COMPARING EFFICIENCIES OF FLOOD AND DRIP IRRIGATION METHODS IN ONION PRODUCTION UNDER FARMER'S PRODUCTION CONDITIONS IN OMUSATI REGION, NAMIBIA

A RESEARCH SUBMITTED IN FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN AGRICULTURE

OF

THE UNIVERSITY OF NAMIBIA

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December 2018

ABSTRACT

The study was conducted in 2015 at Ogongo Campus of the University of Namibia (UNAM) to compare efficiencies of flood and drip irrigation methods, normally used by small scale farmers in the Omusati Region of Namibia, at three different irrigation levels of 100, 80, and 60% Crop evapotranspiration (ETo). Irrigating at lower levels than full irrigation is also referred to as deficit irrigation. Furthermore, the study compared gross margins and assessed yield and growth indicators under the two irrigation systems using onion as the crop. A split-plot in a randomized complete block design (RCBD) experiment was carried out on a 43 m*34 m plot with soil physical and chemical characteristics analyzed before cultivation. The results indicated that 60% of ETo had a higher water use efficiency (WUE) of 4.6 kg m^{-3} in drip irrigation than 2.8 kg m^{-3} for the flood. At 80% level, water use efficiency of drip was 3.6 kg m^{-3} compared to 2.1 kg m^{-3} for the flood. At 100% levels, the water use efficiency was 2.9 kg m^{-3} for drip compared to 1.8 kg m^{-3} for the flood irrigation method. WUE is significantly different at all three levels of irrigation (p =0.008) and also significantly different for the irrigation type (p = <.001).The total volume of water used under the drip irrigation system was less compared to flood irrigation system by 32.3%. Results also show that there was a saving of water in drip irrigation by a margin of 30.7% for the 100% levels, by 33.3% each for the 80 % and 60% levels. As for moisture content, drip irrigation at 100% was better than flood at 100% by 0.74% whist at 80% drip was better than flood by 1.14%, and at 60% drip was better than flood by 0.03%. The yield productions of all treatments were highly significant at 0.4, 0.29 and 0.19 eta squared. The irrigation type was highly significant (p< 0.001). Irrigation level at 20wt is (p=0.008), irrigation level at 10 wt. is significantly different at (p <0.001) and at 5wt, it is also highly significantly different at (p<0.001). However, the interaction between level of irrigation and irrigation type are not significantly different at 20wt (p=0.415) and 10wt (p=0.224). Results show that more yields were obtained in drip irrigation by a margin of 5% for the 100% levels, by 9.4% for the 80 % levels and 9.5 % for the 60% levels. However, plant height/growth rate was not significantly different at all the three levels (p =0.397) of irrigation. A higher growth rate was obtained in drip irrigation treatment by a margin of 28.36% for the 100% levels, by 3.65% for the 80 % levels and 22.38 % for the 60% levels. In addition, the results showed that the gross margin for drip at 60 ETo was higher than for flood by 44.7%, while at 80 of ETo, the gross margin for drip was more than for flood by 64.6%. The gross margin is highly significantly different at all three levels of irrigation (p =0.001) and also significantly different for the irrigation type (p = <.001). The present study suggests that the small scale Namibia farming community should adopt deficit drip irrigation method instead of the old traditional flooding methods.

Keywords—Drip and flood irrigations methods, water use efficiency, yield of onions.

ACKNOWLEDGEMENTS

First and foremost, I would like to thank the Almighty God for giving me strength, patience, and ability and making it possible to successfully finish this work.

I would like to acknowledge the University of Namibia for allowing me to pursue my studies at the Department of Crop Science at Ogongo Campus. I consider it a profound pleasure to express my deep sense of gratitude to my Supervisors, Dr A.A Ogunmokun and Prof. Levi Shadeya-Mudogo Akundabweni for the positive support, professional guidance, constructive comments and encouragement from a proposal stage up to the thesis research writing and completion.

I would like to express my gratitude to my beloved families. They have been the constant source of my strength and hope in every aspect of my life.

Last but not least I express my gratitude to Dr Bertha Mudamburi and Mr Kudakwashe Hove for their words of encouragement and support during my study.

DEDICATION

This research is dedicated to my loving and supportive family for giving me the encouragement to fulfil this research.

DECLARATIONS

I, **Hortensia Kandongo**, hereby declare that this study is a true reflection of my own research and that this work or part thereof, has not been submitted for a degree in any other institution of higher education.

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LIST OF ACRONOMYS AND ABBREVATIONS

AMTA-	Marketing and Trade Agency
ANOVA –	Analysis of Variance
DWA –	Department of Water Affairs
ECw-	Electrical Conductivity
ETc –	Crop Evapotranspiration
ETo –	Reference evapotranspiration
ETo -	Potential evapotranspiration
Kc –	Crop Coefficient
Ha –	Hectare
LSD –	Least Significance Difference
GDP –	Gross Domestic Product
MAWF –	Ministry of Agriculture, Water and Forestry
MSP -	Market Share Promotion
NAB –	Namibian Agronomic Board
NCA –	Northern Communal Area
NCR –	North Central Region
NDP4 –	National Development Plan
NPC –	National Planning Commission
PE -	Polyethene pipe
OM –	Organic Matter
RCBD –	Randomized Complete Block Design
SPSS –	Statistical Package for Social Science
WUE-	Water Use Efficiency

LIST OF STATISTICAL SYMBOLS

Fmax – Test statistic for testing equality of variances

σ^2 - Population variance or parameter estimated by S^2

S^{2} - sample variance or estimate for σ^2

S^2min – Denote the smallest variance for the treatments

S^2max – Denote the largest variance for the treatments

CHAPTER ONE

1. INTRODUCTION

1.1 Background/Situational Analysis

Namibia is one of the driest countries in Sub-Sahara Africa (World Bank, 2009). It is classified as a semi-arid country, characterized by low rainfall, high temperatures and high evaporation rates. Water scarcity in the country is the major problem to agricultural production (World Bank, 2009). The average annual rainfall ranges between 50 mm along the coast to 350 mm in the central interior and 700 mm in the Zambezi region (WWC, 2010-2016; MET, 2011). The distribution of the rainfall is highly unreliable both spatially and temporally and also both within season and on a long-term basis. About 90% of the precipitation falls in the summer period (November-April) when the temperature is at the highest level, thus contributing to potential evaporation of over 2600 mm/annum over most of the country (De Lange, 2006).

Droughts are common, continuously confronting the country year in and year out, which pose a great risk to Namibia's water resources. The impact of droughts in the Northern Central Region conditions is usually very severe. Drought disasters were observed in 1992-1993 and 2011-2012, rainfall seasons (Mendelsohn, Jaris & Robertson, 2013). About 60 % of the population live in Northern Namibia (Fiebiger et al. 2010). The majority of the people living in Northern Central Regions (NCR) of Namibia have little resources, and their livelihood is directly dependent on subsistence agriculture, which is characterized by low input, animal and crop production systems (Mendelsohn, Obeid & Roberts, 2000).

The temperature in Northern Namibia ranges between 20°C - 38°C during the rainy season (Fiebiger *et al.* 2010). The area receives an average rainfall which is between 200 mm and 500 mm, and most of this rainfall is received in the NCR, which consist of communal areas and which have the highest population density (Mendelsohn, 2008, MET, 2011). Rain falls mostly between November to April, and January to March is regarded as the wettest period of the year (Fiebiger, 2002).

According to Mendelsohn *et al.* (2013), soils in the North Central of Namibia are dominated by the Arenosols group of Kalahari. These types of soils have poor nutrient content and little water holding capacity. Combining soil and rainfall factor, only about 1% of the land surface of Namibia is considered to have a medium to high potential for rain-fed and irrigation crop production (Vigne & Whiteside, 1997).

1.2 Agriculture

Most small scale farmers in Southern Africa rely heavily on rain-fed agriculture, and they frequently face dry spells and droughts that affect their agricultural production**.** Although substantial production in staple food takes place, Namibia is still dependent on food imports to address its food security (NAB, 2017). The problem of water shortage will aggravate further if the available water resources are not used efficiently.

Three-quarters of the approximately 2.2 million population of Namibia live in the Northern Communal Area (NCA) (AGRI Views, 2010; NSA, 2015; Shifeta, 2015). The agriculture sector is one of the sectors in Namibia that can economically assists in eradicating poverty and stimulating food security in the country. Agriculture plays an important role in the economy of Namibia by providing food, energy as well as some income for the majority of the population. According to GRN (2015) agriculture, fisheries and forestry accounted for 7.1% of the GDP in 2013. And despite its modest contribution the GDP, agriculture impacts directly on the livelihood of 70% of the population (NSA, 2015; Shifeta, 2015). Shifeta (2015) also reported that agriculture contributed 12% to 15% to the National Gross Development Product (GDP) in 2015. The production of white maize, wheat, pearl millet and livestock including cattle, goats and sheep is divided in the intensive commercial production units and the extensive communal production system. The commercial sector, though occupying 44% of land, has only 10% of population while the communal sector occupies 41% of the land and involves 60% of the population (GRN, 2015). Agriculture therefore continues to play a leading role in the economic development of Namibia. Besides Namibia's water limitation challenge, the agricultural sector still plays a major role in the country's economic development though the usually erratic rainfall and in-season droughts reduce crop yields.

Water is Namibia's most critical natural resource and is an essential commodity for development. The only perennial rivers are found at the country's borders, thus water is the main constraint to agricultural production (World Bank, 2009).

The Government of the Republic of Namibia, through its Green Scheme Policy, has invested in irrigation projects (Hansen & Kathora, 2013). The Green Scheme Program is aimed at encouraging both large scale and small holder farmers to grow field crops, vegeTables, and fruit crops by giving them leasehold land and input subsidies; to achieve the national social development goals, uplift the welfare of communities, skills and capacity building within the irrigation sub-sector (De Lange, 2006).

More than 120 different horticulture products are consumed in Namibia, and these are traded on the formal and informal markets (NAB, 2017). The top 10 formally traded horticultural products of Namibia in tonnage for the 2015/16 financial year were potatoes (39%), onions

(9%), apples (8%), tomatoes (6%), bananas (6%), carrots (4%), oranges (3%), lettuce (3%), cabbage (2%), and cucumber (2%) (NAB, 2017). Estimates from a study undertaken in 2005 by Price Waterhouse Coopers found that investing in the cultivation, marketing and packaging of two horticultural crops alone (potatoes and onions) could infuse as much as N$ 68 million into the local economy, besides creating nearly 1,000 employment opportunities (Price Waterhouse Coopers, 2005). The Namibian Agronomic Board (NAB) also identified potatoes and onions as the two crops with the highest potential for increased national horticultural production, and they agreed with the Ministry of Agriculture Water and Forestry (MAWF) to implement 'Special Potato and Onion Scheme' in 2013 (NAB, 2012).

The New Era of 18 August (2010) reported that onion production was expected to increase from 5500 in 2006 to 10000 tons in 2007. In September and October of 2007 alone, farmers harvested 8800 tons. Namibia consumed 500 tons of potatoes and 300 tons of onions a week, while neighbouring South Africa consumed 3000 tons of onions and 10000 tons of potatoes per week (New Era, 2010). Domestic onion production increased from 13 308 tonnes in 2014 to 15 619 tonnes in 2015, of which 6337 tonnes were traded in the formal domestic market, and 9288 tonnes were exported in 2015 during the time frame of overproduction (NAB, 2015).

