EFFECT OF DRIP IRRIGATION ON THE PRODUCTION AND ECONOMIC RETURNS OF SORGHUM (*Sorghum bicolor*) IN SEMI ARID AREAS OF TANZANIA

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Declaration

I, Athuman Juma Mahinda, do hereby declare to the Senate of the University of Nairobi that; this thesis is the result of my original work and has never been submitted for award of a degree in any other University.

Signature é é é é é é é é é é é é é é é é .Dateé é é é é é é é é é é é

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Dedication

To Almighty God, who broke the long covenant chains that were holding back my life. I highly appreciate His favour for awarding me a free everlasting divine permit to be opened before I knock the door, to be given before I ask, and to be seen before my presence.

To my beloved parents who pray all the time for God to give me courage, strength and blessings on the works of my hands.

To my mentors Prof. Kilasara and Prof. Gachene for their recognition of my presence and for their uncountable support whenever I was about to fail

Copyright

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May Almighty God bless you abundantly!

Table of Contents

List of Tables

List of Figures

List of Appendices

List of Abbreviation and Acronyms

%	Percentage
^{0} C	Celsius degrees
A_g	Ground area
A_L	Leaf area
ANOVA	Analysis of Variance
ARC	Agricultural Research Corporation
ARC	Agricultural Research Council
ASALs	Arid and Semi Arid Areas
ASARECA	Association for Strengthening Agricultural Research in Eastern and Central Africa
bɈ	Bulk density
C:N	Carbon to Nitrogen ratio
C_4	Carbon four
Ca^{2+}	Calcium ion
CAM	Crassulacean Acid Metabolism
Cl^-	Chloride ion
cm	Centimeter
Cmol	Centimol
CO_2	Carbon dioxide gas
CV	Coefficient of Variation
DM	Dry Matter

EABL	East Africa Breweries Limited
EC	Exchangeable Cation
ECARSAM	Eastern and Central Africa Regional Sorghum and Millet Network
EL	Irrigating only Late in the Evening
ELE	Irrigating both Early in the Morning and Late in the Evening
EM	Irrigating only Early in the Morning
ETcr	Crop evapotranspiration/ Crop water requirement
ETo	Reference Evapotranspiration
FACTFISH	World Statistics and Data Research
FAO	Food and Agriculture Organization
FAOSTAT	Food and Agriculture Organization Statistics
FEWSNET	Famine Early Warning System Network
Fig	Figure
F-STAT	Fixation Statistics/ Index
GenStat	General Statistics
GM	Gross Margin
ha	Hectare
ICRISAT	International Crop Research Institute for the Semi Arid Tropics
IPCC	Intergovernmental panel on Climate Change
K^+	Potassium ion
Kc	Crop coefficient
Kcd	Crop coefficient at development stage

Kci	Crop coefficient at Initial stage
Kcm	Crop coefficient at Maturity stage
kg	Kilogram
L	Litres of water
L	Leaf length
LE	Irrigating only Late in the Evening
LSD	Least Significant Difference
m^2	Squared meter
MAFC	Ministry of Agriculture Food security and Cooperative
meq	Milliequvalent
Mg^{2+}	Magnesium ion
mm	Millimeters
mmhos	Millimhos
N	Nitrogen
Na^+	Sodium ion
ns	Non significant
OC	Organic Carbon
p	Probability
P	Phosphorus
PEPcase	Phosphoenolpyruvate carboxylase
pH	Potential hydrogen
ppm	Pert per million

PSII	Photo system two
PVC	Polyvinylchloride
Rubisco	Ribulose-1, 5-bisphosphate carboxylase/oxygenase
SAR	Sodium Adsorption Ratio
SSA	Sub Saharan Africa
TBL	Tanzania Breweries Limited
TMA	Tanzania Meteorological Agency
TR	Total Revenue/Income from sales
Tsh	Tanzania shilling
TVC	Total Variables Cost
USD	United State Dollar
USAID	United States Agency for International Development
USDA	United States Department of Agriculture
W	Leaf width
WUE	Water Use Efficiency
www	world wide web
x	Multiplication
Đ g	Gravimetric water content
Đ v	Volumetric water content

Abstract

Field trials were conducted in semi arid area of Dodoma, central Tanzania with the aim of assessing the effect of three drip irrigation watering regimes on the production and economic returns of sorghum (*Sorghum bicolor*). The irrigation treatments were: EM (early in the morning), EL (late in the evening) and ELE (both early in the morning and late in the evening). Each treatment was replicated three times in a RCBD for two seasons (dry and wet season).

The results showed that both sorghum growth parameters and yield were significantly higher by a factor of >2 ($p < 0.05$) when the crop was irrigated early in the morning and late in the evening than when it was irrigated either early in the morning or late in the evening. The maximum yield of 13.12 ton/ha with economic returns of Tanzania shilling 6,675,900 /= was obtained when sorghum was irrigated twice a day in the dry season. The results indicated that, although irrigating twice a day in the dry season resulted into higher yield, the net income was higher (7,607,780/=) in dry-wet season. This is because during dry season a lot of water had to be bought for irrigation; thus caused the total cost of production to be higher.

When sorghum was grown in dry-wet season, it generated more total biomass than when it was grown in dry season. The highest total biomass (24910 kg/ha) was recorded when the crop was irrigated twice a day. The lowest total biomass (10850 kg/ha) was harvested from the crop which was irrigated late in the evening in the dry season. Contrary to the total biomass performance, the highest water use efficiency (1.973) was recorded from the sorghum which was irrigated late in the evening in the dry season. The lowest water use efficiency (4.53) was recorded on sorghum which was irrigated twice a day in the dry-wet season.

The result suggested that, although irrigating early in the morning or late in the evening resulted into more yield than under rainfed condition, it was economically viable to irrigate twice a day as this had the benefit of giving more economic returns in the study area.

Key words: Semi arid areas, sorghum production, watering regimes, drip irrigation, economic returns, and water use efficiency.

CHAPTER ONE

INTRODUCTION

1.1 Background information

Climate change has the most significant impact on the livelihoods in developing countries compared to developed countries (Thorton and Jones, 2003; IPCC, 2014). Although its impact varies across regions, farming and food systems, households and individuals; it has been observed to affect more inhabitants in arid and semi arid areas (ASALs) (IPCC, 2007; Shemdoe, 2011; Jerry *et al*., 2012). There is clear evidence that, climate change has altered hydrological cycles and weather patterns, resulting into increase of intensity and frequencies of extreme weather conditions, with significant impacts on the agricultural sector (Gregory *et al*., 2005; Jarvis *et al*., 2010; Thorton *et al*., 2011; IPCC, 2014). This has proven to affect both cash and food crops all over the world (Challinor *et al*., 2009, Ahmed *et al*., 2011). According to Thorton and Jones (2003), there will be increasingly crops failure in semi arid areas which dominate most countries of Sub Saharan Africa. Since agricultural activities in this region rely on rainfed condition, any adverse effect on climate change would have a devastating effect on crop production, and subsequently livelihood of the majority in this region (Challinor *et al*., 2005, 2010; Rodima-Taylor, 2012).

Like in other Sub Saharan Africa countries, ASALs of Tanzania are mainly characterized by low rainfall which is unpredictable and unreliable for commercial food production (ECARSAM, 2014; Mike *et al*., 2014). The areas are prone to harsh drought conditions almost throughout the year (Mahoo *et al*., 1999; Slingo *et al.,* 2005). The amount of rainfall received is insufficient and poorly distributed to meet crop water requirement of the major crops grown particularly maize (*Zea mays*), cassava (*Manihot esculentum*), sweet potatoes (*Ipomea batata*), sorghum (*Sorghum bicolor*), finger millet (*Eleusine spp*), grapes (*Vitis vinifera*), sunflower (*Helianthus annuus*), groundnuts (*Arachis hypogea*) and bambaranuts (*Vigna subterranean*) (Nicholas, 2010). Generally the rainfall received annually in ASAL areas ranges from 300 to 700 mm, with a marked average of less than 500 mm (TMA, 2014; VRTC- Makutupora, 2014).

The problem of water scarcity is one of the results of climate change and its variability is expected to adversely affect the food security and economic status in semi arid regions if farmers continue to rely on rain fed agriculture (Beddington, 2010; Rodima-Taylor, 2012; Gimbale *et al.,* 2014). There is already clear evidence for the failure of the crops in ASALs of Tanzania. For instance, the severe sorghum failure as the result of dry spell that led to food insecurity and negative economic impact in Kongwa, Same, Iramba and Tabora districts (Pages *et al*., 2010). This proves that in this era of highly weather and climate variability, farmers should not sorely depend on rainfed agriculture (Ahmed *et al*., 2011; Pravukalyan *et al*., 2012; Kangalawe and Lymo, 2013).

Due to the negative impact of climate change, wheat and barley production in Arusha, Iringa, Mbeya and Kilimanjaro regions have substantially decreased to meet industrial demand, and as a result, sorghum demand in local and international markets has risen (Rohrbach and Kiriwaggulu, 2007; EABL, 2011). Sorghum which has been serving mainly as the main staple food crop in arid and semi arid areas of Tanzania, particularly in marginal regions of the Dodoma, Singida, Tabora, Kilimanjaro Shinyanga, Lindi, Mwanza, Morogoro, and Mara regions, has now become the potential cash crop in Tanzania, and East Africa in general (ECARSAM, 2014). The large quantity of sorghum is now needed in brewery industries for making beer, alcohol and some non alcoholic drinks such as Malta (EABL, 2011; CSP, 2013). Sorghum is also needed in bakery industries for making breads and biscuits (FAO, 2013). This has made the price of sorghum to rise and is now considered as a high value crop in the region (Rohrbach and Kiriwaggulu, 2007; EABL, 2011).

1.2 Problem statement

Dodoma region is representative in terms of climate of many parts of arid and semi arid areas of Tanzania. The area receives very low amount of rainfall which is erratic and unpredictable (MAFC, 2013). In most cases the amount received (300-700 mm) is not sufficient to meet crop water requirement (FEWNET, 2014). For a number of years there has been persistent crop failure, and the problem is more exacerbated by the impact of the climate change (IPCC, 2014). One of the most cited examples is the severe failure of the sorghum in Kongwa district that resulted into the average yield of 62 kg/household; amount of which was only sufficient to supply food for 14 days for the household comprised of three adults, two adolescents (10-18 years old) and two children(<10 years old) (Pages *et al.,* 2010). Since the inhabitants of this area depend on rainfed agriculture, the issue of food insecurity and low standard of life have been increasing yearly (Thurlow and Wobster. 2003; Ahmed *et al.*, 2011; Kangalawe and Lymo, 2013).

Farmers in semi arid central Tanzania have been applying different soil and water conservation measures to improve crop production. Pitting has been used as a traditional sowing method by many farmers to collect water in situ during the early growing stages of the crop (Hatibu and Shemdoe, 1999 Mvungi *et al.,* 2005). Traditional terraces (Matuta), hillside sheet and runoff utilization which exploits valley bottoms and plains where runoff collects, have been widely used by farmers for growing high water demand crops such as maize and grapes in the area, however due to high rate of evapotranspiration demand, the systems have failed (Shemdoe *et al*., 2009b; Shemdoe, 2011).

As in many other arid and semi arid areas of Tanzania, drought is the major cause of poverty in urban Dodoma district and the most vulnerable groups are women, children and people with disabilities (Thurlow and Wobster, 2003; Nelson and Stathers, 2009; Shemdoe, 2010; Lizia, 2014). Although the area experiences water scarcity, it still has opportunity of utilizing underground water resources, intermittent rivers and rainwater harvesting techniques to increase both cash and food production through efficiency means of irrigation during dry spell period. Based on the current technology the area has the potential to utilize drip irrigation to meet crop evapotranspiration demands.

Due to inefficiency use of the scarce water resources, the inhabitants have been maintaining their tradition subsistence farming for production of sorghum which is now one of the most valuable crops in ASALs of Tanzania following grapes (Shemdoe *et al.*, 2011). This method of traditional farming has resulted into low yield production, low income, and low purchasing power of agricultural inputs (Pages *et al.*, 2010; Ahmed *et al*., 2011; Kangalawe and Lymo, 2013).

1.3 Justification

Sorghum is now one of the most high value crops grown in semi arid areas of Dodoma after grapes. Its demand is now increasing more than maize, sunflower and groundnut that were previously considered to be more important than sorghum (Rohrbach and Kiriwaggulu, 2007). Recent research work has shown a decline in wheat and barley production, due to climate change. Sorghum is now used as a substitute to wheat and barley in making beer, alcohol, and non alcoholic drinks such as Malta (EABL, 2011). It is also needed in large quantities by bakery industries for making breads and biscuits (Nicholas, 2010).

Although the value of the crop has increased substantially, its supply to meet industrial market demand is still low (ECARSAM, 2014; EABL, 2013). This is partly because sorghum is still produced in a traditional way that depends on the natural rainfall which is erratic and unpredictable (Changöa *et al*., 2010). The yields obtained are usually below farmös potential, with stagnant or decreasing trends with time (WFP, 2012). Farmers keep on expanding their farms believing that the yield per unit area would increase (Beddington, 2010; Pages *et al.*, 2010; Ahmed *et al*., 2011).

Recent developments in sorghum breeding in Tanzania led to release of promising early maturity drought tolerant varieties whose yield potential under water deficit areas cannot be realized, unless supplemental irrigation is done (Letayo *et al*., 1996; Monyo *et al.*, 2004). This means that with appropriate irrigation watering regimes like the ones proposed in this study, sorghum yield are likely to be much higher.

In the context of increasing yield production that would justify economic returns and improve food security, while sustaining water resource and environment, Hatibu *et al*., (2006) proposed integrated approach in enhancing sorghum production in the semi arid areas of Tanzania. Such approach ought to capitalize on judicious use of existing ground water resources where available as in the Makutupora basin (Rwebugisa, 2008). Already, some grape farms benefit from ground water by drip irrigation in Dodoma. However, it is not certain whether the same can be done profitably with sorghum. Information is needed with regard to quantity of water required and some economic analysis of sorghum irrigation. This research therefore, intends to fill some of the gaps in knowledge on appropriate watering regimes for sorghum production under irrigated conditions.

