 10,000 \qquad (3.14)$$

Harvest index (%): Harvest index is the ratio between seed yield and biological yield. Harvest index (%) was calculated by the following formula.

$$\text{Harvest index (\%)} = \frac{\text{Grain yield } (\frac{\text{kg}}{\text{ha}})}{\text{Biological yield } (\frac{\text{kg}}{\text{ha}})} \text{ X } 100 \qquad (3.15)$$

3.10. Statistical Analysis

The collected data was subjected to ANOVA by using R statistical software (version 4.1.3) for windows based on randomized complete block design. Whenever, the treatment effects were observed significant, treatment means were compared using the least significant difference (LSD at $p = 0.05$) employed (Steel et al., 1997). Descriptive statistics was used to compare those parameters that were not subjected to analysis of variance. Pearson correlation analysis was also used to determine the association of sesame grain yield and yield components. Multiple linear regressions also used to determine the relationship between grain yield and yield components.

4. RESULTS AND DISCUSSION

4.1. Soil Physical and Chemical Properties of Experimental Site

The results on the physical and chemical properties of the studied soil at the experimental site were presented in Table 2. The physical and chemical property of experimental site soil analysis were done for soil samples collected based on the root depth of sesame before field works carried out. Some of the physical and chemical properties of the experimental site soil such as texture class, bulky density, field capacity, permanent wilting point, pH, ECe, organic matter content and organic carbon analysis were done.

4.1.1. Soil physical and chemical properties

The result of soil textural class analysis showed that the relative proportion of sand, silt and clay percentages were 35, 45 and 20 respectively. Therefore, according to USDA soil textural classification, the particle size distribution of experimental soil was classified as loam soil. According to Schroeder et al., (2007) the textural effects of loam soil properties such as internal drainage and plant available water, in relation to irrigation was moderate.

The soil bulky density analysis result of experimental site indicates that the bulky density increases with soil depth. It varied from 1.23 g/cm^3 at upper root zone (0-30) cm to 1.34g/cm^3 at the lower root zone layer (90-120cm) respectively. This could be because of slight decrease of organic matter with depth and compaction due to the weight of overlying soil layer (Brady and Weil, 2002). Similarly, Chaudhari et al., (2013) soil bulky density increases with depth because subsurface layers are more compacted and have a lower OMC than surface layers. The average bulky density of the experimental site soil was 1.3g/cm^3 which was less than the ideal bulky density (1.4g/cm^3) for plant root growth (USDA-NRCS, 1996) and was suitable for crop root growth.

The average soil moisture content at field capacity and permanent wilting point of the experimental soil was 30% and 15% respectively. The experimental soil was within the range of loam soil according to (Rab et al., 2010). The average total available water (TAW) between field capacity and permanent wilting point was found to be 150 mm/m, which was the total water holding capacity of loam soil according to (Davey and Maynard, 2001). The readily available water with allowable soil moisture depletion of 60 %, for sesame according to FOA, (1998), was found to be 90mm/m held in loam soil. The pH value of soils of the study area varied from 7.26 to 7.65 through the soil depth with an average value of 7.48, which is within a suitable range for crop production. The pH of study area soil is suitable for sesame production. Similarly, sesame prefers best in well-drained and medium-textured fertile soil with 5 to 8 soil pH (Geremew et. al., 2012 and Langham et al., 2008).

The result of electrical conductivity for soil saturated paste extract (ECe) was varied from 0.31 to 0.11 (dS/m), with the average value of 0.24 (dS/m), is less than 4(dS/m) at 25˚c, which indicates a non-salinity effect on the experimental soil (Londra et al., 2020). The (ECw) water was 0.35 and 0.4 dS/m, respectively at 25˚c and which is less than 0.8dS/m, is suitable for most crops and pastures on moderately to well-drained soils according to (Davey and Maynard, 2001). The soils of the study area resulted in OC ranges from 1.6% to 1.3% with average value of 1.45% throughout the soil depths, which indicates a medium fertility range (Musinguzi et al., 2016). The average organic matter content of the soil of study area had 2.49% through the soil profile, which indicates the organic matter of the soil is within the range of loam soil (Magdoff and van Es, 2021).

Table 2. Physical and chemical characteristics of the experimental field soil

Soil parameters	Soil depth (cm)				Average
	(0-30)	(30-60)	(60-90)	(90-120)	
Particle size distribution					
Sand (%)	35.8	31.1	33.6	38.3	34.7
Silt (%)	41	46.2	47.5	44.4	44.8
Clay (%)	23.2	22.7	18.9	17.3	20.5
Textural class	Loam	Loam	Loam	Loam	Loam
Bd (g/cm^3)	1.23	1.3	1.32	1.34	1.3
FC (vol %)	32.58	30.45	29.17	27.9	30
PWP (vol %)	17.13	15.24	14.22	13.51	15
TAW (mm/m)	154.5	152.1	149.5	143.9	150
pH	7.26	7.42	7.57	7.65	7.48
Ece (ds/m)	0.31	0.26	0.214	0.18	0.24
OC (%)	1.6	1.5	1.39	1.3	1.45
OM (%)	2.75	2.58	2.39	2.23	2.49

4.1.2. Infiltration characteristics of the experimental site soil

The data collected at the field using double ring infiltrometer was used to generate the cumulative infiltration and infiltration rate curves as shown in Figure 4. The basic infiltration rate for the experimental field was found to be 18.6 mm/hr., which is within the range of loam soil (10 to 20) mm/hr. (FAO, 1990). This means that water layer of 18.6 mm on the soil surface will take one hour to infiltrate. In dry soil, water infiltrates rapidly and as more water replaces the air in the pores, the water from the soil surface infiltrates more slowly and eventually reaches a basic infiltration rate.

Cumulative infiltration is the time integral of infiltration rate and it is an increasing function of time. As can be seen from figure 4, the cumulative infiltration increased sharply at the beginning of the infiltration process after which the rate of increase decreased. This is because at the beginning of the process, though irregular, the initial infiltration rate was relatively resulting in absorption of large quantity of water. The decrease in rate of increase of the cumulative infiltration might be related to the monotonic decrease in infiltration rate with time due to decrease in matric suction gradient and gradual deterioration of the surface soil structure by water. The total amount of water infiltrated with less than four hours of infiltration process was 11.1 cm of water.

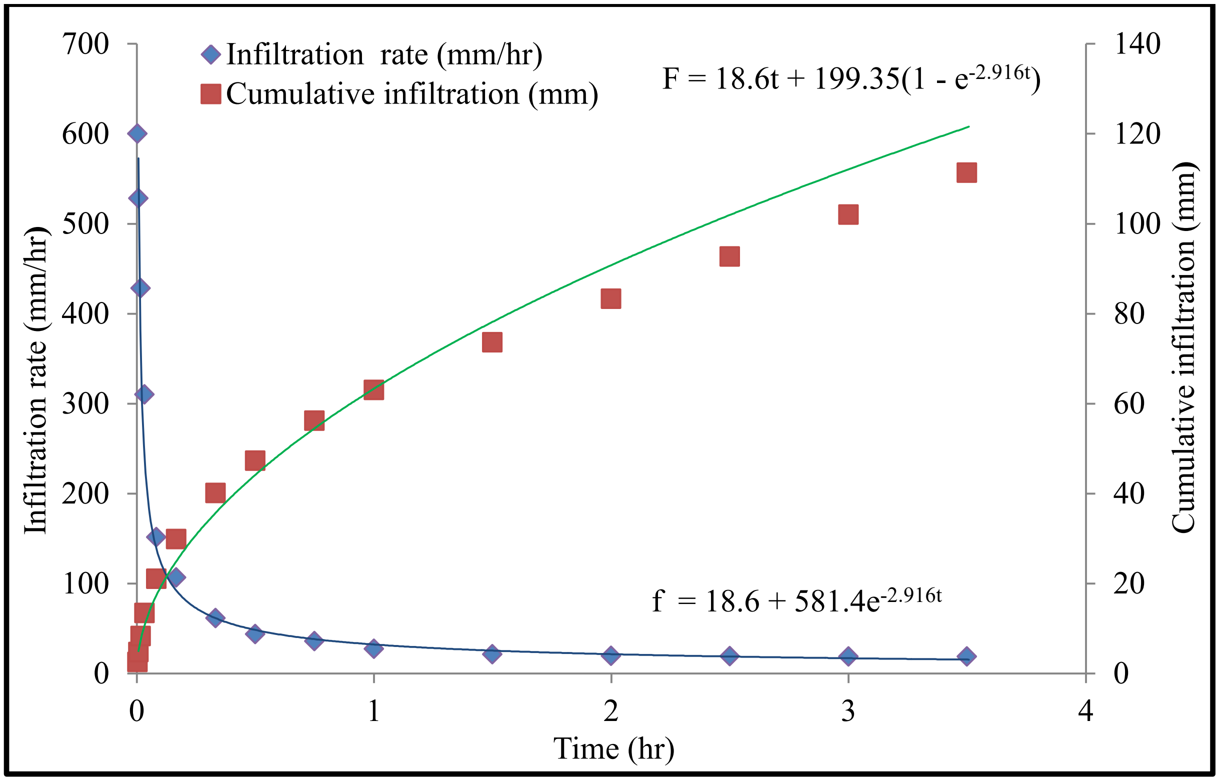

Figure 4. Soil infiltration rate and cumulative infiltration of experimental field

4.2. Crop Water Requirement

The value of the reference evapotranspiration was computed from the meteorological data of the study area by CROPWAT 8.0 model using the FAO56 Penman-Montieth method on daily bases. Since the study area was characterized as semi-arid climatic condition throughout the year, the area had experienced the highest reference evapotranspiration. Accordingly, the maximum reference evapotranspiration was observed at March with average value of 7.06 mm/day whereas, the minimum was observed at November with average value of 5.92 mm/day.

The crop coefficient (kc) value for sesame was constant at initial stage (0.35) and it was started to increase at development stage. At mid-stage it attained its maximum value (1.10) and constant until the start of the crop maturity stage. At maturity stage it was started to decrease and ends with the value of (0.35) according FAO (Savva and Frenken, 2002).

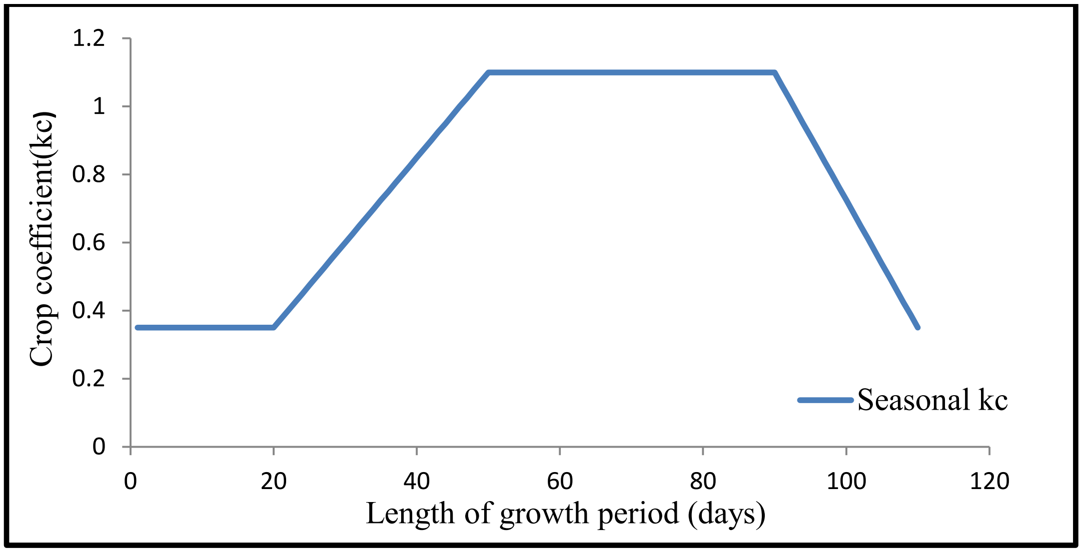

Figure 5. Seasonal crop coefficient curve of sesame crop

The results of daily crop water need (ETc) values showed variation with growth stages. It started small during initial stage and then increased gradually from development up to mid-stage and then declined at maturity stage. The highest value was recorded in the mid-season growth stage followed by development and late-season stage; the lowest value was recorded in initial stages. The highest value of daily crop water need (6.94 mm/day) was obtained during mid-stage, while the lowest value of daily crop water need (2.35 mm/day) was obtained during initial stage. In mid-season stage the crop is physiologically capable of highest water need with having highest crop coefficient value (FAO, 1998). During late season the rate of crop water need was decreased due to the lower leaves of the plants dried and the rate reached its minimum values during harvesting time due to the plant maturity , this was in agreement with (Elshamly et al., 2020).