The New Era of 24th February (2015) also reported that the production of fresh fruit and vegeTables in Namibia was on the increase, and according to statistics from the Namibian Agronomic Board (NAB), the national turnover of fresh produce increased in value from N$ 55million in the third quarter of 2013 to N$ 87 million in the third quarter of 2014. During the same period in 2014, 52 % of the fresh fruit and vegeTables consumed in Namibia were produced locally. This was attributed to borders being closed for the import of onions and potatoes under the provisions made for a Special Potato and Onion Scheme. The implementation of the Special Potato and Onion Scheme was very successful, and between April and August 2014, potatoes and onions were exported due to overproduction. An overproduction of onions achieved an export value of N$ 13 340 640.00 with 3 191 tonnes of overproduction (New Era, 2015).

This shows that there was a need to increase the volume of onions produced in order to meet local and export demands. The potential for fruits and vegeTable production in the communal areas of Northern Namibia is therefore high.

1.4 Irrigation in Namibia

Irrigation is one of the key sectors identified to contribute to poverty reduction in the National Development Plan 4 (NDP4) 2012/13 to 2016/17 and the Namibia Vision 2030. Reduction of poverty is to be through employment creation, diversification of the agriculture economic base and providing a livelihood for the growing rural population (NPC, 2012). The National Development Plan 5 (NDP5) also highlights the need to increase agricultural production for cereals, horticulture and livestock. The strategies are to develop 5 536 ha of land for irrigation and expand the green scheme and support small scale and subsistence farmers. The desired outcomes by 2022 are to have the proportion of food insecure individuals dropped from 25% in 2016 to 12% and to increase food production by 30% over the NDP5 period (NDP5) (2017/18 – 2021/22). During NDP5, priority will also be given to addressing water shortages which is a vital input in irrigated agricultural production (NPC, 2017).

1.4.1 Irrigation in the NCA

According to Haidula (2016), drip and sprinkler irrigation systems are the most common methods of irrigation systems for small-scale farmers in Namibia. Many small scale farmers are already successfully producing vegeTables on a small and medium scale on plots close to the major water sources (Olushandja Dam) from the Calueque canal within the Omusati region (Ndeutapo & Shivute, 2003; Haidula, 2016). Zimmermann (1999) and Haidula (2016) also highlighted that other farmers were using flood irrigation systems that waste water compared to other systems such as sprinkler and drip irrigation. Haidula (2016) went on to report that there was a lack of technical and production efficiency information such as: water use, production efficiency on irrigation systems, and the ability to be easily adapTable by small-scale horticultural farmers in North-central Namibia.

1.4.2 Drip and Flood irrigation

Globally, it is recognized that the drip irrigation systems are typically about 90% efficient as compared to sprinkler systems which are about 75% efficient (Postel, Polak, Gonzales & Keller, 2001). Water-saving can be as high as 50%, and crop yield can be increased by up to 40% with drip irrigation (Postel *et al.* 2001). Maisiri, Senzanje, Rockstrom and Twomlow (2005) reported a water-saving of 50% with drip irrigation compared to surface irrigation in Zimbabwe. The drip irrigation method, if used, can prove to be very useful in dry and semi-dry areas (Postel *et al.* 2001). It is therefore important for agricultural engineers and farmers to understand which irrigation systems contribute to improved water use efficiency in Namibia.

1.5 Statement of the problem

The potential for fruits and vegeTable production in the communal areas of Northern Namibia is high. However, a major constraint to small-scale farming in communal areas is the lack of adequate irrigation facilities (Ogunmokun & Kanyomeka, 2003). VegeTables can hardly be produced in Namibia without supplementary irrigation since they are normally grown throughout the whole year. For rain fed production, they require at least 60 days of sustained rains. In the study area, even the 'best' rain-days hardly exceed five days, and if they do, they may disappear for another two weeks or so before they re-occur. Under such conditions, drip irrigation may also fill the gap (Akundabweni, personal comm. 2017)

In fact, considering the climatic conditions of low rainfall and poor soil of Namibia, and also issues to do with climate change which have negative effects on rainfall, water scarcity in the country remains the critical problem to agricultural production, particularly on crop production. Given the scarcity of fresh water in Namibia and the inefficient use of water for agriculture compared with other sectors of the Namibian economy (De Lange, 2006), there is an urgent need to improve the efficiency with which water can be used by farmers. Irrigation places a high demand on water resources, and under the circumstances prevailing in Namibia, the need to investigate and consider the impact of irrigation development on the environment becomes obvious. The water abstraction, distribution and irrigation infrastructure is in most cases, an expensive exercise because of factors such as topography, locality of water and soils, the marginal suitability of some soil for irrigation (NRC, 2008).

Technologies to increase crop yields need to be sustainable if they are to have any meaning for the future. Since irrigation provides effective means to increase crop yield and drip irrigation has been proven to be the most efficient way of irrigating (Postel *et al*. 2001; Maisiri *et al*.

2005; Holzapfell *et al*. 2009), a gap exists to objectively compare the efficiency with which water is used in flood and drip irrigation systems on onion production in NCR of Namibia. In order to develop the best management practices for onion production, there is a need to compare the water use efficiencies of the flood and drip irrigation methods used for onion production among small scale farmers in NCR. Water-saving can also come in the form of deficit irrigation i.e. applying different levels of irrigation. Investigations have been carried out worldwide regarding the effects of deficit irrigation on the yield of mainly horticultural crops (Fabeiro, Olalla, & de Juan, 2002; Nagaz, Masmoudi, & Mechlia (2012); Ramalan, Nega, & Oyebode (2010)).

The study of Ogunmokun and Kanyomeka (2003) reported that there are few farmers in Namibia irrigating with drippers despite the availability of an affordable drip system for small-scale farmers. A reconnaissance visit by this researcher to the small scale farmers in Omusati Region in late 2015 confirmed that the situation has not changed until now. According to Zimmermann (1999), opinions on the efficiency of water use in Namibia appear to be based upon subjective judgments. No literature could be found to show if this trend has been reversed since then. There are also no scientific studies done focusing on the efficiency of the irrigation methods in the context of the sustainable use of irrigation water in Namibia. While good guidelines for irrigation scheduling can be used, the optimum irrigation practices for onions are unknown by small scale farmers in Northern Communal Areas of Namibia. A gap, therefore, exists to objectively study the efficiency with which water is used by different irrigation methods for onion production in the study area.

Other sources of differences between irrigation methods are seen in capital outlays required to install different irrigation methods. Zimmermann (1999) highlighted the operating costs, the amount of labour and the level of skills required as some of the differences between the irrigation methods. The farmers in the research by Omusati (2015) also reported that the initial cost of installing a drip irrigation system is high. No literature could be found to confirm if the farmers' perception about the high cost of drip irrigation is true. While it is possible that the initial cost of setting up the drip system may be higher compared to that for flood, it is hypothesized that the overall cost of operating the drip system will be low. Prajapati, Khasiya and Agrihotri (2013) compared the cost of production and net profit under irrigated banana and showed higher net profit to the extent of 12 to 20 % under drip irrigation as compared to surface irrigation. Determining all these under the conditions of small scale farmers in the NCR will contribute towards achieving and recommending the better irrigation method to farmers.

Since onion is one of the two crops identified by NAB to implement the Special Potato and Onion Scheme" (NAB, 2012) and also grown by small holder farmers in the NCR, a gap exists to compare the different levels of two irrigation methods i.e. flood that is considered wasteful and drip that is considered efficient. In order to develop best management practices for irrigation systems in Namibia, information is needed pertaining to differences in water use efficiency of flood and drip irrigation systems.

1.6 Objectives of the study

The primary objective of this study was to compare the water use efficiency (WUE) of different levels of drip and flood irrigation systems on onion production and to develop the best technical system for high onion yield for small scale farmers. The specific objectives of the study were:

1. To compare the water use efficiency (also termed productivity of water) as well as the moisture content in the root zone of onion between flood and drip irrigation systems at three

(3) different irrigation levels (100, 80 and 60% potential evapotranspiration (ETo)) at Ogongo in Namibia.

2. To compare the plant height and yield of onions under flood and drip irrigation systems at three (3) levels of irrigation at Ogongo in Namibia.

3. To determine and compare the cost of growing onion under flood and drip irrigation at three (3) levels of irrigation at Ogongo in Namibia.

1.7. Hypothesis

The research hypotheses that were tested under 95% confidence level are as follows:

$H0_1$ The water use efficiency and root zone moisture content of onion cultivated under drip irrigation will not be different to that grown with flood irrigation at three different irrigation levels (100, 80 and 60% potential evapotranspiration (ETo)) at the 95% CI.

$H0_2$ Use of drip irrigation will not result in better plant height and yields of onions than the yields of and plant heights of onion grown with flood irrigation as tested at the 95% CI.

$H0_3$ There will be no differences in the production costs of onion cultivated under drip irrigation and flooding.

1.8. Significance of the study

The expected outcome of this study will be of value to researchers and growers toward more information on vegeTable production in Omusati Region and beyond. The findings of this research are expected to add to the knowledge and understanding of irrigation systems and their potential application in the NCA, in making the right choice between drip and flood irrigation by farmers and the various organizations promoting irrigation of horticultural crops in the region. It will also be beneficial for stakeholders such as students, extension officers, Ministries, NGO's and many others as a source of local resource when studying irrigation. The research findings may also foster information exchange among stakeholders and may assist stakeholders to initiate and encourage the farmers to use the systems accordingly without wasting water. The expected outcome is that saving water is possible, however, such saving could be controlled by using the most optimum level and more efficient method of irrigation.

1.9 Organization of the thesis

This thesis comprises five chapters. Chapter 1 discusses the background to the study, which includes the problem, knowledge gaps, objectives, significance and organization of the thesis. Chapter 2 discusses the literature review on drip and flood irrigation for onion cultivation. Chapter 3 discusses the methodology used for the study. In chapter 4, the results, analysis and discussion of the results are presented. Chapter 5 discusses the major conclusions drawn from the study and recommendations for future research.

CHAPTER TWO

2. LITERATURE REVIEW

2.1 Introduction

Human dependence on irrigation can be traced to the earliest Biblical references. Irrigation in early times was practised by Egyptians, Asians and Native Americans. The earliest records state that the Egyptians were the first people to start irrigation along the Nile River about 500 BC. The Sumerians relied heavily on irrigation to water fields in Southern Mesopotamia now (Southern Iraq) as early as 24 BC. The Chinese had irrigation by 2200 BC (Vaughn et *al.*, 1980). Peruvians built sophisticated systems before the time of Christ, and earlier Native Americans at the same time had more than 101 000 ha of irrigated land in the Salt River valley of Arizona (Vaughn *et al.* 1980). For decades water supplies were available to these people during periods of heavy run-off. Currently, irrigation is made possible by modern power sources, which pump and store water in large quantity in dams or reservoirs.