1.4 Objectives

1.4.1 General objective

- To assess the effect of drip irrigation on increased smallholder sorghum (*Sorghum bicolor*) production in semi arid area of Tanzania

1.4.2 Specific objectives

- To assess the response of *Sorghum bicolor* growth and yield under different watering regimes.
- To determine the water use efficiency of *Sorghum bicolor* under different watering regimes.
- To assess costs and benefits of growing *Sorghum bicolar* under irrigated conditions.

1.5 Hypothesis

- Sorghum growth and yield respond differently under different watering regimes and seasons.
- Sorghum water use efficiency is different under different irrigation regimes and seasons.
- It is economically viable to irrigate sorghum twice a day than once a day in all seasons.
- Irrigating once late in the evening lead to higher sorghum growth and yield than irrigating once early in the morning.

CHAPTER TWO

LITERATURE REVIEW

2.1 Water availability for agricultural production

Water plays a key role in sustaining and increasing crop production all over the world (Barron and Okwach, 2004). It is the main component that without it not only agricultural activities could not exist, but also overall life on the earth (MAFC, 2013). Water scarcity has become an issue globally, with most countries affected being in Sub Saharan Africa (SSA) (Schlenker, and Lobell, 2010**;** Marufu *et al.*, 2010).

The main root cause for water scarcity is insufficient and unreliable rainfall caused by changing rainfall pattern, duration, amount and intensity driven by climate change (IPCC, 2001a). Due to insufficient and unreliable amount of rainfall, particularly in SSA there have been many incidences of crops failure. This has resulted into insufficient food production and poor living standards (Ngigi, 2003; Paavola, 2008; Ahmed *et al.*, 2011; Gimbage *et al.*, 2014).

In trying to make SSA self sufficient in food production, that would eradicate malnutrition and enhance the living standards through crop production, many researchers have shown that most crops can be sustained through irrigation, as it plays a vital role in ensuring continuity and sustainable crop production with good quality produces (Tesfaye *et al.*, 2008; Liz *et al.*, 2005). This is because with irrigation it is easier to monitor soil moisture regime directly at the root zone and hence ensure crop water demand is met throughout the production period (Fox *et al.*, 2000; Abdrabbo and Abou, 2009). Also nutrients and pesticide can be applied along with irrigated water, thus the crops grow vigorously and healthier enough to produce the desirable quality and quantity of the harvestable economic part of the crop (MAFC, 2013).

Since crop production is a business like any other; quantifying crop yield against water uses relationship is of particular importance in matching the crop varieties with rainfall regimes, and offering guidelines on timing and levels of irrigation for maximizing returns (Origa *et al*., 2012; MAFC, 2013). If water supply does not meet crop requirement, water stress adversely affects crop growth and ultimately yield, particularly at critical growth stage (FAO, 2002a; Seleshi *at al*., 2009; MAFC, 2013). The increase of yield as a result of additional unit of irrigation water provides a basis for assessing economic returns of irrigation (Payero *et al.*, 2008). The key successful point to this is to use the drip irrigation, which is a very promising technology in delivering water to the roots of the crop efficiently as high as 90 to 95% (Sijali, 2001).

2.2 Water requirement for sorghum

Soil moisture availability greatly influences sorghum growth development, yield production and seed quality (Vanderllip and Reeve, 1972; Jerry *et al*., 2012). Sorghum requires enough moisture during early growth stage (vegetative phase), and during floral phase (head initiation, flag leaf formation, booting and flowering formation (Tolk and Howell, 2001). Generally sorghum water demand increases with the increasing rate up to booting stage, then starts decreasing slowly (ARC-grain 2008; Seleshi *et al*., 2009). Depending on the variety and climatic condition, FAO estimated water requirement for sorghum to be between 450 to 650 mm per total growing period for optimal yield production (Tolk and Howell, 2001; FAO, 2002).

Early in the growing season, average daily water use is approximately 1 to 2.5 mm/day to avoid water stress; this period is roughly during the first 25 to 30 days up to approximately the 7^{th}-leaf stage (Jerry *et al*., 2012). The water requirement then increases to around 7 to 10 mm/day until the booting stage is attained (Assefa *et al*., 2010). Maximum daily water use occurs from the boot stage to after anthesis. The daily water requirement then decreases gradually during grain filling as the crop begins to senescence (Krieg, 1983; McWilliams, 2003; Stichler and Fipp, 2003; Seleshi *et al*., 2009). About 90% of the total water used by sorghum is extracted from 0 to 1.65 m depth of soil (Yousef *et al*., 1996; Rachidi *et al*., 2001). The rooting depth of sorghum, however, can extend to about 2.50 m (Stone *et al*., 2002). Water stored at deeper soil depths below 1.0 m are an important source of stored water at the end of the growing season (Moroke *et al*., 2005).

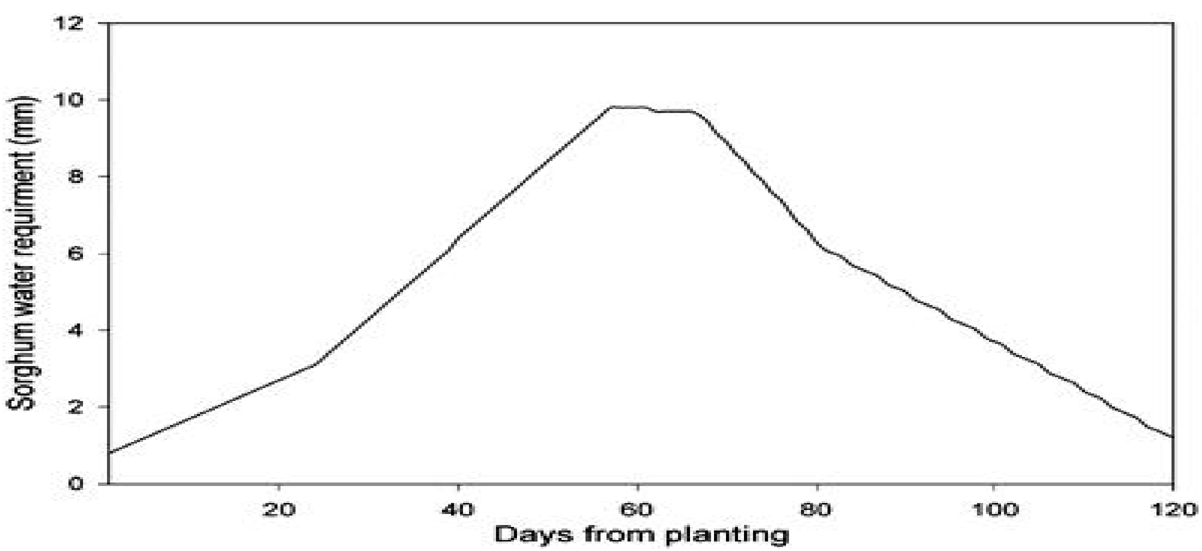


Figure 1: Daily water requirement of grain sorghum maturing in 120 days Source: Assefa *et al*., 2010.

As in any other crops, the crop coefficient (kc) of sorghum related to reference evapotranspiration (ETo) and sorghum water requirement (ETcr), differ with growth stages of the crop (FAO, 2013). Sorghum crop coefficient at initial stage (Kci) is 0.35, at crop development (Kcd) is 0.75, at mid-season (Kcm) is 1.1 and at late season stage/ maturity (Kcl) is 0.65. Generally sorghum takes 120 days to mature. It takes 20, 30, 40 and 30 days for initial growth, crop development, mid season and late season stages, respectively (Seleshi *et al*., 2009; FAO, 2013).

2.3 Sorghum water use efficiency

The amount of water used to produce one gram of dry matter is termed as water use efficiency (WUE). Fan *et al.*, (2005), defined water use efficiency as the crop yield per volume of water used to produce that yield. WUE therefore reveals how efficiently water is being transpired by a crop in converting sunlight energy to chemical energy and its derivatives (Conley *et al*., 2001).Water use efficiency in sorghum is calculated in a similar manner like any other crops (Fan *et al*., 2005; Payero *et al*., 2008).

WUE = Biomass/ Evapotranspiration é .. (i)

Whereby: WUE = Water use efficiency; Biomass =Harvested dry mater; ET = total amount of water used by the plant (mm).

As a C_4 plant, sorghum has high water use efficiency compared to C_3 plants such as rice, wheat and beans. In its group of C_4 plants, sorghum has proved to utilize water more efficiently compared to other C_4 crops such as maize, lablab and sugar cane. The physiological ability of transpiring little amount of water to produce substantial amount of biomass, has given sorghum an added advantage to be grown in ASALs regions, where by other crop would completely fail. High efficiency in utilizing water has made sorghum to be the only crop grown in more than 80% in dry land areas of the world; which occupies approximately 40% of the total global land area, and support about two billion people (Assefa *et al*., 2010; Lizia, 2014).

Being drought tolerant crop, sorghum is often preferred by producers in cases of expected water stress. This is because, grain sorghum tolerates and avoids drought stress more than many other cereal crops; but the drought response of sorghum does not come without a yield loss (Adzemi and Ibrahim, 2014). Water stress at the vegetative stage alone can reduce yield by more than 36%, and water stress at the reproductive stage can reduce yield by more than 55% (Lewis *et al*., 1974; Eck and Musick, 1979; McWilliams, 2003).

WUE in sorghum, like in other grains is useful for yield targeting, and provide a bench mark for farm performance and comparing management options (Fairweather *et al.,* 2004, Adzemi and Ibrahim, 2014). Comparing WUE with different irrigation regimes management within the field, help to understand farming system and identify areas for potential improvement (Mati, 2007).

2.4 Factors affecting sorghum water use efficiency

Factors affecting sorghum water use efficiency include soil management, crop variety, planting time and crop density which are described below.

Soils vary in water and nutrient holding capacity as well as resistance to root penetration (Brady and Weil, 2002). Tolk *et al*., (1997); proved the optimal performance of sorghum in well irrigated clay soils. In places where irrigation or precipitation is not sufficient, loam soil is preferred for grain sorghum production as it has high plant-available water holding capacity (ARC-grain, 2008; Assefa *et al*., 2010). In soils with high bulk density, root growth might be restricted and water use is negatively affected (Urio *et al*., 1979; Juma, 1999; Brady and Weil, 2002).

Soil management practices affect the rate of evapotranspiration by altering the heat balance at the soil surface and altering the exchange rate between the soil and the atmosphere (Hatfield *et al.,* 2001). Contrary to conventional tillage, conservation tillage such as reduced tillage systems, decrease the incoming heat energy capable of evaporating water, enhance exchange rate between soil and atmosphere and trap vaporized water (Assefa *et al*., 2010). Yield increase in sorghum production is mainly a result of an increase in soil water content due to conservation tillage (Unger and Baumhardt, 1999). Stone and Schlegel (2006); proved, sorghum grain yield response to water supply is greater with no tillage than in conventional tillage.

Although physical and chemical properties of the soil influence water uptake by sorghum root, environmental conditions such as rainfall, temperature, relative humidity, solar radiation, and wind also affect water use efficiency of sorghum (Assefa *et al*., 2010). This is due to the fact that crop water use is a function of the crop itself, soil properties and existing weather conditions (FAO, 2002; ARC-grain, 2008; Brady and Weil, 2002; Seleshi *et al*., 2009). Keeping other factors constant, sorghum water requirement is higher in climate with high evapotranspiration demand and lower under mild climatic conditions, defined by moderate temperature of 20 to 25°C, low wind speed of < 2 m/sec and solar radiation, and a humid environment (Tolk and

Howell, 2003). Scientific studies revealed that elevated atmospheric CO_2 also reduces sorghum water requirements and hence increase water use efficiency (Conley *et al*., 2001).

Pest and diseases also affect sorghum water use efficiency by affecting plant physiology and growth (Ogecha, 1995; Muui *et al*., 2013). The less the crop is attacked by pests and diseases the higher the efficiently it is in utilizing water. While the main pests for sorghum are weeds, shoot fly, birds, ants, aphids, borers, head caterpillar and spider mites; the diseases that mostly affect sorghum are reported to be smut, honey dew and charcoal rot (Jaetzold and Schmidt, 1983; Ochieng *et al*., 2011). Plant management practices such as application of required nutrients and appropriate disease, pest and weed-control techniques increase water use efficiency of the plant (Jama *et al*., 1998; Ochieng *et al*., 2011; Muui *et al.,* 2013).

Planting date and planting population in the field also affect sorghum water use efficiency by altering canopy development (Baumhardt *et al*., 2007). Optimizing planting date and planting density on the basis of potential water supply minimizes the constraints for plant water stress that could be raised by high crop water requirement (Krieg, 1983; Ahmad *et al*., 2004).

Also, different sorghum varieties have different ability in extracting and utilizing water efficiently. While some sorghum varieties are drought tolerant and utilize water more efficiently; other varieties are less efficiently and usually fail to reach at physiological maturity under water stressed condition (Lewis *et al.,* 1974; Machado and Paulsen, 2001; MAFC, 2013).

2.5 Sensitivity of sorghum to water stress

Sorghum is more sensitive to water deficit during emergence, head initiation, booting, flowering and grain filling stages (Mastrori *et al*., 1995; FAO, 2002; Seleshi *et al*., 2009). Water stress during vegetative development reduces expansive growth of stem and leaf area index, it also shorten internodes and hence reduces plant height (Assefa *et al*., 2010).

2.5.1 Sensitivity during seed emergence, stand establishment, and vegetative growth

Like any other crops, moisture is important for seed germination (Arau *et al*., 2001). In sorghum, embryoǿs seed is dormant and highly tolerant to water stress; however, there is susceptibility to moisture stress after seed germination and seedling emergence (Blum, 1996). Many studies have shown that water stress at seedling stage reduces endosperm weight of the planted seed as well as growth of the coleoptile, mesoctyl, radicle, shoot, and roots of sorghum, which in turn brings tremendous effect on germination and emergence (Jafar *et al*., 2004; Bayu *et al*., 2005). Since sorghum stand establishment depends on seed germination and emergence, drought stress, therefore causes loss in a sorghum crop even before plant establishment (Arau *et al*., 2001; Assefa *et al*., 2010).

