MAIZE (*Zea mays L.*) RESPONSE TO DEFICIT IRRIGATION LEVELS AT DIFFERENT GROWTH STAGES ON ITS YIELD AND WATER USE EFFICIENCY AT KOKA, CENTRAL RIFT VALLEY OF ETHIOPIA

MSc THESIS

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APPROVAL SHEET

As members of the Examining Board of the Final MSc Open Defense, we certify that we have read and evaluated the thesis prepared by AYELE DEBEBE MENGESHA entitled “Maize (*Zea mays* L.) Response to Deficit Irrigation Levels at Different Growth Stages on its Yield and water use efficiency at Koka, CRV of Ethiopia", and recommend that it can be accepted as fulfilling the thesis requirement for the Degree of Master of Science, in Irrigation and Drainage Engineering.

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DEDICATION

I dedicate this thesis manuscript to my father DEBEBE MENGESHA, who passed once without viewing the fruit of his exertion and for my mother WOINSHET KEFELEGN for nursing me with affection and love and for her dedicated partnership in the success of my life.

STATEMENT OF AUTHOR

I declare that this thesis is my bona fide work and 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.

Name:………………………………………………….**Signature**:…………………

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LIST OF ABBRIVIATIONS AND ACRONYMS

BMC	Billion metric cubes
CO_2	Carbon dioxide
CL	Cob length
CRV	Central rift valley
CSA	Central Statistical Agency
CV	Coefficient of variance
CW	Cob width
CWWOS	Cob weight without seed
DI	Deficit irrigation
DBM	Dry biomass
EH	Ear height
EIAR	Ethiopian Institute of Agricultural Research
ETa	Actual evapotranspiration
ETC	Crop evapotranspiration
ETm	Maximum evapotranspiration
ETO	Reference evapotranspiration
FAO	Food and Agricultural Organization of the United Nations
FC	Field capacity
GY	Grain yield
HI	Harvesting Index
IWMI	International Water Management Institute
KC	Crop coefficient
Ky	Yield response factor
LAI	Leaf area index
LL	Leaf length
LSD	Least significant difference
LW	leaf width
MARC	Melkassa Agricultural Research Center
masl	Meter above sea level
MS	Mean square

PWP	Permanent wilting point
RCBD	Randomized complete block design
SAS	Statistical analysis system
TSW	Thousand seed weight
WGARC	Wondo Genet Agricultural Research Center
WUE	Water use efficiency
Ya	Actual yield
Ym	Maximum yield

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ABSTRACT

Water scarcity is among the major limitations for crop production. Improving water use efficiency of irrigated crops through water management options is crucial in water scarce areas. Field experiment was carried out at Wondo Genet Agricultural Research Center Koka Research site, to investigate the effect of water stress at different growth stage on yield and water use efficiency of maize. one optimum irrigation and eight growth stage based deficit levels(100% ETC at all growth stages, 75% ETC at all growth stages, 50% ETC at all growth stages, 75% ETC at development growth stage, 50% ETC at development growth stage, 75% ETC at mid growth stage, 50% ETC at mid growth stage, 75% ETC at late growth stage and 50% ETC at late growth stage) were imposed on maize (Zea mays L.) variety Melkassa II as a treatment and laid out in randomized complete block design (RCBD) with three replications. Results indicated that the different levels of growth stage based deficit levels had significant (p<0.01) effect on growth parameters, crop yield, harvest index and water use efficiency. Grain yield reduced with increased stress, whereas water use efficiency was increased with stress level increased. The highest grain yield of 6.4 t/ha and WUE of 1.02 kg/m3 were obtained at 100% ETC and 50% ETC at all growth stages, respectively. Also, 75% ETC at development stage and late stage treatments showed no significant variation with 100% ETC in grain yield. Water use efficiency observed at 75% ETC all growth stages treatment was statistically similar with that of 50% ETC at all growth stages treatment. Grain yield obtained from 50% ETC at mid growth stage was similar with 50% ETC at all growth stages, and water use efficiency was the least and this shows that maize was sensitive to moisture stress at mid growth stage than development and late growth stages. Therefore, maize could be irrigated at 75% ETC at all growth stages and by stressing development or late growth stages up to 50% ETC to increase water use efficiency with a small grain yield reduction.

Key words: Deficit irrigation, growth stage, maize, water use efficiency

1. INTRODUCTION

1.1. Background

Agriculture is the main stay of Ethiopian economy and it depends on rainfall. Over 95% of the agricultural production depends on rainfall (IFAD, 2005). Almost 80 - 85% of the population (FAO, 2001 and World Bank, 2006), 40 - 48% of the country's GDP (FAO, 2001) and 90% of export (ONAR, 2002) directly depend on rain fed agriculture.

Due to lack of water storage and large spatial and temporal variations in rainfall, there is not enough water for most farmers to produce more than one crop per year and hence there are frequent crop failures due to dry spells and droughts which have resulted in a chronic food shortage. However, to ensure food security irrigation has its own share. Nata et al. (2007) and Abraham et al. (2011) listed out the benefits of irrigation that includes; increase food production in arid and semi-arid regions, enhances food production, promotes economic growth and sustainable development, create employment opportunities, and improve living conditions of small-scale farmers.

Ethiopia has 12 river basins. The total mean annual flow from all the 12 river basins is estimated to be 125 BMC. The country comprises 112 million hectares (Mha) of land. Cultivable land area estimates vary between 30 to 70 Mha. Currently, high estimates show that only 15 Mha of land is under cultivation. From this area, only about 4 to 5 percent is irrigated, with existing equipped irrigation schemes covering about 640,000 hectares (Seleshi, 2010). This indicated that a significant portion of cultivated land in Ethiopia is currently not irrigated. However, irrigation development is a key for sustainable and reliable agricultural development which leads to overall development in Ethiopia (Makombe et al., 2011).

Agricultural production can be increased by either expanding the irrigated-cropped area or by raising the crop productivity (Qureshi et al., 1994).However, as the population growth increased irrigated crop area will not increased and it is not the exact option to increase agricultural production rather raising crop productivity is the best option to increase agricultural production.

Water is a finite resource used by different sectors like agriculture, domestic, municipal and industry. The competition for this scarce resource is increasing from time to time due to increasing food demand from the highly consuming agricultural sector, which makes less water available for crop production (Ingle *et al.*, 2015; Pereira *et al*., 2009).This competition for water from different sectors made water a very scarce resource. As water scarcity intensifies in many regions of the world, better management of water is becoming an issue of paramount importance (Lorite *et al*., 2007).

Irrigation requirements are necessary to meet the ET needs of a crop depend on the type of crop and growth stage, field soil characteristics, irrigation system type and capacity. Different crops vary in growth characteristics that result in different relative water use rates. Soils differ in texture and hydraulic characteristics such as available water-holding capacity (AWHC) and capillary movement. To know irrigation water requirement, the water needs to be measured and properly utilized; both excessive and inadequate water applications have negative effects. Gauging the water and matching the plant water requirement and the amount of water applied were observed as an inevitable operation in some finger-counted highly performing irrigation schemes in the country (Mihret, 2013).

Crop yield were affected by drought/moisture stress. Occurrence of drought is the common phenomenon in arid and semiarid regions that comprise about 35% of the earth's surface. Drought may also occur in humid regions due to of uneven distribution of rainfall. If drought occurs at a sensitive crop growth stage, crop yields can be reduced even in humid regions. Supplementary irrigation during the rainy season and permanent irrigation during the dry period provides the best solution for coping with drought stress (Fageria *et al.*, 1997). But, it is impossible to provide irrigation facilities to smallholder farmers due to water scarcity or economic reasons in all drought regions rather low cost and easily affordable management practices must be required, in addition to developing and planting drought resistant crop species or cultivars.

Deficit irrigation is an optimization strategy in which irrigation is applied during drought-sensitive growth stages of a crop. Outside these periods, irrigation is limited or even unnecessary if rainfall provides a minimum supply of water. Water restriction is limited to drought-tolerant phenological stages, often the vegetative stages and the late ripening period. Total irrigation application is therefore not proportional to irrigation requirements throughout the crop cycle. While this inevitably results in plant drought stress and consequently in production loss, deficit irrigation maximizes water use efficiency (English, 1990). In other words, deficit irrigation aims at stabilizing yields and at obtaining maximum water use efficiency rather than maximum yields (Zhang and Oweis, 1999).

Under conditions of scarce water supply and drought, deficit irrigation can lead to greater economic gain by maximizing water use efficiency. The term water use efficiency (WUE) is used to describe the relation between crop yield and water use (Oweis and Zhang, 1998; Zhang *et al*., 1998). Increasing the amount of water used by the plant or increasing the yield of the plant can change water use efficiency. In this context, deficit irrigation provides a means of reducing water consumption while minimizing adverse effects on yield (Mermoud *et al*., 2005). Water is also the main limiting factor for production of many crops including maize in the arid and semiarid regions.

1.2. Statement of the Problem

Agriculture is the dominate sector of Ethiopian economy which is highly dependent on rainfall system. The country has many irrigable land and water resource as a whole. However, irrigation development is too low due to limited financial resources, technical challenges, lack of good governance, and lack of efficient resource utilizations.

Population growth is very rapid in Ethiopia and food insecurity is a big concern, because agricultural productivity is very low and highly dependent on rain fall system. However, irrigation has a huge contribution to solve food insecurity problem and to develop the country’s economy.

Physical water scarcity is also a major challenge in Ethiopia to develop irrigation potential and to develop agricultural productivity. Therefore, in this condition effective water management strategies like deficit irrigation are needed to increase water productivity and agricultural productivities.

Crop sensitivity to water differs from crop to crop and from growth stages to growth stages. Deficit irrigation practice requires the knowledge of crops sensitive stages.

Worldwide different researches are done to identify crops sensitive growth stages in water scare areas. For instance, Zhang *et al*. (2019) try to identify response of maize yield components to growth stage-based deficit irrigation and reported that water deficit applied during the maturity stage had a larger impact on maize yield compared with water deficit applied during the vegetative stage. Jin *et al*. (2020) also try to identify the responses of maize yield and water use to growth stage based irrigation on the Loess Plateau in China and reported that when irrigation water is limited, high WUE can be achieved if it is applied at vegetative growth stages, while high yield can be achieved if more available water is applied at tasseling stage.

Maize is one of the cereal crops produced in the study area widely through rainfall. However, there were information gap on effect of deficit irrigation at different growth stages on yield and water use efficiency of maize at the study area. Therefore the study was conducted to meet the following objectives.

1.3. Objectives

1.3.1. General objective

- To assess the effects of deficit irrigation at different growth stage on yield and water productivity of maize

1.3.2. Specific objectives:

- To determine growth stage based deficit irrigation levels on maize yield and dry biomass
- To determine growth stage based deficit irrigation level on water use efficiency of maize
- To identify the most sensitive growth stage of maize crop to deficit irrigation
- To identify growth stage based deficit irrigation levels with optimal yield and water use efficiency

1.4. Scope of the study

The study was conducted at Koka on maize to identify the most sensitive growth stages of maize to moisture stress and to identify growth stage based deficit levels for maize production in the study area.

1.5. Significance of the study

The study was important to:

- Identify sensitive growth stages of maize to deficit irrigate.
- Determine seasonal water demand of maize.
- Determine water productivity of maize with different moisture stress levels at different growth stage based on grain yield and total above ground biomass.
- To generate information for development agents, policy makers and users.

1.6 research questions

The research questions of the study were:

- ✓ What are the impacts of growth stage based deficit irrigation levels on maize performance?
- ✓ What are the impacts of growth stage based deficit irrigation levels on maize yield?
- ✓ What are the impacts of growth stage based deficit irrigation levels on water use efficiency?
- ✓ Which growth stages of maize are sensitive to water stress?

2. LITERATURE REVIEW

2.1. Water Resource of Ethiopia

2.1.1. Surface water resources

Ethiopia is “endowed” with a substantial amount of water resources. The country is divided into 12 basins; 8 of which are river basins; 1 lake basin; and remaining 3 are dry basins, with no or insignificant flow out of the drainage system. The total mean annual flow from all the 12 river basins is estimated to be 125 BMC (Seleshi, 2010).

Ethiopia also has 11 fresh and 9 saline lakes, 4 crater lakes and over 12 major swamps or wetlands. Majority of the lakes are found in the Rift Valley Basin. The total surface area of these natural and artificial lakes in Ethiopia is about 7,500 km^2. The majority of Ethiopian lakes are rich in fish (Seleshi et al., 2007).

2.1.2. Groundwater resources

Ground water is the water which is found below the surface of the earth either in the form of sandwiched between the two impervious layers or impervious at the bottom and open to the upper layer. The availability of the ground water can be determined by the nature of the geology such as porosity, hydraulic conductivity, the characteristics of the carbonate rocks, the type of the aquifer and generally the hydro geological of the aquifer. As compared to surface water resources, Ethiopia has lower ground water potential. Based on the scanty knowledge available on groundwater resources, the potential is estimated varies from 2.6 to 13.5 BMC. But local experts advise that the potential could be much higher than this figure from the experience in different pioneering projects (Seleshi, 2010). Accordingly, the report of Seifu et al. (2018) indicated that the estimated amount of annual renewable groundwater resource is about 36 BMC.

2.2. Irrigation Potential and Development in Ethiopia

Out of the total 112 million hectares of Ethiopia's area, cultivable land area estimates vary between 30 to 70 Mha. However, only about one third of that is currently cultivated which is approximately 15 Mha. Among this cultivated land, only 4 to 5 percent is irrigated, with existing irrigation schemes covering about 640,000 hectares. The total irrigable land potential in Ethiopia is 5.3 Mha with existing technologies and water resource including groundwater and rainwater harvesting. Irrigation potential using only surface water potential from the whole river basin in the country is estimated to 3.73 Mha. Based on the irrigable land potential, only 12% is under irrigation now a day. This indicates that there are potential opportunities to boost the amount of irrigated land (Seleshi, 2010).

The government of Ethiopia gives more emphasis for small-scale irrigation development activities involving farmers in different phases to solve food insecurity problem (Seleshi *et al.,* 2007). This indicates that there are plans of ongoing irrigation based development activities for accelerated and sustained development to end poverty in the country.

2.3. Water Scarcity

Water scarcity is commonly defined as a situation when water availability in a country or in a region is below 1000 m^3/person/year. However, many regions in the World experience much more severe scarcity, living with less than 500 m^3 per person per year, which could be considered severe water scarcity. The threshold of 2000 m^3 per person per year is considered to indicate that a region is water stressed. Desalination, non-renewable groundwater resources and wastewater reuse compensate renewable water scarcity supplementing the renewable resource (Pereira *et al*., 2009).

Water scarcity is the lack of sufficient available water resources to meet water needs within a region. It affects every continent and around 2.8 billion people around the world at least one month out of every year. In some places, water is abundant, but getting it to people is difficult because of lack of infrastructure, restricted access, political and socio-cultural issues. In other places, people’s demands go beyond what the natural resource base can handle, and not everyone is assured access to water (IWMI, 2007).

Also there is a competition for water resources from different sectors like domestic, industrial and agricultural sectors and these competitions make water scarce. These water scarcities are often classified as physical and economical water scarcity (Biswas, 1997).

2.3.1. Physical water scarcity

Physical scarcity occurs when there is not enough water to meet all demands, including environmental flows. Arid regions are most often associated with physical water scarcity, but water scarcity also appears where water is apparently abundant, when water resources are overcommitted to various users owing to overdevelopment of hydraulic infrastructure, most commonly for irrigation purposes. In such cases, there simply is not enough water to meet both human demands and environmental flow needs (IWMI, 2007). Symptoms of physical water scarcity are severe environmental degradation, declining groundwater, and water allocations that favor some groups over others. A fifth of the world's people, more than 1.2 billion, live in areas of physical water scarcity, lacking enough water for everyone's demands. Currently this problem is common in different parts of our country due to inefficient utilization of resources.

2.3.2. Economic water scarcity

Economic water scarcity occurred due to a lacks of investment in water, human capacity, institutional, and financial capital limit, access to water even though water in nature is available locally to meet human demands. About 1.6 billion people live in water-scarce basins, where human capacity or financial resources are likely to be insufficient to develop adequate water resources. Symptoms of economic water scarcity include limited infrastructure development, either small or large scale, so that people have trouble getting enough water for agriculture or drinking. Much of Sub-Saharan Africa is characterized by economic scarcity. Therefore, water development could do much to reduce poverty (IWMI, 2007).

2.4. Deficit Irrigation

Deficit (DI) is one of such strategies maximizing water use efficiency (WUE) for higher yields per unit of irrigation water applied. In this method, the crop is exposed to a certain level of water stress either during a particular period or throughout the whole growing season with the expectation that any yield reduction will be in significant compared with the benefits gained through diverting the saved water to irrigate other crops (English and Raja, 1996).