FAO (2014) estimated that irrigated agriculture uses more than 70% of the water withdrawn from the earth's rivers, whereas the proportion exceeds 80% in developing countries. Water is a variable resource in agricultural food production, remains a finite resource. The competition for this precious resource is increasing significantly due to current and future events such as climate change, agricultural, industrial sector activities and a rapid increase in world population which is expected to reach 9 billion by 2050 (FAO, 2014).

2.1.2 Water sources in Namibia

The agricultural sector is the major user of water in Namibia. In 2008 irrigation accounted for 41% of the total water demand. It is expected that by 2030 water demand for irrigation will be increased to 65% (IWRM, 2010).

Water is Namibia's most critical natural resource and is an essential commodity for development (World Bank, 2009, Haidula, 2016). Of the water that Namibia receives as precipitation, it is estimated that only 2% ends up as surface runoff, and a mere 1% becomes available to recharge groundwater (GRN, 2015). The balance of 97% is lost through direct evaporation (83%) and evapotranspiration (14%) (GRN,2015). The water resource in Namibia is categorized into ground water, perennial and ephemeral rivers. The total renewable water resources of Namibia are about 45% of good water sources, 33% from Border Rivers mainly in the north and 22% impoundments on ephemeral rivers (Christelis & Struckmeier, 2001). In 2008, it was estimated that the total water demand in Namibia was 327 million cubic meters per annum. By 2030, the demand for water is expected to be increased to 765 million cubic meters per annum (Christelis & Struckmeier, 2001).

Perennial rivers lie in the southern or northern part of the country, with the Orange River in the south. The main perennial rivers that form the Northern regions are Kunene, Kavango, Zambezi, Kwando –Linyanti, and Chobe, while the southern borders have the Orange River, which is shared with neighbouring countries such as South Africa and Lesotho (World Atlas, 2018).

Ephemeral rivers are rivers that run for a certain period of time after heavy rain has fallen. The Oshanas (floodplains) are part of the ephemeral rivers formed in the shallow depression of the

Cuvelai system, which originate from Angola and flow into the Etosha Pan during high rainfall. Most of the Oshanas are found in the most densely populated area in the north-central region.

Ephemeral surface water is very limited in Namibia as farmers rely directly on variable rainfall. By 2001, Namibia had constructed about ten dams on ephemeral rivers. The total capacity of the impoundments is 665 m^3, where 95% assured safe yield is only 87 m^3 which is an indication of the low efficiency of surface water storage facilities in arid environments (Christelis & Struckmeier, 2001). Quite a number of dams were excavated in the sixties, the major ones being Hardap, Naute, Swakopport, Von Bach, Omatako, Omaruru Delta, Oanob, Dreihuk, Friedenau, Goreagab, Avis, Tilda Viljoen, Olushandja, just to mention a few (Windhoek Consulting Engineers, 2000). These dams are used for irrigation purposes in Namibia.

In arid areas, where rainfall is limited, and surface water is only available during the rainy season, groundwater is very important as a water source. The sustainable yield of the usable groundwater sources in the country was 300 million cubic meters per annum (Christelis & Struckmeier, 2001).

The current situation shows that unconventional sources like recycling of water for industrial and irrigation purposes, reclamation of domestic sewage and effluent to porTable water quality standards and desalination are important. Demand for water has rapidly increased during the last decade due to a growing population, increased urbanization, industrialization, food production, unemployment and a high standard of living.

The availability of ground water depends on a combination of sufficient rainfall and appropriate geo-hydrological conditions. Groundwater resources can be utilized on a sustainable basis provided that the extraction does not exceed the long-term recharge potential. Aquifers occurring in Namibia are classified as alluvial, Kalahari, fracture, karst or artesian aquifers (Windhoek Consulting Engineers, 2000).

The responsibility for the regulation and management of water lies within the Department of Water Affairs in the Ministry of Agriculture, Water and Forestry (MAWF). The ministry is actually the one that controls ground and surface water resources and allocates licenses for water extraction and borehole construction. The Water Resources Management Act (2013) serves as a guideline for integrated water resources management through the establishment of Basin Management Committees (BMC) (Water Resources Management Act, (2013).

The state-owned company Namibia Water Cooperation Limited (Nam Water) is the major bulk water supplier, operating the long-distance water supply network. The Division of Rural Water Supply within MAWF is responsible for water provision in rural areas that include the establishment of local water consumer group (Werner, 2009). It manages water and agriculture resources to achieve socio-economic development. All these sources could be used for irrigation purposes, and efficient use of these resources is important for a country like Namibia, where water is the most critical natural resource.

2.1.3 Water sources in Northern Namibia

In Namibia, where quite a number of inhabitants depend on agriculture for their livelihood, water is increasingly becoming scarce (Mendelsohn *et al.* 2006). Water scarcity is due to low rainfall with high evaporation rates. The major water source in North-Central Namibia is the 150 km canal resulting from an agreement between the government of Angola and Namibia that led to the building of the Calueque Dam. Water is pumped from the Kunene River at Calueque in Angola into a canal built in the late sixties to feed water into the Northern Central of Namibia. The canal from Kunene River runs for about 155 kilometres through the Omusati and Oshana regions and has made irrigation-based agriculture possible in its vicinity. The canal passes through the Olushandja dam and ends at Oshakati. The canal is found on the Namibian side, and it supplies Oshakati and the surrounding areas with water (Figure 1).

Figure 1: Canal from Kunene River at Calueque in Angola to Oshakati

The main purpose of this canal is to collect and channel floodwater in the rainy season towards the main centres of Oshakati and Ondangwa as well as to those centres using water from the Calueque dam. To minimize evaporation losses, the canal, which is trapezoidal in shape, is usually not filled to its capacity of approx. 63 million m^3 (Fiebiger, *et al*., (2010). According to NamWater, the main challenges are maintenance due to damage caused by illegal extraction on the Angolan side as well high pumping costs caused by evaporation losses. Both commercial and small scale farmers have benefitted in utilizing the canal water as well as producing crops such as tomatoes, onions, carrots, butternut, squash, spinach, sweet potatoes and water melon

(Fiebiger *et al.,* 2010; Haidula 2016). This, therefore, calls for efficient utilization of water in producing the various types of crops.

Olushandja Dam is part of a complex water distribution system that is operated by NamWater on both sides of the border. The Olushandja Dam is situated on a branch of the canal and was constructed as a strategic water reservoir during the period of conflict in the late 1980s. A number of farmers began irrigation activities along the dam in the 1990s. NamWater uses Olushandja Dam to store surplus water accumulated from the Calueque-Oshakati Canal. One effect of this storage system is that the dam's water level sometimes sinks significantly during the dry season when only small amounts of water need be stored in the dam, as a result of higher summer evaporation rates and higher demand along the canal and in Oshakati (Fiebiger, *et al.,* (2010).

2.1.4 Irrigation in Namibia

Namibia, is one of the driest countries in Sub-Sahara Africa. Agriculture is one of the highest water users, followed by domestic use and industrial. Agriculture used 213 million cubic meters, domestic 7 million cubic meters and industrial 14 million cubic meters (FAO, 2005)

The total national irrigation potential estimated in 2005 was 47 300 ha (FAO, 2005). In 2010, 9000 ha were equipped. Most of the irrigated areas produce high-value crops such as grapes, dates, cotton and melons. The value-added per meter cubic of water for irrigation are high compared to manufacturing and service sector at about US$ 120/m^3 compared to US$44/$m^3$ and US$93/$m^3$ respectively (FAO, 2005).

Namibia has average annual rainfall ranging from 50 mm in the Namib Desert to 700 mm in Zambezi region (MET, 2011). The country comprises of four ecological zones (Figure 2) namely (WWC, 2010-2016):

1. The sub-tropical zone spanning 8% of the land, where mean annual rainfall is between 500 and 700 mm;
2. The semi- arid zone, spanning of 37% of land area with mean rainfall of between 300 and 500 mm;
3. The arid zone, spanning of 33% of land area, where mean rainfall varies between 100 and 300 mm and
4. Desert zone, comprising 22% of land area, where mean annual rainfall is less than 100 mm.

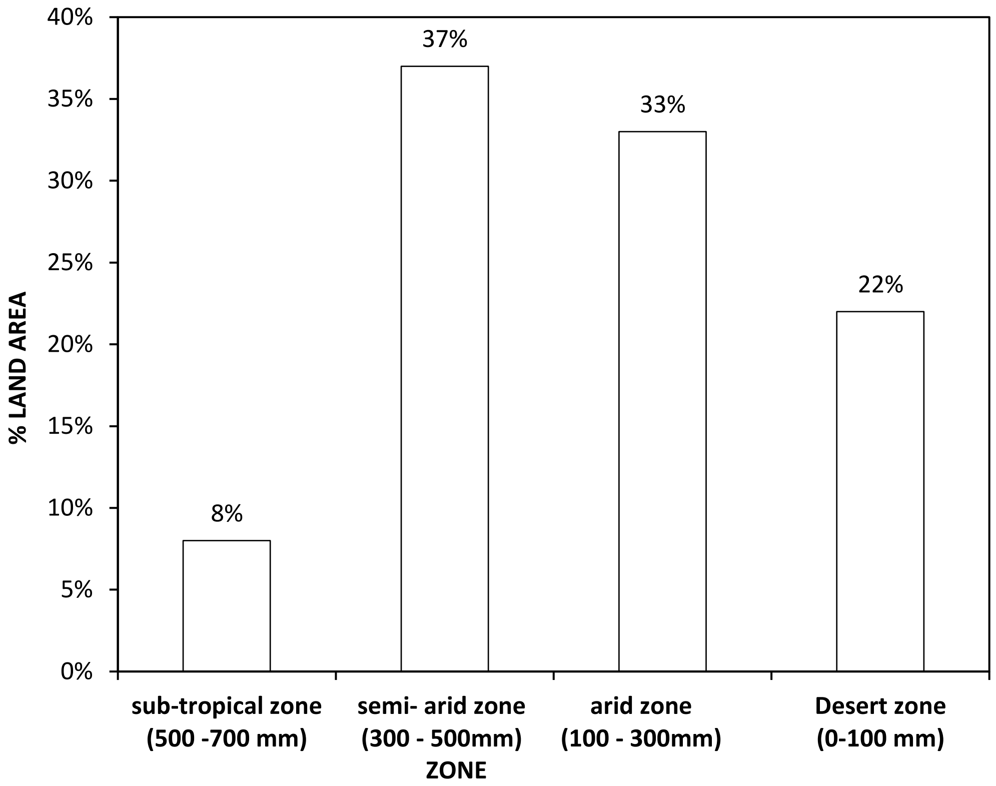

Figure 2: Namibia's four ecological zones

Due to erratic and unreliable rainfall it makes it difficult to practice dry land cultivation of cash crops across the semi-arid, the arid and desert zones. Thus the only feasible way to produce and improve crop production is to supplement rainfall with irrigation. Somewhat reliable crop production under rain fed conditions may be only possible in areas like the subtropical and semi- arid zone receiving an average rainfall of over 400 mm annually.