Hale and Orcutt, (1987) reported that, water stress reduces the rate of cell expansion, hence cell size and thus affect growth rate, stem expansion, leaf area and appearance. It also shorten internodes, hence reduces plant height (ARC-grain, 2008). Study done by Garrity *et al.,* (1984) reported that, 14% to 26% reduction in photosynthesis of water-stressed sorghum accounted for a decrease in leaf area. This is because in every significant leaf area reduction due to drought, there is a decrease in stomata conductance which affect overall rate of photosynthesis (Blum and Arkins, 1984; Salih *et al*., 1999; Younis *et al*., 2000).

2.5.2. Sensitivity of water stress on reproductive growth

Sorghum sensitivity to drought stress at vegetative stage is much lesser compared to reproductive stage (Doorenbos and Kassam, 1979; Seleshi *et al*., 2009). Drought stress of approximately 10 days from boot stage and after anthesis will severely affect yield (Kramer, 1983). Generally, water stress during reproductive stages stop the development of pollen and ovules, prevent fertilization, and induce premature abortion of fertilized ovules (Saini, 1997). Since sorghum yield is a function of the number of harvested seeds per panicle and individual seed weight (McWilliams, 2003), all of which can be affected by severity of water stress during reproductive stages (Assefa *et al*., 2010). Sorghum dry matter decreases due to both water stresses at the early boot stage due to reduction in seed size and seed number; while at heading or later stages biomass reduction is due to reduction in seed size only (Eck and Musick, 1979).

2.5.3. Sensitivity of water stress on sorghum yield

With short periods of less severe water deficit, sorghum can tolerate water stress; but when there is long-term dry spell, sorghum growth and the final yield tend to be affected substantially (Adzemi and Ibrahim, 2014). Mild water stress on irrigated grain sorghum within 13 to 15 days at early boot, heading, and early grain filling stages does not affect grain yield; however from 27 to 28 days stress yield is reduced by 12%, while stress period of 35 and 42 days beginning at boot stage reduce yield by 43% and 54% respectively (Eck and Musick, 1979; Gad El-Rabi *et al*., 1988**;** Machado and Paulsen, 2001).

A drop to ī 13 bars soil water potential from late vegetative to boot stage reduce grain sorghum yield by 17%, while the same drop from boot to bloom and milk stage through soft dough stages cause 10% and 34% yield reductions respectively (Lewis *et al*., 1974; English, 1990). Inuyama *et al.*, (1976); found yield reduction of 16% and 36% yield due to 16 days and 28 days of water deficit respectively during the vegetative stage of sorghum. In the same study, during booting stage, there was 36% yield reduction for 12 days of water deficit. At the early 6- to 8- leaf stage, and at heading and bloom stage, withholding 100 mm of irrigated water reduced sorghum grain yield by 10% and 50%, respectively (Jordan and Sweeten, 1987).

As with all crops, sorghum grain yield is dependent on water supply both from soil water at planting and precipitation (Seleshi *et al*., 2009; Assefa *et al*., 2010). A 30-years study from Tribune, proved that, for every millimeter of water above 100 millimeter results in an additional 16.6 kg of grain (Stone and Schlegel, 2006). But generally, the relationship between grain yield and water is more complex, because yield is more sensitive to water deficits at certain growth stages (Arau *et al*., 2001). Sorghum grain yield is more dependent on well distributed rainfall or irrigation over the growing season depending on crop water requirement at each stage than on total water available through the growing season (Farah, 1983; Assefa *et al*., 2010). Although yield response of grain sorghum is strongly correlated to seasonal evapotranspiration, it is also highly dependent on timing of the evapotranspiration deficit (Howell and Hiler, 1975).

The highest recorded sorghum yield is 20 t/ha under optimum growing conditions (Boyer, 1982, Murdy *et al*., 1994). This is 14.6 times compared to global average annual sorghum production of 1.37 t/ ha (Adzemi and Ibrahim, 2014). It is also 22.2 times more than the average sorghum production of 0.9 t/ha in Tanzania (Mbwaga *et al*., 2007). Many other studies in the USA reported yields above 8 t/ha for fully irrigated sorghum with an average of 4.5 t/ ha (Blum, 1996). In 2010 Jordan had national average yield of 12.7t/ha (www.wikipedia .org/wiki/Commercial_sorghum, visited 25th, May 2014).

2.5.4. Sensitivity of water stress on biophysiochemical traits

Severe water stress in sorghum affects its biochemical and physiological responses (Salih *et al*., 1999). Generally, water stress cause stomata closure hence lower stomata conductance and reduces transpiration rates (Cechin, 1998). Stomata closure in drought stress also reduces CO_2 assimilation by leaves and thus affect rate of photosynthesis (Farooq *et al*., 2009).

Vinita *et al*., (1998), showed a reduction in photochemical efficiency of photosystem II (PSII), activities of phosphoenolpyruvate carboxylase (PEPcase) and ribulose-1,5 -bisphosphate carboxylase/oxygenase (Rubisco) in mild water stress conditions. Physiologically, reduction in PEPcase activity reduces Rubisco regeneration and functionality, which inhibit functional activity of PSII, and therefore lowers the net photosynthetic rate (Shangguan et *al*., 1999).

Water stress usually reduce leaf area index, in turn reduces photosynthetic rate and boost photorespiration rate which eventually reduce total dry matter production (Perry *et al*., 1983; Terbea *et al*, 1995). From physiological point of view photorespiration rate increment under severe drought conditions is mainly attributed by stomata closure which results into decrease in internal CO_2 concentration and increase in the internal oxygen concentration, which reactively damage sorghum cell peroxidationally (Farooq *et al*., 2009).

2.6 Methods of Irrigation

Irrigation methods are broadly divided into two systems, they either fall under surface or non surface irrigation systems. Surface irrigation systems are those whereby water is applied into the ground and flow by gravity over the surface of irrigated field, for instance furrow irrigation, flood irrigation, border irrigation and basin irrigation (MAFC, 2013). Non surface irrigation is the one whereby water applied does not flow by gravity. Non surface systems include sprinkler irrigation, trickle or drip irrigation (MAFC, 2013). In selection of irrigation method, several factors such as land slope, water intake, cropộs water tolerance, water availability and wind action are usually considered (Melvin and Payero, 2007).

2.6.1 Drip irrigation

Of all the methods of irrigation, drip irrigation is mostly preferable in arid and semi arid areas due to scarcity of water and high rate of evapotranspiration (Liz *et al*., 2005). The method is popular in areas with limited water supply and salt problems (Abdrabbo and Abou, 2009). Drip irrigation consists of an extensive network of pipes small in diameter to deliver filtered water directly to the soil nearby plant. The systems apply water slowly to keep the soil moisture within the desired range for plant growth. Therefore conventional losses as deep percolation, runoff and soil water evaporation are minimized (Franken, 2005).

Water emission is delivered in form of small droplets, continuously droplets or tiny streams. With drip irrigation; only active feeding zone of the crop is wetted, and kept moist without being saturated. Because of the high potential that is maintained at the root zone throughout the growing season, adverse effects of the salinity is significantly low when drip irrigation is used (Liz *et al*., 2005).

Drip irrigation offers many advantages over other methods of irrigation. Irrigation water is applied very efficiently to crops with minimum water loss. Under good management; water application efficiency of about 90% to 95% is achieved (Payero *et al*, 2008; MAFC, 2013). Insect, diseases and fungus problem are proven to be reduced by minimizing the wetting of the soil surface. Apart from its ability to give high yield, drip irrigation help to control weeds and reduce soil crusting (Lamm and Trooine, 2003). Due to high rate of evaporation and erratic rainfall; drip irrigation method, is superior over other methods in ASALs, and if used effectively can provide the best means of serving water for crops production throughout the year (Liz *et al*., 2005; Payero *et al*, 2008).

As far as ASALs are concerned, Liz *et al.*, (2005) achieved high yield and water productivity with drip irrigation compared to furrow and sprinkler irrigation. The high yield of sorghum produced under drip irrigation method will ensure food security in ASALs, and meet both local and international markets demands. Sufficient production of grain sorghum is therefore the main solution to reduce malnutrition and improve livelihood of ASALs dwellers (Rohrbach and Kiriwaggulu, 2007).

2.6.1.1 Components of drip irrigation

Generally, drip irrigation system consists of a mainline, sub mains, lateral and emitters. The main lines supply water to the sub mains, lateral and finally to emitters. Emitters which are attached to the laterals, distribute water for irrigation directly into crop root zones. Usually the mains, sub mains and lateral are made of polyvinyl chloride (PVC) tubing. PVC is preferred to drip irrigation as it withstands saline irrigation water and is not affected by chemical fertilizers (Hartz, 1999).

Auxiliary components of drip irrigation system include valves, pressure regulator, filters, pressure gauge and fertilizer application components. Drip irrigation can allow water to flow by gravity, or can utilize pump to lift up water so as to produce desired pressure and distribute the water through emitters (Howell, 2001).

Drip nozzles called emitters are spaced at regular intervals on the lateral. They allow water to be emitted at very low rates, in trickles. Emitters can be made either by spatters inserted and connected to the lateral, or water hole punched from the lateral. Amount of water trickling out for each unit time depends upon nozzleøs pressure, size of the opening and fraction resistance due to length and size of water passage in the drip nozzle (Franken, 2005; MAFC, 2013).

2.6.1.2 Potential problems of drip irrigation

Clogging of small conduits and openings in the emitters is the most serious problem in drip irrigation method. Sand, silt and clay particles, debris, chemical precipitation and organic growth clog the flow of water from emitters (MAFC, 2013). The clogging often occurs gradually, reducing water flow and cause poor water distribution along the laterals. The problems are usually handled by filtering water and remove all clogging materials by regular flashing.

2.7 Commercialization of sorghum in ASALS and impact of climate change

Sorghum has gained popularity in recent years though it has been cultivated for many years dating back to ancient times in warmer tropical and subtropical region of Africa and Asia (Murdy *et al*., 1994, Zohary and Hopf, 2000; CSP, 2013). Climate change and occurrence of extreme weather events could favour sorghum to be the main alternative food and cash crop due to its genetic tolerance to harsh environmental conditions (ICRISAT, 2007; Assefa *et al.*, 2010).

Sorghum market in local and international markets has risen as predicted by Rohrbach and Kiriwaggulu (2007). Due to climate change, wheat and barley production that prefer cool weather conditions have been decreasing yearly to meet industrial demands. Sorghum which had been serving as the main staple food in arid and semi arid areas of Tanzania; now has become the potential cash crop in the country, and the world in general. Large quantity of sorghum is now greatly demanded in brewing industries for making alcoholic and non alcoholic drinks such as Malta. Sorghum is also needed in bakeries industries for making breads and biscuits (ICRISAT, 2007; ARMC, 2011; CSP, 2013; McWilliams, 2003). This has made the price to rise, and made it one of the high value crops in the ASAL region of Tanzania.

Globally sorghum production trends shows that, the yield increased from 40 million tons during early 1960s to 66 million tons in early 1980s. By early 1990s, it had fallen to about 58 million tons due to rainfall variability. However, it rose to 64 million tons by 1996, and was 73 million tons in 2005, before it went down to 55.6 million tons in 2010 as a result of low rainfall. The global increment of area under sorghum cultivation has shown a general slight decline of about 0.2%/yr, and yield of 0.5%/yr, before 2000 (USDA, 2003, FAO, 2004).

Expansion of sorghum acreage in Africa increased at about 3.6%/year, although yields declined to about 1.0 %/year (FAO, 213, MAFC, 2013). Trends indicate that area increased from 45 million hacter in the 1970s to 51 million hacter in the 1980s. Later, there was fluctuation in areas under cultivation by 4 to 10 million hacter and it declined to 40 million hacter by 2009 (FAOSTAT, 2014). In eastern and central Africa, the yield in sorghum production increased from 800 to 940 kg/ha from 1970s to 2009, with a marginal increment of 18% in productivity (FAO, 2013).

Globally, Tanzania ranks number 16 in sorghum production (FACTFISH, 2014). In 1960, the production level was 180,000 tons, and then went down to 171,900 tons in 1970. In 1980 the level of production increased to 510,000 tons and dropped down by 9.02% in 1990 and then rose by 22.43% to 598,200 in 2000. The yield then increased to 709,301, 798,540, 806,575 and 838,717 tons in 2009, 2010, 2011 and 2012, respectively as indicated in Figure 2 and 3.

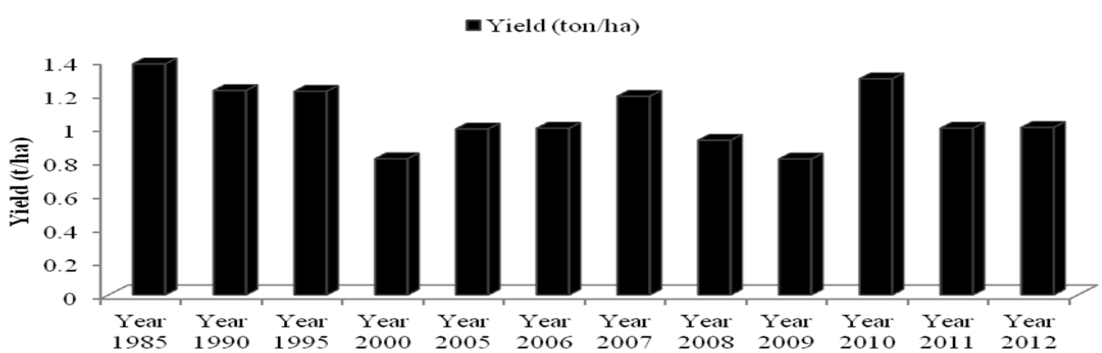


Figure 2: Average sorghum production (t/ha) in Tanzania from 1985 to 2012; Source: FAOSTAT, (2014).

The survey done by Minde and Mbiha (1993) indicated that, sorghum grown in half of the country is white grain; however most of the sorghum grown in Lake Zone regions is browngrained with higher level of tannin. Of the sorghum produced more than 95% is consumed on farm and therefore only low surplus enters into the market. Most farmers experience periodic deficit, and sorghumôs grain trade is between neighbouring households (Rohrbach and Kiriwaggulu, 2007; USAID, 2009).