Irrigation water requirement is not completely fulfilled in deficit irrigation, allowing the soil water to be depleted to a threshold, such that the crop experiences mild water stress. The crop response, which may or may not include a reduction in the rate of water use and/or yield reductions, depends on the degree of soil drying, the crop characteristics and the timing of the water deficit. It is generally thought that with holding water during the vegetative period, as opposed to the flowering or yield forming stages, has less impact on final yields (Loveys *et al*., 2004).

The potential benefits of deficit irrigation are derived from three factors: increased irrigation efficiency, reduced costs of irrigation and the opportunity costs of water (English *et al*., 1990). The water saved by DI can be used to irrigate more land on the same farm or in the water user's community, which, given the high opportunity cost of water, and may largely compensate for the economic loss due to yield reduction (Ali *et al*., 2007). In other words, DI aims at stabilizing yields and at obtaining maximum WP rather than maximum yields (Kazemeini and Edalat, 2011).

In deficit irrigation certain reduction in yield is observed, the quality of the yield (e.g. sugar content, grain size) tends to be equal or even superior to rain-fed or full irrigation (Cui *et al*., 2008). An additional advantage is that DI creates a less humid environment around the crop than full irrigation, decreasing the risk of fungal diseases (Cicogna *et al*., 2005).Compared to full irrigation, DI treatment saved 60% of water and increased irrigation water use efficiency (WUE) without tomato yield reduction (Savic *et al*., 2011).

The amount of irrigation reduction is crop dependent and generally accompanied by no or minor yield loss that increases the water productivity (Ahmadi *et al*., 2010). Deficit irrigation strategies would require an accurate assessment of growth stage-specific stress tolerances for vegetable crops (Upchurch *et al*., 2005) and optimal water management supported by advanced irrigation systems; i.e., able to promptly cope with crop water requirements at sensitive phenological stages (Evans and Sadler, 2008).

2.5. Water use efficiency

Water use efficiency (WUE) is generally defined in agronomy as the ratio of crop yield (usually economic yield) to water used to produce the yield. WUE is a measure of the productivity of the water consumed by the crop. In areas with limited water resources, where water is the greatest limitation to production, WUE is the main criterion for evaluating the performance of production systems (FAO, 2002).

Deficit irrigation provides a means of reducing water consumption while minimizing adverse effects on yield (Mermoud *et al*., 2005). In this method, the crop is exposed to a certain level of water stress either during a particular period or throughout the whole growing season. The expectation is that any yield reduction (especially in water-limiting situations) will be compensated by increased production from the additional irrigated area with the water saved by deficit irrigation (Ali *et al*., 2007).

Deficit irrigation has been widely practiced as a valuable and sustainable production strategy in dry areas. By limiting water applications to drought-tolerant growth stages or throughout the growth period, water use efficiency can be maximized and to stabilize rather than maximize yields. Researches show that deficit irrigation is successful in increasing water productivity for various crops without causing severe yield reductions. Nevertheless, a certain minimum amount of seasonal moisture must be guaranteed (Geerts and Raes, 2009).

2.6. Maize

Maize (*Zea mays* L.) is largely used as livestock feed and as industrial raw material in industrialized countries (Onuh *et. al*., 2008). In developing countries, it is the main source of food for human consumption (Omemu *et al*., 2008), supplying carbohydrate, protein, iron, vitamin B, and minerals (Omemu *et al*., 2008; M’mboyi *et al*. 2010).

Maize is the second most widely cultivated crop in Ethiopia and is grown under diverse agro-ecologies and socioeconomic conditions (Tsedeke *et al*., 2017). It is the most important staple crop in terms of calorie intake in rural Ethiopia. The 2004/5 national survey of consumption expenditure indicated that maize accounted for 16.7 % of the national calorie intake followed by sorghum (14.1 %) and wheat (12.6 %) among the major cereals (Berhane *et al*. 2011). Most farmers grow maize mostly for subsistence, with 75 % of all maize produced is consumed by the farming households (CSA, 2012). The productivity of maize is very low 3.4 t/ha as compared to the yield obtained by research institutions greater than 8 tones/ha in the country. The yield gap is attributed to a number of factors like frequent occurrence of drought, declining of soil fertility, poor agronomic practice, limited use of input, poor seed quality, disease, and others (CIMMYT, 2004).

2.6.1. Improved maize varieties

Maize is growing in different agro ecologies and using improved maize varieties is one option for increasing maize productivity. Several drought tolerant and nitrogen-use efficient maize varieties namely, Melkassa II, III, IV and V—were developed in the 1990s (Banziger and Diallo, 2001; Banziger and Diallo, 2002; and Worku et al., 2002).These varieties were specifically adapted to the semiarid agro-ecologies of Ethiopia’s Rift Valley.

Ethiopia has given high priority to agricultural development, natural resource management, and agricultural productivity (Byerlee *et al.*, 2007, and Diao *et al.*, 2007). The country has followed an agricultural production intensification approach to boost crop productivity on the smallholdings through the application of modern agricultural inputs, primarily improved crop varieties, agronomic practices, and fertilizer technologies (Byerlee *et al.*, 2007, and Alemu *et al.*, 2008). As part of the intensification, the demand for improved technologies, including improved seed and fertilizer, has increased in Ethiopia (Spielman *et al.*, 2010), which could maximize the productivity of farmland with new agricultural inputs (Sisay *et al.*, 2007). Melkassa-II maize variety is also one of the improved maize varieties which are highly drought tolerant and early mature variety.

2.6.2. Maize Response to Water Stresses

To promote maize production, water deficit is one of the most common environmental stresses that affect growth and development of the crop (Ghassemi-Golezani *et al*., 2009), especially in developing countries (Seghatoleslami *et al*., 2008). Maize susceptibility to drought is due to the plant's water requirement for cell elongation and its’ inability to delay vegetative growth. This implies that there is always the danger of yield loss regardless of the timing of dry weather (Sangoi and Salvador, 1998). In maize, a major effect of water stress is a delay in silking, resulting in an increase in the anthesis-silking interval (ASI), which is an important cause of yield failures (Sari-Gorla *et al.,* 1999). Though, the amount of yield loss in dry periods is most pronounced at flowering stage (Guelloubi *et al.*, 2005) the magnitude and the timing of water deficit on growth stage are of major importance in scheduling limited water.

Maize shows different symptoms for moisture stress like a change in color from green to green-gray and rolling of the lower leaves followed by those in the upper canopy. During stomata are closing, photosynthesis is being sharply reduced and growth is slowing. When stress coincides with the 7 - 10 days' period prior to flowering, ear growth will slow more than tassel growth and there is a delay in silk emergence relative to pollen shed, giving rise to an interval between anther extrusion and silk exposure (Edmeades, 2003). This anthesis-silking interval (ASI) was shown to be highly correlated with grain yield, in particular kernel number and ear number per plant (Sari- Gorla *et al.,* 1999). Severe stress at flowering may lead to the complete abortion of ears and the plant becomes barren. Drought-affected ears typically have fewer kernels that will be poorly filled if drought extends throughout grain filling (Edmeades *et al.,* 2000).

Drought severity increases in different cropping environment. Root development systems of crops are affected by moisture stress. That means the development of a root system capable of accessing water far down the soil profile is a valuable trait in drought affected environments (Robertson *et al.,* 1993). Many species, including maize, respond to water deficit by redirecting growth and dry matter accumulation away from the shoot to the root (Hsiao and Xu, 2000).

2.7. Growth Stage Based Deficit Irrigation

Growth stage based deficit irrigation is an important way of managing irrigation water by identifying the most sensitive growth stages to apply the required amount of water on these sensitive growth stages. In this practice full irrigation water is applied only in the sensitive growth stages and a certain level of deficit irrigation can be applied on the growth stages that are not sensitive to water stress. Worldwide these types of research are common to identify crops sensitive growth stages in water scare areas. For instance, Zhang *et al*. (2019) try to identify response of maize yield components to growth stage-based deficit irrigation and reported that water deficit applied during the maturity stage had a larger impact on maize yield compared with water deficit applied during the vegetative stage. Jin *et al*. (2020) also try to identify The responses of maize yield and water use to growth stage based irrigation on the Loess Plateau in China and reported that when irrigation water is limited, high WUE can be achieved if it is applied at vegetative growth stages, while high yield can be achieved if more available water is applied at tasseling stage.

A critical method for managing water limitations at the farm level is through deficit irrigation, i.e. the application of water below crop water requirements (Fereres and Soriano, 2007). Crops under deficit irrigation will experience some level of water stress during the season and often have lower yields than fully irrigated plants. Multiple studies show that targeting irrigation applications to the most sensitive growth stages increases crop productivity per unit of water applied (Geerts and Raes, 2009). In northeastern Colorado, for example, Fang et al. (2014) showed, using the Root Zone Water Quality Model (RZWQM) that in water limited scenarios high corn yield and water use efficiency can be achieved if the crop is fully irrigated in the vegetative stages and deficit irrigation takes place in the reproductive stages.

Crops are more sensitive to water stress when they starts to flower and mature and as a whole mid growth stages of most crops are sensitive to water stress. Different researchers try to identify crops sensitive growth stages and they conclude that mid stages or flowering and maturity stages are sensitive to water stress. For instance, Agyare *et al*. (2013), Song *et al*. (2019), Zhang *et al*. (2019) and Jin *et al*. (2020) conduct growth stage based deficit irrigation on maize and they conclude that mid stages or the stage that plants start to flower, forming seed and matures are the most sensitive stages to water stress.

3. MATERIALS AND METHODS

3.1. Description of Experimental Site

The study was conducted at Wondo Genet Agricultural Research Center, Koka research station, Lome Woreda Ethiopia. The site is situated in the Central Rift Valley of Ethiopia. The site is geographically located between 8^{O}34'36"to 8^{O}36'24' N latitude and 39^{O}02'12" to 39^{O}10'48" E longitude at mean altitude of 1602 m.a.s.l. It is at about 77 km from Addis Ababa on the way to Hawassa. Loam and clay loam soil textures were the dominant soils of the area.

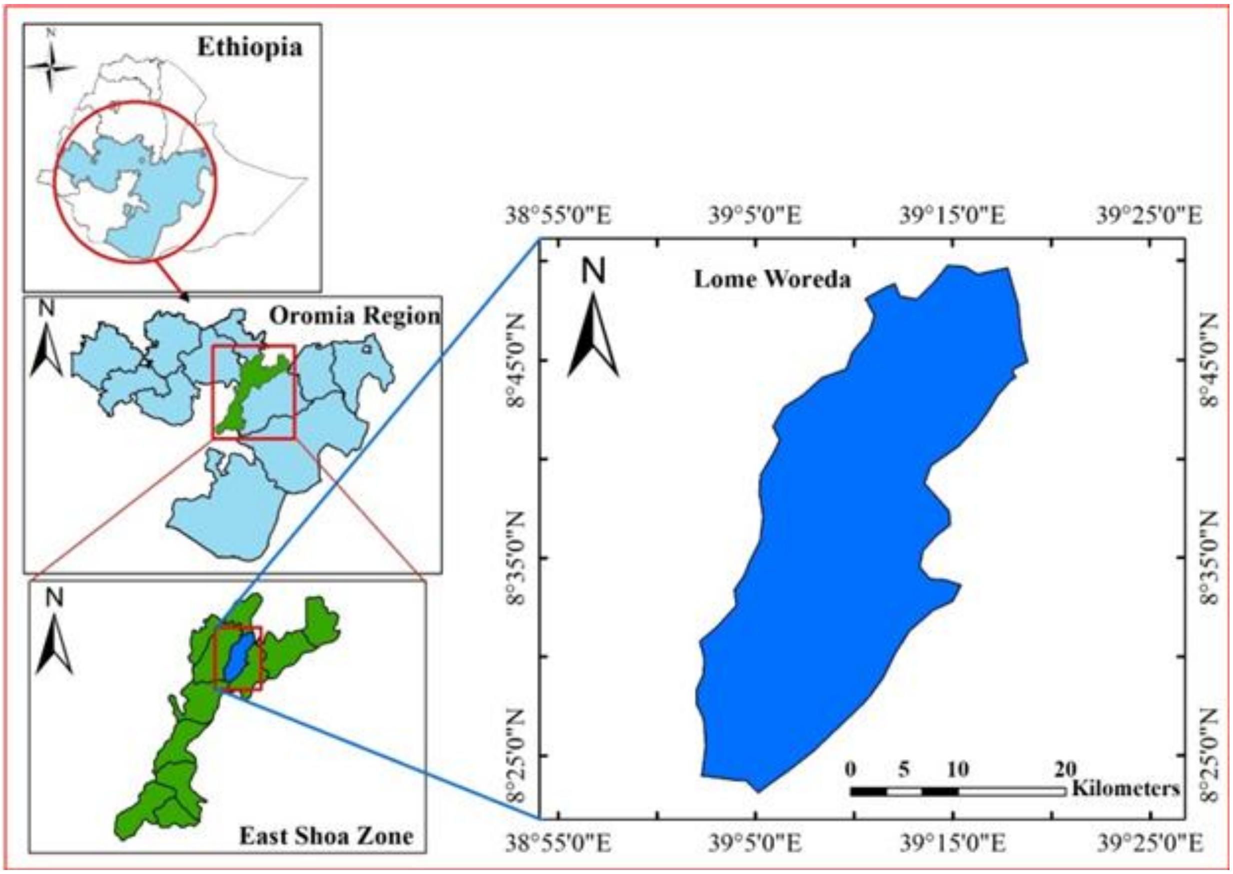

Figure 1: Map of the Study Area

The climate of the area was characterized as semi-arid with uni-modal low and erratic rainfall pattern with annual average of 831.1 mm. About 71.2% of the total rainfall of the area falls from June to September. The mean maximum temperature varied from 26.3 to 30.9C while mean minimum temperature varied from 11.0 to 15.5°C (Table 1).

Table 1: Climatic data of the study area

Month	Tmax (^{o}c)	Tmin (^{o}c)	Relative humidity (%)	Wind speed (m/s)	Sunshine hour (%)	Rainfall (mm)
January	27.4	11.3	54	4.04	75	13.5
February	28.3	12.6	52	4.08	76	26.1
March	30	14.4	51	4.64	74	51.5
April	30.3	15.2	54	3.8	71	58.5
May	30.9	15.1	53	3.98	68	48.5
June	30	15.5	57	4.91	65	72.7
July	26.7	15	67	4.3	54	212.7
August	26.3	15.1	68	3.15	53	202.4
September	27.8	14.9	66	2.3	57	104.3
October	28.3	12.7	56	3.5	73	21.1
November	27.4	11.3	52	4.09	83	9.9
December	26.1	11	54	4.19	76	9.9

Source: Lome Woreda meteorological station

3.2. Experimental Design and Procedure

3.2.1. Land preparation

The study was conducted at Wondo Genet Agricultural Research Center (WGARC) Koka experimental site during 2020/2021 dry season. The experimental field was ploughed on 27thNovember, 2020 with tractor. Then, the land was leveled so that it is suitable for laying the experiment. After the land is leveled, ridge preparation had been done with each block.

3.2.2. Experimental design and layout

Maize seed of Melkassa II variety, a crop that is commonly grown in dry areas under moisture stress condition were sown on the experimental field after land was prepared well. The treatments include optimum irrigation and different level of stress at different growth stages. Treatments were arranged in Randomized Completely Block Design (RCBD) with three replications, following the design by Gomez and Gomez (1984). Blocking was designed across the slope to check water flow condition and soil fertility effect in the experiment. Treatments were arranged in each of the three blocks randomly based on randomization using SAS (Statistical Analysis System 9.3) software for randomized completely block design.

The treatments were different level of irrigation water, one full irrigation as a control and other 8 treatments were deficit at different level.

Treatments

T_1:- Full irrigation of 100%ETc (control)
T_2:- 75%ETc at dev't stage (25% deficit only at dev't stage)
T_3:- 50%ETc at dev't stage (50% deficit only at dev't stage)
T_4:- 75%ETc at mid stage (25% deficit only at mid stage)
T_5:- 50%ETc at mid stage (50% deficit only at mid stage)
T_6:- 75%ETc at late stage (25% deficit only at late stage)
T_7:- 50%ETc at late stage (50% deficit only at late stage)
T_8:- 75%ETc at all stage (25% deficit at all stage)
T_9:- 50%ETc at all stage (50% deficit at all stage)

Layout of the experiment was prepared according to the experimental design. All the experimental area was subdivided into three blocks including free space between blocks and field channels according to the dimensions provided in the layout of the experiment (Fig. 2). Each block was then subdivided to nine experimental units and free space between each plot, maintaining the desired spacing. The plot size was 15.75 m^2, (4.20 m length and 3.75 m width) by taking into account land availability in the experimental site. There were twenty seven experimental units. The distance between each plot and replication were 2m and 4m, respectively. Furrow irrigation was used and two seeds together were sown at 30cm spaces and thinning activities were done after the plant is well established. Each plot had 5 ridges and furrow length of 4.2m. Once the layout was prepared, main canal outside the experimental field and field channels constructed for the conveyance of irrigation water. Prior to sowing seeds, each plot was irrigated as pre-irrigation to create favorable condition for seed germination.