2.1.5 Irrigation Policies in Namibia

The Government's objectives in the agricultural sector derive mainly from the National Agricultural Policy (2015), with the aim of reducing poverty and income inequalities. The policy is formulated within the context of high level national policy documents in order to advance Namibia's overall economic development. The overarching objectives for the policy are to:

- Accelerate the agricultural sector's contribution to the National Gross Domestic product (GDP)
- Create a conducive environment for increased and sustained agricultural production and productivity which is regionally and internationally competitive
- Create a common understanding among national and international stakeholders as well as investors, about the vision of the Government of the Republic of Namibia for the development of Namibia's agriculture sector and its downstream industries
- Create a framework that will enable streamlined efforts by all stakeholders in Namibia's agriculture sector and its downstream industries, towards common developmental goals
- Promote the development of the national agriculture sector across the value chain

Four policies are of relevance for irrigation farming in Namibia: The Green Scheme Policy (GSP) of 2008, the National Agricultural Policy of 2015, the country's main framework for long-term development summarized in Vision 2030 and the Third National Development Plan (NDP5).

2.1. 6 Irrigation Schemes in Namibia

In 1990, the commercial farming sector occupied only 4500 ha of irrigated land while small farmers who made up 95% of the total farming population were only irrigating an area of about 300 ha. In 2004, a total of 8600 ha irrigated land only 650 ha were irrigated by small scale farmers (FAO, 2005). In percentage terms, this is only 7.6%. Irrigating by farmers is done either by flooding using ground water or surface water by pumping from the rivers or from reservoirs onto their farms. Some of the irrigation is confined to the commercial sector or State/ Parastatal farms along the Orange River, the most noTable irrigation schemes are at Noordoewer/Vioolsdrift and Aussenkehr, and from Komsberg to Noordoewer. The Noordoewer Scheme and Aussenkehr Schemes together had the potential to irrigate 2 000 ha (Aquastat Namibia 2009).

Apart from the commercial farming sector, the Government of the Republic of Namibia through the Ministry of Agriculture, Water and Forestry (MAWF) initiated AGRIBUSDEV (Agricultural Business Development Agency), in 2011 with the aim of increasing food production and to monitor and implement the Green Scheme Policy. The objectives of AGRIBUSDEV are to monitor and create the ideal environment for the achievement of the Green Scheme objectives as described by the Green Scheme Policy of 2008 and to monitor the Green Scheme Projects, within the legal framework of the Green Scheme programme. AGRIBUSDEV is involved in eleven (11) Green Scheme Projects. Green Schemes are to encourage the development of irrigation-based agronomic production. Currently total land allocated for the Green Schemes are under production in Karas, Kavango, Zambezi and Omusati regions. Eight of the eleven green schemes in the country have a two-component model – the commercial section and the medium section for individual farmers working small pieces of land. The Schemes also make provision for small Scale farmers. Crops grown are maize, rice, vegeTable, bananas, dates and grapes just to mention a few. The following are the Green Scheme Projects as highlighted in AGRIBUSDEV (2015) and van der Merwe (1999).

2.1.6.1 Etunda Green Scheme Irrigation Project - Omusati Region

Etunda Irrigation Project is a state-owed project which is located at Ruacana, about 150 km west of Oshakati in the Omusati Region in Northern Namibia. The project was established in 1994 as a government initiative to develop and improve agronomic production in the region and also to boost economic development of the agricultural sector through the development of irrigation infrastructures. The project is the largest farm in the Green Scheme in terms of size of land and volume of production. The total farm land earmarked for production is 1200 ha. Etunda is divided into two (2) segments of 450 ha each for small scale and commercial farming. Sixty-seven (67) small scale farmers occupying three (3) hectares each and ten (10) medium-scale farmers utilize the project. The project concentrates on growing maize and wheat, annually and the farm is managed by AGRIBUSDEV through contract agreement and produces maize, wheat, ground nuts, and various vegeTables such as potatoes, butternut, cabbage, green peppers, tomatoes and watermelons, among others.

The small scale farmers are on five years Government renewable contract leased, whereas each is allocated a field of about 3ha for irrigation. Out of those small scale farmers, there are some farmers who are cultivating 6 ha plots. The selection criteria for the farmers selected is based on their level of production, the way they maintain and manage their crops and accountability in terms of paying their accounts on time. By doing that, it is seen as an encouragement to the farmers and also motivation to other farmers as well.

The small scale farmers are growing maize, cabbage, tomatoes, onions, butternuts, groundnuts, sweet potatoes and watermelon. The selected small scale farmers are currently growing wheat because of the additional hectares provided. The farmers get loans from AgriBank and use a voucher system of about N$20000.00 - N$ 100000.00 depending on the programme. The loan is from the Ministry of Agriculture Water and Forestry.

There are also ten service providers with ten center pivots, each of which covers an area of 30 ha. They grow the same crops as those grown by small scale farmers except bananas and wheat. The Government of Namibia assists providers through the infrastructure that they are using, such as the centre pivots, tractors, trucks and cars.

According to Emongor & Kisten (2009), vegeTables are directly bought from the large and small scale farmers who supply supermarkets. Firstly the products supplied should be of large volumes throughout the year and, secondly, they should be of high quality and be produced according to their specifications of grade and standard which are produced under intensive production methods.

According to Fiebiger *et al.* (2001), the markets that farmers around Olushandja and Etunda are supplying are Spar and Pick n Pay in Oshakati. The farmers also sell their products locally in Tsandi, Outapi, Okalongo, Oshikuku, Oshakati, Ondangwa Omuthiya and Oshikango. Most of the vegeTables produced by these farmers are perishable and requires cold facilities to avoid losses. Most small scale farmers sell their products at lower prices because the vegeTables are perishable and cannot last long without cold storage facilities.

2.1.6.2 Musese Green Scheme Irrigation Project – Kavango Region

The total farmland is 1000 ha, of which only 450 ha are currently under commercial production. The Musese project is situated 85 km west of Rundu in Kavango West. Killarney (Pty) Ltd. is managing the project through a lease agreement with the Ministry of Agriculture, Water and Forestry (MAWF). The farm has not made provision for small or medium-scale farmers, although developments are under way to make provision in future. The project produces maize during the summer cropping season and wheat during the winter cropping season.

2.1.6.3 Sikondo Green Scheme Irrigation Project - Kavango Region

The Sikondo project is located in the Kavango Region of Namibia. It covers a total land area of 1000 ha of which 580 ha are used for commercial farming, and 270 hectares are used for medium-scale farming. Nine (9) medium-scale farmers occupy 30 hectares each. The Sikondo project is managed directly by AGRIBUSDEV through contract agreement and produces maize, wheat, and different types of vegeTables such as potatoes, onions, butternut, gem squash, watermelon and sweet melons.

2.1.6.4 Uvhungu Vhungu Green Scheme Irrigation Project

The Uvhungu Vhungu project is about 10km east of Rundu in Kavango West. The farm has a total land surface of 825 ha, of which only 380 ha are under full production. Commercial farming occupies 320 ha, and 60 ha are occupied by ten (10) small-scale farmers. The project is directly managed through a contract agreement by AGRIBUSDEV. A dairy farm is also currently under development for the purpose of national milk production. The project produces maize and wheat as well as different kinds of vegeTables such as tomatoes, lettuce, spinach, butternuts, carrots and cucumbers among others.

2.1.6.5 Mashare Green Scheme Irrigation Project

The Mashare project is about 50 km east of Rundu in Kavango East. The project covers an area of 130 ha, of which 127 ha are currently irrigated and under production. The project is earmarked to expand with an additional 300 ha. There is no provision made for small or medium-scale farmers on the project because the entire farm is confined to commercial production. There are plans underway to accommodate small and medium-scale farmers in the future once the additional 300 ha are available and completed. The project is managed by Mashare (Pty) Ltd. through a lease agreement and produces maize during the summer cropping season and wheat during the winter cropping season, in addition to a gradual introduction of horticulture crops.

Mashare also has a training centre to enhance Government's Green Scheme Project to achieve self-sufficiency in food production by the year 2030. The centre provides assistance to around 120 small-scale farmers in various farming methods.

2.1.6.6 Ndonga Linena Green Scheme Irrigation Project - Kavango West Region

The Ndonga Linena project is located 130km east of Rundu in Kavango West Region. It was the first project in the Kavango region that was identified by the Government as part of its Green Scheme Project. The First phase of developing the Project commenced in September 2008. The farm covers a total land area of 1000 hectares, of which currently only 500 hectares are under commercial and small-scale production. A total of 332 hectares are utilised by commercial farming, and 174 hectares are under small-scale farming. Twenty-nine (29) small-scale farmers are part of the project, each occupying 6 hectares. The project is managed by Shikunino Trading Enterprise (Pty) Ltd. through a profit-sharing agreement and produces maize, wheat, barley groundnuts and different types of vegeTables such as sweet potato, butternut, potatoes, green-pepper, tomatoes, lettuce, watermelon and cucumbers.

2.1.6.7 Shitemo Green Scheme Irrigation Project - Kavango Region

The Shitemo project covers an area of 1000 hectares, of which only 420 hectares is fitted with irrigation infrastructure. The farm is situated 80km east of Rundu in Kavango West and is currently utilised for commercial farming only by AGRI-PRO Namibia (Pty) Ltd. through a lease agreement and produces maize and groundnuts during summer cropping season and wheat during the winter cropping season.

2.1.6.8 Shadikongoro Green Scheme Irrigation Project - Kavango Region

The Shadikongoro project is situated 25 km from Divundu and 180km east of Rundu in Kavango West. The farm covers an area of 590 ha, of which 300 ha are used for commercial farming and 90 hectares occupied by small-scale farmers while 200 ha are under dry land production. Fourteen (14) small-scale farmers are part of the project, of which 12 have 6 ha each and 2 have 9 ha each. Shadikongoro is managed through a contract agreement by AGRIBUSDEV and produces maize, wheat, barley and sunflower. The project also processes sunflower seeds into sunflower oil. Other horticultural crops like tomatoes, cabbages, carrots and green pepper are produced through small scale farmers, while butternuts and pumpkins are produced at a large scale and sold to Agro-Marketing and Trade Agency (AMTA).

2.1.6.9 Kalimbeza Green Scheme Irrigation Project - Zambezi Region

The Kalimbeza project is located 56 km northeast of Katima Mulilo in the Kabbe Constituency of the Zambezi Region. According to the Caprivi Freedom- News (2001), Kalimbeza Rice Project first started its operation in 1987, three years before Namibia's independence and run by the then Ministry of Agriculture of the colonial government. In 1990 the project stopped its operation but however, it was re-established in 2001-2004.

UNAM started the rice project, and the Ministry of Agriculture Water and Forestry (MAWF) continued to develop Kalimbeza into full-fledged rice production. Kalimbeza irrigation project is funded by the Republic of Namibian in conjunction with Public-Private Partnership. Its objectives are:

- To promote the commercial establishment of rice production.
- To complement the production, the MAWF plans
- To increase the contribution of agriculture to the country's Gross Domestic Product (GDP)

The total farm land is 229 ha, of which only 144 ha are currently irrigated. Five (5) small-scale farmers occupying three (3) ha each was placed on the project, while 114 ha are used for commercial farming. The Kalimbeza project produces three (3) varieties of rice, and a smaller section of the farm is used for scientific trials of the crop with the intention to expand to largerscale production based upon growth and performance. Kalimbeza is also managed through contract agreement by AGRIBUSDEV and produces different varieties of rice.