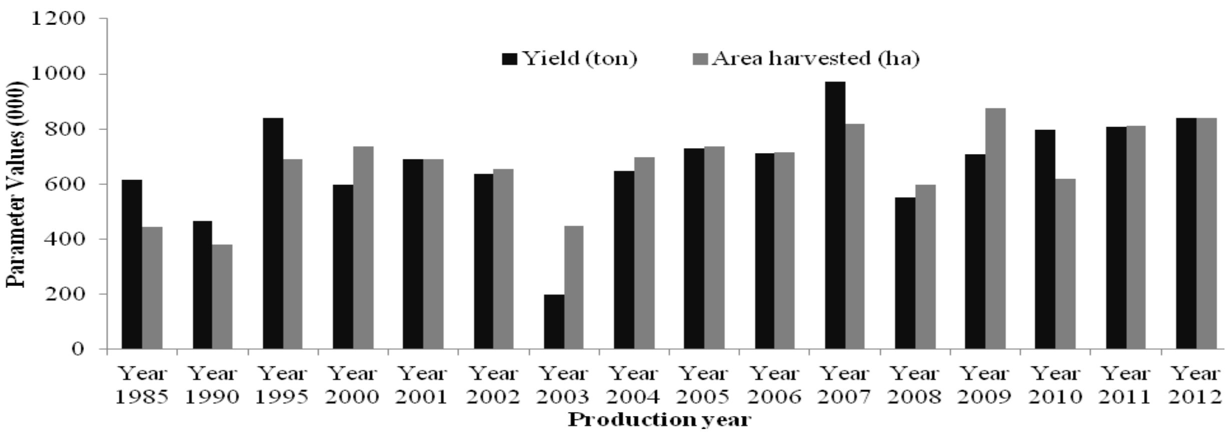


Figure 3: Sorghum yield level and area under production in Tanzania from 1985 to 2012. Source: FAOSTAT (2014).

Currently, the East Africa Breweries Company Limited (EABL) needs more than 45,000 tons of white sorghum versus a supply of 4000 tons a year. Tanzania Breweries Company Limited (TBL) needs 25,000 tons a year and the supply is less than 2100 tons a year after home consumption. The milling industry and bakery industries need more than 20,000 tons a year, but only get less than 6% of the white sorghum from small scale farmers. Though supplied below the demand, the grain quantity supplied is not consistent due to rainfall variability. Traders may have to visit 5 villages to collect 35 tons of sorghum grain (Monyo *et al.*, 2002; Rohrbach and Kiriwaggulu, 2007). In this year (2014), the sorghum performance was very poor as Tanzania government has to distribute 28000 tons of maize as food aid to eight regions including Dodoma (FEWSNET, 2014). This means the supply is going to be even lower.

2.8 Research gap

Although the price of sorghum has increased, the level of supply to meet local and international demand is still very low (Nicholas, 2010). Farmers still produce sorghum under rainfed conditions characterized by low rainfall amount which is unreliable to meet the crop water requirement (FAO, 2011; Muui *et al.,* 2013). In boosting level of yield most of the research has been carried out to breed drought tolerant varieties (Letayo *et al*., 1996; Monyo *et al.*, 2004). Yet the production is still low as the soil moisture level is not sufficient for a crop to produce to its genetic potential. Different soil water conservation methods have been practiced for crop production, but due to high rate of evapotranspiration and regular dry spell occurrences; production under rainfed conditions has more often resulted into crop failure. This has made semi arid dwellers to be food insecure and economically poorer comparing to other regions.

Less effort has been made to grow sorghum under irrigated conditions as a means of boosting yield production in the study area; though there is a chance of utilizing underground water, intermittent rivers, and water harvested from rainfall. This water has to be utilized efficiently and in a sustainable manner, while safeguarding the environment. The only viable and efficient means of utilizing this scarce available water for sorghum production is through the use of drip irrigation, which will be delivering water directly to the effective feeding root zone of the crop. However nothing has been done in the study area to know the most effective watering regime, neither the amount of water needed for sorghum nor the best time for irrigation. There is a need therefore to examine the effect of different drip irrigation regimes on growth, yield and economic returns of sorghum in the semi- arid environment of Tanzania so as to provide detailed and researched valid answers to farmers.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study area

The study was conducted in the periurban area of Dodoma Municipality at Makutupora Agricultural Research Institute which is located at $05^0 58'$S and $35^0 57'$E. The area is classified as semi arid area, and is characterized by mono-modal rainfall pattern. The rainfall commences from December to April followed by long dry season from May to November. The annual rainfall in the area ranges from 300 to 700 mm with a mean of 500 mm marked with high variation in amount and distribution (Msanya and Budotela, 1994; TMA, 2013). Monthly temperatures vary between 15^0 C and 35.1 (ARI- Makutupora, 2014; TMA, 2014).

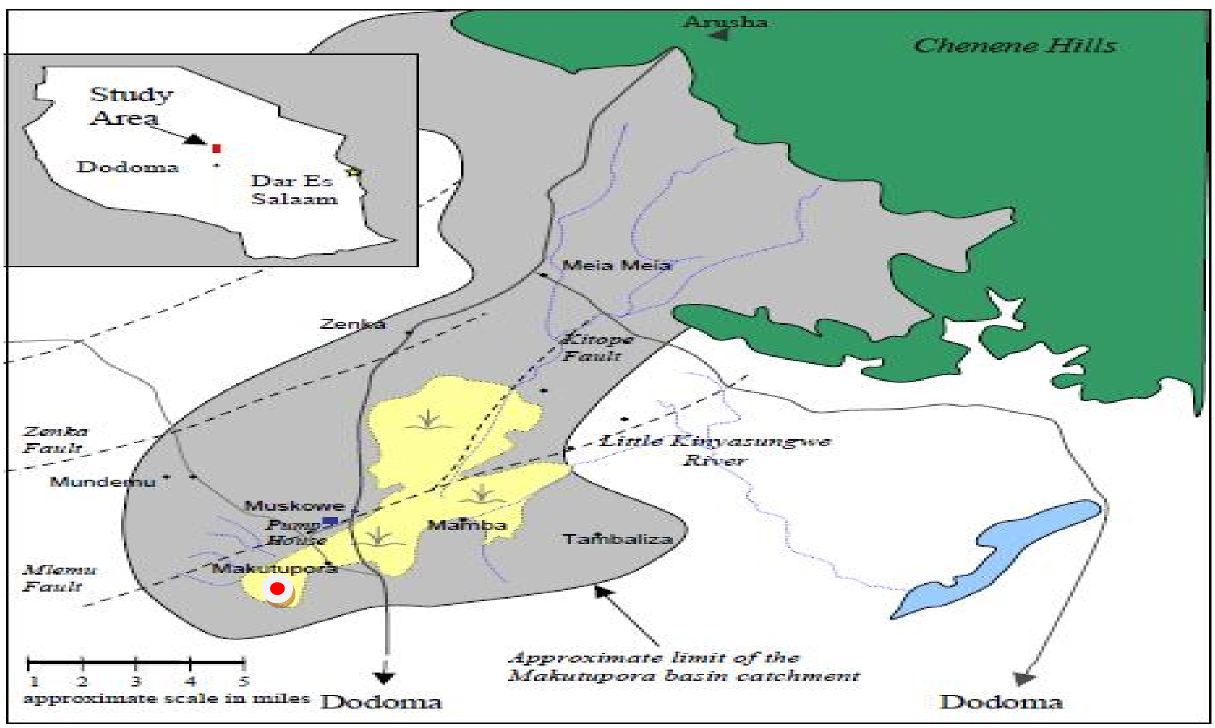


Figure 4: A map showing Makutupora basin, where research study was conducted. Source: Rwebugisa, (2008).

Based on the USDA soil classification, the soil temperature regime is hyperthemic, and the soil moisture regime is ustic / aridic. The area has undifferentiated soil of alluvium derived from granitic rock, and is mainly characterized by sandy clay loam texture. The physiographic position of the area is foot slope (piedmont) with flat surrounding landform with a slope of about 1-2% (FAO-UNESCO, 1989; Soil Survey Staff, 1990; Msanya and Budotela, 1994).

3.2 Methodology

This section describes the major approaches that were used in this study. They include soil sampling and laboratory analysis, field experiment, data collection and analysis.

3.2.1 Soil sampling and analysis

Systematic soil sampling was done, followed by soil testing to determine physical and chemical properties of the soil for sorghum production. Soil chemical and physical properties mainly N, P, K, pH and %OC and soil texture; were determined following standard laboratory procedures as compiled by Okalebo *et al*., (2002). The results of soil properties tested are indicated in Table 1.

Table1: Some chemical and physical properties of the soil in the study area (ARI-Makutupora)

Parameter Measured	Value	Category
Soil pH (H_20)	7.9	Medium
%Total Nitrogen	0.13	Low
Olsen-Extractable P (mm/Kg)	39.17	Low
Exchangeable K (Cmol/Kg)	0.71	Low
%Oganic Carbon	0.74	Very low
% Organic Matter	1.3	Low
C:N	6:1	Very low quality (<8)
%Clay	23	
%Silt	7	
%Sand	70	
Textural Class	Sandy Clay Loam	

Category of the analysed soil properties was rated based on the rating suggested by Landon (1991).

Soil testing was done in order to correlate the level of available soil nutrients with sorghum variety nutrients requirement for optimal growth. %OC was tested to determine the rate the nutrients and moisture holding characteristic of the soil. The ratio of Carbon to Nitrogen was also determined to know rate of mineralization normally influenced by soil microorganisms depending on the C and N ratio in the soil. Based on the soil testing, mineral fertilizers were applied at the rate of 60 Kg N/ha, 40 Kg P_2O_5/ha and 30Kg K_2O/ha. Nitrogen and Potassium nutrients were basal dressed and then top dressed two weeks after planting, Phosphorus was only basal dressed as per agronomic recommendation.

Also, water for drip irrigation was tested for its quality to confirm whether the pumped water from the bore hole could be used to watering sorghum. The irrigation water was analysed for pH, EC, SAR, Cl^-, Na^+, Ca^{2+}, Mg^{2+} and K^+ (Katerji *et al.*, 2003). The results of water quality analysed are indicated in table 2.

Table 2: Water quality analysed for irrigating sorghum in the study area (ARI-Makutupora).

Parameter measured	Value measured	Limit in the criteria	Severity
K^+ (ppm)	14.9	<20	Not a problem
Ca^{2+}(ppm)	50	20-250	Increased problem
Mg^{2+}(ppm)	30	20-40	Increased problem
Na^+(ppm)	60	<70	Not a problem
Cl^- (ppm)	40	<70	Not a problem
EC (mmhos/cm)	0.75	0.5-0.75	Not a problem
pH	7.9	6.5-8.0	Not a problem
SAR meq/L	9.5	<10	Not a problem

Water quality assessment was based on the rating suggested by Dara *et al.,* (2014).

3.2.2 Experiment lay out

A randomized complete block design (RCBD) was used. Treatments in the blocks were assigned in a random manner to avoid biasness. In this research study, treatments were irrigation regimes. There were three irrigation regimes; irrigation once only in the morning (EM), irrigation once only in the evening (LE), and twice a day i.e. early in the morning and late in evening (ELE). The 3 treatments were then replicated thrice in two seasons (dry season and dry-wet season).

There was no experimental control plot in this study. This is because; sorghum was grown during dry and dry-wet season; and experimental control plots could not have survived without water applied. In dry season, sorghum was planted on 18^{th} August, 2013 and harvested on 19^{th} December, 2013; which is purely dry period in semi arid environment of Tanzania. In dry-wet season, sowing was done on 11^{th} October, 2013, two months before the on-set of the rainfall as indicated in Figure 5 bellow.

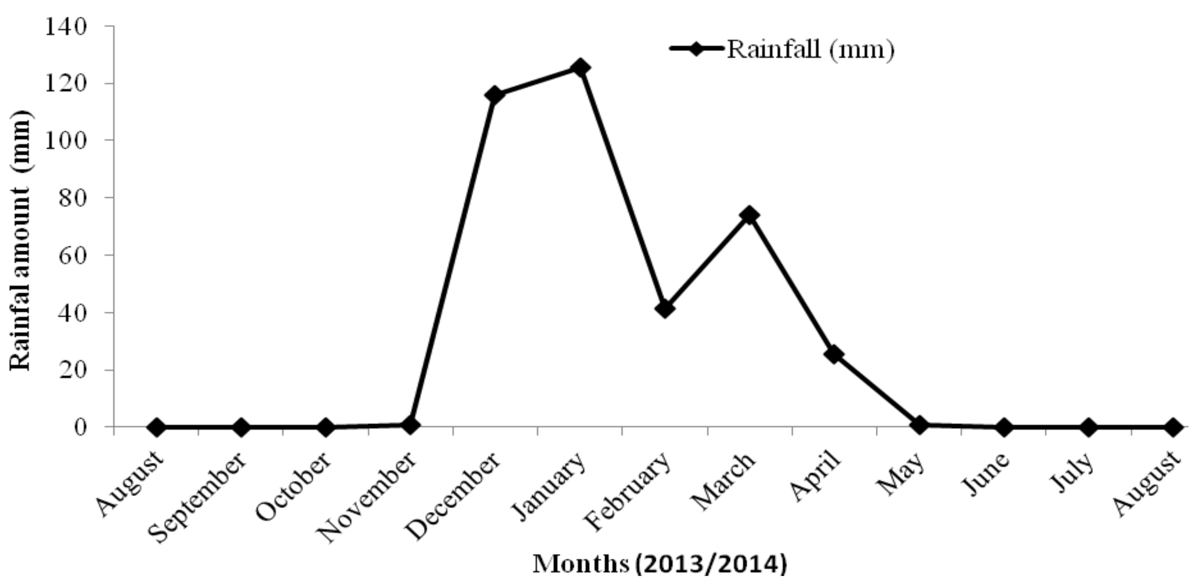


Figure 5: A line graph of rainfall pattern from the study (2013/2014) at ARI-Makutupora.

The size of each plot was 4.5 m x 5 m, giving each experimental plot a size of 22.5 m^2 spaced by one meter path; thus giving the experimental area a total of 214.5 m^2 (Figure. 6). Macia sorghum variety was sown at a spacing of 25 cm x 90 cm. Each experimental plot was having a total of 100 plants, giving 900 plants population in an entire experimental area.

Water was supplied per every plant on daily basis following pan evaporation method, with 7 mm being the highest crop water requirement (McWilliams, 2003; Stichler and Fipp, 2003; Seleshi *et al*., 2009; Assefa *et al*., 2010; FAO, 2013). Some adjustment of water required by the sorghum was made depending on the sorghum growth stage, weather and soil moisture condition as indicated in Table 3.