Table 3. Daily crop water use (mm/day) computed for each treatment base

Treatment levels	Growth stages					Seasonal
	Initial	Development	Mid		Late	
	20 day	30 day	30 day	10 day	20 day	110 days
T1	2.35	4.80	6.94	6.84	4.48	5.08
T2	2.00	4.08	5.90	5.81	3.81	4.32
T3	1.76	3.60	5.21	5.13	3.36	3.81
T4	1.53	3.12	4.51	4.45	2.91	3.30
T5	1.29	2.64	3.82	3.76	2.46	2.80
T6	1.06	2.16	3.12	3.08	2.02	2.29

Where: T- Treatment

The amount of water required by sesame was increasing from the initial stage to mid and then decrease at late stage. The maximum irrigation water (276.6mm) was recorded in mid stage while, the lowest (47mm) was observed at initial stage and (89.7mm) was at late stage respectively. In mid stage sesame attained its maximum irrigation water due to high crop coefficient and high reference evapotranspiration (FAO, 1998). At late stage the water required was reduced due to reduction in crop coefficient values.

The seasonal crop water requirement computed was affected by the water deficit levels through the growth stages of sesame. The result revealed that the average seasonal values of ETc decreased as the percentage of water deficit level increased (more available water extracted). It is clear that increasing the available water deficit level in sesame crop caused a significant decrease in the seasonal water consumption in sesame. The result indicated that the highest seasonal water requirement value was recorded under full irrigation condition, while the lowest one was recorded at 45%ETc. The other treatments seasonal ETc values were between the two treatments levels with their corresponding deficit levels.

The seasonal depth of irrigation water applied to each treatment was based on the corresponding water deficit level during the experimental period. The seasonal irrigation depths applied varied from full (100%ETc) irrigation level 557 mm to 251 mm at (45%ETc) including effective rainfall of 12.3 mm that occurred during the field trial. From the result of seasonal water requirement of sesame, the maximum value was obtained from treatment receiving 100% ETc, while the minimum was observed at treatment receiving 45% ETc through the growth stages.

The current result was in close agreement with Pereira et al., (2017) reported that the seasonal depth irrigation water (567 mm) was obtained from 100%ETc and 305mm irrigation depth obtained from 40%ETC in sesame crop. Similarly, Mekonnen and Sintayehu (2020) reported that the seasonal water required for sesame under no stress condition (100%ETc) was about 548 mm, while the minimum amount was 287 mm (50% ETc) respectively. From the result, seasonal crop water requirement of sesame slightly varied due to seasonal crop water need of the same crop may differ in different climates and regions.

Table 4. Seasonal crop water demand (mm) affected by water deficit levels

Treatments	Seasonal ETc values through growth stages				Seasonal (mm)
	Initial stage	Development stage	Mid stage	Late stage	
T1	47.0	144.2	276.6	89.7	557
T2	39.9	122.5	235.1	76.2	474
T3	35.2	108.1	207.4	67.3	418
T4	30.5	93.7	179.8	58.3	362
T5	25.8	79.3	152.1	49.3	307
T6	21.1	64.9	124.5	40.4	251

Where: ETc – Crop evapotranspiration, T- Treatment

4.3. Effect of Deficit Irrigation on Growth Parameters of sesame

4.3.1. Days to 50% flowering and maturity

The average number of days from planting to 50% flowering and maturity were presented in Table 5. Analysis of variance for the number of days to 50% of flowering revealed that sesame was significantly ($p < 0.01$) affected by deficit irrigation levels. Days to flowering were varied during the study period. Treatment under 45% ETc application throughout the growing season took the shortest number of days to bear flowers, while experimental plots applied with full irrigation application took the longest days of flowering.

Accordingly, Mekonnen and Sintayehu, (2020) pointed that deficit irrigation application throughout the growing season affected the number of days to 50% flowering in sesame. Similarly, Ahmed et al., (2008) pointed out that the number of days to 50% flowering and maturity, for faba bean was noticed that plants try to escape from unfavorable stress conditions by ending their life few days earlier than those under normal or high soil moisture conditions.

The days to maturity varied from 107 to 92 with an average value of 100 days. The analysis of variance for days to maturity showed statically significant ($p < 0.01$) difference among deficit irrigation treatments. The study reveals that the increased deficit irrigation level leads to early maturity, whereas full irrigation treatment matured later. This showed that the higher the water deficit, the earlier was the day to maturity. Similar result has been reported that stressed treatments in wheat lead to early maturity (Li et al., 2011; Kilic and Yagbasanlar, 2010).

4.3.2. Plant height

The mean result of plant height varied from 150.87cm to 105.33cm with the average value of 125.34cm. The analysis of variance revealed that there was a significant ($p < 0.01$) difference on plant height among deficit irrigation levels applied. The maximum plant height 150.87cm was observed under full irrigation water application, while, the lowest plant height 105cm was recorded on experimental plots which received 45%ETC. The mean results of analysis reveals that increased plant height was observed in decreased deficit level, whereas, decreased plant height with increased deficit irrigation level respectively. Accordingly, the less amount of applied water led to smaller plant height. The reduction in pant height was (4.4, 7.4. 19.5, 22 and 26)% for T2,T3, T4, T5 and T6 deficit irrigation treatments respectively compared to full(100%ETc) irrigation.

Some of the research results which support the current finding were, according to (Uçan and Killi, 2010; Gaafar et al., 2019) reported plant height was decreased with increasing water shortage in sesame. Similarly, Suhaibani, (2009) and Simsek et al., (2011) reported that plants under water stress were commonly shorter than those supplied with full amount of irrigation water throughout the whole growth stages. The decrease in height might be either due to inhibition of length of cells or cell division by water deficits.

4.3.3. Number of braches per plant

The mean number of branches per plant slightly increased with decreased deficit irrigation level. The analysis variance revealed that deficit irrigation treatments showed significant ($p < 0.01$) difference on mean number of branches per plant. The irrigation treatments under full (100%ETc) had a greater number of branches per plant (8.9), however, the increased deficit treatment under 45%ETc had the lowest number (6.1) of branch per plant was observed.

The result of study agrees with Sarhadi and Sharif (2014) pointed out on sesame that the number of branches per plant was affected by water deficiency. Also according to Ahmed, (2003) reported that decreased crop water deficit treatments had a greater number of branches per plant.

Table 5. Effects of deficit irrigation levels on phonological stages and growth parameter

Treatments	Days to 50% flowering	Days to maturity	Plant height(cm)	Number of branches per plant
T1	62^{a}	107^{a}	150.87^{a}	8.9^{a}
T2	59^{ab}	105^{ab}	144.2^{a}	8.51^{a}
T3	58^{b}	104^{b}	139.8^{a}	8.27^{ab}
T4	53^{c}	100^{c}	121.4b	7.53^{bc}
T5	51^{cd}	96^{d}	117.73^{b}	7.1^{c}
T6	49^{d}	92^{e}	111.13^{b}	6.1^{d}
Grand mean	55	100	130.86	7.72
CV (%)	3.32	1.18	6.81	6.13
LSD(0.05)	3.33	2.16	16.21	0.86

Where: LSD least significant difference at the 5% level, CV- coefficient of variation, means followed by different superscripts are statistically different.

4.4. Effect of Deficit irrigation on Yield and Yield Components

4.4.1. Number of capsules per plant

Number of capsules per plant at harvest is major determinant factor for seed yield in sesame crop. The analysis of variance revealed that application of crop water deficit level resulted in a statistically significant ($p < 0.01$) effect on the number of capsules per plant throughout the growth stage. The maximum number of capsules (56) per plant was observed under full (100%ETc) irrigation treatment while, the minimum number of capsules (41) per plant was obtained under deficit (45%ETc) irrigation application throughout the whole growth stage. From the study it was observed that with increasing the intensity of water deficit, capsules per plant was decreased significantly. This shows that the number of capsules per plant was significantly influenced by deficit irrigation in sesame.

Some of the research results which support the current finding were, according to Neeshma et al., (2021) pointed out that number of capsules per plant prominently influenced by deficit irrigation in sesame. Similarly, Mehrabi and Ehsanzadeh, (2011) reported in four sesame cultivars under different soil moisture regimes showed that under water stress, capsules per plant lessened by 42%. Similar finding of Nadeem et al., (2015) pointed out in sesame that numbers of capsules per plant have been significantly affected by different levels of soil moisture regimes. Number of capsules per plant was decreased with increasing water shortage (Uçan and Killi, 2010) reported in sesame.

4.4.2. Number of seeds per capsule

The analysis of variance showed that the application of deficit irrigation treatments had significant ($p < 0.01$) effect on mean number seeds per capsule at maturity stage. The maximum number of seeds (71) per capsule was obtained under the full irrigation water application, while the lowest number of seeds (54.3) per capsule was obtained at 45%ETc water application throughout the whole growth season. From the result of study it was observed that the increase in deficit irrigation level decreased the number of seed per capsule at maturity.

The result was in agreement with Mensah, (2006) reported that sesame yield and yield parameters decreased with water deficiency. Similarly, flower abortion due to stress at the midseason growth stage might be an explanation why the number of capsules per plant for sesame is substantially reduced when deficit irrigation is induced at the midseason growth stage (Tinak Ekom et al., 2019). The higher number of seeds per capsule within full irrigation treatments might be due to higher number of capsules and effective translocation of photosynthesis from source to sink (Neeshma et al., 2021).

4.4.3. Thousand Seed weight

The results on mean number of thousand seed weight varied from 4.1 to 3.11 with an average value of 3.7. The highest thousand seed weight (4.1) was observed under full water application while, the least value (3.11) was observed under application of crop water deficit 45% level. Whereas, the mean values for other treatments were in between the two treatments. The analysis of variance revealed that the mean number of thousand seed weight showed significant ($p < 0.01$) differences among deficit irrigation treatments.

The result of analysis showed that an increase in crop water deficit applied resulted in decreased 1000-seed weight (Fig 6). The increase in water deficit from 100 to 45%ETc reduced the thousand seed weight of sesame by 24%. It seems that the reduction in 1000-seed weight under crop water deficit treatment is due to the shortening of the seed filling period and early aging (Esmaeil Gholinezhad, 2019). The result of study indicated that 1000-seed weight of sesame was directly associated with the amount of irrigation water applied and inversely with water deficit level. This agrees El Naim et al., (2010) that highest irrigation (750mm) amount recorded higher 1000-seed weight of sesame. Similarly, Ahmed, (2003) reported that higher water quantities treatment had increased 1000-seed weight.