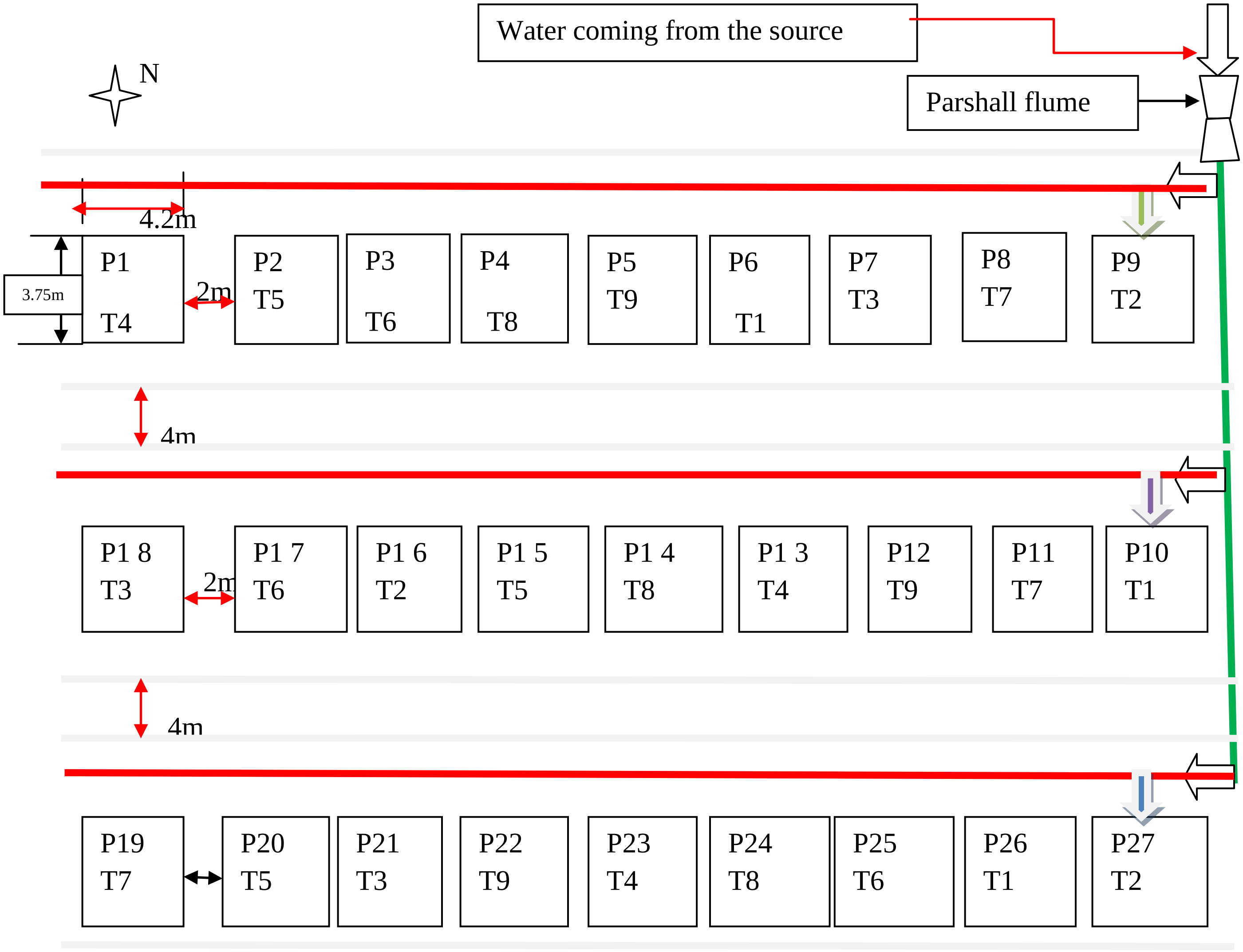

Figure 2: Layout of the experiment

3.3. Irrigation Scheduling

The irrigation scheduling was done based on the optimum irrigation treatment and other treatments were receiving lower water than the control treatment with their level of moisture stress. The control treatment (optimum irrigation) was irrigated based critical moisture deficit for the crop irrigating to refill soil to field capacity. However, stressed treatments were receiving lower amount based on the stress level with the same irrigation interval as control treatment.

Irrigation scheduling was done based on the metrological, soil and crop data using CROPWAT irrigation software and the level of moisture depletion were monitored by soil moisture determination using gravimetric soil sampling. Soil physical data of the experimental site were analyzed from soil sample collected from experimental site.

Pre irrigation and two common irrigations at the early germination time were done for better establishment of the crop. Parshall flume of size 2 inch was used to measure the amount of water to be applied for each treatment. Based on the volume of water and the discharge capacity of Parshall flume the time required to irrigate a given treatment was calculated for different head available at field condition.

3.4. Agronomic Practice

Melkassa – II maize variety was used for this experiment, a crop that is commonly grown in dry areas under moisture stress condition. Planting was done on 7th December 2020 with plant spacing of 75 cm between rows and 30cm between plants. Two seeds were planted per hole. The crop attained 100% germination 13 days after planting and was thinned to 1 plant per stand three weeks after planting. NPS fertilizer was applied at the rate of 150 kg/ha at planting by placing the fertilizer 6-8 cm away from the hole where the seeds were placed. Top-dressing was carried out at five weeks after planting with urea fertilizer. The total amount of nitrogen applied from the two fertilizer applications was 100 kg N/ha according to the recommended rate of fertilizers for the area (Getachew and Jens, 2014).

Hoeing and Weeding was done five times before harvesting. *Celecron* insecticide was sprayed four times to control stem borers. The crop matured for harvest at about 126 days after planting and it was harvested by cutting the aboveground biomass. After cutting, the crop was left on the field for one week for further drying before weighing and removing the cob maize from the stalks. The maize was dried in the open sun for 5 days, then threshed and weighed.

3.5. Determination of Soil Physical Properties

3.5.1. Soil texture and bulk density

For textural analysis, disturbed soil samples were collected from five depths 0-15 cm, 15-30 cm, 30-60cm, 60-90cm and 90-105cm using soil auger at three locations along the diagonal of the experimental block. Hydrometer method was employed for analyzing particle size distribution and the textural class was determined based on percent of sand, silt and clay in textural triangle.

The soil bulk density was determined from undisturbed soil samples using core sampler for collection of the samples at similar location with sample collected for textural analysis. The core sample volume is known and the oven dry weight were computed divided to volume of core sample to determine the bulk density using the following equation (Jaiswal, 2003).

$$\rho_b = \frac{W_s}{V_c} ------------------------------ (3.1)$$

Where: - ρ_b is soil bulk-density (g/cm^3), W_s is mass of dry soil (g) and V_c is volume of soil in the core (cm^3).

3.5.2. Soil moisture determination

Determinations of moisture content of the soil were carried out during the experiment using gravimetric method since it is the only available method in the experimental site. Other soil moisture measuring method like neutron probe, gypsum block, tensiometer and the like were not available in the experimental site. The soil sample were collected using soil auger at different depth to root depth based on the growth stage (0-15cm, 15-30cm, 30-60cm and 60-90cm) for monitoring moisture content of the soil until it lower to critical moisture content in the control treatment. The collected samples were weighted using sensitive balance and oven dried at 105^{O}C until the change in weight is constant. Then the oven-dried samples were weighed to determine the water content of the soil. The water content in the soil was determined in weight base using the following equation (Jaiswal, 2003).

$$\theta_m = \frac{(W_w - W_d)}{W_d} \times 100 ----------------------------(3.2)$$

Where: - θ_m is water content on weight basis (%),

W_d is weight of dry soil (g), and

W_w is weight of wet soil (g).

The volumetric water content was calculated using the following formula.

$$\theta_v = \theta_m \times \frac{\rho_b}{\rho_w} ------------------------------(3.3)$$

Where: -$\theta_v$is volumetric moisture content in (%);

ρ_b issoil bulk density (g/cm^3), and

ρ_w is water density (g/cm^3)

3.5.3. Field capacity and permanent wilting point

Soil sample for determination of moisture content at field capacity (FC) and permanent wilting point (PWP) from five depths 0-15 cm, 15-30 cm, 30-60cm, 60-90 cm and 90 – 105 cm were collected from three locations of the experimental plot at similar locations where the soil was collected for texture and bulk density. Moisture content at field capacity and permanent wilting point were done using pressure plate apparatus to adjust the suction force at field capacity (1/3 bar) and permanent wilting point (15 bar) and oven dry to determine the weight of water.

The moisture content in weight base was converted to volumetric base by multiplying it with bulk density. The total available water (TAW) was calculated based on the data of FC, PWP and root depth as using the following equation.

$$\mathrm{TAW} = 1000 \sum (\theta_{\mathrm{FC}} - \theta_{\mathrm{PWP}})\, \mathrm{Z_d} ----------------------(3.4)$$

Where: - TAW is the total available water in the root zone (mm/m)

Z_d is root depth (m)

θ_{FC} is volumetric moisture content at field capacity (m^3/m^3)

θ_{PWP} is volumetric moisture content at permanent wilting point (m^3/m^3)

3.6. Determination of Crop Water Requirement

Crop water requirement is the depth of water needed to meet the loss through evapotranspiration of a disease free crop growing in large fields under non-restricting soil conditions including soil water and fertility and achieving full production potential under the given growing environment. It was estimated using the following equation (Allen *et al.*, 1998).

$$ET_C = K_C \; x \; ET_o ------------------------------(3.5)$$

Where: - ET_C is crop evapotranspiration which is about equivalent with crop water requirement

Kc is crop coefficient, which is a function of crop type and stage of growth

ET_O is reference evapotranspiration

Referenceevapotranspiration (ET_O), which is the rate of evapotranspiration from reference surface with no short of water, were estimated from climatological data obtained from Woreda Agricultural Office using Penman-Monteith approach which is used in CropWat 8.0 model.

$$\mathrm{ET_O} = \frac{0.408\Delta(\mathrm{R_n} - \mathrm{G}) + \gamma\left(\frac{900}{\mathrm{T}+273}\right)\mathrm{u_2}(\mathrm{e_s} - \mathrm{e_a})}{\Delta + \gamma(1 + 0.34\mathrm{u_2})} ---------------(3.6)$$

Where: - ETo is reference evapotranspiration (mm/day), R_n is net radiation at the crop surface ($MJ/m^2/day$), G is soil heat flux density ($MJ/m^2/day$), T is mean daily air temperature at 2 m height (°C), U_2 is wind speed at 2 m height (m/s), e_s is saturation vapor pressure (kPa), e_a is actual vapor pressure (kPa), e_s - e_a is saturation vapor pressure deficit (kPa), Δ is slope of vapor pressure curve (kPa/°C), $\gamma$is psychometric constant (kPa/°C).

The equation uses standard climatologically records of solar radiation (sunshine), air temperature, humidity and wind speed. To ensure the integrity of computations, the weather measurements should be made at 2 m (or converted to that height) above an extensive surface of green grass, shading the ground and not short of water.

3.7. Determination of Net Irrigation Water Requirement

Crop water requirement as defined by Doorenbos and Pruitt (1977) as "The depth of water needed to meet the water loss through evapotranspiration of a disease free crop, growing in large fields under non-restricting soil conditions including soil water and fertility and achieving full production potential under the given growing environment". Determination of net irrigation water requirement was done based on the water holding capacity of the soil from critical depletion level to field capacity in the effective root depth for 100% ETC treatment based on the following formula.

$$I_n = (FC - PWP) * P * \rho_d * R_d - Pe - (3.7)$$

Where: - I_n: net irrigation water requirement (mm) FC: Mass base moisture content at field capacity (decimal) PWP: Mass base moisture content at permanent wilting point (decimal) P: Allowable soil moisture depletion level for wheat (decimal) ρ_d: Soil bulk density (g/cc) R_d: Root depth (mm) P_e: Effective precipitation (mm)

3.7.1. Effective rainfall

Effective rainfall is the water retained in the root zone and obtained by subtracting the sum of runoff, evaporation and deep percolation from total rainfall. If other information is not available like runoff, evaporation and deep percolation it can be calculated by:

$$P_e = 0.8P - 25, when\ P > 75\ mm - (3.8)$$

$$P_e = 0.6P - 10, when\ P < 75\ mm, -------------------------(3.9)$$

Where: - P is precipitation

However, there was no rainfall during the experiment season and effective rain fall was not considered.

3.8. Irrigation Efficiency and Gross Irrigation Water Requirement

Field irrigation application efficiency (e_a) is the ratio of water directly available to the crop to water received at the field inlet. It is affected by the rate of supply, infiltration rate of the soil, storage capacity of the root zone and land leveling. Water is mostly lost through deep percolation at the head end and through runoff at the tail end in furrow irrigation and deep percolation and evaporation in basin. Furrow irrigation could reach a field application efficiency of 65% when it is properly designed, constructed and managed. The average ranges vary from 50 to 70%. However, a more common figure is 60% (FAO, 2002**b**). Moreover, field application efficiency of heavy soil is 60 % (Chandrasekaran et al., 2010). For this particular experiment, irrigation efficiency was taken as 60%, which is common for surface irrigation method in furrow irrigation. Based on the net irrigation depth and irrigation application efficiency, the gross irrigation water requirement was calculated based on the following formula.

$$I_g = \frac{d_n}{E_a} ------------------------------(3.10)$$

Where: - I_g: gross irrigation (mm)

$d_{n:}$ net irrigation depth (mm)

E_a: irrigation application efficiency

3.9. Discharge Measurement using Parshall Flume

Parshall fume operates very satisfactorily with a loss of head much less than required for a weir, and under normal operating conditions, the discharge can be determined with an accuracy of 2 to 5 percent (Skogerboe et al., 1966). Out of the experimental field, 2-inch Parshall flume made from metal was set at 10 m away from the nearest plot to it in the main canal. The Parshall flume was set inside straight and uniform section of the canal. The leveling in all direction in the converging part was checked. Leveling for the diverging part was checked only across the waterway, as the base of the diverging part of Parshall flume was slightly slope upward. The bottom of the converging part was set 3 cm above the bed of the canal in the upstream side and stone riprap was put in the downstream side below the canal bottom level to minimize the erosion downstream of Parshall flume. Ruler was used at a point two-thirds the lengths of the entrance section upstream from the flume crest. The gross irrigation calculated were finally applied to experimental plots based on the treatment. Volumes of water applied for every treatment were determined based by multiplication of plot area and gross irrigation requirement. The irrigation time required to irrigate each treatment was calculated based on the discharge head relation of 2-inch Parshall flume. Since the discharge level may vary at field condition, the time required to irrigate each treatment were calculated from 5 cm to 10 cm head levels.

3.10. Data Collection

Maize growth performance, yield and yield components at different stages were collected. The data includes plant height, leaf area, cob length, cob diameter, ear height, cob weight with seed, cob weight without seed, number of grains, thousand seed weight, grain yield per hectare, and dry biomass.

Plant height (cm): These were taken from a sample of ten randomly selected maize plants marked within each plot. When the plant reaches at maturity stage, the plant height was measured from the ground level to the top-most leaf. The mean from the ten plants were then taken as the mean plant height.

Leaf area (cm^2): The leaf area was determined by the non-destructive length x width methodusing the relation (Francis *et al.*, 1969)

$$LA = K\,(L \times W) ----------------------------(3.11)$$

Where LA – leaf area, L – length of the leaf, W – width of the leaf and K – constant = 0.75 for maize (McKee, 1964),

Ear height (cm): These were taken from a sample of ten randomly selected maize plants marked within each plot. When the plant reaches at maturity stage, the ear height was measured from the ground level to the first leaf formation of maize. The mean from the ten plants were then taken as the mean ear height.

Cob length and cob diameter (cm): when the plants full matured, cob length and cob diameter were measured from the samples marked to measure plant height. The mean from the ten plants were then taken as the mean cob length and cob diameter.

Cob weight with and without seed (gm): after the cob length and cob diameter were measured cob weight with seed and without seed were measured by using sensitive balance. The mean from the ten plants were then taken as the mean cob weight with seed and without seed.

Thousand grain weight (gm): One thousand numbers of grains were counted from each plot and weighed.

Above Ground Dry Biomass Yield (t/ha): Fifteen plants from the net plot area were harvested at physiological maturity and weighed after sun drying to a constant weight.

Grain yield (kg/ha): The total numbers of plants in the net plot were harvested and grain yield per plot were measured using electronic balance and then adjusted to 12.5% moisture and converted to hectare basis.