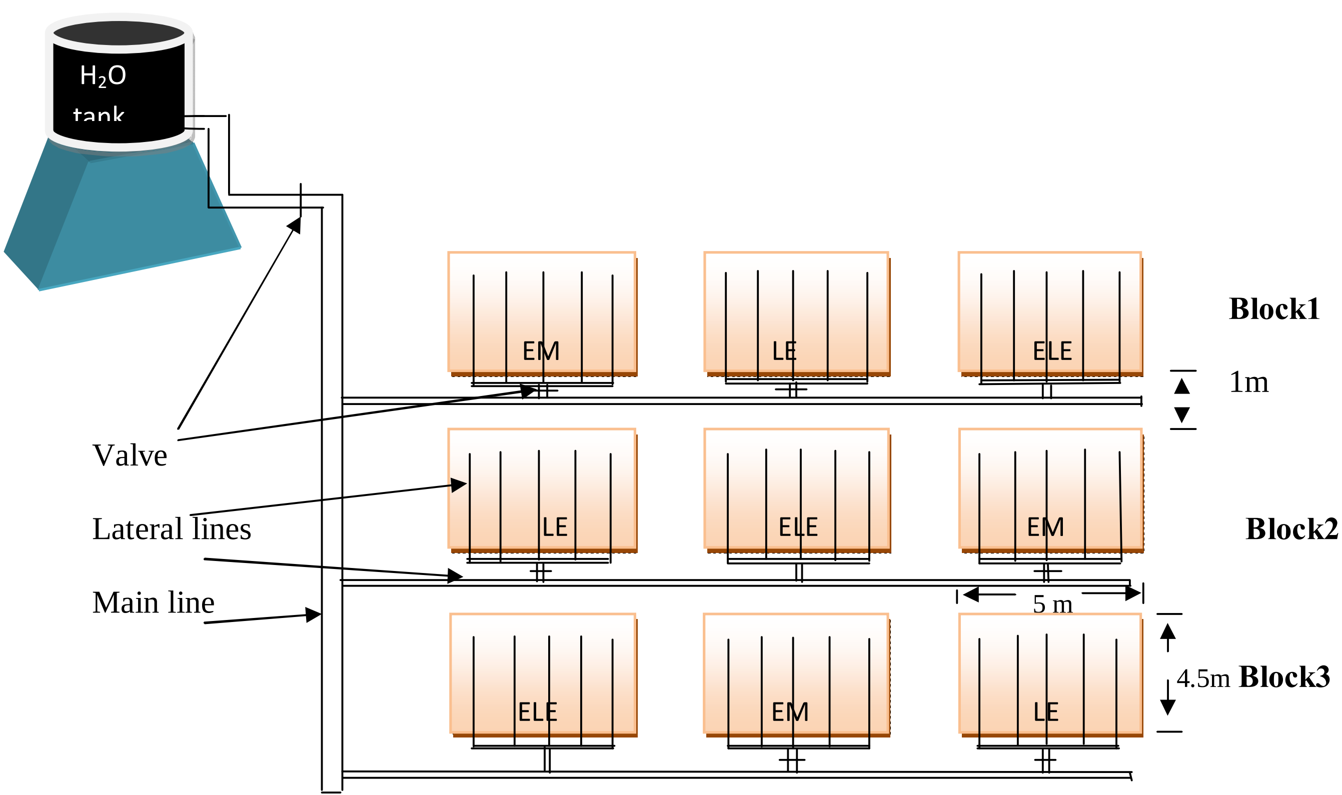


Figure 6: Experimental field layout.

Tensiometer and gravimetric water content methods were used to monitor the amount of water in the sorghum root zone. Tensiometers were inserted at depth of 10, 25 and 40 cm after thoroughly calibration and calibration curve was been drawn on excel sheet. Calibration curve was used to convert tensiometer reading (bars) into volumetric water content.

Augering was done to confirm the validity of the tensiometer installed at different depths. It was also used in calibration of the tensiometers. Soil augered was oven dried at 105 ^{o}C to a constant weight, for determination of gravimetric water content and hence volumetric water content.

Ð v = Ð g x bɟ é é é é é é é é é é é é é é é é é é . é é é é é é é é é é é é ..... (ii)

Also, Ð g = ((Fresh soil weight - Oven dried soil weight)/Oven dried soil weight) x 100é é . (iii)

Whereby: Ð v =Volumetric water content; Ð g = gravimetric water content; bɟ = bulk density.

Table 3: Amount of water used to irrigate sorghum during dry and dry wet season.

			Dry-wet season				**Dry Season**		
Crop stage	**Crop Kc**	**Growing days**	**Total rainfall (mm)**	**Gross water Irrigation mm/crop/day**	**Suppl. Irrigation (mm/crop)**	**Gross Irrigation (L/ha)**	**Gross irrigation mm/crop/day**	**Gross Irrigation mm/ha/day**	**Gross irrigation (L/ha)**
Initial growth	0.35	20	0	18.0	18	13333.3	18	666666.0	13333.3
Develop.	0.75	30	0	93.9	93.9	104333.2	93.9	3477774.3	104333.2
Mid season	1.1	40	128.3	230.1	101.8	157036.9	234.8	8696287.6	347851.5
Late stages	0.65	30	58.7	159.0	100.3	116999.9	164	6074068.0	182222.0
Total		120	109.5	510.0	323.2	39170.3	510.7	18914795.9	647740.1

Develop. = Development; Suppl. = Supplemental; Kc = Crop coefficient.

3.2.3 Determination of water use efficiency (WUE)

In determining sorghum water use efficiency, two important parameters were measured i.e. Sorghum biomass in kg, and amount of water used by sorghum (ET_{cr}) in mm. The biomass was obtained by harvesting the whole mature sorghum crop at the soil surface level. The harvested sorghum plant was then oven dried at 75 ^{o}C to a constant weight (Rowell, 1994). The dry matter weight in kg was determined using an electronic weighing balance.

The water used by the sorghum was obtained by summing up the recorded daily consumptive water use (ET_{cr}) of the sorghum at every growth stage, from initial growth stage (first day of sowing) to late (maturity) stage. The total amount of water used by the sorghum in a season was then obtained. Water use efficiency was determined by dividing the total amount of dry matter (kg) from the total amount of water used by the crop in a season (mm).

$WUE = DM / ET_{cr}$..,(iv)

Whereby: WUE: Sorghum water use efficiency; DM: Dry matter or Biomass in kg;

$ET_{cr:}$ Amount of water transpired or used by Sorghum in a season (mm)

3.2.4 Economic returns analysis

Gross margin analysis was used to determine sorghum economic returns under drip irrigation. The justification of the net profit was obtained by subtracting the cost of production from total income (Kuboja and Temu, 2013). The total cost of production included the following costs: ploughing, seeds, fertilizer, pesticide, drip irrigation,cost of water used for irrigation, weeding, bird scaring and winowing. The cost of input was based on the market price of the area. The price of grain sorghum used was the one offered by East Africa Brewery Limited (EABL) and Tanzania Brewery Limited (TBL). The equation for computing gross margin was as the one shown bellow.

GM = (TR ï TVC) / ha é é é é é é é é é é . é é é é é é é é é é é é é é é é é (v)

Whereby: GM= Gross margin, TR = Total income from sales; TVC = Total variables cost spent on production; ha = Area of production in hectare.

3.2.5 Measurement of growth parameters

Plant height, stem thickness, leaf width, leaf length and leaf numbers were determined in every growth stage for each irrigation regime. Plant height and leaf area were measured using a ruler, while stem girth was measured using vernier calliper. The leaf area was then used to calculate LAI by Linear method (Kvet and Marshall, 1971; Craig, 1990).

LAI = A_L / A_g é é é é é é é é .... (vi), Also, A_L = b_1LWé é é ..é é é é é é é é (vii)

Whereby: LAI = Leaf Area Index; A_L =Leaf Area; b_1 =Sorghum leaf regression coefficient factor (0.75); A_g = Ground Area; L = Leaf length (cm) and W =Leaf width (cm).

3.3 Statistical Data Analysis

Data was analysed using simple statistical method of two ways as linear additive model of ANOVA, under assumption that observations and errors were normally distributed, and all observations within and across the sample were independent with the same variance. GenStat Discovery 20 version was used as aiding software tool in analyzing the data at 95% level of significance. The means were separated by using New Duncanôs Multiple Range (Wim *et al*., 2007).

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Effect of different drip irrigation regimes on the growth and development of sorghum

The parameters whose data are reported are sorghum seedling emergence, sorghum plant height, number of leaves, stem girth and leaf area index.

4.1.1 Effect of different irrigation regimes on sorghum's seedlings emergence

Seedling emergence ranged from 70-80% with the dry-wet season germination having the highest numeric increment over that of the dry season (Figure.7). However, the results showed no significant differences ($p>0.05$) in sorghum seedlings emergence between treatments in both seasons. This is because the amount of water that was irrigated after sowing was optimal for seed germination and emergence in all plots. The results agree with Hossein *et al*., (2009), who reported uniform seed emergence in seeds sown under optimal soil moisture conditions. The rate of seedling emergence in both seasons was the same because seeds were sown in the dry season when the temperatures were higher enough to influence rapid seed germination and seedling emergence in presence of adequate soil moisture condition as explained by Lore *et al.*, (1990); Osman *et al.*, (1991) and Bayu *et al*., (2005).

Although statistical data showed no differences in seedlings emergence across the seasons and within the treatments, there was a higher performance of seedling emergence in dry- wet season by 7.7%, 9.0% and 3.0% for EM, LE and ELE, respectively.

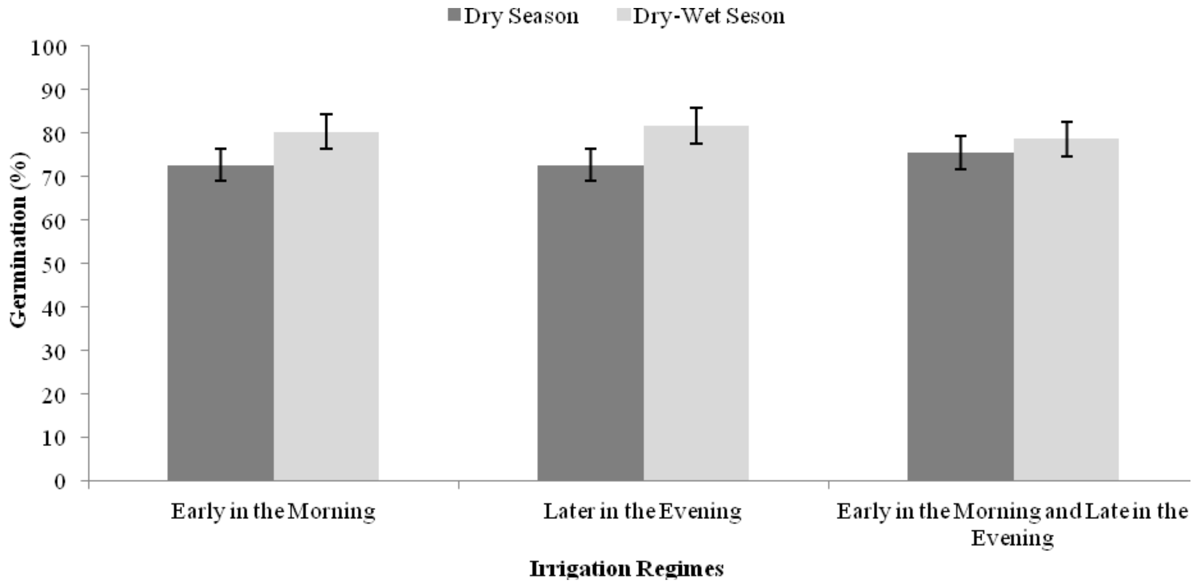


Figure 7: Sorghum emergence at different irrigation regimes in dry and dry wet season.

4.1.2 Effect of different irrigation regimes on sorghum height

Plant height varied between irrigation regimes and seasons (Table 4). In all seasons, there was no significant difference of plant height among treatments at the vegetative stage. However, in all subsequent growth stages, the ELE treatment significantly ($p<0.05$) outperformed the rest. The same trend was observed in the dry-wet season.

The sorghum height in dry-wet season was significantly higher comparing to the one in the dry season. This was due to more favourable weather conditions (temperature, rainfall, relative humidity and averagely wind speed) for crop growth and low incidences of pests and diseases in the nearby and during the rainfall period of December, 2013 and January, 2014. It was also been influenced by amount of effective rainfall (amount of rainfall Ó 10 mm) that fell during the previous two months of the crop growth.

Table 4: Sorghum height (cm) and germination percentage in two seasons under different irrigation regimes and seasons

Season	Irrigation Regime	Germination percentage	Plant Height (cm)				
			Vegetative	Flag leaf	Flowering	Soft dough	Hard dough
1	**EM**	72.67a	41.3a	54.21a	55.75a	74.6a	75.9a
1	**LE**	72.67a	36.6a	61.26b	69.0ab	78.2a	79.6a
1	**ELE**	75.65a	45.85a	82.78d	98.37c	115.9c	118c
2	**EM**	80.33a	66.15b	78.5cd	88.05c	97.6b	98.2b
2	**LE**	81.67a	64.69b	75.54c	83.69c	91.9b	92.2b
2	**ELE**	78.67a	83.56c	104.9e	121.3d	138d	136 d
LSD	**Season**	11.33	8.97	5.996	10.42	6.17	6.25
(p=0.05)	**Irrigation**	13.88	10.99	3.462	12.76	7.56	7.65
	Season*Irrigation	19.63	15.54	4.240	18.04	10.69	10.82
CV (%)		14	15.2	4.3	11.5	5.9	5.9
F-	**Season**	ns	***	***	***	***	***
STAT	**Irrigation**	ns	*	***	***	***	***
	Season*Irrigation	ns	ns	ns	ns	ns	ns

p>5%: Non significant (ns), **p=5-1%:** Significant (*), **p=1-0.1%:** Very significant (**), **p< .001%:** Very highly significant (***), [1]Dry season, [2]Dry-wet season.