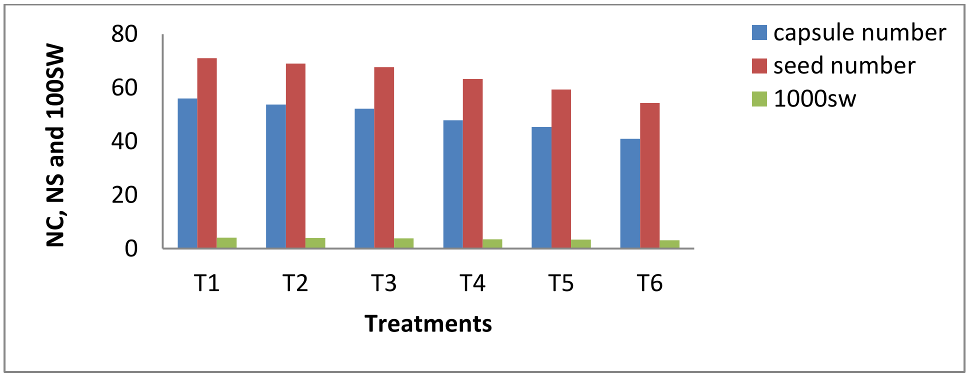

Figure 6. Effect of deficit irrigation on capsule number, seed number and 1000sees weight

Table 6. Effect of deficit irrigation levels on growth and yield components of sesame

Treatments	Number of capsule per plant	Number of seed per capsule	1000-Seed Weight (g)
T1	56 ^{a}	71 ^{a}	4.1 ^{a}
T2	53.7^{ab}	69^{b}	4.0^{ab}
T3	52.17^{b}	67.7^{b}	3.89^{b}
T4	47.9 ^{c}	63.3 ^{c}	3.52^{c}
T5	45.3^{c}	59.33^{d}	3.4^{d}
T6	41 ^{d}	54.3^{e}	3.11^{e}
Grand mean	49.4	64.1	3.7
CV (%)	3	1.6	2.0
LSD(0.05)	2.6	1.8	0.1

Where: LSD-least significant difference of means at 5% level, CV- coefficient of variation

4.4.4. Aboveground biomass

The crop biomass is major determinant factor for seed yield produced in sesame crop. Any reduction or increment in biomass may also effect on yield. The mean result of aboveground biomass of sesame under deficit irrigation treatments were varied from 9196.7 to 12025.8 kg/ha with an average value of 11098 kg/ha. The analysis of variance revealed that the aboveground biomass produced was significantly ($p < 0.01$) influenced among the variation in deficit irrigation water application. However, among irrigation treatments (T2 and T3) no significant difference was observed. The maximum aboveground biomass was observed in T1 (100%ETc) and it was superior to other treatments. However, the lower aboveground biomass was obtained from 45%ETc, which was significantly lower than those of all the other treatments.

The aboveground biomass produced during the experimental season was proportional to the depth of irrigation water applied. From the study, it was observed that for low crop water deficit applied associated with larger amount of biomass produced and increased crop water deficit applied resulted in less amount of biomass produced. This was similar with Tripathy and Bastia, (2012) reported that for higher irrigation water applied the maximum biological yield and for lower irrigation water applied the minimum biological yield was observed on sesame crop. Similarly, Sadeghipour, (2008) pointed out that increased total biomass of mung bean was responsive to both throughout the growth stages and at the specific growth stages for the amount of irrigation water applied. Similar finding of Phiri and Zimba, (2018) reported on biomass of sunflower was decreased with a decrease in applied irrigation water.

As the level of crop water deficit increase, the amount of water applied is not sufficient for the production of higher biomass. The decreased aboveground biomass in water stressed treatments might be due to reduction in photosynthesis in which amount of water and chlorophyll is important for photosynthesis. Water stress affects photosynthesis capacity through reduction of chlorophyll content and damage of the reaction center of photosystem according to (Guo *et al*., 2013). This could results lower biomass as 90% of crop biomass is derived from photosynthetic products (Amane, 2011).

4.5.3. Grain yield

The mean results for grain yield of sesame at different levels of deficit irrigation treatments were varied from 1377.74 to 2164.56 kg/ha with grand mean value of 1854.25kg/ha. The analysis of variance revealed that the grain yield produced was significantly ($p < 0.01$) affected with the variation in deficit irrigation water application. However, irrigation treatments T2 did not show significant difference for grain yield in comparison to control treatment whereas, significant difference was observed between other irrigation treatments.

The grain yield produced during the experimental season was proportional to the crop water requirement, this implies that when the crop water deficit intensity increased the grain yield was decreased and vise-versa. Accordingly, the greatest grain yield (2164.56 kg/ha) was observed under full irrigation water application, while, the lowest grain yield (1377.74 kg/ha) was obtained from crop water deficit treatment at 45%ETc, whereas, the mean grain yield values of other irrigation treatments were in between the two treatments.

The result of present study was in agreement with Kassab et al., (2012) pointed out that seed yield for three sesame varieties was decreased by reducing irrigation water quantities from 100% to 50%ETc. Similarly, Ucak and Bagdatli, (2017) reported that the greatest seed yield of sunflower was obtained from full irrigation treatment while, the lowest value was seen under irrigation treatment (I_{50}). Similar finding of Kazemeini et al. (2009) reported that the greatest seed yield in full irrigation treatment and the lowest values in severe water deficits. The reduction of grain yield under water deficit can be due to the closure of stomata, increasing enzymes of protein degradation and chlorophyll which reduces the rate and amount of photosynthesis, the amount of photosynthesis materials and finally the seed yield (Gholinezhad et al., 2009 and 2010).

The result of analysis showed that full irrigation treatment yielded significantly higher grain yield than other treatments, this was in accordance to Manjeru et al., (2007) reported that normal irrigation treatments yielded significantly higher than all other treatments. Similarly, Ahmed et al., (2010) pointed out on sesame that significantly higher grain yield was recorded with highest water quantities treatments. From the study it was observed that decreased crop water deficit treatments had a better performance of yield and yield components. Significant increment in sesame grain yield with decreased crop water deficit level may be the cumulative effect of significant improvement in the value of yield and yield components.

The mean result of grain yield showed that crop water deficit significantly reduced grain yield of sesame with comparison to full irrigation. Irrigating sesame crop with a volume of water 15, 25, 35, 45 and 55% lower than full irrigation (zero deficit irrigation) resulted in reduction of about 3.63, 7.13, 14.26, 24.64 and 36.35% in grain yield was observed. From the result of yield reduction in comparison to full irrigation, deficit irrigation at 85%ETc (474mm) resulted in insignificantly minimum yield reduction and 75%ETc (418mm) resulted in significantly optimum yield reduction respectively. However, deficit application at 65, 55 and 45% crop water requirement resulted in significantly higher yield reduction were observed. From the result of grain yield in relation to deficit water applied, indicated that applying smaller irrigation depth caused decrease in the grain yield of sesame.

This agrees with Kassab et al., (2012) pointed out on sesame that seed yield decreased by reducing irrigation water quantity from 100% to 50% ETc in the growing season. Similarly, Ucak and Bagdatli, (2017) pointed out on sunflower that yield decreased by 2 and 26.4% with irrigation at 75 and 50%, compared to full irrigation. Similar finding of Ucan et al., (2007) reported that in smaller applied depths, sesame was very sensitive to water stress condition, causing the decrease in yield. This was also similar with Sarhadi and Sharif, (2014) reported on yield of sesame was affected by water deficiency and the yield decreases considerably, when crop subjected to drought stress during flowering and grain filling stage.

The relationship between grain yield produced and water deficit level applied indicated that there was a polynomial relationship. The value of coefficient of determination ($R^2 = 0.99$) revealed that 99% of the variation in the dependent variable has been explained by the independent variable. The result revealed that the rate of water deficit effect on grain yield was higher on increased deficit treatments and slight for lower deficit treatments. This may be for the reason that applying the increasing the amounts of irrigation depth in highly stressed treatments increase grain yield significantly more than that of lower stressed treatments.

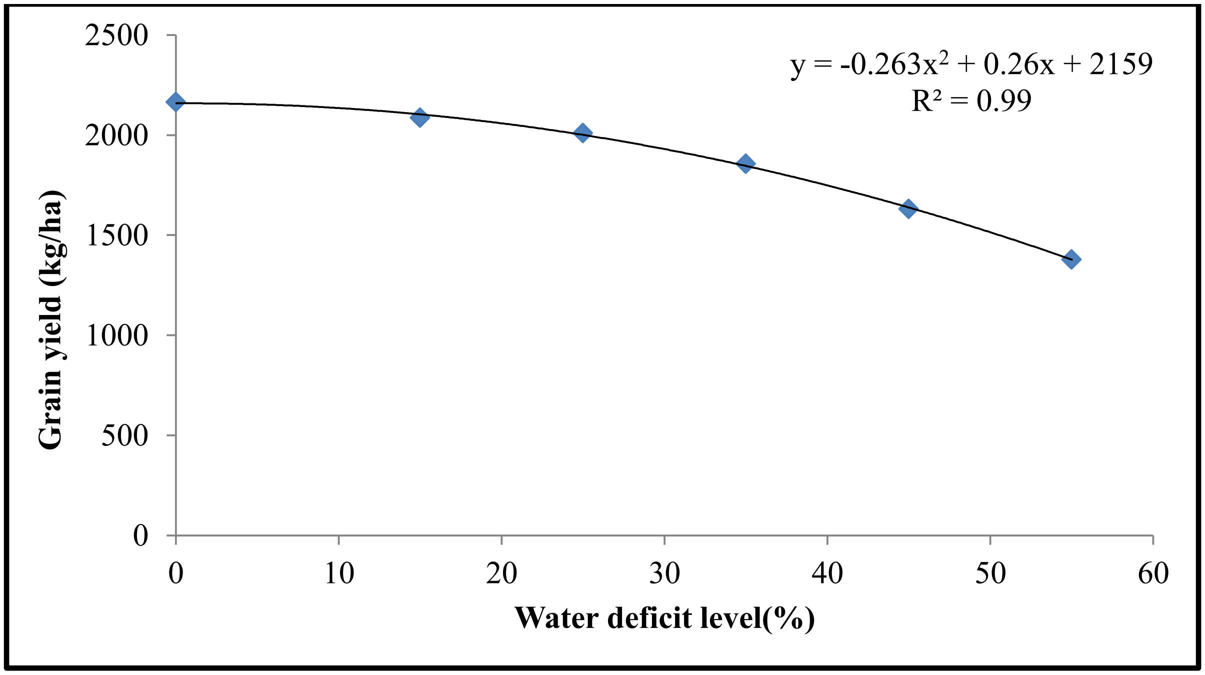

Figure 7. Crop yield response to water stress levels applied

4.5.4. Harvest Index

The mean value of HI was varied from 15 to 18% with the average value of 16.7%. The analysis of variance revealed that the irrigation treatment showed significant ($p < 0.01$) effect on harvest index of sesame. The result of analysis showed that the highest harvest index was observed at full crop water requirement level; however, the lowest HI was observed at irrigation treatment receiving 45%ETc level. The mean value of HI for the rest treatments were lies between the two treatments values.