2.1.6.10 Hardap Green Scheme Irrigation Project

The Hardap Irrigation scheme has a fully developed irrigation potential of 2 260 ha (Aquastat Namibia 2009). The Hardap project is situated 10 km before Mariental in southern Namibia, along the B1 highway. The farm is in the arid Hardap region and was a MAWF research station, which the ministry passed to AGRIBUSDEV in 2013. The project covers 96.5 ha, of which 73 ha are currently under production. Fourteen (14) medium-scale farmers are registered with the Hardap project, and each farmer has six (6) ha assigned for production. Commercial production covers 12.5 ha of the project. There is currently no provision for small-scale farmers, although plans are under way to accommodate small-scale farmers on the project. The Hardap project is also managed through a contract agreement by AGRIBUSDEV and produces lucerne, vegeTables such as cabbage, onions, green pepper and butternut, among others.

The scheme serves to promote agro-projects in the south using the Orange River and dams such as Naute and Hardap. Water is being supplied to the scheme from the Hardap Dam of about 300 m^3 in capacity via a reticulation network of concrete-lined canal. The canal was designed to use flood irrigation only. Centre pivot irrigation has been introduced in the scheme. For the flood irrigation system, the concrete-lined open canal supplies the water to the scheme.

2.1.6.11 The Orange River Irrigation Project -Karas Region

The Orange River Irrigation Project is situated on the extreme southern border of Namibia in Noordoewer in the Karas Region. The farm covers a total land area of 600 ha, of which 232 ha are currently under production. The farm is divided into commercial and small-scale farming areas, of which the largest section of 152 ha is under commercial production. Small-scale farming covers 80 ha. The Orange River is the primary source of water for irrigation. The Orange River Irrigation Project is managed by Cool Fresh Namibia through a profit-sharing agreement and produces Table grapes and dates for export as well as for local markets. In addition, the project also produces vegeTables such as tomatoes, butternut, pumpkin and cabbage, among others. The aim is to attract private investment and irrigation expertise to assist the government in achieving its objectives of increasing local production and facilitating skills transfer to emerging irrigation farmers.

2.1.7 Aussenkehr irrigation scheme

According to Aquastat Namibia (2009), the scheme was implemented by the National Development Cooperation. It consists of approx., 170 ha under Table grapes which are irrigated by means of micro irrigation systems (Figure 3). There is a development of expansion for vineyards through joint ventures with other individuals while another area is in the planning process. Grapes are the major and high value crop. Crops like Table grapes, mangos, vegeTable and lucerne are grown under micro and flood irrigation.

Figure 3: Irrigation to sustain vineyards in Aussenkehr- Source: DRFN 2007

2.2 Irrigation systems in Namibia

There are three common methods of irrigation used in Namibia. They are, surface irrigation, sprinkler irrigation and drip irrigation (Haidula, 2016).

2.2.1 Flood irrigation

Flood irrigation is the oldest irrigation method used in Namibia (Zimmermann, 1999). Flood is the common method of irrigation in semi- arid countries besides Namibia under which water flows away from channel and floods over the soil surface. The water moves across the field and is confined by earth bunds made on either sides of the plot. Small scale farmers in Namibia value flood irrigation as an effective method of irrigation and it is certainly not efficient compared to other methods. With flood irrigation only half of water applied ends up irrigating the crop. The other half is lost to evaporation, infiltration, runoff and transpiration through leaves of plants (Postel *et al*. 2001).

Walker (2013) stated the following advantages and disadvantages of the flood irrigation system as follows:

Advantages of Flood irrigation system

- Flood irrigation can be developed with minimal capital investment.
- It is the most common irrigation activity
- Easiest water supplies to develop stream or river flows required a canal to provide water to adjacent land.
- At the conveyance and distribution level, Flood does not require expensive equipment.
- Energy costs are substantially lower

Disadvantages

- The high amount of excess water used
- Flood irrigation is less efficient in applying water than other irrigation systems.
- It tends to be affected by water logging and salinity problems.
- Land levelling costs are high.

2.2.2 Sprinkler irrigation

Sprinkler irrigation is the method of applying water that is similar to rain (Brouwer, Prins, Kay & Heibloem, 2001). Water is distributed via a system of pipes by pumping. It is sprayed into the air through sprinklers so that it breaks up into smaller water drops that fall on the ground.

For good uniformity, several sprinklers must be positioned close together so that their patterns overlap. In sprinkler irrigation, the overlap must be at least 65% of the wetted diameter in order to achieve good uniformity (Brouwer *et al.,* 2001). The operating pressure of sprinkler irrigation will be affected if it is too low. This normally happens when the pump and pipes are worn out. The low pressure will also contribute to the poor distribution of water (Brouwer *et al.,* 2001).

2.2.3 Drip irrigation

Drip irrigation saves water and fertilizers by allowing water to drip slowly into the root zone of the plant through a network of valves, pipes, tubing and emitters. It is done with the help of narrow tubes, which deliver water directly to the base of the plant. Water is applied close to plants so that only part of the soil in which the roots grow is wetted, unlike surface and sprinkler irrigation which involves wetting the whole soil profile. Drip irrigation provides a favourable high moisture level in soil in which plants can flourish (Postel *et al*. 2001).

2.2.3.1 Advantages and disadvantages of Drip Irrigation System

Postel *et al.* (2001) and Elobeid (2006) highlighted the following as some of the advantages and disadvantages of drip irrigation system:

- Drip irrigation offers special agronomical and economic advantages for the efficient use of water and labour.
- It saves water at about 40% with an application efficiency of 85 – 95% as compared to other systems.
- The system produces high yield/unit area as well as yield /unit volume of water than other irrigation systems.
- It prevents foliar diseases by minimizing water contact with the leaves of the plants.

- The system saves time, money and water as the system is efficient. A high level of water management is achieved because plants can be supplied with the correct amount of water.
- Labour is lower than other systems due to decreased labour.
- Lower pressure is used, and this means reduced energy for pumping.
- With drip irrigation, low soil moisture tensions in the root zone can be maintained regularly with frequent applications. The dissolved salt accumulates at the periphery of the wetted soil mass, and plants can easily obtain the moisture needed.
- A drip irrigation system allows the rows between plants to remain dry, resulting in better weed control and lower production costs.
- Fertilizers can be applied at the root zone through a drip system. Soil erosion and leaching can be minimized.

Disadvantages

The major disadvantages of drip system are:

- High initial costs.
- Clogging of emitters by biological, chemical and physical matters
- Insect, rodent and human damage to drip tubes may cause leaks
- Drip tape cost extra clean-up cost after harvesting
- Waste of water, time and harvest if not installed properly

Filtration of water for drip irrigation is vital to prevent clogging of the emitters (drippers) in the drip line. The application of water leaches the salts out to the limit of the wetted zone; once the systems stop supplying water, the salts may enter the plant's root, causing wilting of the plant (Elobeid, 2006). High management requirements are needed. A critical delay in operation decision may cause irreversible damage to crops.

2.2.4 Distribution uniformity of irrigation systems

According to Letey *et al.* (1984), the distribution uniformity of a system has an effect on the system's application efficiency and on crop yield. Solomon (1984) reported that irrigation with poor distribution uniformity experience a reduction in yield due to water stress and water logging. Clemens and Solomon (1997) reported that poor distribution uniformity contributes to financial and environmental costs. Fertilizer and pump cost also may have environmental impacts if the excess runoff and deep percolation are contaminated with nutrients (Solomon, 1990).

Camp, Garrett, Sadler and Busscher, (1993) reported that the uniformity of subsurface systems is lower than that of flood irrigation. Wu *et al.* (1986) also reported that system uniformity is affected by system design factors like lateral diameter as well as emitter spacing. Globally, it is recognized that the drip irrigation systems are typically about 90% efficient as compared to sprinkler systems which are about 75% efficient (Postel *et al.* 2001). Table 1 shows a wide variety of irrigation techniques with degrees of efficiencies.

Table **1: Irrigation System Efficiency**

Irrigation methods	Field application efficiency
Surface irrigation (border, furrow, basin)	60%
Sprinkler irrigation	75%
Drip irrigation	90%

Source: Postel *et al.* 2001

Water saving can be as high as 50% with drip irrigation (Postel, *et al.* 2001). Maisiri, et al., 2005) did an on- farm evaluation of the effect of low cost drip irrigation on water and crop productivity compared to conventional surface irrigation system. They reported water saving of 50% with drip irrigation compared to surface irrigation in Zimbabwe. Ibragimov et al., (2007) conducted a study on water use efficiency of irrigated cotton in Uzbekistan under drip and furrow irrigation and showed that water use efficiency in drip was better than under furrow by 35 to 103%.

Results of the study by Tagar, Chandio, Mari and Wagan (2012) revealed that total volume of water consumed under furrow irrigation was more than twice that of flood method. Postel *et al.*, (2001), Holzapfell et al., (2009), Prajapati, et al., (2013) also mentioned that drip irrigation can prove to be very useful in dry and semi dry areas. Tagar *et al*., (2012) also reported that drip irrigation method saved 56.4% water compared to that of furrow irrigation method. It is therefore important for agricultural engineers and farmers to understand which irrigation systems contribute to improved water use efficiency in Namibia.

Studies in Zimbabwe showed that over 50% of the water applied as surface irrigation on traditional, irrigated gardens can be lost as soil evaporation (Batchelor, Lovell, & Murata, 1996). According to Maisiri *et al*., (2005) and Polak and Yoder (2006), water in large scale systems is distributed much more efficiently with drip irrigation than conventional flood and sprinkler systems, reducing the total amount of water required to grow a crop. To the contrary, flood irrigation system as a traditional technique used by small scale farmers within the North Central region of Namibia (Zimmermann, 1999; Ogunmokun & Kanyomeka, 2003) requires a large volume of water and uses more water compared to drip system. When pumping water for irrigation high energy is required and by doing so high cost entails. Generally flood irrigation system requires more water than drip irrigation due to higher evaporation rate. Flood irrigation is however cheaper than drip irrigation (Zimmermann, 1999; Ogunmokun & Kanyomeka, 2003). In order to develop best management practices for irrigation systems in Namibia, information is needed pertaining to differences in flood and drip irrigation systems under Ogongo conditions. A gap therefore exits to compare the two systems with regards to water use.

Salvin, Baruah and Bordoloi (2000); Bharambe, Shelke, Oza and Vaishanava (2002); Agrawal and Agrawal (2007) compared water saving of drip and basin irrigation systems in fruit crop and reported water savings of 40-60% with drip compared to basin irrigation method. Camp *et al.*, (1989) and Hutmacher *et al.*, (1996) reported that drip irrigation system has been proven to save water and is effective for growing crops. They continue to state that the method can be applied for crop growth, optimal soil moisture, increased water use efficiency, improved crop yield and quality as well as fertilizer application on crop growth and water quality.

2.2.4 Family Drip Irrigation

The family drip system (FDS) is used for irrigation of small and medium plots and backyard gardens. It is suiTable for 100 m² to 2000 m² and can be used for irrigation of vegeTables, orchards, fruit trees, row crops and greenhouses (Netafim, 2017). The FDS, being gravity-based, does not require any energy source for its operation. FDS is suiTable for all types of soils, climates and water sources. It is suiTable for use in flat land or slight slopes. The water source must be available near by the plot. Figure 4 shows a family drip system and it requires that one fills up the tank, cleans the filter, continue to open the valve, irrigate and monitor the crop growing.