The highest plant height (138 cm) was measured at soft dough stage in plots that were irrigated twice a day; and the shortest plant height (36.6 cm) was recorded from sorghum which was irrigated late in the evening in dry season. The highest plant heights were 138 cm, and 118 cm, for the dry-wet and dry season respectively. The shortest height recorded in LE plot is explained by the fact that; during the evening and night hours, the rate of transpiration drops down and plant water uptake decreases to negligible level as relative humidity is higher and atmospheric demand for water is very low; therefore the normal metabolic activities of the plant is affected (Seleshi *et al*., 2009; Assefa *et al*., 2010). During this time, there is readily available moisture in the soil, but the plant cannot take it as soil-water-atmospheric continuum process ceases

(Monsour, 2013). According to Guangï Cheng *et al*., (2008) when irrigated water is not taken up by the plant in the root zone due to low atmospheric demand, water starts moving down the gradient until it is equally distributed.

During the day water is highly utilized for photosynthesis, much of water is taken up by the plant for transpiration purpose. Therefore, when the sorghum was irrigated early in the morning it took advantage of the available soil moisture to equilibrate with atmospheric moisture demand; and in the process, assimilates manufactured were translocated for the normal growth and other physiological activities of the crop; resulting in higher plant height as shown in Figure 8.

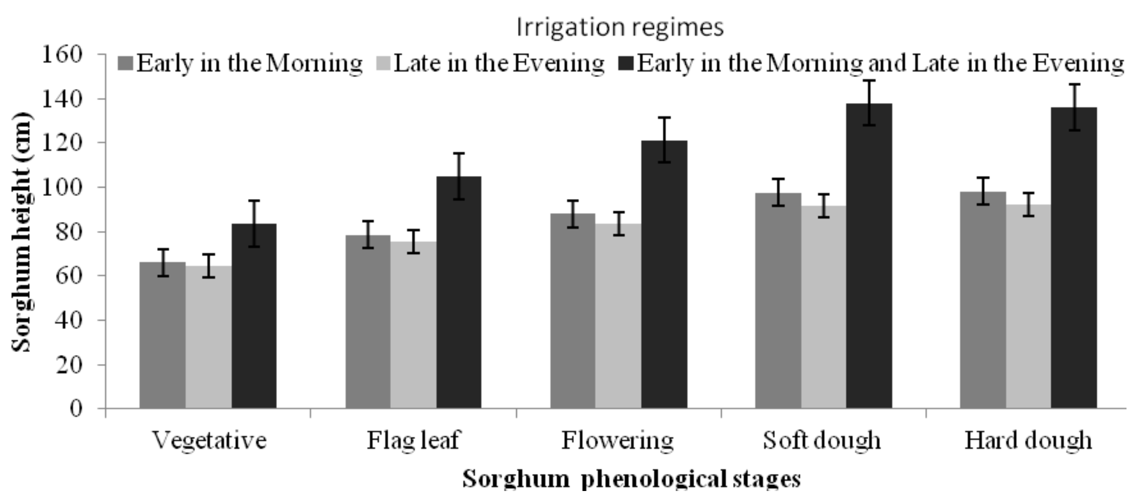


Figure 8: Response of sorghum height to different irrigation regimes at different phenological stages.

The results showed that sorghum which was irrigated twice a day (ELE) was significantly taller ($p<.001$) compared to those which were irrigated once a day, either early in the morning (EM) or late in the evening (LE). This indicates that irrigating twice a day maintains appreciable amount of soil moisture that would be easily taken up by the crop for optimal crop growth. These results are in agreement with those reported by Abdel-Motagally, (2010) that, steady maintenance of tenacity of readily available soil moisture in the root zone results into higher primary crop growth rate.

4.1.3 Effect of different irrigation regimes on leaf numbers

The response of leaf numbers to different irrigation regimes was different at different phenological stages across and within the treatments. In both seasons, the maximum average numbers of leaves were at flag leaf stage as shown in Table 5. The leaves numbers were observed to increase from vegetative to flag leaf stage, thereafter started decreasing. This implies that flag leaf is the last leaf the sorghum plant can produce apart from those arising from tillers as was similarly observed by ARC, (2008).

Table 5: Sorghum leaf numbers in two seasons under different irrigation regimes and seasons.

Season	**Irrigation Regime**	**Number of Leaves**				
		Vegetative	**Flag leaf**	**Flowering**	**Soft dough**	**Hard dough**
1	**EM**	8.67a	10.4ab	10.4a	10.2abc	10.2abc
1	**LE**	8.593a	10.6ab	10.5a	9.93ab	9.93ab
1	**ELE**	8.44a	10.07a	10.3a	9.7a	9.7a
2	**EM**	9.29ab	10.5ab	10.5b	11.bcd	10.3bc
2	**LE**	10.15b	10.9ab	10.9a	10.93d	10.93d
2	**ELE**	10.1b	10.7ab	10.7a	10.7c	10.67d
	Season	0.560	0.3990	0.468	0.3229	0.3085
LSD (p=5%)	**Irrigation**	0.662	0.4887	0.573	0.3955	0.3779
	Season*Irrigation	0.963	0.6911	0.810	0.5592	0.5344
%CV		5.6	3.6	4.2	3.0	2.9
	Season	***	ns	ns	***	***
F-STAT	**Irrigation**	ns	ns	ns	ns	ns
	Season*Irrigation	ns	ns	ns	ns	*

p>5%: Non significant (ns), **p=5-1%:** Significant (*), **p=1-0.1%:** Very significant (**), **p< 0.01%:** Very highly significant (***), [1]dry season, [2]Dry-wet season.

The results showed significant difference ($p<.001$) in the two seasons at vegetative, soft dough and hard dough stages between the treatments. In both seasons, sorghum which was irrigated twice a day appeared to have low number of leaves (8, 10, 10 and 10 for vegetative, flowering, soft dough and hard dough stage respectively). Similar findings were also reported by Stone and Schlegel; (2006) indicating that well irrigated sorghum have long internodes which take relatively longer time to grow and resulted into few numbers of leaves. Physiologically, when the plant is grown under constantly replenished appreciable soil moisture, it tends to grow at its genetic potential while extending out greenish, broad and long leaves for active photosynthesis (Salih *et al*., 1999). However, these results contrast those obtained by Monsourôs work (2013) who reported decrease in sorghumôs leaf number as a result of decrease in soil moisture.

Most leaves were maintained to flowering stage, thereafter started decreasing at soft dough, and hard dough stage. Similar results were also reported by Monsour, (2013) and Unlu *et al*; (2000); Moseki and Dintwe; (2011); that decline in leaves numbers after flag leaf stage is due to senescence.

4.1.4 Effect of different irrigation regimes on stem thickness

The data on variation of sorghum stem girth with irrigation regimes for two seasons are shown on Table 6. The effect of different irrigation regimes to plant thickness varied significantly ($p=0.01$) at vegetative and soft dough stages, and were highly significant ($p<.001$) at flag leaf stage. The highest plant thickness (3.28 cm) was measured at flag leaf stage of the sorghum which was irrigated twice a day in the dry season (ELE1), while the lowest plant thickness (2.0 cm) was measured from sorghum which was irrigated late in the evening (EL1) in the same season. The thickest sorghum was recorded in ELE because application of water in both morning and late evening ensures constant distribution of easily available soil moisture throughout the growing season and lowers any soil moisture deficit that might lead to plant stress; along with its effect to biochemical process for optimal growth of the plant. The result is in agreement with Zhang *et al*, (2004) and Morison *et al*, (2008). The authors reported that, irrigating late in the evening provides little room for photosynthesis process as most of stomata pores are closed at night. During this time transpiration ceases, and respiration is favoured resulting into much utilization of assimilates synthesized in daytime. This phenomenon has been widely reported by Howell, 2001; Liu *et al*., 2006b; Adzemi and Ibrahim, 2014; Donavon, 2012.

Table 6: Sorghum stems thickness (cm) under different irrigation regimes and seasons.

Season	**Irrigation Regime**	**Plant stem thickness (cm)**				
		Vegetative	**Flag leaf**	**Flowering**	**Soft dough**	**Hard dough**
1	**EM**	2.02ab	2.74ab	2.9a	2.4a	2.55a
1	**LE**	1.989a	2.65ab	3.0a	2.5a	2.6a
1	**ELE**	2.161b	3.280c	3.1a	3.0b	3.13c
2	**EM**	2.374c	2.66ab	2.7a	2.8b	3.18
2	**LE**	2.589d	2.576a	2.8a	3.1b	3.14c
2	**ELE**	2.726d	2.813d	2.9a	2.9b	3.0bc
	Season	0.0874	0.1120	0.30	0.19	0.214
LSD,(p=0.05)	**Irrigation**	0.1071	0.1372	0.36	0.24	0.262
	Season*Irrigation	0.1514	0.1940	0.51	0.32	0.37
% CV		3.6	3.8	9.7	6.4	6.9
	Season	***	**	ns	**	**
F-STAT	**Irrigation**	**	***	ns	*	ns
	Season*Irrigation	ns	*	ns	*	*

p>5%: Non significant (ns), **p=5-1%:** Significant (*), **p=1-0.1%:** Very significant (**), **p< 0.01%:** Very highly significant (***), [1]Dry season, [2]Dry-wet season.

The performance of sorghum thickness in the seasons appeared to be significantly different at vegetative, flag leaf, soft dough and hard dough stage. The difference was brought by favourable climatic condition in the dry-wet season such as presence of rainfall and low incidences of pest and diseases.

The sorghum thickness in the plot which was irrigated early in the morning appeared to be thicker at vegetative (2.02 cm) and flag leaf stage (2.74 cm) compared to the sorghum which was irrigated late in the evening. This phenomenon is explained by the fact that, during the daytime the rate of evapotranspiration is very high. At this time stomata pores are open and more water is taken up by the plant for its biophysiochemical activities including photosynthesis and transpiration.

In the dry season, the stem thickness was observed to increase up to flowering stage and then decreased at soft dough stage. This decrease could be explained by the observations made in earlier studies (Kiniry *et al*., 1992; Younis *et al.,* 2000; Bahashti and Behbood, 2010) that assimilates tend to be translocated from the sink to fill the grains soon after flowering stage to milking stage.

These results suggest that different irrigation regimes have different influence in plant girth. The change from a single to a double irrigation regime in a day increased sorghum plant thickness. This is in agreement with the finding of Arau *et al.*, (2001), who reported that additional increment in water to a certain point did influence expansion of the plant cell, thus resulting into increase in plant thickness. The variation of stem thickness in the order ELE> EM>EL in both seasons were attributed due to the different watering regimes that were supplied to the plant to meet crop water requirement.

4.1.5 Effect of different irrigation regimes on leaf area index

The data on the effect of different irrigation regimes on LAI are shown on Table 7. Different drip irrigation regimes and seasons have different influence on LAI at phenological stages of the sorghum plant. In the dry season, the highest LAI (0.17) was recorded under the ELE treatment, while the lowest LAI (0.075) was recorded from the plot which was irrigated late in the evening. The overall highest LAI (0.295) was recorded at the ELE treatment of the dry season at the flag leaf stage.

Table 7: Sorghum leaf area index under different irrigation regimes and seasons

Season	Irrigation Regime	Leaf Area Index				
		Vegetative	Flag leaf	Flowering	Soft dough	Hard dough
1	**EM**	0.08ab	0.13a	0.133a	0.119a	0.122a
1	**LE**	0.075a	0.13a	0.148a	0.12a	0.121a
1	**ELE**	0.101b	0.17ab	0.17ab	0.16b	0.167a
2	**EM**	0.132c	0.145a	0.148a	0.15b	0.148a
2	**LE**	0.144c	0.15ab	0.16ab	0.17bc	0.158a
2	**ELE**	0.168d	0.295b	0.238b	0.188c	0.129a
	Season	0.0128	0.0806	0.0442	0.0129	0.037
LSD, p=(0.05)	**Irrigation**	0.0157	0.987	0.0541	0.0158	0.046
	Season*Irrigation	0.0222	0.1395	0.077	0.0224	0.0654
%CV		10.4	45	25.4	8.2	25.6
	Season	***	ns	ns	***	ns
F-STAT	**Irrigation**	**	ns	ns	***	ns
	Season*Irrigation	ns	ns	ns	ns	ns

p>5%: Non significant (ns), **p=5-1%:** Significant (*), **p=1-0.1%:** Very significant (**), **p< 0.01%:** Very highly significant (***), [1]Dry season, [2]Dry-wet season.

The effect of the three irrigation regimes on leaf area index (LAI) in the two seasons was significant different (p<.001) at vegetative and soft dough stages respectively. However, there was no significant difference (p>0.05) among irrigation regimes at flag leaf, flowering and hard dough stages. The LAI measured under ELE treatment outperformed the rest of the irrigation regimes in almost all phenological stages of the sorghum crop. These results are in agreement with those of Breda, (2003); Dodd, (2009) and Du, *et al*., (2010) work who indicated that maintaining appreciable soil moisture at the rhizosphere resulted into increment on leaf area of the crop.

4.2 Effect of different irrigation regimes on biomass yield and water use efficiency

The result showed that when sorghum is grown in dry-wet season, it generates more biomass than when it is grown in dry season (Table 8). The highest biomass (24.9 t/ha) was recorded from sorghum which was irrigated twice a day (ELE), while the lowest biomass (10.9 t/ha) was obtained in the dry season when sorghum was irrigated late in the evening (LE).

Table 8: Sorghum biomass and water use efficiency under different irrigation regimes.

Season	Irrigation Regime	Biomass (kg/ha)	Water use efficiency
1	EM	11070a	2.012a
1	LE	10850a	1.973a
1	ELE	17450b	3.188b
2	EM	18620b	3.385b
2	LE	17450b	3.173b
2	ELE	24910c	4.530c
	Season	183.9	0.3343
LSD (p=0.05)	Irrigation regime	225.2	0.4094
	Season*Irrigation regime	318.4	0.5790
%CV		10.5	12.0
	Season	***	***
F-STAT	Irrigation regime	***	***
	Season*Irrigation regime	ns	ns

p>5%: Non significant (ns), **p=5-1%:** Significant (*), **p=1-0.1%:** Very significant (**), **p< 0.01%:** Very highly significant (***), [1]dry season, [2]Dry-wet season.