From the result of HI, increasing water stress from 100 to 45%ETc decreased HI significantly. The reduction of aboveground biomass yield produced in comparison to grain yield, caused a decrease in harvest index in deficit irrigation treatments. Similar research by (Gholinezhad and Darvishzadeh, 2019) on sesame reported as, the low reduction of biomass yield compared to seed yield caused a decrease in HI in moisture stress conditions. Similarly, (Langeroodi et al., 2014) reported that severe water shortage treatments on sunflower decreased grain yield more than biological yield resulting in a decrease in HI.

4.5.4. Straw yield

The analysis of variance showed significant ($p < 0.01$) differences in straw yield among the deficit irrigation treatments. The highest straw yield was observed at non water stress (100% ETC) level, which was not significantly different from T2. However, the minimum straw yield was observed at 45% ETC application and it was significantly different from all irrigation treatments applied. The result of study indicates that when crop water deficit level increases, the straw yield was reduced and vise-versa.

The study reveals that there was a direct relationship with the amount of water applied with straw yield produced. The higher amount of irrigation water applied resulted with larger straw yield production, while, less amount of irrigation water application also results in lower straw yield. This was in agreement with Meskelu et al., (2017) reported on wheat. This may be due to the increase in physiological growth contributes to the total above ground biomass production for full irrigation treatment, which has a direct relation with evapotranspiration and photosynthesis.

Table 7. Effect of deficit irrigation on yield and yield component of sesame

Treatments	AGBM (kg/ha)	Grain yield(kg/ha)	HI (%)	STY(kg/ha)
T1	12025.8 ^{a}	2164.56^{a}	18^{a}	9861.2^{a}
T2	11848.2^{ab}	2086.04^{ab}	17.6^{a}	9762.15^{a}
T3	11729.8^{ab}	2010.19^{b}	17.34^{ab}	9696.1^{ab}
T4	11342.9^{b}	1855.85^{c}	16.76 ^{b}	9444.6^{ab}
T5	10444.8^{c}	1631.12^{d}	15.62^{c}	8813.6^{b}
T6	9196.7^{d}	1377.74 ^{e}	15^{cd}	7818.9^{c}
Grand mean	11098.0	1854.25	16.7	9232.8
CV (%)	3.4	5.00	2.7	3.4
LSD(0.05)	682.0	154.13	0.8	567.6

Where: AGBM-aboveground biomass, STY-Straw yield, HI- Harvest Index

4.6. Water Productivity

Crop water productivity values for grain yield response to seasonal applied water were presented in Table 8, for different deficit irrigation treatments. Water productivity values were varied with crop water deficit levels applied with corresponding depths. From the result of study, the highest water productivity (0.55kg/m^3) was observed from application of crop water deficit level at (45%ETc), while the lowest water productivity (0.39 kg/m^3) was observed from full water application. The water productivities for other irrigation treatments were in between these two irrigation treatment values.

The result of study indicated that the highest water productivity of sesame was observed in the lowest amount of water applied treatment through the season. Accordingly, the deficit irrigation level at 45%ETc achieved the highest value of water productivity throughout the season. This agrees with, Abdelaouf and Anter, (2020) pointed out that the highest values of water productivity of sesame were achieved with irrigation at 50% of full irrigation during study seasons. Similarly, Fereres and Soriano, (2007) reported that the WP of irrigation water under DI must be higher than that under full irrigation.

It was observed that the decreased crop water deficit applied resulted in lower water productivity, while, increased crop water deficit applied resulted in higher water productivity. This was in accordance with Meskelu et al., (2017) reported on wheat that the lower water productivity at 100%ETc might be attributed to higher irrigation water depth applied. Similarly, Zwart and Bastiaanssen, (2004) CWP can be increased significantly if irrigation is reduced and crop water deficit is intently induced.

The relation between crop water productivity and water deficit level revealed that there was a strong and positive linear relationship with correlation coefficient value of (r = 0.99). The result indicated that maximum water productivity was observed under increased water deficit level, while the minimum was observed obtained at decreased deficit level. Similarly, Zwart and Bastiaanssen, (2004) reported that water productivity increases under deficit irrigation relative to its value under full irrigation.

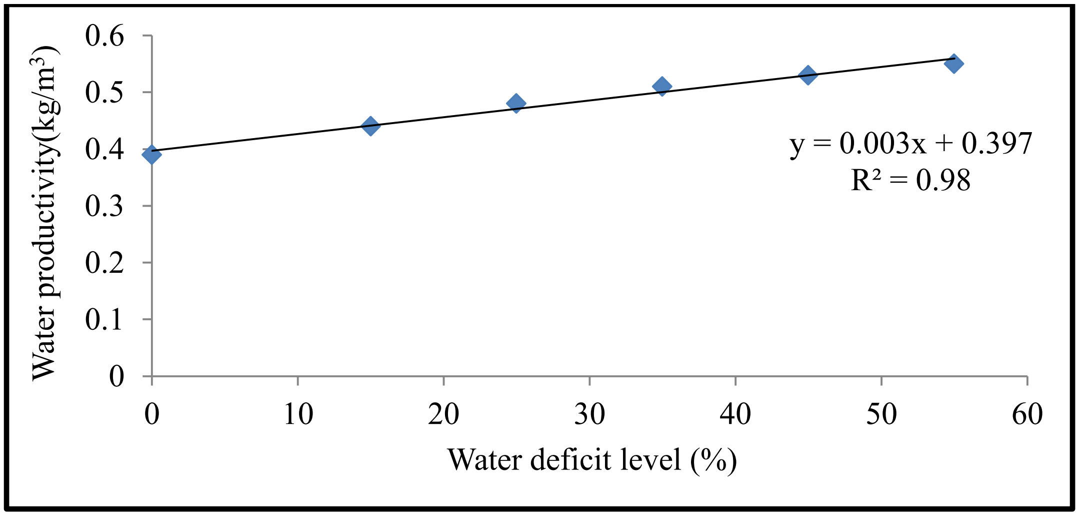

Figure 8. A plot of water productivity versus water stress level applied

The deficit irrigation treatments 15, 25, 35 and 45% lower than full irrigation resulted in WP of 0.44, 0.48, 0.51 and 0.53kg/m^3 respectively. From the result, application of deficit irrigation at 15 and 25% lower than full irrigation saved 14.9 and 24.96% of irrigation water with having relative yield reduction of 3.63 and 7.13% respectively. This indicates that using saved amount of water to irrigate additional area could compensate for any yield loss due to deficit irrigation.

For instance, in T2 saved water could compensate the decrease in grain yield by producing 322 kg more grain yield on additional 0.14ha of land. In addition T3 and T4 could compensate for the yield reduction occurred and resulted in additional yield of (540 and 757) kg on additional area of 0.24 and 0.34ha of land respectively. From the deficit irrigation point of view, the more flexibility under obtaining of optimum grain yield relies on having relatively optimum water productivity, minimum yield reduction and comparable water saving were under consideration. Acceptable level of water saving and WP that can be achieved without significant reduction in yield was under consideration. Consequently, the use of deficit irrigation at 25% of full irrigation resulted in optimum water productivity observed without significant reduction on yield in comparison to other deficit treatments.

The grain yield responded to deficit irrigation water application was in a curvilinear manner; however the response was relatively consistent among the water deficit levels. The quadratic regression showed that the reduction in grain yield T1 to T 3 was relatively very small compared to other water deficit level. However, the decline in grain yield was more prominent beyond the water stress level of T3. The water applied at T3 levels indicates that, the point beyond which the productivity of irrigation water starts to decrease.

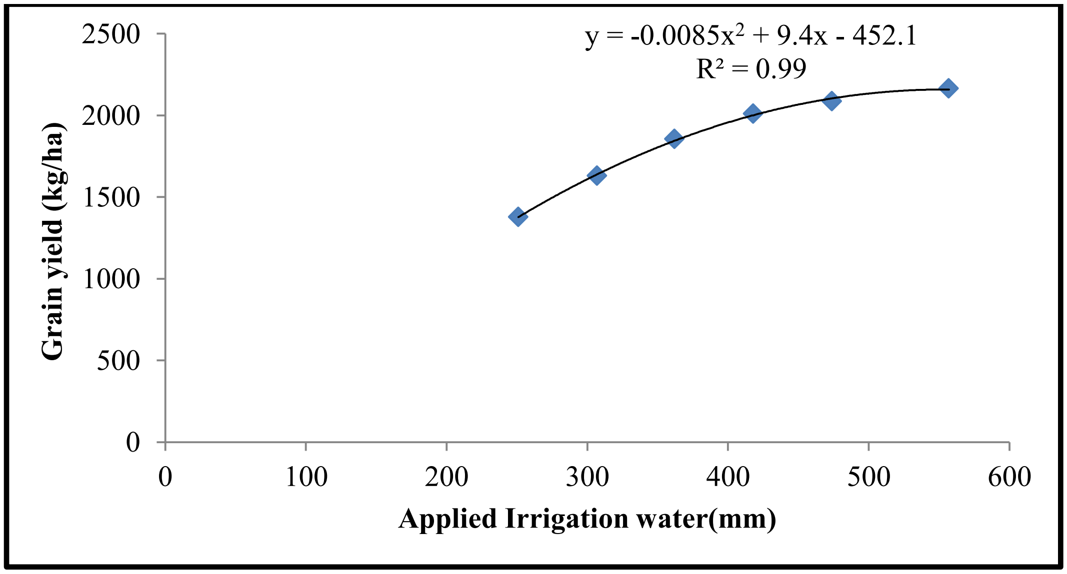

Figure 9. The relationship between grain yield and seasonal irrigation water for sesame

Table 8. Water productivity for different deficit irrigation treatments of sesame

Treatments	Applied water(m^3/ha)	Grain yield(kg/ha)	WP (kg/m^3)	Relative water saved (%)	Relative yield reduction (%)
T1	5570	2164.56	0.39	0.00	0.00
T2	4740	2086.04	0.44	14.90	3.63
T3	4180	2010.19	0.48	24.96	7.13
T4	3620	1855.85	0.51	35.01	14.26
T5	3070	1631.12	0.53	44.88	24.64
T6	2510	1377.74	0.55	54.94	36.35

Where: WP- stands for water productivity, T- for treatments

4.7. Yield Response Factor

Sesame crop yield response factor (Ky) was determined for the different deficit irrigation treatments. From the results of yield response factor data for sesame was ranged from T2 (0.27) to T6 (0.66) treatments respectively. A lower yield response factor was related with decreased deficit treatments whereas, the highest relates with the increased crop water deficit treatments. Among all deficit irrigation treatments, the highest Ky value (0.66) was observed at 45%ETc, when the deficit was induced throughout the growth stage. This represents the sensitivity of the crop to water deficit with proportionally higher yield reduction when deficit was practiced throughout the season.

The result of yield response factor indicated that the calculated Ky value was less than unity (1.00). According to FAO, (2002) reports for crops with a lower yield response factor (Ky < 1) is tolerant to water stress and can generate significant savings in irrigation water through deficit irrigation. Similar finding according to Allen et al., (2006) pointed out that sesame is tolerant to water stress. This was due to, Bezerra et al., (2010) pointed out that the plant has a quite high stomata resistance, mechanism used to reduce evapotranspiration and save water for more critical periods in the growth stage.