Harvest index (HI) (%):- is a ratio of economical yield (grain yield per hectare) to biological yield (total aboveground biomass per hectare) were determined using the fallowing formula:-

$$\text{Harvest index} = \frac{\text{Economical Yield}}{\text{Biological yield}} \text{x}100 ------------------ (3.12)$$

Water use efficiency (WUE) (%):- is the ratio of economical yield to amount of water used. WUE were computed based on grain yield and total aboveground biomass yield obtained and the total amount of water used using the following formula.

$$\text{Water use efficiency} = \frac{\text{Economical Yield}}{\text{Amount of water used}} \text{x}100 --------------- (3.13)$$

Yield Response factor: - it is the relative yield decrease to relative evapotranspiration deficit using the following equation (FAO 2002).

$$K_y = \frac{1 - \frac{\mathrm{Y_a}}{\mathrm{Y_m}}}{1 - \frac{ET_a}{ET_m}} ------------------------------ (3.14)$$

Where: - Y_a = actual yield (kg/ha)

Y_m = maximum yield (kg/ha)

ET_a = actual evapotranspiration (mm)

ET_m = maximum evapotranspiration (mm)

K_y = yield response factor

3.11. Data Analysis

The collected data were statistically analyzed using statistical analysis system (SAS version 9.3 statistical package). Mean separation was executed using least significant difference (LSD) at 5% probability level to compare the statistical difference among treatment means. Correlation analysis was also used to see the association of Maize growth parameters, yield component, yield and water use efficiency.

4. RESULT AND DISCUSSION

4.1. Selected Physico-Chemical Properties of Soils of the Experimental Site

The result of the soil analysis from the experimental site showed that the average composition of sand, silt and clay percentages were 16.0, 35.8 and 49.0%, respectively. Thus, according to the USDA soil textural classification, the soil texture had been classified as clay soil. The top soil surface had slightly lower bulk density (1.16 g/cm^3) than the subsurface (1.18 g/cm^3) this might be due to high organic matter contents in the top soil surface and the average bulk density was 1.17 g/cm^3 (Table 2).

Moisture content at field capacity for the experimental site soil was 34.0% and Moisture content at permanent wilting point was also 17.1%.The mean value of total available water (TAW) which is the amount of water that a crop can extract from its root zone was found to be 170 mm per meter depth of soil (Table 2).

Table 2: Physico-chemical properties of soils of the experimental site

Soil property		Soil depth				
		0-15	15-30	30-45	45-60	Average
Particle size	Sand (%)	18	18	20	8	16
distribution	Silt (%)	38	36	34	35	35.8
	Clay (%)	44	46	58	48	49
Textural class		Clay	Clay	Clay	Clay	Clay
Bulk density (g/cm^3)		1.16	1.17	1.17	1.18	1.17
FC (Vol %)		34.4	34.8	33.6	33.2	34.0
PWP (Vol %)		17.5	16.5	16.7	17.5	17.1
TAW (mm/m)		165	168	172	175	170
pH						7.3
EC (ds/m)						0.17
OM (%)						2.15

Soil pH was found to be at the optimum value (7.3) for maize and other crops. The value of EC (0.17 ds/m) was lower considering the standard rates in literature (Landon, 1991). Soil salinity was not a problem at the time. Generally, according to USDA soil classification, a soil with electrical conductivity of less than 2.0 dS/m at 25°C and pH less than 8.5 are classified as normal soil. Therefore, the soil of the study area was normal soil. The weighted average organic matter content of the soil was about 2.15%. As Staney and Yerima (1992) reported, the organic matter content of the soil is medium class (Table 2).

4.2. Crop Water Requirement of Maize

Seasonal crop water requirement determined based on the seasonal water application depth from germination to harvest, vary based on the treatment moisture level. Common irrigation depth of 38.3 mm was applied for all treatments after germination. The highest and minimum seasonal crop water requirement obtained was 726.3 mm and 382.6 mm at 100% ET_C at all growth stages and 50% ET_C at all growth stages respectively (Table 3).

Table 3: Seasonal net irrigation water depth applied for each treatment

Treatments	Common irrigation (mm)	Irrigation during treatment application (mm)	Total irrigation (mm)
100% ETc @ all	38.3	688.0	726.3
75% ETc @ dev	38.3	645.4	683.7
50% ETc @ dev	38.3	612.9	651.2
75% ETc @ mid	38.3	606.0	644.3
50% ETc @ mid	38.3	461.0	499.3
75% ETc @ late	38.3	635.4	673.7
50% ETc @ late	38.3	555.7	594.0
75% ETc @ all	38.3	516.2	554.5
50% ETc @ all	38.3	344.3	382.6

4.3. Effects of Growth Stage Based deficit irrigation on Growth Parameters of Maize

4.3.1. Plant height

Plant height was significantly affected (p<0.01) due to different level of moisture stress at different growth stages. The highest plant height was obtained from the control treatment that gained 100% ETc at all growth stages and has no significance difference from treatments that received 75% ETc at development and late growth stages. The minimum plant height was obtained from the treatment that received 50% ETc at all growth stages and it was statistically inferior from all other treatments. Plant height was reduced as stress level increased from 100% ETc to 50% ETc on the treatments that were stressed at all growth stages and mid growth stage. However, plant height was not reduced as the stress level increased from 100% ETc to 50% ETc on the treatments that were stressed at development and late growth stages.

Maximum plant height of 193.5 cm was obtained from the control treatment that gained 100% ETc at all growth stages and which was statistically similar with that of treatments that received 75% ETc at development and late growth stages that obtained 192.1 and 191.1 cm, respectively. On the other hand, minimum plant height of 161.9 cm obtained from the treatment that received 50% ETc at all growth stages (Table 4). The decrease in irrigation level from 100% ETc to 50% ETc leads to a decrease of 16.3% that stressed at all growth stages and 12.1% that stressed at mid growth stage in plant height.

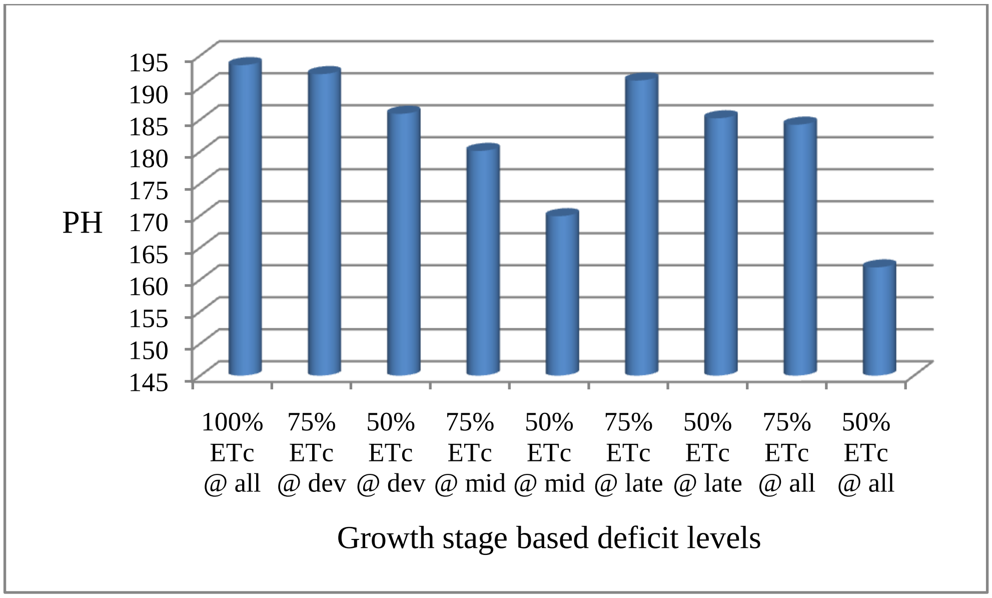

Figure 3: Effects of growth stage based deficit levels on plant height

The result showed that plant height was directly associated with the amount of irrigation water applied and inversely with the stress level. When the stress level increase plant height become shortest. This might be due to the adverse effects of deficit soil moisture stress on plant growth, development and yield which lead to Loss of turgidity leading to cell enlargement and stunted growth, decrease in photosynthesis due to decreased diffusion of CO_2 with the closure of stomata to conserve water and reduced leaf area. Similar studies also showed that plant height is affected due to growth stage based moisture stress in different crops. This finding is in line with the results reported by Istanbulluoglu et al. (2002), Çakir (2004), Karasu et al. (2015) and Kuscu and Demir (2012).

4.3.2. Ear height

Growth stage based deficit irrigation were significantly affected ($p<0.01$) ear height. The highest ear height was obtained from the control treatment that gained 100% ETc at all growth stages and has no significance difference from treatments that received 75% ETc at development and late growth stages and 50% ETc at development stage. The minimum ear height was obtained from the treatment that received 50% ETc at mid growth stages and has no significant difference from treatments that received 75% and 50% ETc at all growth stages. Ear height was reduced as stress level increased from 100% ETc to 50% ETc on the treatments that were stressed at all growth stages, development and mid growth stage. However, plant height was not reduced as the stress level increased from 100% ETc to 50% ETc on the treatments that were stressed at late growth stages.

Maximum ear height of 92.3cm was obtained from the control treatment that gained 100% ETc at all growth stages and which was statistically similar with that of treatments that received 75% ETc at development and late growth stages and 50% ETc at development stage that obtained 91.1, 90.8 and 88.1 cm, respectively. On the other hand, minimum ear height of 75.8 cm obtained from the treatment that received 50% ETc at mid growth stage and which was statistically similar with that of treatments that received 75% and 50% ETc at all growth stages that obtained 78.6 and 77.9 cm, respectively (Table 4).The decrease in irrigation level from 100% ETc to 50% ETc leads to a decrease of 15.6% that stressed at all growth stages and 14.8% that stressed at mid growth stage in ear height.

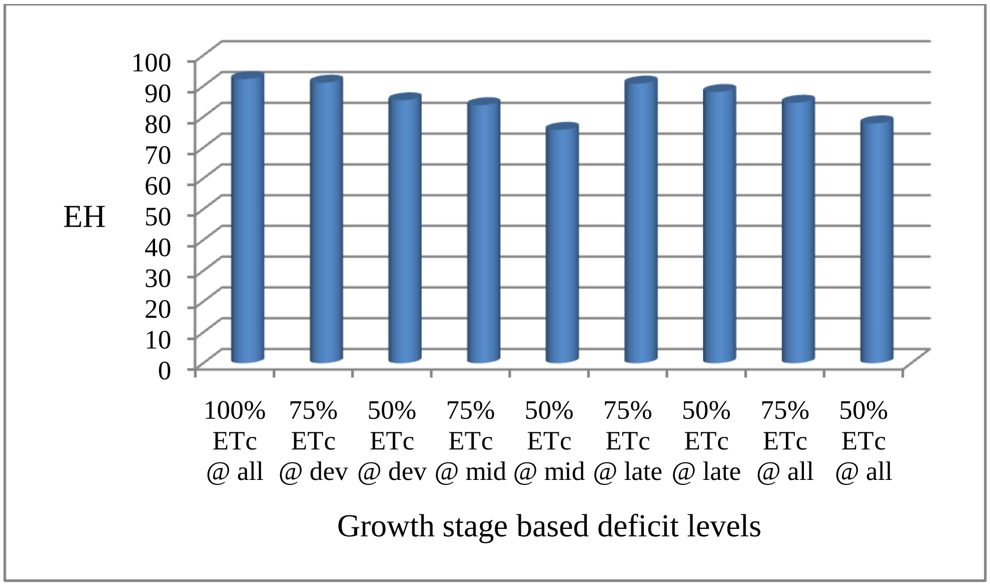

Figure 4: Effects of growth stage based deficit levels on ear height

The result showed that ear height was also directly associated with the amount of irrigation water applied and inversely with the stress level. When the stress level increase ear height become shortest. This might be due to decrease in photosynthesis due to decreased diffusion of CO_2 with the closure of stomata to conserve water and reduced leaf area. Similar studies also showed that ear height is affected due to growth stage based moisture stress in different crops. This finding is in line with Sohail *et al.* (2019) who reported highest ear height was recorded from full irrigation and lowest ear height was recorded from deficit irrigation (one irrigation missing at six leaves stage). Water stress in vegetative stage produced stunted maize plant due to high evapotranspiration rate and low photosynthetic rate, so ear was produced near the ground surface. Gonzalez *et al.* (2015), Golzardi *et al.* (2017) and Wang *et al.* (2017) reported the same result that deficiency of water before reproductive stage produce ear at low height from the ground.

4.3.3. Leaf length

Leaf length was significantly affected (p<0.01) due to different level of growth stage based moisture stresses. The highest leaf length was obtained from the control treatment that gained 100% ETC at all growth stages and has no significance difference from treatments that received 75% ETC at development and late growth stages. The minimum leaf length was obtained from the treatment that received 50% ETC at mid growth stage and has no significance difference from treatments that received 50% ETC at all growth stages. Leaf length was reduced as stress level increased from 100% ETC to 50% ETC in the treatments that were stressed at different growth stages.

Maximum leaf length of 77.6 cm was obtained from the control treatment that gained 100% ETC at all growth stages and which was statistically similar with that of treatments that received 75% ETC at development and late growth stages that obtained 75.8 and 77.3 cm, respectively. On the other hand, minimum leaf length of 60.2 cm was obtained from the treatment that received 50% ETC at mid growth stage and which was statistically similar with that of treatments that received 50%ETC at all growth stages that obtained 62.1 cm (Table 4). The decrease in irrigation level from 100% ETC to 50% ETC leads to a decrease of 20% that stressed at all growth stages and 22.4% that stressed at mid growth stage in leaf length.

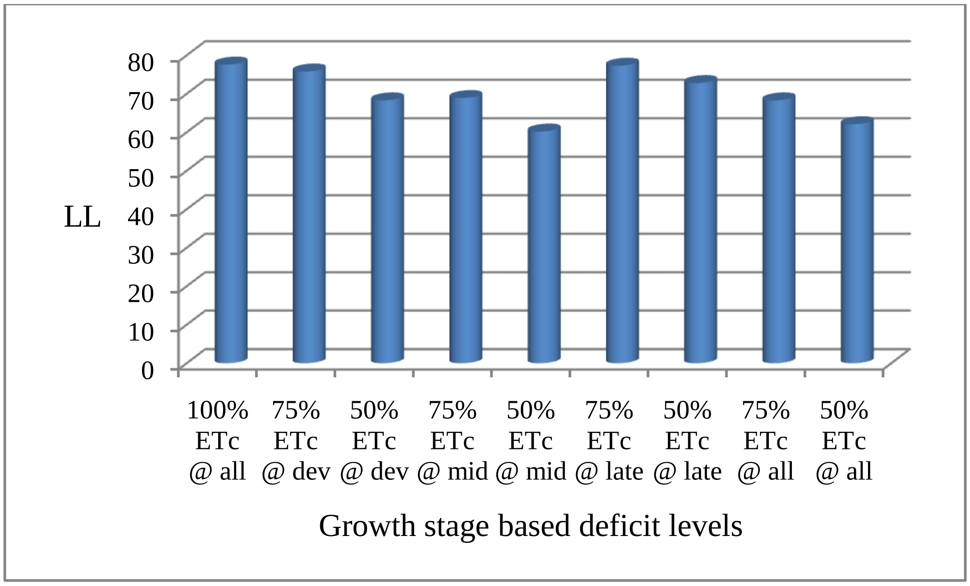

Figure 5: Effects of growth stage based deficit levels on leaf length

The result showed that leaf length was directly associated with the amount of irrigation water applied and inversely with the stress level. When the stress level increase leaf length become shortest. This might be due to the adverse effects of deficit soil moisture stress on plant growth, development and yield which lead to Loss of turgidity leading to cell enlargement and stunted growth. Similar studies also showed that leaf length is affected due to growth stage based moisture stress in different crops. This finding is in line with the results reported by Abrecht *et al.* (1993) who reported that, water stress delays leaf tip emergence and reduces leaf expansion in maize. Also Hussain *et al.* (2014) reported that plant water stress also retards leaf expansion and thus reduced leaf area, which is more important for decrease in crop growth.

4.3.4 Leaf width

Leaf width was also significantly affected ($p<0.01$) due to different level of growth stage based moisture stresses. The highest leaf width was obtained from the control treatment that gained 100% ETc at all growth stages and has no significance difference from treatments that received 75% and 50% ETc at development and late growth stages. The minimum leaf width was obtained from the treatment that received 50% ETc at all growth stages and has no significance difference from treatments that received 50% ETc at mid growth stage. Leaf width was reduced as stress level increased from 100% ETc to 50%

ETc on the treatments that were stressed at all growth stages and mid growth stage. However, leaf width was not reduced as the stress level increased from 100% Etc to 50% ETc on the treatments that were stressed at development and late growth stages.

Maximum leaf width of 9.3 cm was obtained from the control treatment that gained 100% ETc at all growth stages and which was statistically similar with that of treatments that received 75 and 50% ETc at development and late growth stages that obtained 9.3, 9.3, 9.2 and 9.1 cm, respectively. On the other hand, minimum leaf width of 7.5 cm was obtained from the treatment that received 50% ETc at all growth stages and which was statistically similar with that of treatments that received 50% ETc at mid growth stage that obtained 7.7 cm (Table 4). The decrease in irrigation level from 100% ETc to 50% ETc leads to a decrease of 19.4% that stressed at all growth stages and 17.2% that stressed at mid growth stage in leaf width.