Contrary to the biomass performance, the highest water use efficiency (1.973) was recorded from the sorghum which was irrigated late in the evening in the dry season, while the lowest water use efficiency (4.53) was recorded in sorghum which was irrigated twice a day in the dry wet season.

The response of sorghum biomass and water use efficiency under three irrigation regimes and the seasons were significantly different (p<.001). This indicates that sorghum biomass and water use efficiency were highly influenced by irrigation regimes and cropping seasons (Figure 9).

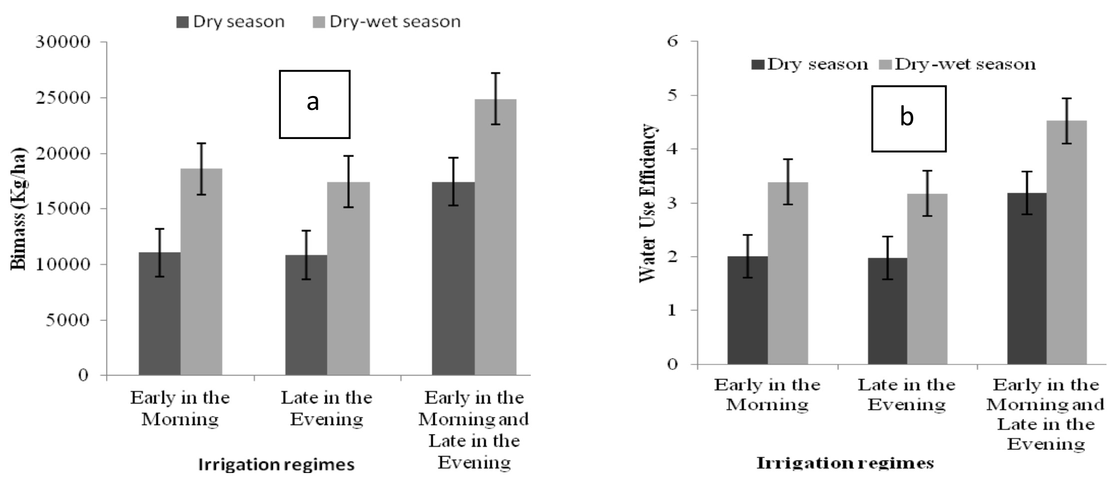


Figure 9: Effect of irrigation regimes on (a) biomass (b) water use efficiency.

Biomass trend was in the order: ELE>EM>LE while water use efficiency was LE>EM>ELE. This showed that biomass accumulation is not only a function of water but also the time of irrigation. Watering late in the evening produced little biomass indicating that transpiration during night hours was very low and the rate of photosynthesis was insignificant. Only little water was used by the plant for its physiological activities during night hours. Since less amount of water (1. 973) was used to produce one gram of biomass, LE appeared to be using water more efficiently in biomass production as compared to other irrigation regimes (Table 8). The result is in agreement with Zhang, (2004) and Morison *et al.*, (2008) who reported that, the less the water is used to produce a gram of biomass the more efficiently it is. The result is also in agreement with the works of Adzemi and Ibrahim, (2014), who reported that crops transpire little amount of water during the night as compared to day time. This is because during night hours the stomata close, light reaction ceased and dark reaction of photosynthesis activated; resulting into low biomass production as observed in this study. These findings are in agreement with a number of previous studies (Abdel-Motagally, 2010; Monsour 2013; Olufayo *et al.*, 1996; El-sang *et al.*, 2009).

These results suggested that, when sorghum is grown during the dry season it uses water more efficiently than when it is grown during the dry-wet season. It also cleared the doubt that irrigating water once a day (either early in the morning or late in the evening) makes higher water productivity compared to when crop is irrigated twice a day; although it does not lead to an increase in total biomass.

4.3 Yield Response and Economic Returns under Different Irrigation Regimes

The data presented in this section demonstrate effect of irrigation regimes on the grain yield and economic returns of sorghum under different irrigation regimes.

4.3.1 Effect of irrigation regimes on sorghum grain yield

Sorghum grain yield in the dry season was higher than dry-wet seasonôs yield by 3.85% (13.212 versus 12.701 t/ha) in ELE treatments. Also, the EM treatment had yielded more grain sorghum by 2.54 % as compared to LE treatment in the dry-wet season. The response of sorghum grain yield to drip irrigation under different watering regimes was significantly different ($p<.001$) for the sorghum which was irrigated twice a day (ELE) compared to those which were irrigated once a day. The highest yield (13.212 t/ha) was recorded in the sorghum that was irrigated twice a day, and the lowest yield (6.822 t/ha) was recorded from the sorghum which was irrigated late in the evening (LE) in the dry season as indicated in Table 9.

Table 9: Sorghum yield grown under different drip irrigation regimes.

Season	**Irrigation Regime**	**Yield (t/ha)**
1	EM	6.833a
1	LE	6.822a
1	ELE	13.212b
2	EM	8.383a
2	LE	8.170a
2	ELE	12.703b
	Season	1.090
LSD, (p=0.05)	Irrigation regime	1.335
	Season*Irrigation regime	1.887
%CV		11.1
	Season	ns
F- STAT	Irrigation regime	***
	Season*Irrigation regime	ns

p>5%: Non significant (ns), **p=5-1%:** Significant (*), **p=1-0.1%:** Very significant (**), **p< 0.01%:** Very highly significant (***):[1]Dry season, [2]Dry-wet season.

The observed yield trends in the dry and dry-wet season showed that ELE> EMÓLE regime. The results showed no significant difference (p>0.05) for the plots which were irrigated once a day, though EM performed better than EL as indicated in Figure 10. The results showed that irrigating twice a day (ELE) lead to higher yield than irrigating once a day by more than 50.5% . That increment in sorghum yield was a function of water productivity stored at rhizosphere without percolating. The results also showed that it is possible to double the sorghum grain yield by maintaining constant soil moisture supply at the effective root zone by irrigating twice a day. This proved that sorghum grain yield is more dependent on well distributed soil moisture throughout the growing season based on the crop water requirement rather than the total water amount. Application of water twice a day maintained additional available soil moisture for crop water requirement that created a favourable microclimatic condition for sorghum growth. The result is in agreement with Stone and Schlegel, (2006), who reported that for every millimeter of water applied above 100% results in an additional of 16.6 kg of grain.

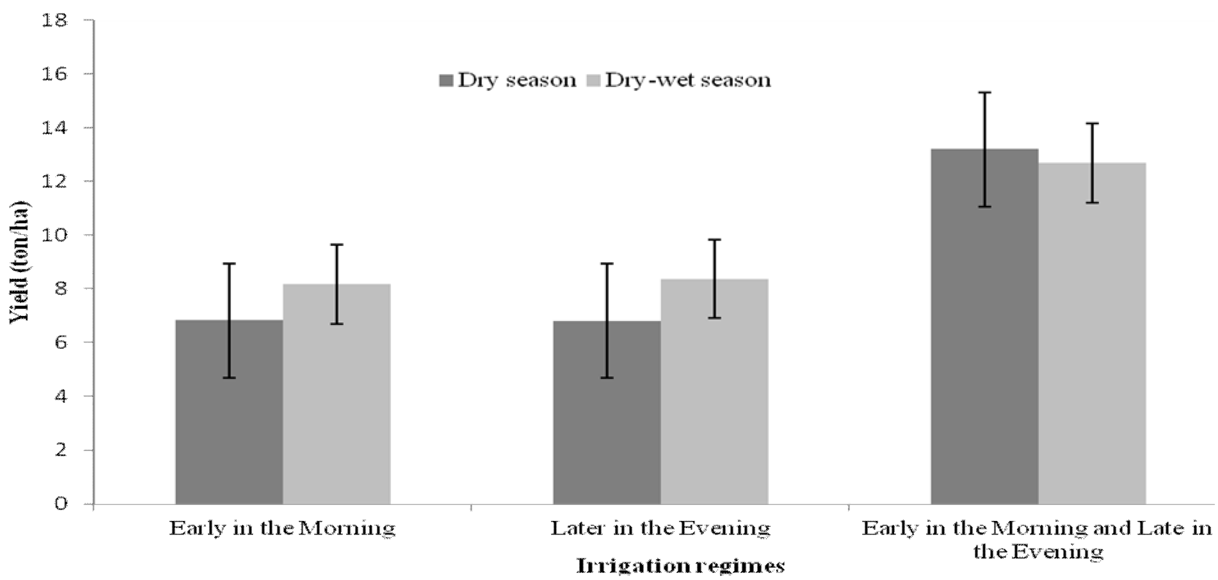


Figure 10: Effect of different irrigation regimes on sorghumôs grain yield.

The result suggested that, irrigating once a day result into reduction of leaf and affect overall photosynthetic activities of the plant as also reported by Sepaskhah and Ghasemi, (2008) and Zhagh *et al*., (2004). The low yield in sorghum which was irrigated once a day in the morning hours was influenced by higher rate of evaporation and soil moisture deficit occurring during the day. The result also suggested that irrigating only late in the evening result into hidden water stress (water stress that reduces cropôs yield without apparently cropôs leaves wilting) that reduce yield significantly. The hidden water stress due to moisture deficit has effect on phosphoenolpyruvate carboxylase (PEPcase). Physiologically, a reduction in PEPcase activity reduces Ribulose-1, 5-bisphosphate carboxylase/oxygenase (Rubisco) regeneration and functionality, which inhibits functional activity of photosystem two (PSII), and therefore lowers the net photosynthetic rate and hence overall yield as was reported by Shangguan and Dyckmans, (1999).

Comparing to the average global production of 1.37 t/ha under rainfed condition that was reported by Adzemi and Ibrahim, (2014), the total yield obtained from this study appered to be five and six times more for sorgum yield which was irigated once a day; and ten and nine times more for sorghum yield which was irrigated twice a day in dry and dry-wet season, respectively. The result showed that, the lowest yield (8.38 t/ha) in dry- wet season was more by 0.383 t/ha compared to the maximum yield which was harvested under full irrigated condition in USA as was reported by Blum, (1996). It is also far much more from the maximum average yield of 0.9 ton /ha which was produced in Tanzania under rainfed condition as was reported by Saadan *et al*., (2000); Mbwaga *et al*., (2007) and MAFC, (2013).

Based on the yields obtained from this study it showed that a farmer could get 7.58, 7.59 and 14.68 t/ha; more times by irrigating LE, EM and ELE, respectively during dry season. It also showed that if sorghum would have been supplemented with drip irrigation in LE, EM or ELE during dry-wet season; a yield of 9.1, 9.3 and 14.1 t/ha more times would have been obtained respectively.

4.3.2 Economic returns of sorghum under different irrigation regimes and seasons

The highest net income (7,607,780/=) (1 Tsh. =1500 USD) was obtained from the treatment where irrigatation was done twice a day during dry-wet season while the minimum income

(3183, 000/= Tsh) was obtained from treatment in which irrigatation was done late in the evening in the dry season. It is impotant to note that all irrigated treatments gave better economic returns compared to sole rainfed based income (65000/=Tsh). However, the highest returns (7,607,780/=) were obtained under double irrigation regime (morning and evening) in the dry-wet season as shown in Table 10.

Table 10: Economic return of sorghum grown under different irrigation regimes and seasons

Season	Irrigation Regime	Yield (t/ha)	Market price (Tsh/kg)	Other cost (000)	Irrigation water cost (000)	Total Production cost (000)	Gross income (000)	Net Income (000)	Cost Benefit Ratio (000)
1	EM	6.833	800	655	1619.35	2274.35	5466.4	3192.05	1:1.4035
1	LE	6.822	800	655	1619.35	2274.35	5457.6	3183.25	1:1.3996
1	ELE	13.212	800	655	3238.70	3893.70	10569.6	6675.9	1:1.7145
2	EM	8.383	800	655	949.81	1604.81	6706.4	4417.14	1:2.7524
2	LE	8.170	800	655	949.81	1604.81	6485.6	4196.34	1:2.6149
2	ELE	12.703	800	655	1899.62	2554.62	10162.4	7607.78	1:2.9785

[1]Dry season, [2]Dry-wet season

On the basis of cost to benefit ratio in sorghum production, the result showed that for every shilling invested there was a return of 1403.5, 1399.6, and 1714.5/= Tsh for EM, LE and ELE, respectively in the dry season. The corresponding values for the wet dry season were 2752.4, 2614.9 and 2978.5/= Tsh for EM, EL and ELE treatments, respectively as indicated in Table 10. This means that despite the higher cost associated with the ELE treatment, it had the best economic performance. It is also noted that, the wet dry season outperformed the dry season. From economic point of view, these results suggest that, it is far much economically rewarding to do supplemental irrigation rather than doing pure irrigation.

Table 11: Consumptive water use and total cost of water incurred for pure irrigation during dry season (18th August to 19th December, 2013).

Crop stage	Crop kc	Growing days	Gross irrigation mm/crop/ day	Gross Irrigation mm/ha/day	Gross irrigation mm/ha/gro wing days	gross irrigation (L/ha)	Cost of water (Tsh/L)	Cost of irrigation water/ha
Initial growth	0.35	20	18	666666	13333320	13333.32	2.5	33,333.3
development	0.75	30	93.9	3477774.3	104333229	104333.2	2.5	260,833.1
Mid season	1.1	40	234.8	8696287.6	347851504	347851.5	2.5	869,628.8
Late stages	0.65	30	164	6074068	182222040	182222	2.5	455,555.1
Total		120	510.7	18914795.9	647740093	647740.1	10	1,619,350

Table 12: Consumptive water use and total cost of water supplemented during dry-wet season (11th October, 2013 to 12 April 12th, 2014).

Crop stage	Crop kc	Growing days	Total rainfall (mm)	Gross water Irrigation mm/crop/day	Supplemented Water (mm/crop)	Cost of water Tsh/L	Gross water in L/ha	Cost of Irrigation water/ha
Initial growth	0.35	20	0	18.0	18	2.5	13333.32	33333.3
Development	0.75	30	0	93.9	93.9	2.5	104333.229	260833.073
Mid season	1.1	40	128.3	230.1	101.8	2.5	157036.88	377036.66
Late stages	0.65	30	58.7	159.0	100.3	2.5	116999.883	278610.833
Total		120	109.5	510.0	323.2	10	39170.312	94,9813.866

The results indicated that, although irrigating ELE in the dry season resulted in higher yield than in dry-wet season, the net income for ELE in dry-wet season was higher than in dry season.This is because during dry season much water was bought for irrigation (Table. 11) as compared to dry- wet season (Table. 12). This caused the total cost of production in dry season to be higher by 931,880, 1,013,090 and 1,225,090/= Tsh for ELE, LE and EM, respectively.