Table 9. Yield response factor for different deficit irrigation treatments of sesame crop

Treatments	Applied water(m^3/ha)	Grain yield(kg/ha)	$1-(\frac{ETa}{ETm})$	$1-(\frac{Ya}{Ym})$	Ky
T1	5570	2164.56	0.00	0.00	-
T2	4740	2086.04	0.15	0.04	0.27
T3	4180	2010.19	0.25	0.07	0.28
T4	3620	1855.85	0.35	0.14	0.40
T5	3070	1631.12	0.45	0.25	0.56
T6	2510	1377.74	0.55	0.36	0.66

Where: ETa - actual evapotranspiration, ETm - maximum evapotranspiration, Ya – actual grain yield, Ym – maximum grain yield, Ky – yield response factor.

4.8. Correlation between Yield and Yield Components

The analysis for the association of yield and its contributing characters were done according to Pearson correlations coefficient (r) method. The result of correlation coefficient analysis showed that yield and yield components of sesame were significantly affected and had positively strong associations to each other with corresponding magnitude through the crop water deficit levels applied. This indicates an increase in one variable is associated with an increase in the other variable and a decrease in one variable is associated with the decrease in other variable.

From the results of correlation analysis, most of the yield components such as aboveground biomass (r = 0.953**), straw yield (r = 0.916**), harvest index (r = 0.941**), 1000-seed weight (r = 0.931**), plant height (r = 0.848**), number of capsules per plant (r = 0.976**) and number of seed per capsule (r = 0.817**) had positively strong and highly significant ($p < 0.01$) association with grain yield. This indicates that application of crop water deficit irrigation treatments on sesame positively affects its yield and yield components.

This agrees with Jooyban and Moosavi, (2012) pointed out on sesame that seed yield significantly and positively correlated to seed yield per capsule, biomass yield and straw yield. According to Sasipriya et al., (2022) the correlation results on sesame revealed that number of capsules per plant, 1000 seed weight, number of branches per plant and number of seeds per capsule were the important characters and may be selected to improve the seed yield. Similarly, Haruna et al., (2012) reported that a significant and positive correlations between yield traits and final seed yield in sesame crop.

The aboveground biomass had positive and highly significant correlation with straw yield (r = 0.994**), 1000-seed weight (r = 0.91**), number of capsule per plant (r = 0.919**) and number seed per capsule (r = 0.875**). The positive and significant correlation observed among the yield parameters indicating that the final yield is directly dependent on the values of these parameters. This agrees with Sokoto et al., (2012) reported that the positive and significant correlation coefficient between growth and yield competent explains the true relationship among the parameters.

Table 10. The correlation coefficient matrix result of yield and yield components of sesame

	GY	BM	SY	HI	TSW	PH	NB	NCPP	NSPC
GY	1	0.953**	0.916**	0.941**	0.931**	0.848**	0.615**	0.976**	0.817**
BM		1	0.994**	0.805**	0.91**	0.791*	0.656**	0.919*	0.875**
SY			1	0.738**	0.886**	0.759*	0.658**	0.882*	0.879**
HI				1	0.832**	0.778**	0.503*	0.91**	0.646**
TSW					1	0.865**	0.77**	0.955**	0.888**
PH						1	0.72**	0.876**	0.824**
NB							1	0.616**	0.868**
NCPP								1	0.807**
NSPC									1

* = significant at ($P < 0.05$), ** = highly significant at ($P < 0.01$), GY = Grain yield, BM = biomass, HI = Harvest index, SY = Straw yield, TSW = thousand seed weight, PH = Plant height, NB = Number of branch, NCPP: Number of capsules per plant and NSPC = Number of seed per capsule.

4.9. Multiple Linear Regression analysis of relation between Yield and Yield components

The MLR model is known as robust modeling approaches, especially when there are linear relationships between the input and output variables (Parimala and Mathu, 2006). MLR used as a predictive analysis attempts to model the relationship between two or more independent variables and a response variable by fitting a linear equation to observed data. To determine the strength of the linear regression in predicting yields with a MLR using fit model in JMP software carried out for the input of independent and dependent variable data used for the model and the following equation was developed to predict yield.

$$GY = 1.7BM - 1.86SY - 121.9HI + 1.5PH - 9.15NB + 11NT - 1056.9 \tag{4.1}$$

and with $R^2 = 0.99$

Where: GY = grain yield (kg/ha) PH = plant height (cm)
BM = biomass (kg/ha) NB = number of branch
SY = straw yield (kg/ha) NT = number of tiller (plant/m^2)
HI = harvest index (%)

According to (Eq. 4.1), the predicted value of GY was a linear transformation of BM, SY, HI, PH, NB and NT variables. The Pearson's correlation coefficient for GY versus (BM = 0.953, SY = 0.916, HI = 0.94, PH = 0.848, NB = 0.62 and NT = 0.93). Therefore, strong linear relationship between GY and other independent variables in the model can predict GY with high accuracy. This model helps to understand how GY changes with BM, SY, HI, PH, NB and NT and what values of these variables are required to achieve the optimal value of GY (Abdipour et al., 2018). The coefficient determination 99% revealed that the variation in the dependent variable have been explained by the independent variable.

Table 11. Stepwise regression analysis for sesame grain yield as dependent variable

predicted variables	Coefficient	Std Error	t Ratio	Prob>ltl
Intercept	-1056.88	704.142	-1.5	0.1615
BM	1.7	0.237	7.16	0.0001*
SY	-1.86	0.282	-6.61	0.0001*
HI	-121.94	32.65	-3.73	0.0033*
PH	1.5	0.391	3.85	0.0027*
NB	-9.15	3.915	-2.34	0.0393*
NT	11.01	2.474	4.45	0.0010*

Where:

Std Error: - represents the average distance that the observed values fall from the regression line

T-ratio: - measures how many standard errors the coefficient is away from zero

P-value: - measures the probability of obtaining the observed results, assuming that the null hypothesis is true

R^2:- tells us how much of the variation in the dependent variable yield is explained by the equation according to independent variables.

5. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1. Summary

Drought incidence and scarce water resource are the most significant limiting factors affecting the intensity of agricultural production in the arid and semi-arid regions of the lowlands of South Omo Zone. Efficient use of scare water with appropriate irrigation management strategy is an important consideration in the drought prone areas. The strategies such as deficit irrigation have to be applied in order to alleviate the problem and improving agricultural water productivity. With deficit irrigation, a significant water saving can be achieved and larger areas are served with the available water. The study was practiced by withholding the crop water requirement below the full level throughout the growing season and it was used to identify at which water deficit would have a limited effect on crop yield was observed.

The research was conducted to determine the effect of deficit irrigation levels on yield and yield component of sesame (Sesamum indicum L.) and to identify crop water deficit level where yield is not severely affected. The field experiment was conducted at Benastemay Woreda, South Omo Zone Southern Ethiopia consists of six irrigation treatments with different level of irrigation water application (100, 85, 75, 65, 55 and 45) %ETc throughout the growth stage. The treatments were replicated three times and assigned in randomized complete block design.

The result of study significantly explained the effects of the crop water deficit levels applied on yield and yield components of sesame produced in the study area. The effects of water deficit on crop yield and yield comments such as days to 50% flowering, days to maturity, plant height, number of seeds per capsule, number of capsules per plant, 1000-seed weight, grain yield, aboveground biomass, harvest index and straw yield were significantly influenced by water deficit level. Higher number of capsule per plant, number of seeds per capsule, plant height and thousand seed weight were observed in the treatments which received the full irrigation, however, all the components were decrease with the increased water deficit. From the study it was observed that increasing water deficit level, decreased yield and yield components of sesame.

From the result of study it was indicated that when crop water deficit increases, increased water productivity observed and vice versa. From the result of water productivity, the lowest (0.39 kg/m^3) was observed under full irrigation water application, while, the highest (0.55 kg/m^3) was at 45%ETc water deficit level throughout the season. Applying water deficit at 15, 25, 35 and 45 % lower than full irrigation resulted in WP of 0.44, 0.48, 0.51 and 0.53kg/m^3 respectively.

It was also observed that, application deficit irrigation at 15 and 25% lower than full irrigation saved 14.9 and 24.96% of irrigation water with having relative yield reduction value of 3.63 and 7.13% respectively. Acceptable level of water saving in combination with increased WP that can be achieved without significant reduction in yield was under consideration. Consequently, the use of deficit irrigation at 25% of full irrigation resulted in optimum water productivity observed without significant reduction on yield in comparison to control treatments.

5.2. Conclusions

The following conclusions were drawn based on the results of study:

- From the results of climatic data, growth stages and kc values of sesame, the net seasonal water requirement of 557 and 251 mm was observed under 100 and 45%ETc respectively.
- The maximum yield and yield components of sesame was observed under T1 (100%ETc), while, the minimum was under (45%ETc) water deficit level. Also it was observed that application of 85%ETc was not significantly different from the control treatment however, there was significant difference observed under 75% crop water deficit application.
- Application of deficit irrigation under 75%ETc of full crop water requirement insignificantly reduces yield and enhance the water productivity in comparison to control treatment. It could be concluded that more positive results could be obtained from imposing water deficit level under 75% through the growth stages.
- Application of deficit irrigation at 25% lower than full irrigation saved 24.96% of irrigation water with having relative yield reduction of 7.13%. This indicates that using

saved amount of water to irrigate additional area could compensate for yield loss due to deficit irrigation.

- Water productivity increased with increased water deficit application. The highest water productivity was observed under most stressed treatment, while, the lowest was under full irrigation. High WP does not make any sense alone, however, increased water productivity value in combination to grain yield produced, resulted in significant yield increment, was observed under 75% water deficit level.
- From the result of study it was observed that the obtained yield response factor (Ky) was less than unity (Ky < 1), this indicates that sesame is tolerant to water stress and can generate significant savings in irrigation water through deficit irrigation.

5.2. Recommendations

Based on the overall results of the research, the following recommendations were made:

- Based on the results of study, sesame could be produced by applying full crop water requirements throughout the growth season in condition where irrigation water is not a limiting factor.
- Since the study area characterized as semi-arid climate with limited water resource, therefore, irrigating sesame at 75%ETc could be recommended for its water saving and optimizing water productivity without significant effect on grain yield in the study area.
- This study was one year, single location experiment; therefore, similar studies should be conducted for one more season and for further possible growth stage combinations under deficit irrigation to recommend this finding and to refine crop water productivity of sesame in the study area.