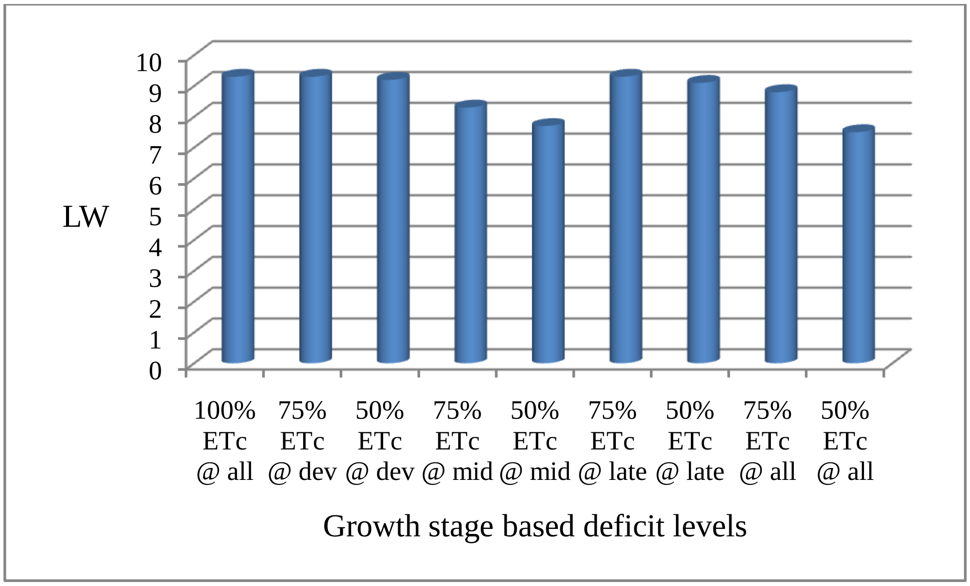

Figure 6: Effects of growth stage based deficit levels on leaf length

The result showed that leaf width was directly associated with the amount of irrigation water applied and inversely with the stress level. When the stress level increase leaf width become narrow. This might be due to the adverse effects of deficit soil moisture stress on plant growth, development and yield which lead to Loss of turgidity leading to cell enlargement and stunted growth, decrease in photosynthesis due to decreased diffusion of CO_2 with the closure of stomata to conserve water and reduced leaf area. Similar studies also showed that leaf width is affected due to growth stage based moisture stress in different crops. This finding is in line with the results reported by Hussain *et al.* (2014) who reported that plant water stress also retards leaf expansion and thus reduced leaf area, which is more important for decrease in crop growth. Traoré *et al.* (2000) and Abrecht *et al.* (1993) also reported that, water stress delays leaf tip emergence and reduces leaf expansion in maize, due to this leaf width of maize is reduced as moisture stress increases which is agreed with the current findings.

Table 4: Effect of growth stage based moisture stress on plant height, ear height, and leaf length and leaf width of maize

Treatments	plant height(cm)	Ear height(cm)	Leaf length(cm)	Leaf width (cm)
100% ETc @ all	193.5a	92.3a	77.6a	9.3a
75% ETc @ dev	192.1ab	91.1a	75.8ab	9.3a
50% ETc @ dev	185.9bc	85.4b	68.3d	9.2ab
75% ETc @ mid	180.1c	83.8b	68.9cd	8.3c
50% ETc @ mid	169.9d	75.8c	60.2e	7.7d
75% ETc @ late	191.1ab	90.8a	77.3a	9.3a
50% ETc @ late	185.2bc	88.1ab	72.8bc	9.1ab
75% ETc @ all	184.2bc	84.6b	68.3d	8.8b
50% ETc @ all	161.9e	77.9c	62.1e	7.5d
$LSD_{0.05}$	5.5	4.3	4.1	0.4
CV (%)	1.8	3.0	3.3	2.7

Means followed by different letters in a column differ significantly and those followed by the same letter are not significantly different at $p<0.05$ level of significance. NS: non significant at $p<0.05$.

4.3.5 Leaf area index

Leaf area index was also significantly affected ($p<0.001$) due to different level of growth stage based deficit levels. The highest leaf area index was obtained from the control treatment that gained 100% ETc at all growth stages and this has no significance difference from treatments that received 75% ETc at development and late growth stages. On the other hand, the minimum leaf area index was obtained from the treatment that received 50% ETc at all growth stages and has no significance difference from treatments that received 50% ETc at mid growth stage. Leaf area index was reduced as stress level increased from 100% ETc to 50% ETc in the treatments that were stressed at different growth stages.

Maximum leaf area index of 252.2 cm^2 was obtained from the control treatment that gained 100% ETc at all growth stages and which was statistically similar with that of treatments that received 75% ETc at development and late growth stages that obtained 245.6 and 251.3 cm^2, respectively. On the other hand, minimum leaf area index of 161.3 cm^2 was obtained from the treatment that received 50% ETc at mid growth stage and which was statistically similar with that of treatments that received 50%ETc at all growth stages (163 cm^2) (Table 5). The decrease in irrigation level from 100% ETC to 50% ETc leads to a decrease of 35.4% that stressed at all growth stages and 36% that stressed at mid growth stage in leaf area index.

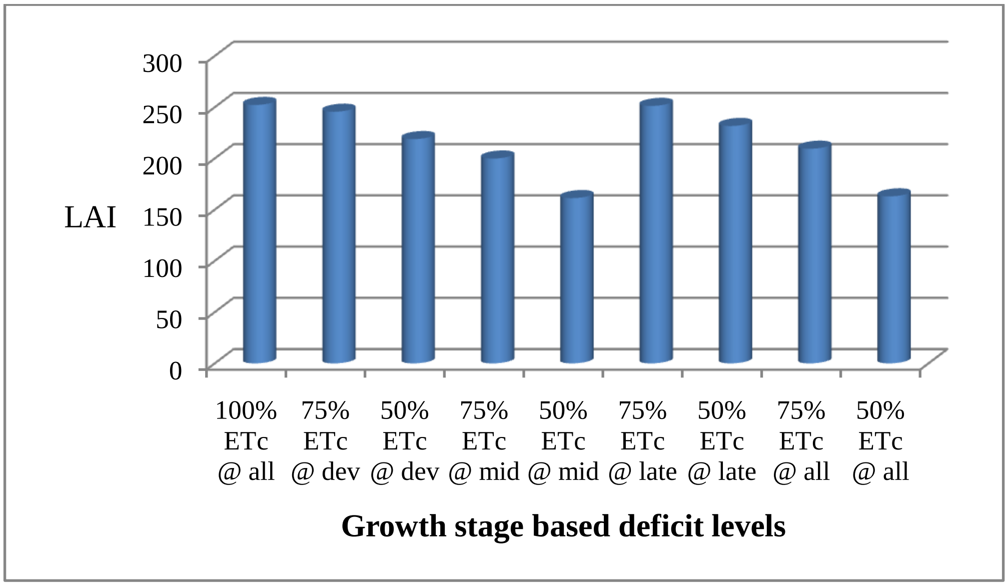

Figure 7: Effects of growth stage based deficit levels on leaf area index

The result showed that leaf area index was also directly associated with the amount of irrigation water applied and inversely with the stress level. Similar studies also showed that leaf area index is affected due to growth stage based moisture stress in different crops. This finding is in line with Sohail *et al.* (2019) who reported highest leaf area index was recorded from full irrigation and lowest leaf area index was recorded from deficit irrigation (one irrigation missing at twelve leaves stage). Water stress in vegetative stage decreased leaf area index due to more transpiration from plant canopy and evaporation from the soil surface. Tari, 2016 and Lopez *et al.* (2017) investigated that leaf area index is decreased by water stress in vegetative stages.

4.4. Effects of Growth Stage Based deficit irrigation on Yield Component of Maize

4.4.1. Cob length

Growth stage based deficit irrigation significantly affected ($p<0.01$) cob length of maize. The highest cob length was obtained from the control treatment that gained 100% ETC at all growth stages and has no significance difference from treatments that received 75% and 50% ETC at development and late growth stages and 75% ETC at mid growth stage. The minimum cob length was obtained from the treatment that received 50% ETC at all growth stages and has no significance difference from treatments that received 50% ETC at mid growth stage. Cob length was reduced as stress level increased from 100% ETC to 50% ETC on the treatments that were stressed at all growth stages and mid growth stage. However, cob length was not reduced as the stress level increased from 100% ETC to 50% ETC on the treatments that were stressed at development and late growth stages.

Maximum cob length of 17.4 cm was obtained from the control treatment that gained 100% ETC at all growth stages and which was statistically similar with that of treatments that received 75% and 50% ETC at development and late growth stages and 75% ETC at mid growth stage that obtained 16.9, 16.8, 16.5, 16.4 and 16.3 cm, respectively. On the other hand, minimum cob length of 11.7 cm was obtained from the treatment that received 50% ETC at all growth stages and which was statistically similar with that of treatments that received 50%ETC at mid growth stage that obtained 12.7 cm (Table 5). The decrease in irrigation level from 100% ETC to 50% ETC leads to a decrease of 32.8% that stressed at all growth stages and 27% that stressed at mid growth stage in cob length.

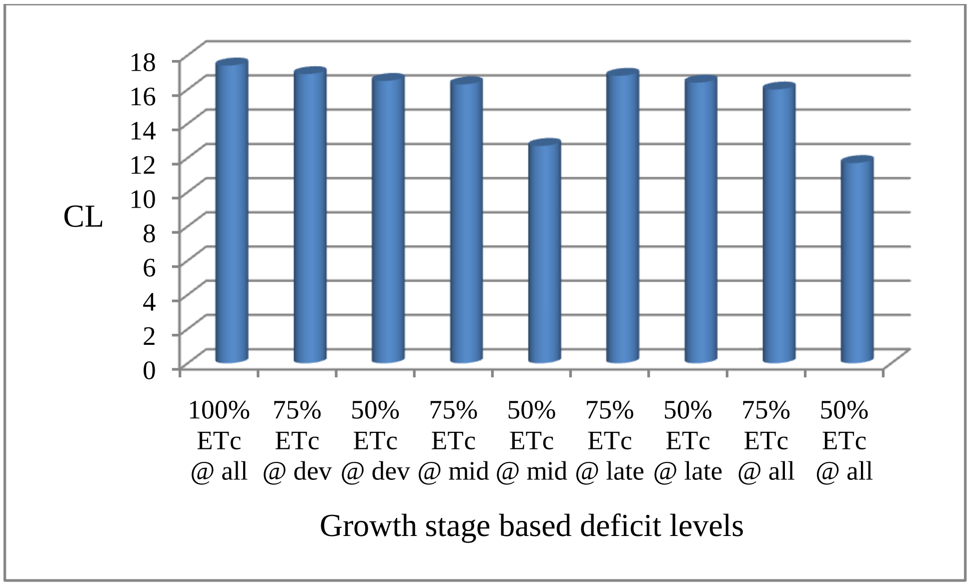

Figure 8: Effects of growth stage based deficit levels on cob length

Here also the result showed that cob length was directly associated with the amount of irrigation water applied and inversely with the stress level. When the stress level increase cob length become shortest. This might be due to decrease in photosynthesis due to decreased diffusion of CO_2 with the closure of stomata to conserve water and reduced leaf area. Similar studies also showed that cob length is affected due to growth stage based moisture stress in different crops. This finding is in line with Sohail *et al.* (2019) who reported highest ear length was recorded from full irrigation and lowest ear length was recorded from deficit irrigation (one irrigation missing at grain filling stage).Ear length was decreased when plant not receiving enough water in reproductive stage. Li *et al.* (2018), Mohammadi et *al.* (2017), and Ha BM (2017) reported that water stress in reproductive stage decreased ear length of maize due to low photosynthetic rate and high evapotranspiration rate.

4.4.2. Cob width

Growth stage based deficit irrigation were also significantly affected (p<0.01) cob width. The highest cob width was obtained from the control treatment that gained 100% ETc at all growth stages and has no significance difference from treatments that received 75% and 50% ETc at development and late growth stage. The minimum cob length was obtained from the treatment that received 50% ETc at all growth stages and has no significance difference from treatments that received 50% ETc at mid growth stage. Cob width was reduced as stress level increased from 100% ETc to 50% ETc on the treatments that were stressed at all growth stages and mid growth stage. However, cob width was not reduced as the stress level increased from 100% ETc to 50% ETc on the treatments that were stressed at development and late growth stages.

Maximum cob width of 16.2 cm was obtained from the control treatment that gained 100% ETc at all growth stages and which was statistically similar with that of treatments that received 75% at development and late growth stages and 50% ETc at development and late growth stages that obtained 16, 15.7, 15.7and 15.7 cm, respectively. On the other hand, minimum cob width of 12.6 cm was obtained from the treatment that received 50% ETc at all growth stages and which was statistically similar with that of treatments that received 50%ETc at mid growth stage that obtained 13.2 cm (Table 5). The decrease in irrigation level from 100% ETc to 50% ETc leads to a decrease of 22.2% that stressed at all growth stages and 18.5% that stressed at mid growth stage in cob width.

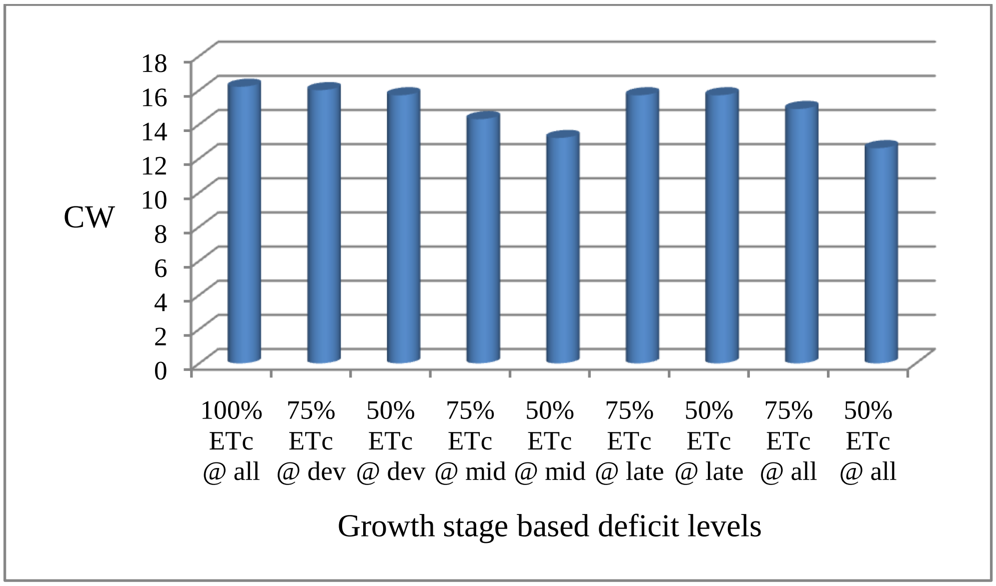

Figure 9: Effects of growth stage based deficit levels on cob width

The result showed that cob width was directly associated with the amount of irrigation water applied and inversely with the stress level. When the stress level increase cob width become narrow. This might be due to the adverse effects of deficit soil moisture stress on plant growth, development and yield which lead to Loss of turgidity leading to cell enlargement and stunted growth. Similar studies also showed that cob width is affected due to growth stage based moisture stress in different crops. This finding is also in line with Sohail *et al.* (2019) who reported highest ear diameter was recorded from full irrigation and lowest ear diameter was recorded from deficit irrigation(one irrigation missing at grain filling stage).

Table 5: Effect of growth stage based moisture stress on leaf area index, cob length and cob width of maize

Treatments	Leaf area index(cm^2)	Cob length (cm)	Cob width (cm)
100% ETc @ all	252.2a	17.4a	16.2a
75% ETc @ dev	245.6ab	16.9ab	16.0a
50% ETc @ dev	218.9cd	16.5ab	15.7ab
75% ETc @ mid	199.9e	16.3ab	14.3c
50% ETc @ mid	161.3f	12.7d	13.2d
75% ETc @ late	251.3a	16.8ab	15.7ab
50% ETc @ late	231.7bc	16.4ab	15.7ab
75% ETc @ all	209.5de	16.0ab	14.9bc
50% ETc @ all	163.0f	11.7d	12.6d
$LSD_{0.05}$	16	1.2	0.9
CV (%)	4.3	4.9	3.4

Means followed by different letters in a column differ significantly and those followed by the same letter are not significantly different at p<0.05 level of significance. NS: non significant at p<0.05.