In the dry season, sorghum was irrigated by gross amount of water of 18, 93.9, 234.8 and 164 mm/ crop at initial, development, middle and late growth stgaes, respectively as indicated in Table 11. This was the highest gross amount of water irrigated comparing to 18,93.9, 1001and 1003 mm/crop that was supplimented during dry-wet season. While the total gross amount of water watered during dry season was 510.7, the total gros water amount for dry-wet season was 323.3 mm.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

These results showed that when drip irrigation was used, sorghum grain yield varied with the irrigation regimes administered. Irrigating both early in the morning and late in the evening doubled sorghum grain yield compared to single irrigation (early in the morning or late in the evening).

Also, with regard to growth performance, biomass production, yield response, economic returns and cost benefit ratio the observed trend was as follows: irrigating twice both early in the morning and late in the evening > Irrigating once early in the morning > Irrigating once late in the evening. As far as water use efficiency is concerned, the trend was as follows: Irrigating once late in the evening > Irrigating once early in the morning > irrigating both early morning and late evening. The results also showed discrepancy between maximum yield and economic returns, as the highest grain yield did not correspond with highest profit due to differences of cost of the irrigated water bought.

Growth and development of sorghum crop and hence the grain yield in the studied area varied with the cropping seasons and irrigation regimes. With the local market being the target, growing sorghum crop during the rainy season with supplemented irrigation was more profitable than growing the crop solely on irrigation during the dry season. Economic returns per each invested shilling were highest when irrigation was carried out both in the morning and late afternoon.

5.2 Recommendations

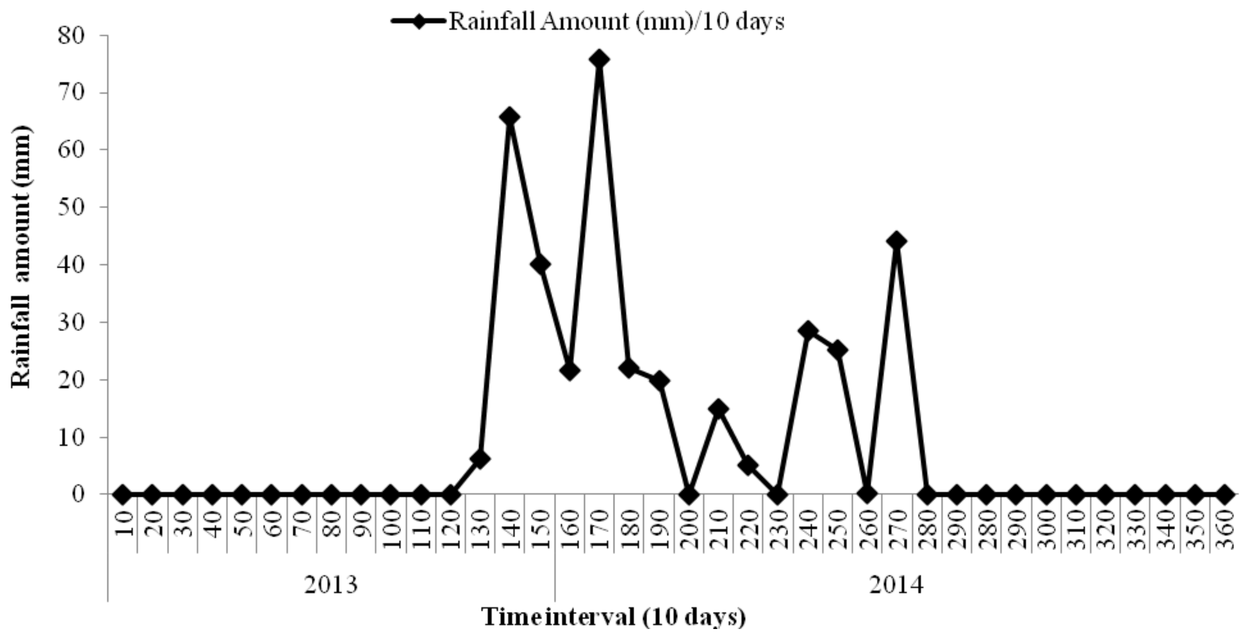
The study recommends that, quantifying crop yield against water uses relationship is of particular importance in matching the crop varieties with effective watering regimes that would maximize returns. In order to make more profit, a farmer should irrigate both early in the morning and late in the evening. This is because such kind of irrigation regime compensate higher rate of evapotranspiration while replenishing the constant flow of water from soil to plant to atmosphere throughout the growth period without creating deficit. In order to make more benefit out of each shilling invested it is economically reasonable to supplement water to the crop rather than practicing pure irrigation in the dry season. However this might change depending on the price fluctuation which is determined by market demand and supply.

The study also recommends that, further studies should be carried out in multiple sites in different agro ecological zones. It will be of particular importance to use more than one sorghum variety to investigate their genetic yield potential under different irrigation regimes. Such study should be carried both on station and on field conditions before being validated for farmers to use.

6.0 APPENDICES

Appendix 1: summary table of rainfall data collected during experimentation at ARI- Makutupora

Day	2013					2014							
	August	September	October	November	December	January	February	March	April	May	June	July	August
1	NIL	NIL	NIL	NIL	NIL	0.2	NIL	NIL	0.4	NIL	NIL	NIL	NIL
2	NIL	NIL	NIL	NIL	NIL	12	NIL	NIL	NIL	NIL	NIL	NIL	NIL
3	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	18.6	NIL	NIL	NIL	NIL
4	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL
5	NIL	NIL	NIL	NIL	NIL	NIL	0.2	NIL	NIL	NIL	NIL	NIL	NIL
6	NIL	NIL	NIL	NIL	NIL	NIL	1.8	NIL	NIL	NIL	NIL	NIL	NIL
7	NIL	NIL	NIL	NIL	NIL	NIL	17.8	NIL	NIL	NIL	NIL	NIL	NIL
8	NIL	NIL	NIL	NIL	NIL	NIL	NIL	5.2	NIL	NIL	NIL	NIL	NIL
9	NIL	NIL	NIL	NIL	NIL	5.6	NIL	NIL	6.2	NIL	NIL	NIL	NIL
10	NIL	NIL	NIL	NIL	6.2	8	NIL	NIL	NIL	NIL	NIL	NIL	NIL
11	NIL	NIL	NIL	NIL	3	27.2	NIL	NIL	NIL	NIL	NIL	NIL	NIL
12	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	0.2	NIL	NIL	NIL	NIL
13	NIL	NIL	NIL	NIL	NIL	6	6.4	NIL	NIL	NIL	NIL	NIL	NIL
14	NIL	NIL	NIL	NIL	16.4	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL
15	NIL	NIL	NIL	NIL	20.4	24.2	NIL	NIL	NIL	NIL	NIL	NIL	NIL
16	NIL	NIL	NIL	NIL	21	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL
17	NIL	NIL	NIL	NIL	NIL	1.4	NIL	NIL	NIL	NIL	NIL	NIL	NIL
18	NIL	NIL	NIL	NIL	NIL	4.4	NIL	NIL	NIL	NIL	NIL	NIL	NIL
19	NIL	NIL	NIL	NIL	NIL	4.6	NIL	NIL	NIL	NIL	NIL	NIL	NIL
20	NIL	NIL	NIL	NIL	5	NIL	8.2	NIL	NIL	NIL	NIL	NIL	NIL
21	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL
22	NIL	NIL	NIL	NIL	NIL	22	NIL	NIL	NIL	NIL	NIL	NIL	NIL
23	NIL	NIL	NIL	NIL	NIL	10	7	NIL	NIL	NIL	NIL	NIL	NIL
24	NIL	NIL	NIL	NIL	30.8	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL
25	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL
26	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL
27	NIL	NIL	NIL	NIL	NIL	NIL	NIL	15.2	NIL	NIL	NIL	NIL	NIL
28	NIL	NIL	NIL	NIL	9.4	NIL	NIL	9.6	NIL	NIL	NIL	NIL	NIL
29	NIL	NIL	NIL	NIL	NIL	NIL		NIL	14	NIL	NIL	NIL	NIL
30	NIL	NIL	NIL	NIL	NIL	NIL		NIL	30.2	NIL	NIL	NIL	NIL
31	NIL		NIL		3.8	NIL		3.8		NIL		NIL	NIL
Total	0	0	0	0	116	125.6	41.4	33.8	69.6	0	0	0	0



Appendix 2: Figure representing rainfall pattern of the study area for the year 2013/2014 at 10 days interval.

Appendix 3: Table representing chemical and physical properties of the soil analysed from the study area

Soil Parameters	Value	Unit	Method used
Soil pH (H_20)	7.9		McLean (982)
Total Nitrogen	0.13	%	Kjedal
Extractable Phosphorus	39.17	mm/Kg	Olsen method
%Oganic Carbon	0.74	%	Walkley
Clay	23	%	Hydrometer
Silt	7	%	Hydrometer
Sand	70	%	Hydrometer
Textural Class	Sandy Clay Loam		Hydrometer

Appendix 4: Table representing rating criteria used for interpretation of the water quality analysed for sorghum irrigation in the study area: Source: Dara *et al.,* 2014.

Parameter	Not a problem	Increasing Problem	Severe problem	Issue
Potassium (K^+)	< 20 ppm	20-50 ppm	>50 ppm	Excess K+ in plant tissue limit plant uptake of other required nutrients
Calcium (Ca^{2+})	<25 ppm	25 ï 250 ppm	>250 ppm	Contribute to hard water and salinity
Magnesium (Mg^{2+})	<20 ppm	20 ï 40 ppm	>40 ppm	Contribute to hard water and salinity
Sodium (Na^+)	<70 ppm	70 ï 200 ppm	>200 ppm	Higher concentration speed up corrosion of by other element. It also cause foliage burning
Chloride (Cl^-)	< 70	70 ï 300 ppm	>300 ppm	When in excess accumulate in leaves and cause toxicity
Electrical Conductivity (EC)	0.50- 0.75 mmhos/cm	0.75- 3 mmhos/cm	<0.5 or >3 mmhos/cm	Initial identifier of the existing problem
Potential Hydrogen (pH)	6.5 ï 8.0 Normal range		<6.0 or >8.0	Influence availability of plant nutrients and other soil elements. pH <5.5 or > 8.5 cause corrosion of pipes and irrigation equipment
Sodium Adsorption Ratio	<10 meq/L	10 ï 18 meq/L	>18 meq/L	Cause disperses, soil crust, reduce porosity. It also reduces infiltration and prevent root from absorbing water

Appendix 5: Table representing analysis of variance (ANOVA) for plant height (cm) of sorghum under different irrigation regimes and seasons

Source of variation	DF	Plant height				
		Vegetative	Flag leaf	Flowering	Soft dough	Hard dough
Replication	2	145.60	89.39	0.01	16.07	19.46
Season	1	4104.52	1839.66	0.18	1714.38	1372.30
Irrigation reg.	2	327.23	1408.17	0.05	3410.91	3305.15
Season x Irrigation reg.	2	67.19	41.40	0.01	39.57	34.51
Residual	10	73.00	10.86	0.08	34.53	35.36
Total	17					
F prob.	S	<.001	<.001	0.163	<.001	<.001
	IR	0.041	<.001	0.523	<.001	<.001
	S x IR	0.430	0.059	0.923	0.356	0.410

Appendix 6: Table representing analysis of variance (ANOVA) for leaf numbers of sorghum under different irrigation regimes and seasons

Source of variation	DF	Leaf numbers				
		Vegetative	Flag Leaf	Flowering	Soft dough	Hard dough
Replication	2	0.1379	0.18	0.28	0.01	0.06
Season	1	7.28	0.58	0.28	2.47	2.08
Irrigation reg.	2	0.24	0.24	0.10	0.09	0.09
Season x Irrigation reg.	2	0.47	0.09	0.08	0.26	0.41
Residual	10	0.26	0.14	0.20	0.1	0.09
Total	17					
F prob. S		<.001	0.073	0.284	<.001	<.001
F prob. IR		0.433	0.239	0.616	0.414	0.383
F prob. S X IR		0.221	0.566	0.674	0.111	0.035

Appendix 7: Table representing analysis of Variance (ANOVA) for plant thickness (cm) of sorghum under different irrigation regimes and seasons

Source of variation	DF	Plant thickness				
		Vegetative	Flag leaf	Flowering	Soft dough	Hard dough
Replication	2	0.01	0.02	0.01	0.01	0.07
Season	1	1.15	0.19	0.18	0.46	0.50
Irrigation reg.	2	0.09	0.32	0.06	0.14	0.07
Season x Irrigation reg.	2	0.03	0.08	0.01	0.16	0.28
Residual	10	0.01	0.01	0.08	0.03	0.04
Total	17					
F prob.	S	<.001	0.002	0.163	0.003	0.006
	IR	0.002	<.0.01	0.523	0.041	0.249
	S x IR	0.056	0.014	0.523	0.029	0.014

Appendix 8: Table representing analysis of variance (ANOVA) for biomass and water use efficiency of sorghum under different irrigation regimes and seasons

Source of variation		DF	BIOMASS	WATER USE EFFICIENCY
Replication		2	66.00	0.0002
Season		1	2318638	7.6649
Irrigation reg.		2	912566	3.0167
Season x Irrigation reg.		2	3836	0.0127
Residual		10	30638	0.1013
Total		17		
	S		<.001	<.001
F prob.	IR		<.001	<.001
	S x IR		0.884	0.884

Appendix 9: Table representing analysis of variance (ANOVA) for gross margin analysis of sorghum under different irrigation regimes and seasons

Source of variation	DF	YIELD	TOTAL INCOME	ECONOMIC RETURNS
Replication	2	0.09	179834	179834
Season	1	2.85	5598639	5598639
Irrigation reg.	2	58.45	114563194	114563194
Season x Irrigation reg.	2	1.934	3791520	37915733
Residual	10	1.076	2109733	2109733
Total	17			
	S	0.134	0.134	0.134
F. prob.	IR	<.001	<.0.01	<.0.01
	S x IR	0.215	0.215	0.215

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