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7. APPENDICES

Appendix Table 1. Soil infiltration test data using double ring infiltrometer

Time		Block – I				Block - II				Block - III				Average	
Elapse time (min)	Cum time (min)	Infiltr Ation (mm)	Infiltr Ation Rate (mm/min)	Infiltr Ation Rate (mm/hr)	Cum Infiltr Ation (mm)	Infiltr Ation (mm)	Infiltr Ation Rate (mm/min)	Infiltr Ation Rate (mm/hr)	Cum infiltr ation (mm)	Infiltr ation (mm)	Infiltr ation Rate (mm/min)	Infiltr ation Rate (mm/hr)	Cum. infiltr ation (mm)	Infiltr Ation rate (mm/hr)	Cum. Infiltr Ation (mm)
0.0	0.0	0.0			0.0	0.0			0.0	0.0			0.0		0.0
0.3	0.3	2.6	10.4	624.0	2.6	2.5	10.0	600.0	2.5	2.4	9.6	576.0	2.4	600.0	2.5
0.3	0.5	2.3	9.2	552.0	4.9	2.2	8.8	528.0	4.7	2.1	8.4	504.0	4.5	528.0	4.7
0.5	1.0	3.7	7.4	444.0	8.6	3.6	7.2	432.0	8.3	3.4	6.8	408.0	7.9	428.0	8.3
1.0	2.0	4.8	4.8	288.0	13.4	5.1	5.1	306.0	13.4	5.6	5.6	336.0	13.5	310.0	13.4
3.0	5.0	7.3	2.4	146.0	20.7	7.6	2.5	152.0	21.0	7.8	2.6	156.0	21.3	151.3	21.0
5.0	10.0	8.5	1.7	102.0	29.2	8.4	1.7	100.8	29.4	9.7	1.9	116.4	31.0	106.4	29.9
10.0	20.0	10.2	1.0	61.2	39.4	10.1	1.0	60.6	39.5	10.3	1.0	61.8	41.3	61.2	40.1
10.0	30.0	7.2	0.7	43.2	46.6	7.1	0.7	42.6	46.6	7.4	0.7	44.4	48.7	43.4	47.3
15.0	45.0	8.9	0.6	35.6	55.5	9.1	0.6	36.4	55.7	8.7	0.6	34.8	57.4	35.6	56.2
15.0	60.0	6.8	0.5	27.2	62.3	6.7	0.5	26.8	62.4	6.9	0.5	27.6	64.3	27.2	63.0
30.0	90.0	10.6	0.4	21.2	72.9	10.7	0.4	21.5	73.1	10.5	0.4	21.0	74.8	21.2	73.6
30.0	120.0	9.7	0.3	19.4	82.6	9.6	0.3	19.1	82.7	9.7	0.3	19.4	84.5	19.3	83.3
30.0	150.0	9.5	0.3	18.9	92.1	9.4	0.3	18.8	92.1	9.5	0.3	19.0	94.0	18.9	92.7
30.0	180.0	9.3	0.3	18.6	101.4	9.2	0.3	18.4	101.3	9.4	0.3	18.8	103.4	18.6	102.0
30.0	210.0	9.3	0.3	18.6	110.7	9.3	0.3	18.6	110.6	9.3	0.3	18.6	112.7	18.6	111.3

Appendix Table 2. Long term monthly average minimum temperature

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1998	23.0	23.4	23.0	21.2	20.5	21.0	21.1	20.8	21.1	20.4	20.4	20.6
1999	22.6	23.6	23.0	21.6	20.7	20.0	20.3	20.5	20.8	21.3	19.5	20.1
2000	23.7	23.8	24.3	21.3	20.4	20.7	20.8	21.2	21.6	20.6	19.9	20.2
2001	22.1	22.7	23.5	23.2	21.5	21.7	21.9	21.6	21.5	21.2	20.5	20.3
2002	22.6	24.0	23.3	23.0	22.2	22.4	21.7	21.6	21.6	21.5	20.8	20.1
2003	23.4	23.5	24.4	23.3	22.1	22.3	22.8	21.3	22.5	21.7	20.8	19.7
2004	22.6	22.6	23.3	21.7	21.1	20.8	21.2	21.8	21.6	20.2	19.9	20.6
2005	22.9	23.5	22.8	21.8	19.7	19.9	20.9	20.8	20.6	20.5	20.6	20.2
2006	21.9	23.3	23.3	21.5	20.5	20.6	20.7	20.3	21.0	20.6	20.6	19.5
2007	22.8	23.4	23.8	21.3	20.8	21.0	21.0	21.8	21.5	21.4	21.0	20.8
2008	22.4	24.4	22.9	22.1	20.2	20.7	20.4	20.9	20.8	20.0	19.8	20.9
2009	23.3	23.6	22.8	21.2	20.9	21.3	21.8	20.5	21.1	21.1	20.1	19.7
2010	21.8	22.6	23.3	22.1	21.2	20.8	20.7	20.7	20.8	20.2	19.9	20.4
2011	23.2	23.4	22.7	21.2	20.4	20.9	21.0	21.2	21.0	19.8	20.1	21.0
2012	23.0	23.7	24.3	22.3	20.9	21.3	21.4	21.6	21.6	21.1	20.9	21.0
2013	23.0	23.2	22.4	21.4	20.7	21.3	21.1	20.7	21.5	21.1	20.9	21.0
2014	23.6	23.4	23.6	21.8	20.8	20.8	21.0	20.8	21.2	20.4	20.1	20.3
2015	22.0	22.5	23.3	20.8	20.1	20.8	20.2	20.6	20.9	20.1	19.8	20.1
2016	22.7	23.9	23.1	21.1	20.9	21.4	21.6	20.7	21.4	20.8	20.7	20.4
2017	23.4	23.5	23.5	22.4	21.4	21.4	22.2	21.4	21.3	20.8	20.4	20.2
2018	22.9	23.4	23.0	21.3	20.5	21.0	21.1	20.8	21.1	20.4	20.4	20.6
2019	22.2	22.8	24.5	23.6	22.2	21.8	22.1	21.6	21.4	20.8	20.3	20.1
2020	23.0	23.4	23.0	21.1	20.5	21.0	21.1	20.8	21.1	20.4	20.5	20.6
Average	22.8	23.4	23.4	21.8	20.9	21.1	21.2	21.0	21.3	20.7	20.3	20.4

Source: Woito climatic data from National Meteorological Agency, Hawassa Branch

Appendix Table 3. Long term monthly average maximum temperature

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1998	36.1	37.2	36.3	32.6	31.2	32.1	32.5	32	32.3	31.7	31.4	33
1999	36.7	37.8	35.6	32.6	32	30.5	31.7	33.3	31.6	31.7	33.8	35.4
2000	38.2	39	38.1	31.8	32	32.7	33.1	34.5	35.9	31.4	30.4	31.3
2001	34.1	36	37.3	34.8	33.4	32.8	33.2	33.3	34.9	33.5	34.9	36.3
2002	38.3	39.4	36.6	34.2	34	34.7	33.7	34.4	35	33.6	34.4	33.9
2003	39.1	38.9	38.8	35	32.4	33.9	35.1	32.7	35.3	32.5	32.9	34
2004	36.4	37.2	36.8	32.1	32.9	32.2	32.3	33.1	32.5	32.4	32.8	34.5
2005	35.7	38.4	36.4	34.1	32	32.5	33.4	33.8	33.7	32.7	34	33
2006	35.7	38.5	38.1	33.5	31.3	32.1	32.7	32	34.2	34.5	34.2	33.8
2007	36.2	37.2	38.8	32.4	32.9	32.7	34	34.5	33.9	33.3	32.4	33.4
2008	36.4	37.9	36.8	33.8	31	31.2	32.3	33.1	33	32.4	33.3	35.5
2009	38.1	37.1	35.2	32.2	32.1	32.5	32.9	32.7	33.4	32.2	30.9	31.6
2010	34.7	36.8	38	33.7	31.9	30.6	31.1	30.8	31.9	31.8	32.2	34
2011	37	37.6	37.1	31.2	32.2	33	32.9	33.3	32.8	31.2	32.3	34.6
2012	36.5	37	37.1	32.5	31.4	33	34	34.8	34	32.5	33.1	32.4
2013	35.6	36.4	35.2	32.7	30.9	31.8	31.9	32.8	33	32.9	33.5	34
2014	37	37.4	37.4	34.4	31.7	32.2	32.2	31.9	32.5	31.6	30.1	32.3
2015	35.8	37.5	38	32.6	30.5	31.9	31.5	32.3	32.3	32.2	31.4	32.8
2016	36.1	39.3	35.2	31.6	32	32.6	33.3	32	33.1	31.9	31.7	34.1
2017	37.2	36.4	35.2	33.4	32.7	33	33.5	32	32.3	30.7	31.5	33.3
2018	36.2	37.2	36.4	32.6	31.3	32.2	32.5	32.1	32.4	31.7	31.5	33.1
2019	37.4	37.1	36.9	33.7	33.5	33.5	33.6	34	34.2	33.2	33.1	34.4
2020	36.1	37.2	36.3	32.5	31.1	32.1	32.5	31.9	32.2	31.6	31.3	32.9
Average	36.5	37.6	36.9	33.0	32.0	32.4	32.9	32.9	33.3	32.3	32.5	33.6

Source: Woito climatic data from National Meteorological Agency, Hawassa Branch

Appendix Table 4. Long term average relative humidity (%)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1998	21.9	18.4	22.5	29.0	30.4	28.7	28.3	28.7	28.7	29.4	27.8	23.9
1999	20.9	18.3	24.1	26.2	28.9	28.9	28.6	28.2	25.7	26.9	29.0	26.2
2000	22.6	23.5	25.5	25.8	28.4	29.2	29.2	28.2	26.0	26.1	25.7	25.0
2001	21.0	23.8	27.3	28.3	28.1	30.3	30.1	29.0	26.8	26.5	25.0	23.8
2002	19.7	20.3	22.3	25.4	24.6	26.6	28.0	25.8	22.3	27.7	32.2	30.3
2003	31.3	28.3	27.4	30.1	32.1	32.0	30.9	30.1	27.3	29.6	26.2	20.8
2004	18.7	16.8	28.0	28.8	27.1	26.6	26.0	26.6	25.6	29.3	26.4	25.5
2005	19.3	16.2	19.0	26.5	27.9	27.6	27.8	29.1	26.4	30.5	28.0	24.2
2006	25.1	22.3	25.8	32.8	29.7	30.2	28.8	28.7	29.8	29.5	29.1	24.4
2007	25.9	21.2	28.2	28.7	31.3	28.3	26.1	26.5	24.4	30.4	30.5	31.9
2008	35.2	22.4	25.6	28.1	32.3	29.7	29.6	31.0	27.6	28.6	28.0	28.1
2009	26.0	22.3	20.8	30.8	29.5	26.1	27.0	28.0	28.0	27.9	31.3	29.0
2010	24.4	18.3	25.3	27.6	31.8	29.3	28.4	27.2	27.1	28.4	26.9	18.6
2011	20.9	22.1	28.0	31.3	31.4	29.4	27.6	28.8	25.6	29.5	32.2	33.1
2012	29.6	28.1	25.0	29.1	29.9	32.5	29.7	30.5	29.2	29.0	28.3	22.0
2013	22.1	19.0	21.4	27.8	27.8	26.2	28.8	28.0	27.7	30.2	28.0	21.8
2014	21.2	18.6	23.0	29.1	27.9	25.7	23.0	22.9	24.6	28.2	26.4	28.3
2015	24.4	23.5	28.0	29.8	30.7	28.3	27.3	26.8	27.5	27.8	22.5	19.7
2016	17.8	14.8	20.1	24.7	27.7	29.1	28.6	29.1	28.4	28.0	26.0	23.6
2017	16.7	15.0	19.1	27.7	31.6	31.3	33.0	31.4	30.3	28.2	29.6	21.9
2018	22.1	18.7	22.6	29.0	30.3	28.7	28.3	28.6	28.5	29.4	27.8	24.0
2019	28.9	25.9	26.1	27.5	29.7	29.4	27.1	25.1	24.5	25.7	26.6	23.0
2020	21.8	18.2	22.3	29.1	30.5	28.7	28.3	28.7	28.9	29.5	27.8	23.8
Average	23.4	20.7	24.2	28.4	29.5	28.8	28.3	28.1	27.0	28.5	27.9	24.9