4.4.3. Cob weight with seed

Cob weight with seed was significantly affected (p<0.01) due to different level of growth stage based deficit levels. The highest cob weight with seed was obtained from the control treatment that gained 100% ETc at all growth stages and has no significance difference from treatments that received 75% ETc at development and late growth stages. The minimum cob weight with seed was obtained from the treatment that received 50% ETc at all growth stages and has no significance difference from treatments that received 50% ETc at mid growth stage. Cob weight with seed was reduced as stress level increased from 100% ETc to 50% ETc in the treatments that were stressed at different growth stages.

Maximum cob weight with seed of 253.2 gm was obtained from the control treatment that gained 100% ETc at all growth stages and which was statistically similar with that of treatments that received 75% ETc at development and late growth stages that obtained 247.8 and 246.4 gm, respectively. On the other hand, minimum cob weight with seed of 123.3 gm was obtained from the treatment that received 50% ETc at all growth stages and which was statistically similar with that of treatment that received 50% ETc at mid growth stages that obtained 129 gm (Table 6). The decrease in irrigation level from 100% ETc to 50% ETc leads to a decrease of 51% that stressed at all growth stages and 49% that stressed at mid growth stage in cob weight with seed.

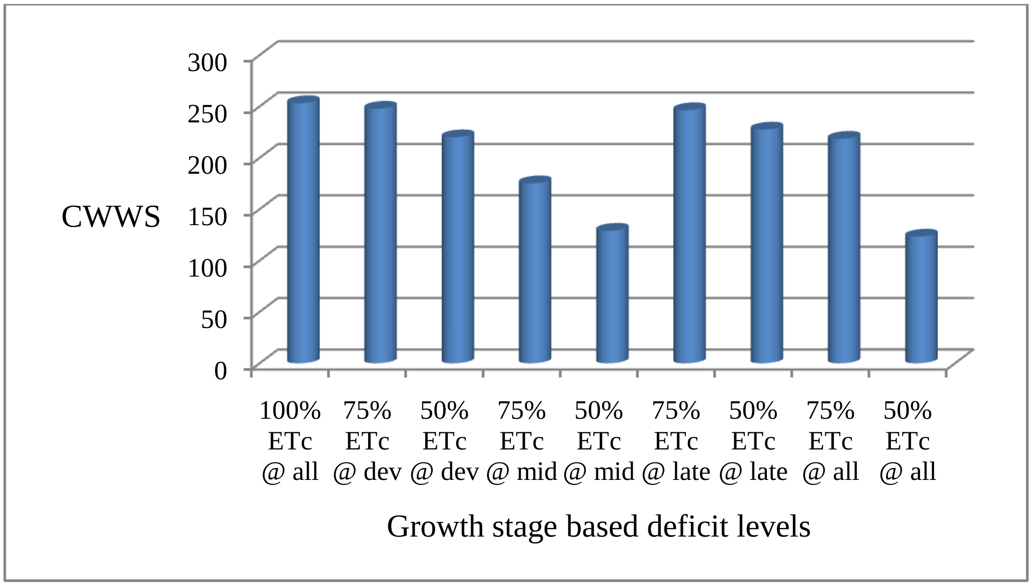

Figure 10: Effects of growth stage based deficit levels on cob weight with seed

The result showed that cob weight with seed was directly associated with the amount of irrigation water applied and inversely with the stress level. When the stress level increase cob weight with seed become small. This might be due to the adverse effects of deficit soil moisture stress on plant growth, development and yield which lead to Loss of turgidity leading to cell enlargement and stunted growth. Similar studies also showed that cob weight with seed is affected due to growth stage based moisture stress in different crops.

The result is in line with Meskelu et al. (2018) and Jemal and Agegnehu (2020) who reported that maximum cob weight with seed is obtained from conventional furrow irrigation methods that received more irrigation water. Yazar et al. (2012) reported that maximum mean maize grain weight per cob produced by complete irrigation which is agreed with the current finding. The study is also in line with Hanson et al. (2007) who reported that irrigation frequencies increased cob weight with seed.

4.4.4. Cob weight without seed

Cob weight without seed was also significantly affected (p<0.01) due to different level of growth stage based deficit levels. The highest cob weight without seed was obtained from the control treatment that gained 100% ETc at all growth stages and has no significance difference from treatments that received 75% ETc at development and late growth stages. The minimum cob weight without seed was obtained from the treatment that received 50% ETc at all growth stages and has no significance difference from treatments that received 50% ETc at mid growth stage. Cob weight without seed was reduced as stress level increased from 100% ETc to 50% ETc in the treatments that were stressed at different growth stages.

Maximum cob weight without seed of 60.8 gm was obtained from the control treatment that gained 100% ETc at all growth stages and which was statistically similar with that of treatments that received 75% ETc at development and late growth stages that obtained 60 and 58.5 gm respectively. On the other hand, minimum cob weight without seed of 32.4 gm was obtained from the treatment that received 50% ETc at all growth stages and which was statistically similar with that of treatment that received 50% ETc at mid growth stages that obtained 34.7 gm (Table 6). The decrease in irrigation level from 100% ETc to 50% ETc leads to a decrease of 46.7% that stressed at all growth stages and 42.9% that stressed at mid growth stage in cob weight without seed.

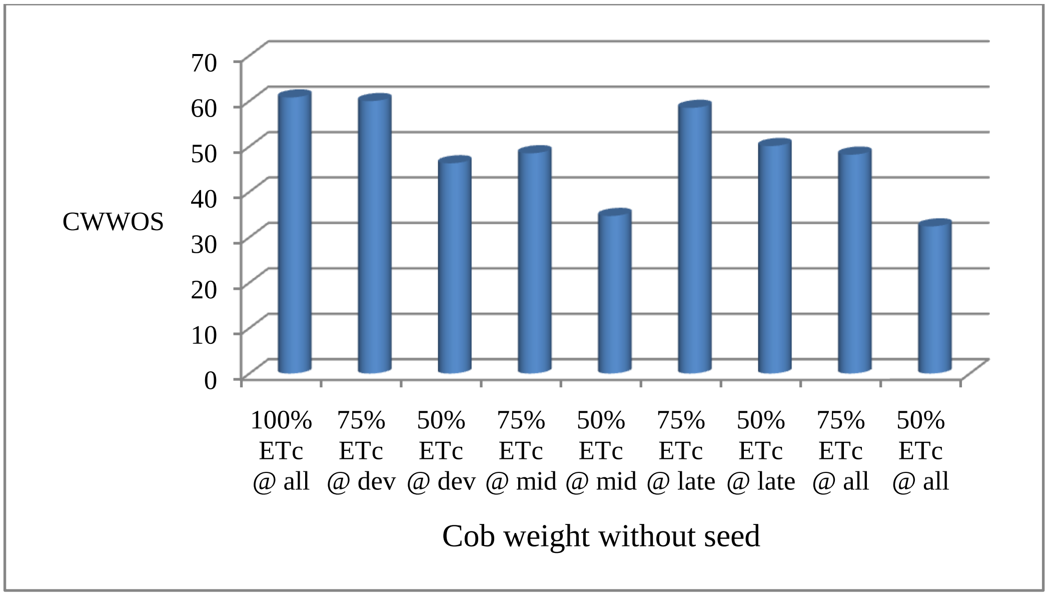

Figure 11: Effects of growth stage based deficit levels on cob weight without seed

The result showed that cob weight without seed was directly associated with the amount of irrigation water applied and inversely with the stress level. When the stress level increase cob weight without seed also become small. This might be due to decrease in photosynthesis due to decreased diffusion of CO_2 with the closure of stomata to conserve water and reduced leaf area. Similar studies also showed that cob weight without seed is affected due to growth stage based moisture stress in different crops. The result is in line with Meskelu et al. (2018) and Jemal and Agegnehu (2020) who reported that maximum cob weight without seed is obtained from conventional furrow irrigation methods that received more irrigation water.

Table 6: Effect of growth stage based moisture stress on cob weight with seed and cob weight without seed of maize

Treatments	Cob weight with seed (gm)	Cob weight without seed (gm)
100% ETc @ all	253.2a	60.8a
75% ETc @ dev	247.8a	60.0a
50% ETc @ dev	220.0b	46.3c
75% ETc @ mid	175.2c	48.5bc
50% ETc @ mid	129.0d	34.7d
75% ETc @ late	246.4a	58.5a
50% ETc @ late	227.5b	50.1b
75% ETc @ all	218.5b	48.2bc
50% ETc @ all	123.3d	32.4d
LSD(0.05)	17.0	3.4
CV(%)	4.9	4.1

Means followed by different letters in a column differ significantly and those followed by the same letter are not significantly different at $p<0.05$ level of significance. NS: non significant at $p<0.05$.

4.4.5. Thousand Seed weight

Growth stage based deficit irrigation significantly ($p<0.01$) affected thousand seed weight. The highest thousand seed weight was obtained from the control treatment that gained 100% ETC at all growth stages and has no significance difference from treatments that received 75% ETC at development and late growth stages. The minimum thousand seed weight was obtained from the treatment that received 50% ETC at all growth stages and has no significance difference from treatments that received 50% ETC at mid growth stage. Thousand seed weight was reduced as stress level increased from 100% ETC to 50% ETC in the treatments that were stressed at different growth stages.

Maximum thousand seed weight of 570 gm was obtained from the control treatment that gained 100% ETC at all growth stages and which was statistically similar with that of treatments that received 75% ETC at development and late growth stages that obtained

567.3 and 565 gm, respectively. On the other hand, minimum thousand seed weight of 353.2 gm was obtained from the treatment that received 50% ETc at all growth stages and which was statistically inferior from all other treatments (Table 7). The decrease in irrigation level from 100% ETc to 50% ETc leads to a decrease of 38% that stressed at all growth stages and 34.9% that stressed at mid growth stage in thousand seed weight.

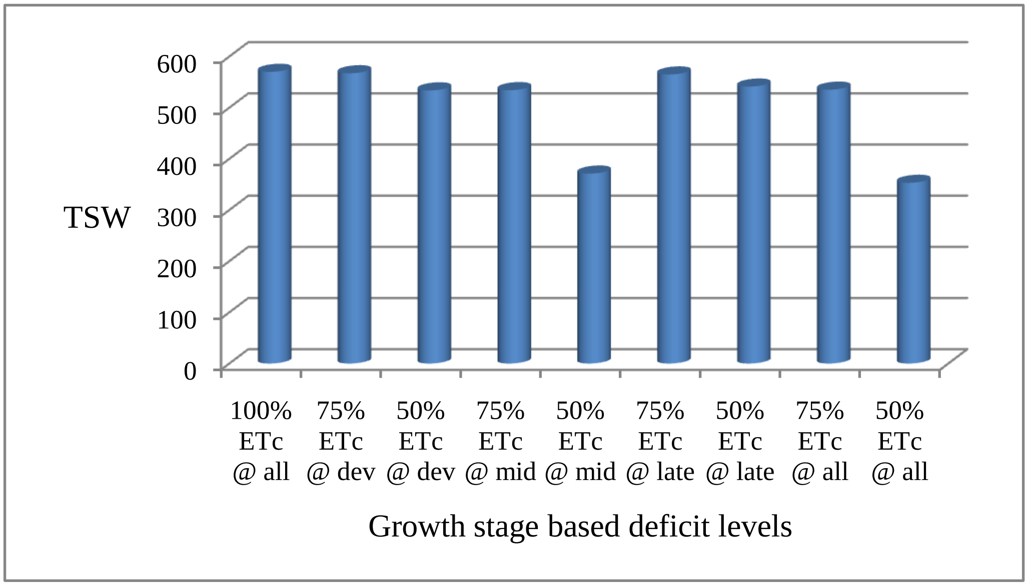

Figure 12: Effects of growth stage based deficit levels on thousand seed weight

Here the result showed that thousand seed weight was directly associated with the amount of irrigation water applied and inversely with the stress level. When the stress level increases thousand seed weight is small. This might be due to the adverse effects of deficit soil moisture stress on plant growth, development and yield which lead to Loss of turgidity leading to cell enlargement and stunted growth. Similar studies also showed that thousand seed weight is affected due to growth stage based moisture stress in different crops. The finding is agreed with the result of Mansouri-Far et al. (2010) reported that when the amount of water decreased, both the 1000 grain weight and grain yield were decreased. Reduction of 1000 grains weight due to soil water deficits have also been reported by Cakir (2004) and Karam et al. (2003).Similarly, Ogretir (1993) reported that the application of deficit irrigation on maize at the flowering period decreased the thousand seed weight. The result also supported by Hesamoddin *et al.* (2012.) Which stated that, thousand seed weight is higher for full irrigation.

4.4.6. Grain yield

Growth stage based deficit irrigation highly significantly ($p<0.01$) affected grain yield. The highest grain yield was obtained from the control treatment that gained 100% ETc at all growth stages and has no significance difference from treatments that received 75% ETc at development and late growth stages. The minimum grain yield was obtained from the treatment that received 50% ETc at all growth stages and has no significance difference from treatments that received 50% ETc at mid growth stage. Grain yield was reduced as stress level increased from 100% ETc to 50% ETc in the treatments that were stressed at different growth stages.

Maximum grain yield of 6.4 t/ha was obtained from the control treatment that gained 100% ETc at all growth stages and which was statistically similar with that of treatments that received 75% ETc at development and late growth stages that obtained 6.1 and 6.2 t/ha, respectively. On the other hand, minimum grain yield of 3.9 t/ha was obtained from the treatment that received 50% ETC at all growth stages and which was statistically similar with that of treatment that received 50% ETc at mid growth stages that obtained 4.1 t/ha (Table 7). The decrease in irrigation level from 100% ETc to 50% ETc leads to a decrease of 39% that stressed at all growth stages and 35.9% that stressed at mid growth stage in grain yield.

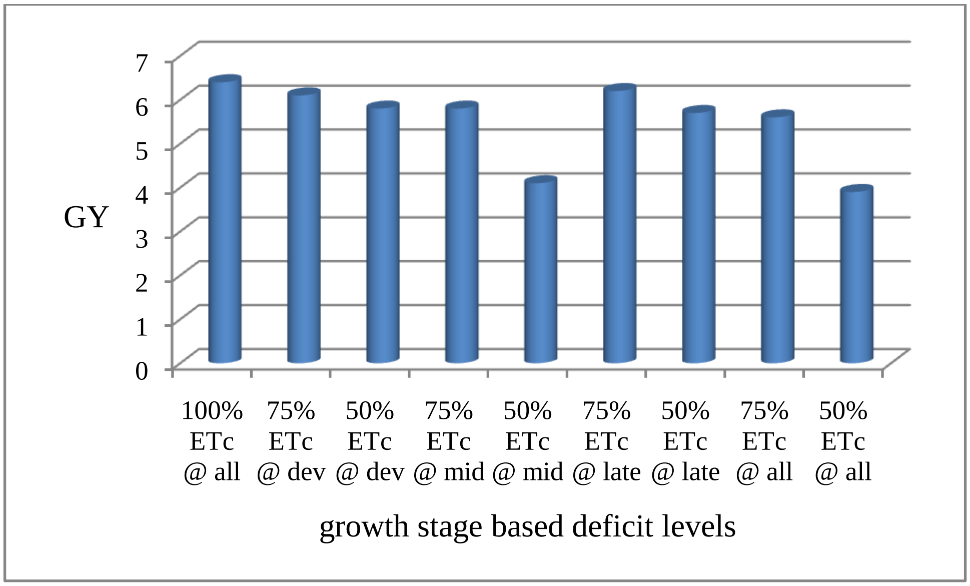

Figure 13: Effects of growth stage based deficit levels on grain yield

The result showed that grain yield was directly associated with the amount of irrigation water applied and inversely with the stress level. When the stress level increase grain yield become small. This might be due to the adverse effects of deficit soil moisture stress on plant growth, development and yield which lead to Loss of turgidity leading to cell enlargement and stunted growth, decrease in photosynthesis. Similar studies also showed that grain yield is affected due to growth stage based moisture stress in different crops. This finding is in line with Song *et al.* (2019) who reported that the maximum LAI, canopy height, biomass, unit kernel weight, kernels per spike, and yield were highest in FullIRR treatment during all treatments, while water stress during different growth stages has different effects on those variables. Different researches conducted on maize (Admasu et al., 2019) and wheat (Meskelu et al., 2017) also showed that, as the moisture stress level increased the production of the crop will declined, which agreed with the current finding.

Agyare et al. (2013) also reported that moisture stress in the sensitive stages (tasseling and silking or grain filling) resulted in highest grain yield reduction which is in line with the current finding. Çakir (2004) also reported that highest grain yield was obtained in the fully irrigated treatment and the treatment which allowed water stress during the vegetative growth stage and he also stated that even a single irrigation omission during one of the sensitive growth stages, caused up to 40% grain yield losses during dry years and Igbadun et al. (2008) also reported that deficit irrigation at any crop growth stage of the maize crop led to decrease in grain yields and dry matter yields in which their findings are in line with the current findings.