The family drip system consists of a 200 litres water tank at an elevation of 1.5 m to allow water to flow from the tank to the main liners, laterals and emitters with the help of gravity. The water tank had a 25.4 mm valve outlet installed at a height of 15 cm above tank's bottom. It consists of a drainage outlet installed at the bottom of the tank to allow sediments to be washed out and a 25.4 mm main valve installed at the tank's outlet. A 25.4 mm screen filter and a polythene pipe, distribution line was installed between the tank and dripper lines.

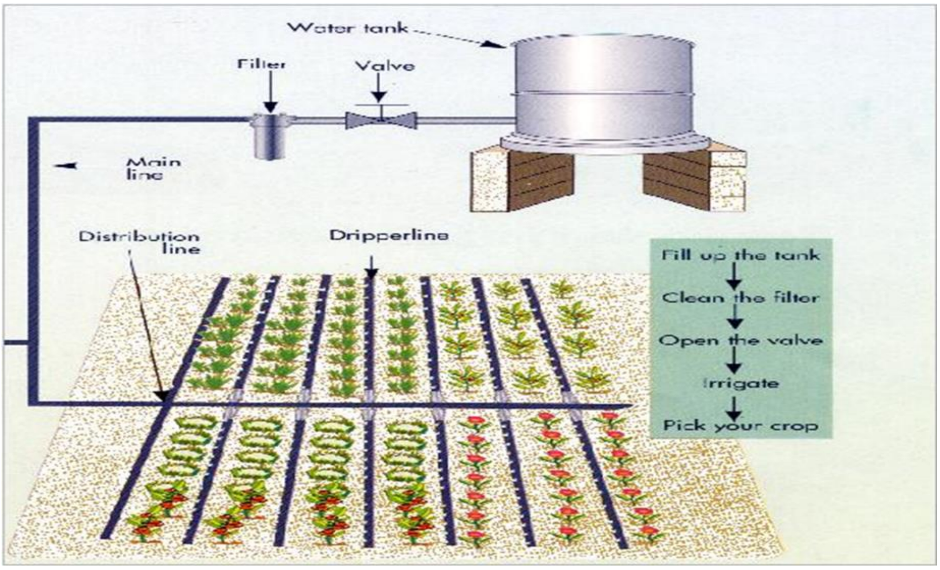

Figure 3: Family drip system (Source- NETAFIM, 2017)

2.3. Crop water Requirements

The variable amount of water contained in a soil and its energy state are important factors affecting growth of plants (Hillel, 2004). The accuracy of determination of crop water requirements will be largely dependent on the type of the climatic data available and the accuracy of the method chosen to estimate the evapotranspiration (Hatibu & Mahoo, 2000). Crops will transpire water at the maximum rate when the soil water is adequate. Broner (2003) cited by Adeniran *et al*., (2010) reported that knowing seasonal crop water requirements is crucial for planning crop planting mixture especially during drought years. The growth and yield of any crop is related to the amount of water used.

The amount of water that is required to compensate the amount of water lost via crop evapotranspiration (ETc), requires reference crop evapotranspiration (ETo) and crop coefficients (Kc) at different growing stages. This can be determined according to Allen *et al*., (1998) using Equation 1.

$$ETc = ETo \times Kc \ldots \qquad \textbf{(1)}$$

Where ETc – crop evapotranspiration (mm/day)

Kc – crop coefficient

ETo – reference crop evapotranspiration (mm/day)

2.4 Water Use Efficiency

Water use efficiency (WUE) was identified as one of the key water use indicators derived in a study of indicators of sustainable irrigated agriculture (Stewart, 2001; van der Merwe, 2008) and is of most benefit to individual farmers. The definition focuses farmer's attention on both water use and production, and provides an indication of whether the resource has been used effectively. This WUE definition was applied to conducting design audits for both Ida Valley-Central Otago (2005) and the Hawke's Bay Region of New Zealand (McIndoe, 2000).

WUE can be expressed either in terms of the efficiency with which different plants use transpired water for their photosynthesis or in terms of the efficiency with which plants make use of water inputs to produce dry matter outputs (Tolk & Howell, 2002; van der Merwe, 2008). However there are various definitions on WUE (Tolk & Howell, 2002; Ramalan, et al., (2010); De Pascale *et al.* 2011). Irrigation Training and Research Centre, California State University, California used a definition called irrigation sagacity (IS) which is considered to be a better measure of water use than irrigation efficiency, as follows in Equation 2:

$$IS = \frac{Irrigation\ water\ beneficially\ or\ reasonably\ used}{Irrigation\ water\ applied} \qquad (2)$$

Although this definition is probably a better measure of good water use, it has not been widely adopted, primarily because of the difficulty of measuring beneficial or reasonable use. One useful measure of irrigation efficiency that encompasses both water use and production is water use efficiency (WUE) (McIndoe, 2002). It is commonly defined as in Equation 3:

$$WUE\ (kg/m^3) = \frac{\Pr oduction\ (kg/ha)}{Irrigation\ water\ used\ \ (m^3\ ha-1)} \qquad (3)$$

De Pascale *et al.*, (2011), further defined agricultural water use efficiency as the ratio of crop yield per unit of water applied. For the purposes of this study, WUE (kg/m^3) will be used.

Yang *et al.,* (2000) and Haijun *et al.,* (2011) compared the effect of sprinkler and flood irrigation on winter wheat yield and water use efficiency. Both obtained high winter wheat yield and water use efficiency in sprinkler irrigation as compared to surface irrigation system. Aujla, Thind and Buttar (2007) conducted a study on fruit yield and water use efficiency of eggplant as influenced by different quantities of nitrogen and water applied through drip and furrow irrigation. They reported that the water use efficiency at 75% for drip irrigation produced the highest fruit yield than that of furrow irrigation. Another study on the effect of drip and furrow irrigation and plant spacing on yield of tomato at Dire Dawa in Ethiopia was conducted by Yohannes and Tadesse (1998). They reported that the water use efficiency and irrigation application efficiency values were higher in drip system compared to furrow.

Sharmasarkar *et al.,* (2001) assessed the drip and flood irrigation on water and fertilizer use efficiency for sugar beet. They reported the water use efficiency and fertilizer use efficiency for drip irrigation were higher than the flood irrigation. Studies were conducted by Salvin *et al.,* (2000) on bananas under drip irrigation. They reported that water use efficiency was considerably higher in drip than basin irrigation. Another study was conducted by Narayanamoorthy (2003) on two water intensive crops and reported water use efficiency of up to 90% in drip irrigation against the efficiency of 30-40% under furrow method.

Al-Omran et *al.*, (2005) studied the effect of drip irrigation on squash yield and water-use efficiency in sandy calcareous soils amended with clay deposits and reported the water use efficiency values increased linearly with applied irrigation water and decreased at the highest irrigation level.

El-Boraie, Abo-El-Ela and Gaber (2009) conducted a study on water requirements of peanuts grown in sandy soil under drip irrigation. They found the highest value of water use efficiency was obtained by applying the drip irrigation with 100% of ETc distributed every day.

Enciso, Jifon, Anciso and Ribera (2012) studied productivity of onions using subsurface drip irrigation versus furrow irrigation systems. They found that the irrigation water use efficiency obtained with the drip irrigation system ranged from 17.5 to 25.2 kg per m^3 compared to 4.2 to 6.2 kg per m^3 for the furrow system in two locations. Drip irrigation systems more than doubled yields and increased onion size while using at least 44% less water. Tagar *et al*., (2012) reported a higher water use efficiency of about 4.87 kg m^{-3} in drip irrigation method; whereas lower water uses efficiency of about 1.66 kg m^{-3} was obtained in furrow irrigation method.

Sharmasarkar, *et al*., (2001) conducted a study on assessment of drip and flood irrigation on water and fertilizer use efficiencies for sugar-beet and reported that water use efficiency values for drip irrigation were greater than flood irrigation. The study of Ellis, Kruse, McSay, Neale and Horn (1986) compared water use efficiency for furrow, sprinkler and surface drip irrigation when growing onion. They found out that higher water use efficiency for drip irrigation followed by sprinkler and furrow irrigation. Liao, Zhang and Bengtsson (2008) and Collaizzi, Lamm, Howell and Evett (2006) demonstrated that drip irrigation increases yield accompanied with higher field level application efficiency as compared to surface irrigation systems.

Muhammad, Raza, Ahmad, Afzal and Mian (2006) compared the efficiency of drip to flood irrigation system with variable plant density on cotton under southern Punjab climatic conditions. They recorded maximum water use efficiency of 7.9 kg/ha and water saving of 53.3% by drip irrigation method for cotton crop as compared to flood irrigation method. Raina, Thakur and Bhournal (1998) studied the effect of drip irrigation and plastic mulch on yield, water use efficiency and benefit cost ratio of pea cultivation reported that water use efficiency was greater under drip as compared to flood irrigation. Results on onion reported by Samson and Tilahun (2007) showed that deficit irrigation throughout the growing season at 50 and 75% of ETc resulted in the highest water saving and crop water use efficiency.

2.5 Deficit Irrigation

Water saving that can be used to counter the shortage of water for irrigation can be done through the use of deficit irrigation which is based on irrigating crops with water that is less than full crop water requirements (Teferi, 2015). Ahmadi *et al.*, (2010) goes on to say that the amounts of irrigation reduction are crop dependent and generally accompanied by no or minor yield loss that increases the water productivity.

A number of studies have been carried out all over the world regarding the effects of deficit irrigation on yield of horticultural crops (Fabeiro *et al.*, 2003; Olalla, Padilla and Lopez 2004). The yield reduction resulting from deficit irrigation will be insignificant compared with the benefits gained through diverting the saved water to irrigate additional cropped area (Gijón *et al.* 2007). According to Fereres and Soriano (2006) the grower must have prior knowledge of the crop yield responses to deficit irrigation. It is possible to identify the periods during which water deficit would have a limited effect on crop production by maintaining the moisture content of the soil below the optimum level during specific growth stages of the season or throughout the growing season.

Kumar, Imtiyaz, Kumar and Singh (2007) investigated the impact of deficit irrigation strategies on onion yield and water savings and reported that applying 80 and 60% of ETc resulted in yield decreases of 14% and 38%, respectively, and saved 18% and 33%, respectively, of irrigation water compared to full irrigation. Other studies by Owusu-Sekyere *et al.,* (2010) reported that reduction in 20% water need had no significant effect on growth, development and fruiting of hot pepper. Samson and Tilahun (2007) also showed that deficit irrigation throughout the growing season as 50 and 75% of ETc reduced yields of onion from full irrigation and resulted in the highest water saving and crop water use efficiency.