Source: Woito climatic data from National Meteorological Agency, Hawassa Branch

Appendix Table 5. Long term sun shine hours

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1998	8.17	9.23	8.60	8.62	9.67	8.04	8.01	8.37	8.41	7.43	8.24	8.34
1999	8.23	9.23	8.62	7.75	8.22	8.04	8.03	8.36	8.40	7.47	8.24	8.37
2000	8.50	9.50	8.50	7.50	9.20	7.50	8.50	8.50	8.50	8.50	7.80	8.50
2001	9.20	9.20	9.20	8.70	7.20	8.20	8.20	8.20	8.20	8.20	8.20	8.20
2002	9.60	8.30	9.50	7.80	8.80	7.30	8.30	8.30	8.30	8.30	8.30	8.30
2003	9.50	9.40	9.50	8.20	8.10	7.10	8.90	8.50	8.70	8.20	8.10	9.20
2004	9.20	9.20	9.60	8.10	8.20	9.20	9.20	8.90	9.20	8.20	9.20	9.20
2005	9.80	8.80	8.90	7.60	9.10	8.10	7.80	7.80	7.80	7.10	8.10	8.90
2006	8.80	8.80	8.80	8.10	8.34	8.60	7.80	7.80	8.80	7.80	8.80	8.80
2007	8.70	9.10	8.70	8.70	7.60	8.50	7.70	8.20	8.70	7.70	7.90	8.70
2008	8.70	9.60	8.80	7.80	6.80	7.80	7.80	7.80	7.60	7.80	7.80	8.80
2009	9.30	9.30	9.30	9.30	8.10	9.30	8.30	9.30	8.30	8.60	8.30	9.30
2010	8.30	9.30	8.30	8.30	8.90	8.30	8.10	8.30	8.30	8.30	8.30	8.30
2011	8.50	8.90	8.50	8.50	8.50	8.50	8.50	8.50	8.50	7.20	8.50	8.50
2012	8.90	9.60	8.90	7.90	7.90	8.90	8.20	8.90	8.90	7.90	7.90	8.90
2013	9.10	8.70	8.70	8.90	8.70	8.70	8.30	8.70	8.70	7.10	8.70	8.70
2014	7.80	9.70	8.70	7.80	7.80	7.80	7.60	7.80	7.80	7.80	7.80	7.90
2015	8.40	8.90	8.40	9.13	8.40	6.60	8.40	8.40	8.40	7.30	8.40	8.40
2016	8.30	9.90	8.90	7.80	8.20	8.10	8.20	8.20	8.20	7.50	8.20	8.20
2017	8.10	9.30	8.90	8.60	8.10	6.90	8.10	8.10	8.10	7.80	8.10	8.50
2018	9.70	9.90	8.70	7.80	7.80	7.60	8.70	8.10	7.60	7.90	8.20	9.50
2019	8.90	9.80	9.30	7.60	9.20	7.90	8.10	8.20	7.80	8.10	8.10	8.90
2020	8.11	9.23	8.57	8.90	8.30	8.04	7.99	8.37	8.42	7.39	8.24	8.31
Average	8.77	9.26	8.86	8.23	8.31	8.04	8.21	8.33	8.33	7.81	8.24	8.64

Source: Woito climatic data from National Meteorological Agency, Hawassa Branch

Appendix Table 6. Long term monthly average wind speed (m/s)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1998	2.21	2.19	2.39	2.24	2.23	2.29	2.26	2.34	2.35	2.27	2.36	2.25
1999	2.03	1.70	1.78	2.13	3.37	1.23	1.24	1.15	3.38	1.96	1.50	1.60
2000	1.60	3.79	0.95	2.24	1.71	2.13	1.58	1.32	1.95	1.45	1.15	1.92
2001	1.78	1.31	1.31	1.20	2.06	2.64	2.67	0.87	1.30	0.96	1.07	1.57
2002	2.18	2.29	2.01	2.02	2.06	2.16	2.03	2.41	2.10	1.99	2.18	1.98
2003	2.30	2.36	2.64	2.66	2.40	2.11	2.23	2.27	2.15	2.35	2.17	2.24
2004	2.31	2.28	2.36	2.16	2.23	2.23	2.18	2.56	2.11	2.30	2.38	2.33
2005	2.13	2.35	2.10	2.25	2.23	2.31	2.16	2.06	2.12	1.90	1.78	2.09
2006	2.48	2.32	2.46	2.24	2.45	2.15	2.03	2.23	2.28	2.16	1.74	2.31
2007	2.39	2.18	2.21	2.40	2.25	2.25	2.04	2.56	2.56	2.43	2.28	2.31
2008	2.29	2.20	2.56	2.34	2.47	2.46	2.70	2.43	2.41	2.24	3.05	2.40
2009	2.31	2.60	2.47	2.05	2.34	2.15	2.19	2.20	2.15	2.11	2.16	2.41
2010	2.24	2.08	2.46	2.15	2.53	2.41	2.23	2.00	3.65	2.03	2.09	2.19
2011	2.12	2.17	2.14	2.30	2.15	2.43	2.39	2.00	2.26	2.12	2.70	2.23
2012	2.44	2.12	2.38	2.43	2.32	2.14	2.46	2.36	2.04	2.53	2.02	2.28
2013	2.12	2.24	2.21	2.09	2.13	2.17	2.19	2.10	2.18	2.15	2.11	2.29
2014	2.03	2.11	2.19	2.01	2.12	2.19	2.04	2.07	2.19	2.24	2.01	2.02
2015	2.00	2.18	2.37	2.06	2.21	2.24	2.16	2.12	2.27	2.25	2.14	2.07
2016	2.10	2.26	2.23	2.13	2.26	2.31	2.10	2.05	1.99	2.07	2.00	2.10
2017	2.22	2.00	2.21	2.35	2.00	2.27	2.07	2.19	2.29	2.08	2.12	2.11
2018	2.19	2.24	2.17	2.17	2.26	2.18	2.11	1.96	2.16	2.00	1.88	2.09
2019	2.55	1.85	2.43	2.18	1.59	1.38	2.40	1.73	1.39	2.31	1.42	2.29
2020	2.21	2.19	2.39	2.24	2.23	2.29	2.26	2.34	2.35	2.27	2.36	2.25
Average	2.18	2.22	2.19	2.18	2.24	2.18	2.16	2.06	2.24	2.09	2.03	2.14

Source: Woito climatic data from National Meteorological Agency, Hawassa Branch

Appendix Table 7. Long-term monthly climatic data and ETo of the study area

Month	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	ETo	ETo
	°C	°C	%	m/s	Hours	MJ/m?/day	mm/day	mm/moth
January	22.8	36.6	24	2.2	8.8	21.3	6.72	208.32
February	23.4	37.6	21	2	9.3	23.1	6.99	195.72
March	23.4	36.9	24	2	8.8	23.1	7.06	218.86
April	21.9	33.1	28	2.2	8.2	22	6.71	201.3
May	21	32	29	2.3	8.3	21.4	6.46	200.26
June	21.1	32.5	29	2.2	8	20.4	6.22	186.6
July	21.2	32.9	28	2.2	8.2	20.9	6.36	197.16
August	21.1	32.9	28	2.1	8.3	21.7	6.39	198.09
September	21.3	33.3	27	2.2	8.3	22.1	6.66	199.8
October	20.7	32.3	29	2.1	7.8	20.9	6.19	191.89
November	20.3	32.5	28	2	8.2	20.5	5.92	177.6
December	20.4	33.6	25	2.1	8.6	20.6	6.09	188.79
Average	21.6	33.9	27	2.1	8.4	21.5	6.48	2364.39

Appendix Table 8. Crop coefficient (Kc), daily ETo and daily CWR values

Day	Kc	Eto	Etc	Day	Kc	Eto	Etc	Day	Kc	Eto	Etc
1	0.35	6.71	2.4	38	0.8	6.46	5.2	75	1.1	6.22	6.8
2	0.35	6.71	2.4	39	0.83	6.46	5.4	76	1.1	6.22	6.8
3	0.35	6.71	2.4	40	0.85	6.46	5.5	77	1.1	6.22	6.8
4	0.35	6.71	2.4	41	0.88	6.46	5.7	78	1.1	6.22	6.8
5	0.35	6.71	2.4	42	0.9	6.46	5.8	79	1.1	6.22	6.8
6	0.35	6.71	2.4	43	0.93	6.46	6.0	80	1.1	6.22	6.8
7	0.35	6.71	2.4	44	0.95	6.46	6.1	81	1.1	6.22	6.8
8	0.35	6.71	2.4	45	0.98	6.46	6.3	82	1.1	6.22	6.8
9	0.35	6.71	2.4	46	1	6.46	6.5	83	1.1	6.22	6.8
10	0.35	6.71	2.4	47	1.03	6.46	6.7	84	1.1	6.22	6.8
11	0.35	6.71	2.4	48	1.05	6.46	6.8	85	1.1	6.22	6.8
12	0.35	6.71	2.4	49	1.08	6.46	7.0	86	1.1	6.22	6.8
13	0.35	6.71	2.4	50	1.1	6.46	7.1	87	1.1	6.22	6.8
14	0.35	6.71	2.4	51	1.1	6.46	7.1	88	1.1	6.22	6.8
15	0.35	6.71	2.4	52	1.1	6.46	7.1	89	1.1	6.22	6.8
16	0.35	6.71	2.4	53	1.1	6.46	7.1	90	1.1	6.22	6.8
17	0.35	6.71	2.4	54	1.1	6.46	7.1	91	1.06	6.22	6.6
18	0.35	6.71	2.4	55	1.1	6.46	7.1	92	1.03	6.36	6.6
19	0.35	6.71	2.4	56	1.1	6.46	7.1	93	0.99	6.36	6.3
20	0.35	6.71	2.4	57	1.1	6.46	7.1	94	0.95	6.36	6.0
21	0.38	6.71	2.6	58	1.1	6.46	7.1	95	0.91	6.36	5.8
22	0.4	6.71	2.7	59	1.1	6.46	7.1	96	0.88	6.36	5.6
23	0.43	6.71	2.9	60	1.1	6.46	7.1	97	0.84	6.36	5.3
24	0.45	6.71	3.0	61	1.1	6.46	7.1	98	0.8	6.36	5.1
25	0.48	6.71	3.2	62	1.1	6.22	6.8	99	0.76	6.36	4.8
26	0.5	6.71	3.4	63	1.1	6.22	6.8	100	0.73	6.36	4.6
27	0.53	6.71	3.6	64	1.1	6.22	6.8	101	0.69	6.36	4.4
28	0.55	6.71	3.7	65	1.1	6.22	6.8	102	0.65	6.36	4.1
29	0.58	6.71	3.9	66	1.1	6.22	6.8	103	0.61	6.36	3.9
30	0.6	6.71	4.0	67	1.1	6.22	6.8	104	0.58	6.36	3.7
31	0.63	6.46	4.1	68	1.1	6.22	6.8	105	0.54	6.36	3.4
32	0.65	6.46	4.2	69	1.1	6.22	6.8	106	0.5	6.36	3.2
33	0.68	6.46	4.4	70	1.1	6.22	6.8	107	0.46	6.36	2.9
34	0.7	6.46	4.5	71	1.1	6.22	6.8	108	0.43	6.36	2.7
35	0.73	6.46	4.7	72	1.1	6.22	6.8	109	0.39	6.36	2.5
36	0.75	6.46	4.9	73	1.1	6.22	6.8	110	0.35	6.36	2.2
37	0.78	6.46	5.0	74	1.1	6.22	6.8				

Appendix Table 9. Time to irrigate 1st irrigation net depth 87.92mm on March 18, 2021