4.4.7. Dry biomass

Growth stage based deficit irrigation highly significantly ($p<0.01$) affected dry biomass. The highest dry biomass was obtained from the control treatment that gained 100% ET_C at all growth stages and has no significance difference from treatments that received 75% ET_C at development and late growth stages. The minimum dry biomass was obtained from the treatment that received 50% ET_C at all growth stages and has no significance difference from treatments that received 50% ET_C at mid growth stage. Dry biomass was reduced as stress level increased from 100% ETc to 50% ETc in the treatments that were stressed at different growth stages.

Maximum dry biomass of 13.6 t/ha was obtained from the control treatment that gained 100% ETc at all growth stages and which was statistically similar with that of treatments that received 75% ETC at development and late growth stages that obtained 13.5 and 13.6 t/ha, respectively. On the other hand, minimum dry biomass of 9.1 t/ha was obtained from the treatment that received 50% ETc at all growth stages and which was statistically similar with that of treatment that received 50% ETc at mid growth stages that obtained 9.6 t/ha (Table 7). The decrease in irrigation level from 100% ETc to 50% ETc leads to a decrease of 33% that stressed at all growth stages and 29.4% that stressed at mid growth stage in dry biomass.

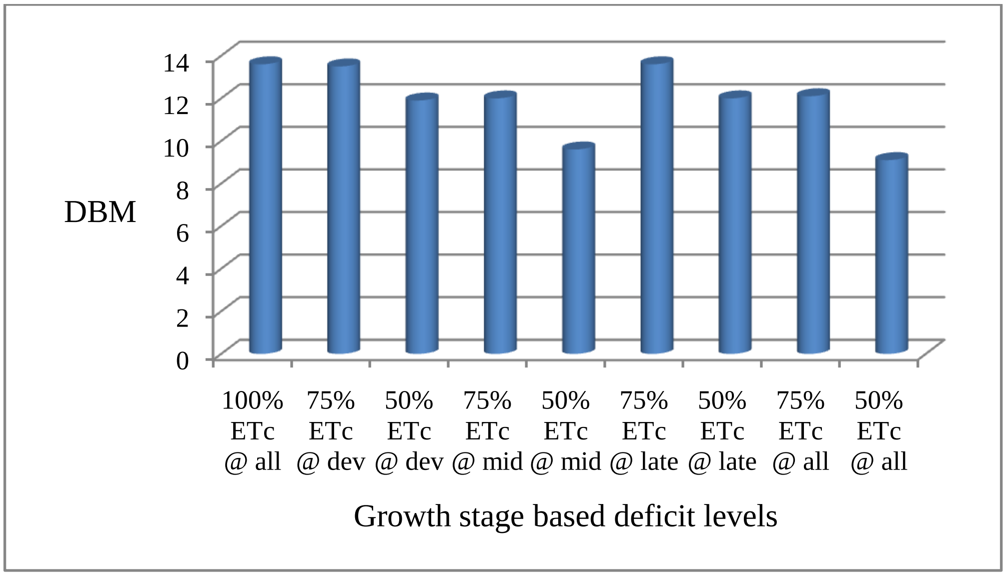

Figure 14: Effects of growth stage based deficit levels on dry biomass

Here also the result showed that dry biomass was directly associated with the amount of irrigation water applied and inversely with the stress level. When the stress level increase dry biomass also become small. This might be due decrease in photosynthesis due to decreased diffusion of CO_2 with the closure of stomata to conserve water and reduced leaf area. Similar studies also showed that dry biomass is affected due to growth stage based moisture stress in different crops. This finding is agreed with Admasu *et al.* (2019) who reported that water supply reduced from 100 to 25% ETc the above ground dry biomass yield decreased by 44.6%. Kuscu and Demir (2012) also reported that Moisture stress resulting from the limited water supply at vegetative and flowering stages affected crop canopy development which led to low dry matter yield which is agreed with the current finding. The findings were also agreed with the reports of Çakir (2004) and Igbadun et al. (2008) that the effect of the deficit irrigation on dry matter of the maize crop depends on the crop growth stage and the frequency of the deficit, irrespective of whether it was at one or more growth stages.

Table 7: Effect of growth stage based deficit levels on thousand seed weight, grain yield and dry biomass of maize

Treatments	Thousand seed weight (gm)	Grain yield (t/ha)	Dry biomass (t/ha)
100% ETc @ all	570.0a	6.4a	13.6a
75% ETc @ dev	567.3a	6.1a	13.5a
50% ETc @ dev	533.8b	5.8ab	11.9b
75% ETc @ mid	534.2b	5.8ab	12b
50% ETc @ mid	371.2c	4.1c	9.6c
75% ETc @ late	565.0a	6.2a	13.6a
50% ETc @ late	541.2b	5.7b	12.0b
75% ETc @ all	535.2b	5.6b	12.1b
50% ETc @ all	353.2d	3.9c	9.1c
LSD(0.05)	17.2	0.3	0.9
CV(%)	2.0	3.3	4.2

Means followed by different letters in a column differ significantly and those followed by the same letter are not significantly different at $p<0.05$ level of significance. NS: non significant at $p<0.05$.

4.5. Effects of Growth Stage Based deficit levels on Harvesting Index, Water Use Efficiency and Yield Response Factor

4.5.1. Harvesting index

Harvesting index was also highly significantly ($p<0.01$) affected due to different level of growth stage based moisture stresses. The highest harvesting index was obtained from the treatment that gained 50% ETc at development growth stages and has no significance difference from the control, treatments that received 75% ETc at development, mid, late and all growth stages and 50% ETc at late stage. The minimum harvesting index was obtained from the treatment that received 50% ETc at mid growth stages and has no significance difference from treatments that received 50% ETc at all growth stage.

Maximum harvesting index of 49% was obtained from the treatment that gained 50% ETc at development growth stages and which was statistically similar with that of treatments that received 100% ETc at all growth stages, 75% ETc at development, mid, late and all growth stages and 50% ETc at late stage that which leads to harvesting index of 47, 45, 48, 46, 46 and 48%, respectively. On the other hand, minimum harvesting index of 43% was obtained from the treatment that received 50% ETc at mid and all growth stages (Table 8).

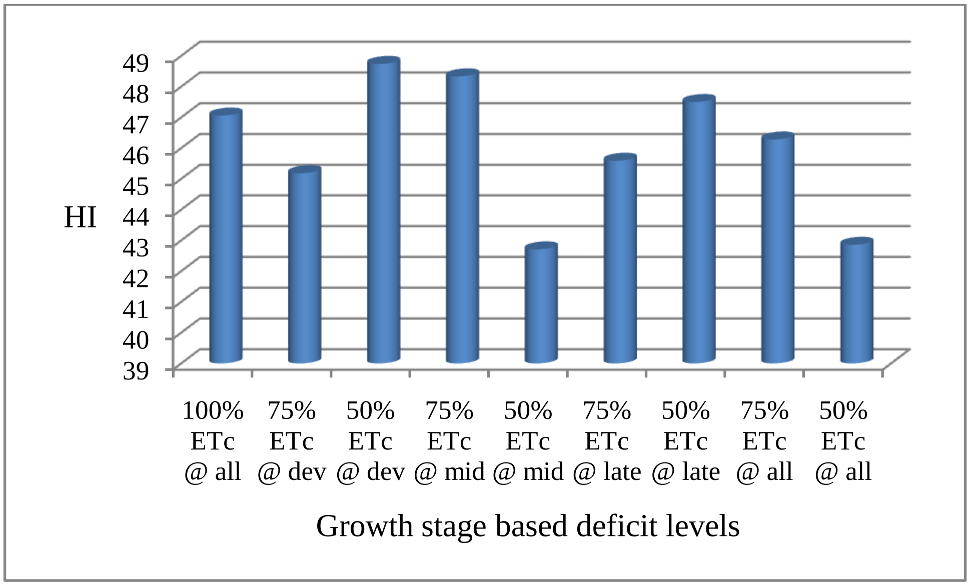

Figure 15: Effects of growth stage based deficit levels on harvest index

The result also showed that there is no clear trend or relationship between amount of water applied and harvesting index. Different studies also showed that harvesting index is affected due to growth stage based moisture stress in different crops. for instance, Admasu *et al.* (2019) reported that highest harvesting index of maize was observed from100ETc and the lowest harvesting index was observed from 25% ETc where as Kuscu and Demir (2012) reported that the highest harvest index was obtained from VF treatment (weekly irrigation in the vegetative and flowering stages) and the lowest values of harvest index were determined from control. Bryant et al. (1992) also indicated that water stress reduces yield by reducing accumulated biomass and the harvest index. However, Traore et al. (2000) found that the harvest index was affected by water deficit only when stress was imposed during anthesis.

4.5.2. Water use efficiency

Water use efficiency of maize was also highly significantly ($p<0.01$) affected due to different level of growth stage based deficit levels. The highest water use efficiency was obtained from the treatment that gained 50% ETc at all growth stages and has no significance difference from treatment that received 75% ETc at all growth stages. The minimum Water use efficiency was obtained from the treatment that received 50% ETc at mid growth stages and statistically it was inferior from all other treatments.

Maximum Water use efficiency of 1.02 kg/m^3 was obtained from the treatment that gained 50% ETc at all growth stages and has no significance difference from treatment that received 75% ETc at all growth stages that obtained 1.01kg/m^3. On the other hand, minimum water use efficiency of 0.82 kg/m^3 was obtained from the treatment that received 50% ETc at mid growth stages and statistically it was inferior from all other treatments (Table 8).

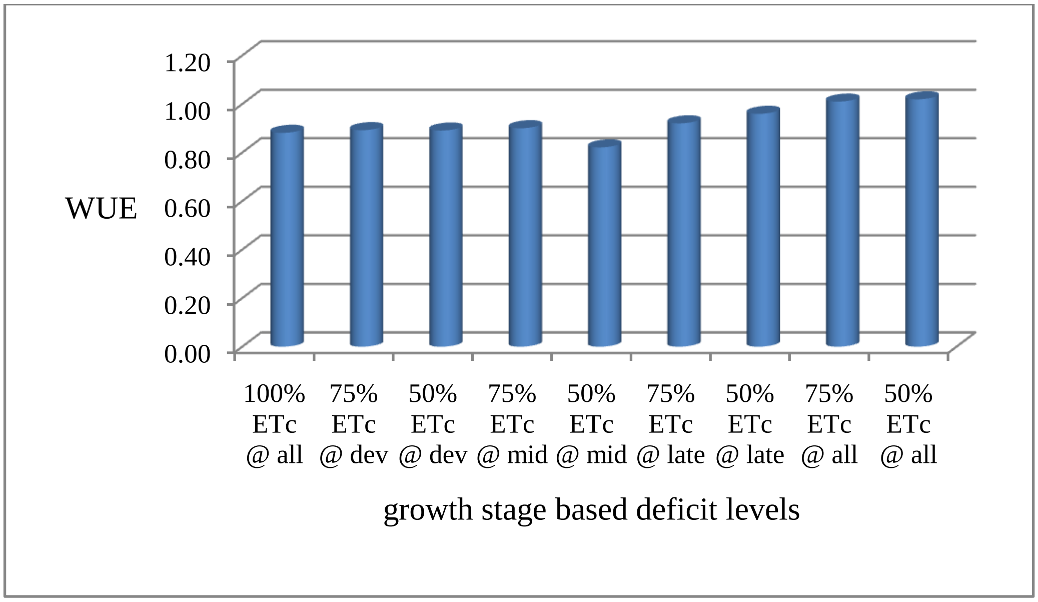

Figure 16: Effects of growth stage based deficit levels on water use efficiency

The result showed that water use efficiency were higher for the treatments that received lower amount of irrigation water than the treatments that received higher amount of irrigation water even if their yield were lowered. Different researches conducted on maize (Yenesew et al., 2009), maize (Admasu et al., 2019) and wheat (Meskelu et al., 2013) also showed that, as the moisture stress level increased the production of the crop will declined and the water use efficiency were increased, which agreed with the current finding. This shows that deficit irrigation to a certain level increases or improves water use efficiencies to without significant yield reduction.

From growth stage aspects WUE in a treatment that received 50% ETC at mid growth stages was smaller than from the other treatments. This might be due to the condition that the treatment gained unwanted amount of water at development and late growth stages that increase total amount of water and do not gained the required amount of water in its water sensitive growth stages that leads to yield reduction at mid growth stages. Ayas (2019) reported that lowest value of WUE was obtained from the treatment that stressed at flowering and yield formation periods in tomato which is in line with the current finding.

Table 8: Effect of growth stage based deficit levels on harvesting index and water use efficiency of maize

Treatments	Harvest index (%)	Water use efficiency (kg/M^3)
100% ETc @ all	47ab	0.88c
75% ETc @ dev	45bc	0.89c
50% ETc @ dev	49a	0.89c
75% ETc @ mid	48ab	0.90c
50% ETc @ mid	43c	0.82d
75% ETc @ late	46abc	0.93bc
50% ETc @ late	48ab	0.97b
75% ETc @ all	46abc	1.01ab
50% ETc @ all	43c	1.02a
LSD(0.05)	3	0.05
CV(%)	3.0	5.2

Means followed by different letters in a column differ significantly and those followed by the same letter are not significantly different at p<0.05 level of significance. NS: non significant at p<0.05.

4.5.3. Effect of growth stage based deficit levels on yield response factor

Yield response factor is one of the most important parameters that indicate whether moisture stress due to reduce irrigation is advantageous or not in terms of enhancing the water use efficiency. Any significant decrease in soil water storage has an impact on water availability for a crop and, subsequently, on actual yield and actual evapotranspiration.

The result indicated yield response factor ranges from 0.53 to 1.15 for stressed treatments (Table 9). A lower yield response factor associated with lower stressed treatments and higher values associated with highly stressed treatments. The higher K_y values of 1.15 could be an indication of severe water stresses or low water stress resistance of the variety of Melkassa II used. This implies that the rate of relative yield decrease resulting from water stress is proportionally the same to the relative evapotranspiration deficit. From the result the lowest was 0.53 observed at 75% ETc at all growth stages and it indicates that the tolerance of the crop to water deficit. The lowest Ky values of 0.53 could be an indication of medium water stress or high water stress resistance of the variety of maize used.According to FAO (2002a), yield response factor of different crops and different stress condition varies from 0.20 for tolerant crops to 1.15 for sensitive crops.

A response factor greater than unity indicates that the relative yield decrease for a given evapotranspiration deficit is proportionately greater than the relative decrease in evapotranspiration (FAO, 2002a).

Table 9: Effect of growth stage based deficit levels on yield response factor

Treatments	1-(Ya/Ym)	1-(ETa/ETm)	$K_y = \frac{\left(1 - \frac{Y_a}{Y_m}\right)}{\left(1 - \frac{ET_a}{ET_m}\right)}$
100% ETc @ all	0	0.00	-
75% ETc @ dev	0.05	0.06	0.80
50% ETc @ dev	0.09	0.10	0.91
75% ETc @ mid	0.11	0.11	0.97
50% ETc @ mid	0.36	0.31	1.15
75% ETc @ late	0.06	0.07	0.86
50% ETc @ late	0.17	0.18	0.94
75% ETc @ all	0.13	0.24	0.53
50% ETc @ all	0.39	0.47	0.83

4.6. Correlation of Yield and Yield Components

The result shows that grain yield production per hectare was very highly significantly ($p<0.01$) associated positively with all recorded parameters (Table 10). The correlation analysis showed that there is a strong association between grain yields with yield components with the Pearson coefficient of 0.864, 0.800, 0.904, 0.858, 0.875, 0.942, 0.935, 0.900, 0.958 and 0.641 for plant height, ear height, leaf area index, cob length, cob width, cob weight with seed, cob weight without seed, thousand seed weight, dry biomass, and harvesting index. On Maize Admasu et al. (2019) and wheat (Meskelu et al. (2017) reported that grain yield is positively associated with yield and yield components. Iftikhar *et al*. (2012) and Rameez *et al*. (2012) reported grain yield had a positive correlation with thousand seed weigh and spike length. This shows that the increase in these parameters might lead to enhancement of grain yield. Among these parameters, aboveground biomass had the highest positive direct effect on grain yield followed by cob weight with seed and cob weight without seed.

Plant height was positively correlated from ear height, and leaf area index, cob length, and cob width, cob weight with seed, cob weight without seed, thousand seed weight, grain yield, dry biomass and harvesting index. Similarly, like that of plant height all the recorded growth parameters, yield and yield components were positively correlated each other. However, all the recorded parameters were not correlated with water use efficiency (table 10).

The result also shows that grain yield was not correlated with water use efficiency (table 10). This implies that the increment or decrement of water use efficiency doesn’t contribute to the increment or decrement of grain yield. The result is in conflict with different workers who reported different condition in correlation between grain yield and WUE. Meskelu et al., (2017) reported WUE correlate negatively with grain yield when wheat imposed to different level of moisture stress during the whole growth stage. However, Shamsi *et al*. (2010) reported WUE correlate positively with grain yield of Wheat. Blum (2009) reported that the relation between yield and water productivity range from no relationship to negative or positive relationships, depending on the crop and the environment. Akhter *et al*. (2008) reported there is no significant association between grain yield and WUE. However, this is not an all-time circumstance and WUE may vary due to different factors like environment, crop type and variety, water stress condition and crop growth stage in which moisture stress happen.