Karasu, Kuşcu, Öz and Bayram (2015) studied the effect of different irrigation water levels on grain yield of silage maize in Marmara Region of Turkey. They found that irrigation levels significantly affected the maize grain yield, all morphological and quality parameters. Mahmoud (2006) conducted a study to compare the effects of three levels of drip irrigation compared with those of surface irrigation on yield and quality parameters of bananas. The three levels were 40%, 60% and 80% of pan evaporation. Irrigation level of 40% in main crop substantially improved growth, bunch, fingers and fruit quality characters. In the ratoon crop, irrigation level of 60% was reported to be most economical and effective in getting the best banana bunch and fingers characters and fruit quality .

In another study Salokhea, Babel and Tantauc (2005) tested the effect of four levels of drip fertigated irrigation equivalent to 100, 75, 50 and 25% of crop evapotranspiration (ETc) on crop growth, crop yield, and water productivity of tomato. The maximum crop yield and high irrigation water productivity was found to be at 75% of ETc.

Basal, Dagdelen, Unay and Yilmaz (2009) conducted a trial to observe the effects of various drip irrigation ratios (0%, 25%, 50%, 75% and 100% of soil water depletion) on water use efficiency (WUE), lint yield, yield components and fiber quality on cotton. Water use efficiency was found to increase from 0.62 to 0.71 kg/m^3 as the irrigation water applied was reduced from 100 % to 75 %. The results revealed that irrigation of cotton with a drip irrigation method at 75 % level had significant benefits in terms of saved irrigation water without reducing yield, and high WUE indicated a definitive advantage of employing deficit irrigation under limited water supply conditions.

Ramalan, et al., (2010) studied the effect of deficit irrigation and mulch on water use and yield of drip irrigated onions. Effect of deficit levels on Crop water use and irrigation water use showed significant differences in seasonal values of the water use. An onion crop in the Central Rift Valley required 527.18 mm of irrigation water per season with yields of 37.2 tons per hectare with no irrigation deficit, compared to where there was a deficit level of 75% of total available water, the yield dropped to 24.32 tons per hectare (Ramalan *et al.,* 2010) .

Nagaz et al., (2012) also studied yield response of drip-irrigated onion under full and deficit irrigation with saline water in arid regions of Tunisia. They found that the bulb fresh yields of deficit-irrigated treatment (deficit irrigation-60) were significantly lower than those in full irrigation treatment (full irrigation-100). They concluded that the full irrigation (full irrigation-100) and continuous and regulated deficit-irrigation (deficit irrigation-80 and full irrigation-100) strategies offered significant advantage for both onion yields and WUE compared to the deficit irrigation-60 in onion production under arid conditions.

Patel and Rajput (2013) reported that a deficit irrigation at 40% throughout the growing season of onion, water productivity i.e. WUE can be significantly ameliorated with saving of 272-mm water, which may be used to irrigate additional 0.5 ha of cropped area. Igbadun, Ramalan and

Oiganji (2012) showed that the water consumption of onion crop was reduced by about 20% when a deficit of 50% ETo was applied.

2.6 Effect of flood and drip irrigation systems yield and growth parameters.

Sammis (1980) reported that tomato yields under drip were twice those of over flood irrigation method. Maisiri *et al.,* (2005) reported that crop yield can be increased by up to 40% with drip irrigation compared to flood. Tagar *et al.,* (2012) also reported that drip irrigation method gave 22% more yield as compared to that of furrow irrigation method. A study by Ibragimov, *et al*., (2007) showed high yield increase of 18-42% in drip compared to flood irrigation. Kumar, Imtiyaz, Kumar, and Singh (2007) also investigated the impact of deficit irrigation strategies on onion yield and water savings. They reported that applying 80% and 60% of crop water requirements resulted in yield decreases of 14% and 38% and saved 18 and 33% of irrigation water compared to full irrigation in 2 years, respectively.

Enciso *et al.,* (2012) studied productivity of onions using subsurface drip irrigation versus furrow irrigation systems. They found that drip irrigation systems more than doubled yields and increased onion size while using at least 44% less water. In contrast to the others, Oktem et al., (2003) reported yield reduction in maize production in drip irrigation. Results on onion reported by Samson and Tilahun (2007) showed that deficit irrigation throughout the growing season at 50 and 75% of ETc reduced yields from full irrigation.

Ashifa *et al*., (2015) studied the effect of drip and furrow irrigation method on water saving, yield and yield components of sunflower crop. They found that the total yield of crop under drip irrigation method was higher by almost 1.5 times as compared to flood irrigation method. The water saving, yield and water use efficiency shows that 45 - 96% water was saved under drip irrigation as compared to flood irrigation method. Drip irrigation produced 32.7% more yield over furrow irrigation method. Ahmad (1990), Rashid, (1992) and Soomro (1999) reported that plant height is an important indicator of yield. Muhammad *et al*., (2006) concluded that drip irrigation method significantly increased seed cotton yield as well as yield components over flood irrigation.

Bilal (2009) showed that drip irrigation system improves irrigation uniformity and ensure precise use of nutrients and allows timely application of herbicides, insecticides and fungicides. Sammis (1980) reported that tomato yield under drip irrigation was twice more than the furrow irrigation method. The same as Bogle (1995) who observed that drip irrigation required 45% less water and produced higher tomato yield by 22% as compared to flood irrigation. Hansen, Schwanki, Schulbach and Pettygrove (1997) compared lettuce yield under furrow, surface drip and subsurface drip irrigation methods. They concluded that drip irrigation saved 40% of irrigation water as compared to flood irrigation with no significant difference in crop yield.

Sakellariou, Kalfountzos and Vyrlans (2002) compared the sugar beet yield and water use efficiency under irrigation and surface drip irrigation system. They indicated that surface drip irrigation leads to a greater yield with significant water saving compared to drip irrigation. Bajracharya and Sharma (2005) observed higher cucumber and tomato yields under low cost drip irrigation than low cost surface irrigation.

Soussa (2010) compared the yield and water use efficiency of drip irrigation and surface drip irrigation for growing tomato in open fields and pepper in greenhouses. The experiment shows higher yield and water use efficiency at surface drip irrigation compared to drip irrigation for the two crops. Malash *et al.*, (2008) compared the tomato yield and water use efficiency under furrow and drip irrigation with two saline water management strategies. The result showed higher yield and water use efficiency occurred under drip irrigation. Enchalew *et al*., (2016) conducted a study on the effect of deficit Irrigation on water productivity of onion (Allium cepa) under drip irrigation. They reported that deficit irrigation did not affect that much the plant height of onion.

Srinivas and Hegde (1990) studied bananas under drip irrigation. They reported that the plants were 3% taller under the drip irrigation than the basin irrigation. Dagdelen *et al.*, (2009) studied the effect of different drip irrigation regimes on cotton yield, water use efficiency and fiber quality in Western Turkey. They found that leaf area index and dry matter yields increased with increasing water for treatments of cotton. Meanwhile Karam *et al.*, (2002) reported that water stress caused by the deficit irrigations significantly reduced leaf number, leaf area index and dry matter accumulation of lettuce.

Khalid (1999) compared drip and furrow irrigation system under the same conditions on two varieties of okra. He obtained highest yield using drip irrigation as compared to furrow irrigation system.

2.7 Cost and total labour requirements for crop production under flood and drip irrigation.

According to Kadigi, Tesfay, Bizoza and Zinabou (2012) many irrigation schemes in the past failed due to a combination of factors, including high investment costs, poor planning and a lack of maintenance. Mendelsohn, Shixwameni and Nakamhela (2011) reported that crop commercialization in the northern communal areas is only possible for farmers with the resources to provide high cost of inputs such as irrigation, fertilizer and labor to produce surpluses which can be sold for cash incomes.

In comparing the cost of production and net profit under irrigated banana, Prajapati et al., (2013) reported higher net profit to the extent of 12 to 20 % under drip irrigation than that realized under surface irrigation. The main advantages of drip irrigation compared to other methods as highlighted by Michael (2008) include, saving in water, reduced labor cost, higher crop yields, increased fertilizer use efficiency and reduced energy consumption.

Kadigi *et al*., (2012) highlighted that irrigation has the potential to enhance food security and economic growth and to achieve this, investment must be profiTable for the farmer. This can be partially achieved by increasing water application efficiency particularly important in countries like Namibia with increasing shortages of, and competition for, limited water resources used in agriculture such as water. A gap exists to compare the costs encountered in the two irrigation systems at Ogongo.

According to Martin and Folk (2004) flood irrigation cost were greater than drip irrigation costs due to labor. Labor requirements for drip irrigation are low and the system is easily automated or could be operated manually with little effort and proper design. The cost of drip irrigation systems is reasonable on wide spaced crops such as trees. The closer the crop spacing the higher the system cost is per hectare. In a conventional row crop pattern, drip irrigation is about the most expensive system available.

Caswell and Zilberman (1985) and Green *et al*., (1996) stated that increased economic returns through water and labour savings as well as yields under drip irrigation are better suited for the production of high value crops and reduce the amount of water used to grow crops. Tsegaye *et al.*, (2016) reported that deficit irrigation at 75% of ETc was economically recommended in their studied region, in southern Ethiopia.

2.8 Origin and Distribution of Onion

Onion, *Allium Cepa* (L.), is one of the most important vegeTable crops in the world and is cultivated world-wide. It is the second most produced vegeTable in the world after tomatoes (Eviatar & Offenbach, 2003). Onion was domesticated from wild ancestors in the central Asian Mountains (Brewster, 1994). Onion is grown in many countries and dates back in Egypt to 2700 BC.

2.9 Uses of Onion

Onions are found in large numbers of recipes and preparations globally. The whole plant is actually edible and is used as food source. Currently, onions are made available in fresh, canned, frozen, powdered, chopped or sliced as well as pickled forms. The sliced/ chopped onions are used daily on cooked or fresh food and salads. Some of the varieties can be spicy, sharp, mild or sweet. The pickled onions in vinegar are normally eaten as snack. They are served with fish and chips throughout Australia or served with cheese in the United Kingdom and Eastern Europe. The onion crop is liked for its flavor and pungency which is due to the presence of a volatile oil. The bulb is a rich resource of minerals like Calcium, Phosphorus and

Carbohydrate. It also contains Vitamin C and Protein and several anti-cancer agents which have been shown to prevent cancers in human and animals (Kumar, 2010).

In many parts of the world, onions are used for healing such as relieving headaches, coughs, snake bites and hair loss. Some doctors used to prescribe the use of onion to help with infertility in women (Ashwini & Sathishkumar, 2014). In ancient Greece, athletes use to eat large quantities of onion as they believe that it would lighten the balance of blood. Some studies have shown that increased consumption of onions reduces the risks of head and neck cancers.

2.10. Production of onion in Namibia

The potential for fruits and vegeTable production in the communal areas of Northern Namibia is high. In fact the horticulture sector in Namibia has been growing since 2006/7 season with increases of 18.3% for 2007/8, 4.8% for 2008/9 and 20.8% for 2009/10 season in that order (NAB, 2014). Local horticultural produce has increased from 5% to 41.5% in terms of market share in Namibia (Fig. 5). Figure 5 and Figure 6 show that the local production has increased from 1200 tons in 2010/11 to about 3400 tons in 2012/13. Thus onion production has increased by 65% from 2010/11 to 2012/13 season (NAB, 2014). Consequently imports of Onions have decreased from 3400 tons to 2800 tons from 2010/11 to 2012/13 respectively (Fig 7).