H	T1		T2		T3		T4		T5		T6	
	100%Etc		85%Etc		75%Etc		65%Etc		55%Etc		45%Etc	
cm	min	Sec	min	Sec	min	Sec	min	Sec	min	Sec	min	Sec
5	17	14	14	39	12	56	11	13	9	29	7	46
6	12	44	10	50	9	34	8	17	7	1	5	44
7	10	7	8	35	7	35	6	34	5	34	4	33
8	8	22	7	7	6	17	5	26	4	37	3	46
9	6	59	5	56	5	14	4	32	3	50	3	8
10	5	52	4	59	4	24	3	49	3	13	2	38
11	5	3	4	17	3	47	3	17	2	47	2	16
12	4	26	3	46	3	20	2	53	2	26	2	0
13	3	55	3	19	2	56	2	32	2	9	1	46
14	3	29	2	58	2	37	2	16	1	55	1	34
15	3	7	2	39	2	20	2	2	1	43	1	24

Appendix Table 10. Time to irrigate 2nd irrigation net depth 89.15mm on April 19, 2021

H	T1		T2		T3		T4		T5		T6	
	100%Etc		85%Etc		75%Etc		65%Etc		55%Etc		45%Etc	
cm	min	Sec	min	Sec	min	Sec	min	Sec	min	Sec	min	Sec
5	17	29	14	52	13	7	11	22	9	37	7	52
6	12	55	10	59	9	41	8	24	7	7	5	49
7	10	15	8	43	7	41	6	40	5	38	4	37
8	8	29	7	13	6	22	5	31	4	40	3	49
9	7	5	6	1	5	19	4	36	3	53	3	11
10	5	56	5	3	4	28	3	52	3	16	2	40
11	5	7	4	22	3	50	3	20	2	49	2	19
12	4	30	3	50	3	23	2	56	2	29	2	2
13	3	58	3	22	2	58	2	35	2	11	1	47
14	3	32	3	1	2	39	2	18	1	57	1	35
15	3	10	2	41	2	22	2	3	1	44	1	25

Appendix Table 11. Time to irrigate 3rd irrigation net depth 92.22mm on May 5, 2021

H	T1		T2		T3		T4		T5		T6	
	100%Etc		85%Etc		75%Etc		65%Etc		55%Etc		45%Etc	
cm	min	Sec	min	Sec	min	Sec	min	Sec	min	Sec	min	Sec
5	18	5	15	22	13	34	11	45	9	57	8	8
6	13	22	11	22	10	1	8	41	7	21	6	1
7	10	36	9	1	7	57	6	53	5	50	4	46
8	8	47	7	28	6	35	5	43	4	50	3	57
9	7	19	6	13	5	29	4	46	4	2	3	17
10	6	9	5	14	4	37	4	0	3	23	2	46
11	5	18	4	31	3	59	3	27	2	55	2	23
12	4	40	3	58	3	29	3	2	2	34	2	6
13	4	6	3	29	3	4	2	40	2	15	1	24
14	3	40	3	7	2	44	2	23	2	1	1	39
15	3	16	2	47	2	27	2	8	1	48	1	0

Appendix Table 12. Time to irrigate 4th irrigation net depth 88.95mm on May 18, 2021

H	T1		T2		T3		T4		T5		T6	
	100%Etc		85%Etc		75%Etc		65%Etc		55%Etc		45%Etc	
cm	min	Sec	min	Sec	min	Sec	min	Sec	min	Sec	Min	Sec
5	17	26	14	50	13	5	11	20	9	35	7	51
6	12	53	10	58	9	40	8	23	7	5	5	48
7	10	13	8	41	7	40	6	39	5	37	4	36
8	8	28	7	12	6	21	5	31	4	40	3	49
9	7	4	6	0	5	17	4	35	3	53	3	11
10	5	56	5	2	4	27	3	51	3	16	2	40
11	5	7	4	21	3	50	3	19	2	55	2	18
12	4	29	3	49	3	22	2	55	2	28	2	1
13	3	57	3	22	2	58	2	34	2	10	1	47
14	3	32	3	0	2	39	2	17	1	56	1	35
15	3	9	2	41	2	22	2	3	1	44	1	25

Appendix Table 13. Time to irrigate 5th irrigation net depth 88.95mm on May 31, 2021

H	T1		T2		T3		T4		T5		T6	
	100%Etc		85%Etc		75%Etc		65%Etc		55%Etc		45%Etc	
cm	min	Sec	min	Sec	min	Sec	min	Sec	min	Sec	min	Sec
5	17	26	14	50	13	5	11	20	9	35	7	51
6	12	53	10	58	9	40	8	23	7	5	5	48
7	10	13	8	41	7	40	6	39	5	37	4	36
8	8	28	7	12	6	21	5	31	4	40	3	49
9	7	4	6	0	5	17	4	35	3	53	3	11
10	5	56	5	2	4	27	3	51	3	16	2	40
11	5	7	4	21	3	50	3	19	2	49	2	18
12	4	29	3	49	3	22	2	55	2	28	2	1
13	3	57	3	22	2	58	2	34	2	10	1	47
14	3	32	3	0	2	39	2	17	1	56	1	35
15	3	9	2	41	2	22	2	3	1	44	1	25

Appendix Table 14. Time to irrigate 6th irrigation net depth 89.62mm on June 13, 2021

H	T1		T2		T3		T4		T5		T6	
	100%Etc		85%Etc		75%Etc		65%Etc		55%Etc		45%Etc	
Cm	min	Sec	min	Sec	min	Sec	min	Sec	min	Sec	Min	Sec
5	17	34	14	56	13	11	11	25	9	40	7	55
6	12	59	11	2	9	44	8	26	7	8	5	50
7	10	18	8	46	7	44	6	42	5	40	4	38
8	8	32	7	15	6	24	5	33	4	41	3	50
9	7	7	6	3	5	20	4	37	3	55	3	12
10	5	58	5	5	4	29	3	53	3	17	2	41
11	5	9	4	23	3	52	3	21	2	50	2	19
12	4	32	3	51	3	23	2	56	2	29	2	2
13	3	59	3	23	2	59	2	35	2	11	1	47
14	3	34	3	1	2	40	2	19	1	58	1	36
15	3	11	2	42	2	23	2	4	1	45	1	26

Appendix Table 15. Time to irrigate 7th irrigation net depth 17mm on June 22, 2021

H	T1		T2		T3		T4		T5		T6	
	100%Etc		85%Etc		75%Etc		65%Etc		55%Etc		45%Etc	
cm	Min	Sec	min	Sec	min	Sec	min	Sec	min	Sec	min	Sec
5	4	2	3	26	3	2	2	37	2	13	2	0
6	2	59	2	32	2	14	2	0	2	0	1	20
7	2	22	2	1	2	0	2	32	1	18	1	4

Appendix Table 16. Analysis of Variance for day’s to 50% flowering

Source of variation	Degree of Freedom	Sum of Squares	Mean Square	Computed F^b	Tabular F	
					5%	1%
Replication	2	12.44	6.222			
Treatment	5	353.78	70.756	21.086**	3.33	5.64
Error	10	33.56	3.356			
Total	17	399.78				

** Significant at 1% level

Appendix Table 17. Analysis of Variance for day’s to maturity

Source of variation	Degree of Freedom	Sum of Squares	Mean Square	Computed F^b	Tabular F	
					5%	1%
Replication	2	5.45	2.727			
Treatment	5	479.6	95.92	68.19**	3.33	5.64
Error	10	14.07	1.407			
Total	17	499.12				

** Significant at 1% level

Appendix Table 18. Analysis of Variance for Plant height

Source of variation	Degree of Freedom	Sum of Squares	Mean Square	Computed F^b	Tabular F	
					5%	1%
Replication	2	221	110.48			
Treatment	5	3929.4	785.88	9.896**	3.33	5.64
Error	10	794.1	79.41			
Total	17	4944.5				

** Significant at 1% level

Appendix Table 19. Analysis of Variance for number of branches per plant

Source of variation	Degree of Freedom	Sum of Squares	Mean Square	Computed F^b	Tabular F	
					5%	1%
Replication	2	8.029	4.01			
Treatment	5	16.15	3.23	14.4**	3.33	5.64
Error	10	2.239	0.22			
Total	17	26.418				

** Significant at 1% level

Appendix Table 20. Analysis of Variance for number of capsules per plant

Source of variation	Degree of Freedom	Sum of Squares	Mean Square	Computed F^b	Tabular F	
					5%	1%
Replication	2	15.21	7.61			
Treatment	5	476.43	95.29	45.59**	3.33	5.64
Error	10	20.9	2.09			
Total	17	512.54				

** Significant at 1% level

Appendix Table 21. Analysis of Variance for number of seed per capsule

Source of variation	Degree of Freedom	Sum of Squares	Mean Square	Computed F^b	Tabular F	
					5%	1%
Replication	2	172.4	86.2			
Treatment	5	609.11	121.82	121.5**	3.33	5.64
Error	10	10.02	1			
Total	17	791.53				

** Significant at 1% level

Appendix Table 22. Analysis of Variance for 1000-seed weight

Source of variation	Degree of Freedom	Sum of Squares	Mean Square	Computed F^b	Tabular F	
					5%	1%
Replication	2	0.02	0.0097			
Treatment	5	2.04	0.408	131.5**	3.33	5.64
Error	10	0.031	0.0031			
Total	17	2.091				

** Significant at 1% level

Appendix Table 23. Analysis of Variance for Straw yield

Source of variation	Degree of Freedom	Sum of Squares	Mean Square	Computed F^b	Tabular F	
					5%	1%
Replication	2	691873	345936			
Treatment	5	9328140	1865628	19.165**	3.33	5.64
Error	10	973440	97344			
Total	17	10993453				

** Significant at 1% level

Appendix Table 24. Analysis of Variance for Grain yield

Source of variation	Degree of Freedom	Sum of Squares	Mean Square	Computed F^b	Tabular F	
					5%	1%
Replication	2	36906	18453			
Treatment	5	1353559	270712	37.7**	3.33	5.64
Error	10	71784	7178			
Total	17	1462249				

** Significant at 1% level

Appendix Table 25. Analysis of Variance for Harvest Index

Source of variation	Degree of Freedom	Sum of Squares	Mean Square	Computed F^b	Tabular F	
					5%	1%
Replication	2	2.991	0.81			
Treatment	5	21.275	4.98	21.64**	3.33	5.64
Error	10	1.97	0.23			
Total	17	26.236				

** Significant at 1% level

Appendix Table 26. Analysis of Variance for Aboveground Biomass

Source of variation	Degree of Freedom	Sum of Squares	Mean Square	Computed F^b	Tabular F	
					5%	1%
Replication	2	764561	382281			
Treatment	5	17773619	3554724	25.29**	3.33	5.64
Error	10	1405332	140533			
Total	17	19943512				

** Significant at 1% level

Appendix Figure 10. During soil sampling and parshall flume setting

Appendix Figure 11. During field preparation and planting

Appendix Figure 12. During field management and harvesting

Appendix Figure 13. During harvesting and data recording

8. BIOGRAPHICAL SKETCH

The author was born on July 12, 1986 in Boloso Sore Woreda, Wolaita Zone of SNNPRS, Ethiopia. He attended his elementary, junior and secondary school education at Tiyo Hembecho Elementary School, Hembecho Junior School in Wolaita Zone and Hadero Secondary and Preparatory School in Kembata Timbaro Zone respectively. He then joined Jimma University in 2004 to study for his BSC degree and graduated in Hydraulic and water Resource Engineering in 2008 E.C.

After graduation, since September 2009 he is employed by the Jinka Agricultural Research Center of South Agricultural Research Institute in the position of Junior Irrigation Researcher-II and worked there until he joined the School of Graduate Studies of Hawassa University in October 2012 E.C to pursue his Master of Science Degree in Irrigation and Drainage Engineering.