Table 10: Pearson’s correlation coefficient (r) of yield and yield components of maize as influenced by different levels of moisture stress

	PH	EH	LAI	CL	CW	CWWS	CWWOS	TSW	GY	DBM	HI	WUE
PH	1											
EH	0.853 ***	1										
LAI	0.891 ***	0.807 ***	1									
CL	0.884 ***	0.746 ***	0.842 ***	1								
CW	0.825 ***	0.727 ***	0.892 ***	0.841 ***	1							
CWWS	0.907 ***	0.860 ***	0.942 ***	0.866 ***	0.905 ***	1						
CWWOS	0.865 ***	0.852 ***	0.908 ***	0.810 ***	0.801 ***	0.933 ***	1					
TSW	0.893 ***	0.822 ***	0.934 ***	0.841 ***	0.929 ***	0.978 ***	0.873 ***	1				
GY	0.864 ***	0.800 ***	0.904 ***	0.858 ***	0.875 ***	0.942 ***	0.935 ***	0.900 ***	1			
DBM	0.878 ***	0.825 ***	0.943 ***	0.831 ***	0.858 ***	0`.958 ***	0.962 ***	0.915 ***	0.958 ***	1		
HI	0.421 *	0.352 *	0.382 *	0.537 **	0.511 **	0.454 *	0.420 *	0.435 *	0.641 **	0.398 *	1	
WUE	-0.19 ns	0.036 ns	0.062 ns	-0.16 ns	-0.08 ns	0.044 ns	0.039 ns	-0.01 ns	0.120 ns	0.081 ns	0.171 Ns	1

**= statistically highly significant ($p<0.01$), *= statistically significant ($p<0.05$) and ns= statistically not significant ($p>0.05$). PH: plant height’ EH: ear height, LAI: leaf area index, CL: cob length, CW: cob width, CWWS: cob weight with seed, CWWOS: cob weight without seed, TSW: thousand seed weight, GY: grain yield, DBM: dry biomass, HI: harvesting index, WUE: water use efficiency

5. CONCLUSION AND RECOMMENDATION

5.1. Conclusion

The study was aimed to enhance the water productivity of irrigated maize in water scarce areas. An attempt was made to growth stages based moisture stress through reduction of irrigation water applied to the crop. The optimum irrigation water application was determined based on the CropWat model and the irrigation water applied to each stressed treatments was based on their stress levels. As a result, seasonal water demands for maize (*Zea mays*L.) Melkass II variety under the study area and for the specified planting date (during the dry season of the area), could be 726.3 mm net irrigation depth for non-stress scenario (100% ETC). Yet, for stressed scenario, the net irrigation depth reduced based on the moisture stress level until 382.6 mm for the least treatment that received 50% ETC at all growth stages. For the treatments that received 75% ETC at all, development, mid and late growth stages and 50% ETC at development, mid and late growth stages seasonal net irrigation depth were 554.5, 683.7, 644.3, 673.7, 673.7, 499.3, and 594.0 mm, respectively.

The experiment showed that growth stage based moisture stress affects crop growth parameters like plant height, ear height, leaf length, leaf width and leaf area index. Plant height, ear height, leaf length, leaf width and leaf area index were shortened from 193.5 cm to 161.9 cm, 92.3 cm to 77.9 cm, 77.6 cm to 62.1 cm, 9.3 cm to 7.5 cm and 252.2 cm^2 to 163 cm^2, respectively, due to reduction of irrigation water from 100% ETC to 50% ETC at all growth stages. Yield components like cob length, cob width, cob weight with seed, cob weight without seed and thousand seed weight was also reduced from 17.4 cm to 11.7 cm, 16.2 cm to 12.6 cm, 253.2 gm to 123.3 gm, 60.8 gm to 32.4 gm and from 570 gm to 353.2 gm as the irrigation water reduced from 100% ETC to 50% ETC at all growth stages.

Grain yield and dry biomass was significantly affected due to growth stage based moisture stress. The reduction in irrigation water amount by 50% leads to reduction of grain yield and dry biomass by 39% and 33% respectively. Maximum and minimum grain yield of 6.4 t/ha and 3.9 t/ha was obtained from the treatment that received 100% ETC and 50% ETC, at all growth stages respectively. Maximum and minimum dry biomass of 13.6 t/ha and 9.1t/ha was also obtained from the treatment that received 100% ETc and 50% ETc, at all growth stages respectively.

Reducing irrigation water also leads to improving the Water use efficiency. Water use efficiency was increased as the irrigation water applied reduced. Water use efficiency at 100% ETc at all growth stages, 75% ETc at all, development, mid and late growth stages and 50% ETc at all, development, mid and late growth stages was 0.88 kg/m^3, 1.01 kg/m3, 0.89 kg/m3, 0.9 kg/m3, 0.92 kg/m3, 1.02 kg/m3, 0.89 kg/m3, 0.82 kg/m3, and 0.96 kg/m3 respectively. The result showed reduction of irrigation water amount by 50% leads to enhancement of water productivity by 14%. The maximum water use efficiency was obtained from 50% ETc at all growth stages and statistical similar with that of 75% ETc at all growth stages and the minimum water use efficiency was obtained from 50% ETc at mid growth stages.

Reduction of irrigation water from 100% ETC to 50 ETc at mid growth stage also have an effect on all the recorded growth parameters, yield and yield components. However, Reduction of irrigation water from 100% ETc to 50 ETc at development and late growth stage has no that much effect on the recorded growth parameters, yield and yield components as compared to mid growth stages. This shows that mid growth stage was very sensitive to moisture stress than development and late growth stages.

5.2. Recommendation

Based on the study and the results obtained on yield, yield component and water use efficiency, the following were recommended.

- For non stressed condition, maize Melkassa II variety should be irrigated with net seasonal irrigation depth of 726.3 mm for optimum irrigation (100% ETc) at all growth stages to attain maximum grain yield and aboveground biomass.

- For water stressed area to enhance the water productivity, it could be irrigated to 75% of the full irrigation amount at all growth stages to improve the water productivity to 1.01 kg/m^3 with a compromise of yield reduction by 12.5%. The seasonal net irrigation water depth required for this case should be 554.5 mm and the grain yield obtained could be 5.6 t/ha.

- Since mid growth stage was sensitive to moisture stress, moisture stress at this stage should be avoided for maize Melkassa II variety. Rather for improving water productivity, it could be grown by stressing development or late growth stages up to 50% ET_C.
- The study should be repeated in other areas under similar agro-ecological condition in order to confirm the validity of the present findings since the research is done in one location for a single season. Also, the study should be conducted with different maize varieties and different crops, including stress under different growth stages for enhancing the water productivity of irrigated crops. Economical analysis should also be carried out to evaluate the associated cost of labor, land, water pumping costs and others with that of water saved for optimization of the stress level in economic term.

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7. APPENDICES

Appendix table 1: First treatment application on January 05/2021

Date	Stage	Net Irr	Gr. Irr	treatments	Head	Time		irrigated trts
		Mm	Mm		Cm	Min	Sec	
5-Jan	Init	38.3	54.6	100%	6	8	39	T1-T7
					7	6	49	
					8	5	32	
					9	4	37	
					10	3	55	
		28.7	41.0	75%	6	6	29	T8
					7	5	7	
					8	4	9	
					9	3	28	
					10	2	56	
		19.2	27.4	50%	6	4	20	T9
					7	3	25	
					8	2	47	
					9	2	19	
					10	1	58	

Appendix table 2:2nd treatment application on January 25/2021

Date	Stage	Net Irr	Gr. Irr	treatments	Head	time		irrigated trts
		mm	mm		Cm	min	sec	
25-Jan	Dev	59.5	85	100%	6	13	27	T1, T4,T5,T6,T7
					7	10	35	
					8	8	36	
					9	7	10	
					10	6	5	
		44.6	63.7	75%	6	10	5	T2, T8
					7	7	56	
					8	6	27	
					9	5	23	
					10	4	34	
		29.8	42.6	50%	6	6	44	T3, T9
					7	5	18	
					8	4	19	
					9	3	36	
					10	3	3	

Appendix table 3: 3rd treatment application on February05/2021

Date	Stage	Net Irr	Gr. Irr	treatments	Head	time		irrigated trts
		mm	mm		Cm	min	sec	
7-Feb	Dev	70.9	101.3	100%	6	16	1	T1, T4,T5,T6,T7
					7	12	37	
					8	10	15	
					9	8	33	
					10	7	15	
		53.2	76	75%	6	12	1	T2, T8
					7	9	28	
					8	7	42	
					9	6	25	
					10	5	27	
		35.5	50.7	50%	6	8	1	T3, T9
					7	6	19	
					8	5	8	
					9	4	17	
					10	3	38	

Appendix table 4: 4th treatment application on February 18/2021

Date	Stage	Net Irr	Gr. Irr	treatments	Head	time		irrigated trts
		mm	mm		Cm	min	sec	
18-Feb	Mid	82.1	117.3	100%	6	18	33	T1, T2, T3, T6,T7
					7	14	36	
					8	11	53	
					9	9	54	
					10	8	24	
		61.6	88	75%	6	13	55	T4, T8
					7	10	58	
					8	8	55	
					9	7	25	
					10	6	18	
		41.1	58.7	50%	6	9	17	T5, T9
					7	7	19	
					8	5	57	
					9	4	57	
					10	4	12	

Appendix table 5:5th treatment application on February 28/2021

Date	Stage	Net Irr	Gr. Irr	treatments	Head	time		irrigated trts
		mm	mm		Cm	min	sec	
Feb 28	Mid	80.2	114.6	100%	6	18	7	T1, T2, T3, T6,T7
					7	14	16	
					8	11	36	
					9	9	40	
					10	8	13	
		60.2	86	75%	6	13	36	T4, T8
					7	10	43	
					8	8	43	
					9	7	15	
					10	6	10	
		40.1	57.3	50%	6	9	4	T5, T9
					7	7	8	
					8	5	48	
					9	4	50	
					10	4	6	

Appendix table 6:6th treatment application on March 10/2021

Date	Stage	Net Irr	Gr. Irr	treatments	Head	time		irrigated trts
		mm	mm		Cm	min	sec	
10-Mar	Mid	85.7	122.5	100%	6	19	22	T1, T2, T3, T6,T7
					7	15	15	
					8	12	24	
					9	10	20	
					10	8	46	
		64.3	91.9	75%	6	14	32	T4, T8
					7	11	26	
					8	9	18	
					9	7	45	
					10	6	35	
		42.9	61.3	50%	6	9	42	T5, T9
					7	7	38	
					8	6	12	
					9	5	10	
					10	4	23	

Appendix table 7:7th treatment application on March 19/2021

Date	Stage	Net Irr	Gr. Irr	Treatments	Head	time		irrigated trts
		Mm	mm		Cm	min	sec	
19-Mar	Mid	80.6	115.2	100%	6	18	13	T1, T2, T3, T6,T7
					7	14	20	
					8	11	40	
					9	9	43	
					10	8	15	
		60.5	86.4	75%	6	13	40	T4, T8
					7	10	46	
					8	8	45	
					9	7	18	
					10	6	12	
		40.3	57.6	50%	6	9	6	T5, T9
					7	7	10	
					8	5	50	
					9	4	51	
					10	4	7	

Appendix table 8: 8th treatment application on March 29/2021

Date	Stage	Net Irr	Gr. Irr	treatments	Head	time		irrigated trts
		mm	mm		Cm	min	sec	
29-Mar	End	85.7	122.5	100%	6	19	22	T1,T2,T3,T4,T5
					7	15	15	
					8	12	24	
					9	10	20	
					10	8	46	
		64.3	91.9	75%	6	14	32	T6, T8
					7	11	26	
					8	9	18	
					9	7	45	
					10	6	35	
		42.9	61.3	50%	6	9	42	T7, T9
					7	7	38	
					8	6	12	
					9	5	10	
					10	4	23	

Appendix table 9: Last treatment application on April 16/2021

Date	Stage	Net Irr	Gr. Irr	treatments	Head	time		irrigated trts
		mm	mm		Cm	min	sec	
16-Apr	End	105	150	100%	6	23	44	T1,T2,T3,T4,T5
					7	18	41	
					8	15	11	
					9	12	39	
					10	10	45	
		78.8	112.6	75%	6	17	48	T6, T8
					7	14	1	
					8	11	24	
					9	9	30	
					10	8	4	
		52.5	75	50%	6	11	52	T7, T9
					7	9	20	
					8	7	36	
					9	6	20	
					10	5	22	

Appendix table 10: Analysis of variance for plant height, ear height, leaf length, leaf width and leaf area index

source of variation	degree of freedom	mean squares				
		PH	EH	LL	LW	LAI
Replication	2	14.1ns	13.9ns	1.9ns	0.1	86.9ns
Treatments	8	322.6***	101.5***	119.0***	1.5***	3668.3***
Error	16	10.1	6.3	5.4	0.1	85.2

***=very highly significant at p<0.001 level of probability, **=highly significant at p<0.01 level of probability, and *=significant at p<0.05 level of probability and ns= not significant at p<0.05 level of probability. MS: mean squares, PH: plant height, EH: ear height, LL: leaf length, LW: leaf width, LAI: leaf area index

Appendix table 11:Analysis of variance for cob length, cob width, cob weight with seed, con weight without seed, thousand seed weight, grain yield, dry biomass, harvesting index and water use efficiency

Source of variation	Degree of freedom	Mean squares								
		CL	CW	CWWS	CWWOS	TSW	GY	DBM	HI	WUE
Replication	2	1.1ns	0.3ns	300.1ns	51.1**	116.3ns	0.1 ns	0.5 ns	0.0003 Ns	0.003 Ns
Treatments	8	12.1***	5.0***	7695.3 ***	321.7 ***	23163.9 ***	2.3 ***	8.3 ***	0.0013 ***	0.019 ***
Error	16	0.5	0.3	96.4	3.9	98.3	0.1	0.2	0.0002	0.002

***=very highly significant at p<0.001 level of probability, **=highly significant at p<0.01 level of probability, and *=significant at p<0.05 level of probability and ns= not significant at p<0.05 level of probability. MS: mean squares,CL: cob length, CW: cob width, CWWS: cob weight with seed, CWWOS: cob weight without seed, TSW: thousand seed weight, GY: grain yield, DBM: dry biomass, HI: harvesting index, WUE: water use efficiency

Appendix table 12: Free flow discharge values for different size of Parshall flumes

Head (cm)	Throught width (inches)				
	1	2	3	6	9
	Discharge (l/s)				
2	0.140	0.281			
3	0.263	0.526	0.772	1.496	2.504
4	0.411	0.822	1.206	2.357	3.889
5	0.581	1.162	1.705	3.354	5.471
6	0.771	1.541	2.261	4.473	7.232
7	0.979	1.957	2.872	5.707	9.155
8	1.205	2.407	3.532	7.047	11.231
9	1.446	2.889	4.239	8.489	13.448
10	1.702	3.402	4.991	10.027	15.801
11	1.973	3.943	5.786	11.656	18.281
12	2.258	4.513	6.621	13.374	20.885

Appendix figure 1: Land preparation and sowing

Appendix figure 2: Discharge measuring Parshal flume

Appendix figure 3: Startup of treatment application at initial growth stages

Appendix figure 4: Maize growth stages at the start of development stages

Appendix figure 5: At the end of development stages and start of mid stages

Appendix figure 6: At the middle of mid stages

Appendix figure 7: At the end of mid stage

Appendix figure 8: At late growth stage

Appendix figure 9: During growth parameter recording and data collection

Appendix figure 10: Drying of maize via sun

Appendix figure 11: Threshing of maize

Appendix figure 12: During measuring dry biomass, yield and yield components

BIOGRAPHY

The author was born on October 12, 1991 at Amhara Region, North shoa Zone, Menz Mama Woreda, Kolomargefia kebele, from his father DEBEBE MENGESHA and his mother WOINSHET KEFELEGN. He attended his elementary education at Kolomargefia Elementary School and secondary education at Molale High School and Preparatory School. After completing his high school education in 2011, he joined Debre Birhan University in November 2012 and graduated with BSc degree in Water Resource and Irrigation Management in July 2014.

After graduation, he was employed at Gewane Agricultural Vocational Education Training (ATVET) College as junior instructor by Ministry of Agriculture and worked there for 2 years. He then joined Wondo Genet Agricultural Research Center of Ethiopian Institute of Agricultural Research in October 2017 and worked there until he joined the School of Graduate Studies of Hawasa University in October 2019 to pursue his MSc Degree study in Irrigation and Drainage Engineering.