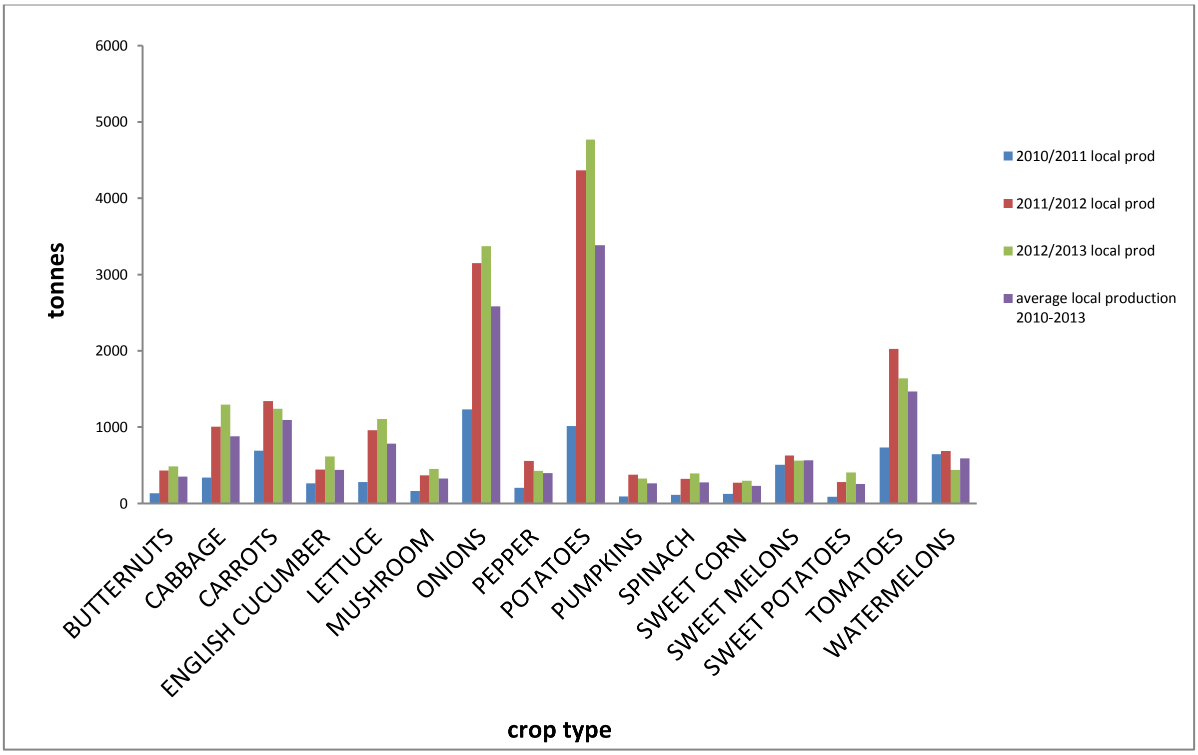

Figure 4: Local horticultural production in Namibia (NAB, 2014)

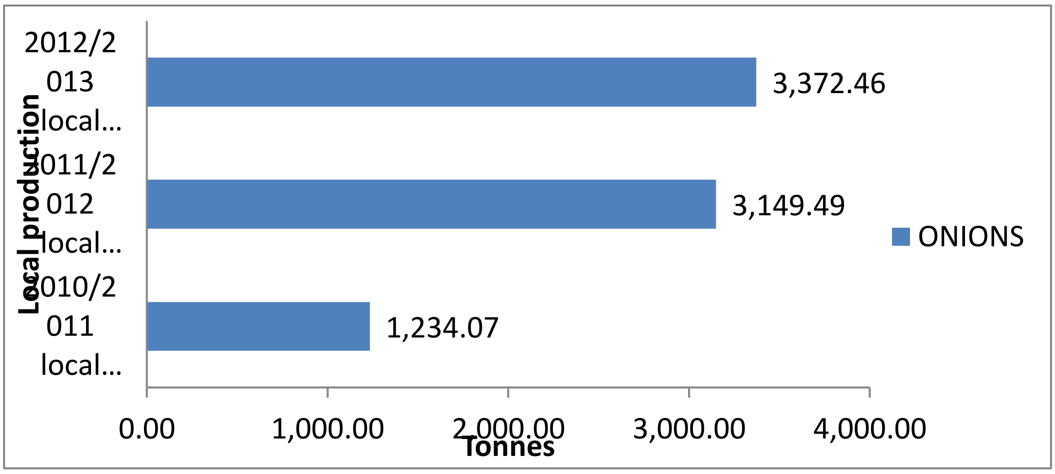

Figure 5: Local Onion production trend for the period 2012 to 2013 (NAB, 2014)

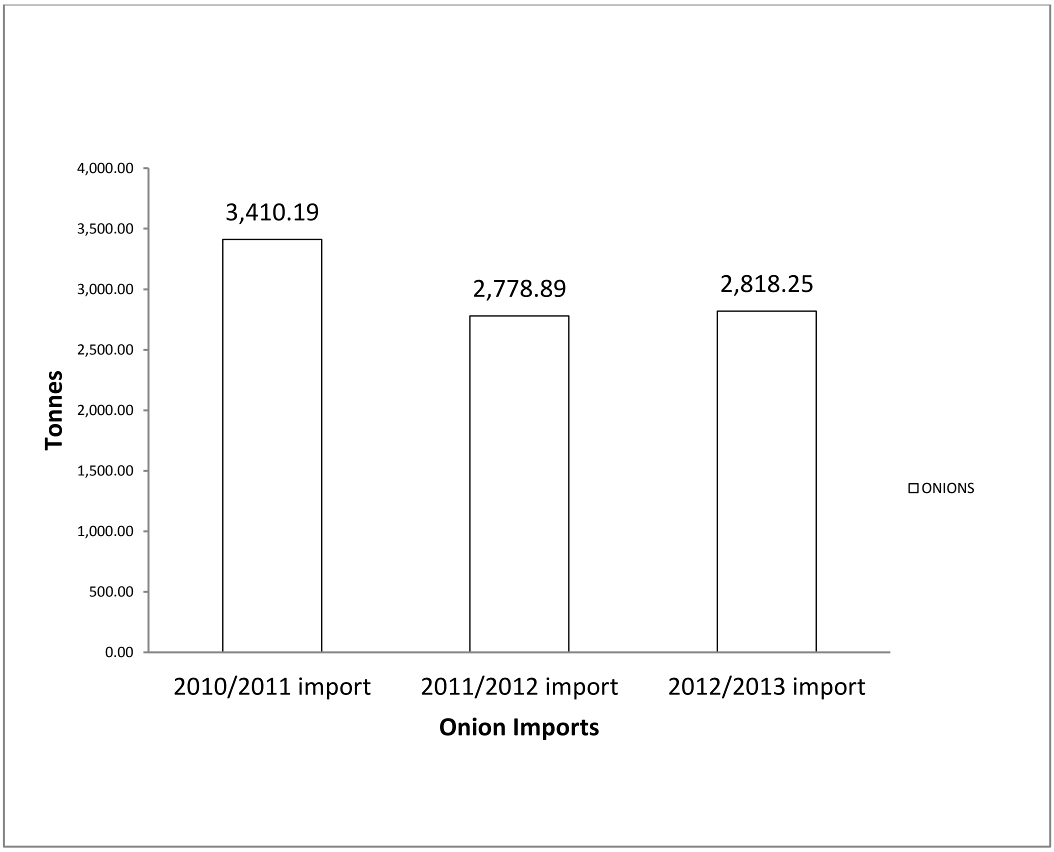

Figure 6: Onion imports for the period 2010 to 2013 (NAB, 2014)

Estimates from a study undertaken in 2005 by Price Waterhouse Coopers found that 'investing in the cultivation, marketing and packaging of two horticultural crops alone (potatoes and onions) could infuse as much as N$68 million into the local economy, besides creating nearly 1,000 employment opportunities (Price Waterhouse Coopers, 2005). The Namibian Agronomic Board (NAB) has thus identified potatoes and onions as the two crops with the highest potential for increased national horticultural production and they agreed with Ministry of Agriculture, Water and Forestry (MAWF) to implement a "Special Potato and Onion Scheme" in 2013 (NAB, 2012).

Onion is one of the main horticultural crops grown by small scale farmers in Northern Communal Areas (NCA). Apart from this, onion is a controlled product in Namibia (NAB, 2014) as gazetted under Section 2 of the Agronomic Industry Act of 1992, whereby imports are controlled through the Market Share Promotion (MSP), in order to achieve import substitution and to enhance the market facilitation of domestically cultivated products in Namibia. The MSP was established by the NAB in 2005, as a tool to facilitate the increased production of horticulture products in Namibia with the aim of achieving food self- sufficiency. Therefore onion contributes significantly to the horticultural industry and that is why it would be important for farmers to use the most efficient methods of irrigation for onion production, from among irrigation systems such as sprinkler, flood and drip irrigation. A gap exists to study and compare efficiencies of flood and drip irrigation methods used for onion production under farmer's production conditions in Omusati Region of Namibia.

2. 11 Summary

The potential for fruits and vegeTable production in the communal areas of Northern Namibia is high. However, a major constraint to small-scale farming in communal areas is lack of adequate irrigation water. Deficit irrigation can be one of the techniques that can be used to conserve water in irrigation scheme so as to increase the irrigated area for small scale farmers in Omusati Region. But before deficit irrigation can be promoted to farmers as a feasible water management practice, there is a need to evaluate its likely impact on water use efficiency and thereby on onion yield. Farmers are not likely to take up deficit irrigation unless it improves water productivity with no or minor yield reduction. It is obvious that the crop yield and the amount of water saved can be the best indicators of water productivity. Therefore, there is an urgent need to find efficiencies of flood and drip irrigation methods used for onion production under farmer's production conditions in Omusati Region of Namibia.

CHAPTER THREE

3. METHODOLOGY

3.1 Introduction

This chapter deals with materials and methods including study area (spatial and temporal) description. Research design, data collection and analysis methods used to meet the objectives are also included.

3.2 Study Area

The study was conducted at Ogongo Campus farm over a period of five months of 2015 during the dry season. Ogongo Campus is located at 17˚40’ 42”S, and 15˚ 17’47”E and the farm covers an area of 4350 ha of which 1000 ha serves as a game park (UNAM, 2017; Niipele & Klutenberg, 2006). The study area is situated in Omusati region of the Northern part of Namibia, along the main road from Oshakati to Ruacana. Figures 8 and 9 show the study area in relation to the map of Namibia and the Cuvelai basin and the Olushandja dam with the Calueque-Oshakati canal in the Northern regions of Namibia. Ogongo is also shown on Figure 5.

Climate in the region can be described as semi-arid with the rain falling from November to April. The annual rainfall ranges between 300 - 400 mm. Monthly mean temperatures is between 26˚C in November to 16˚C in July. During the coolest period in June to August, the night temperature drops to 10˚C while day temperature reaches 38˚C (Niipele & Klutenberg 2006).

According to Mendelsohn *et al.*, (2013), soils at Ogongo are dominated by Arenosols group of Kalahari in the North Central of Namibia. These types of soils have poor nutrient content and little water holding capacity.

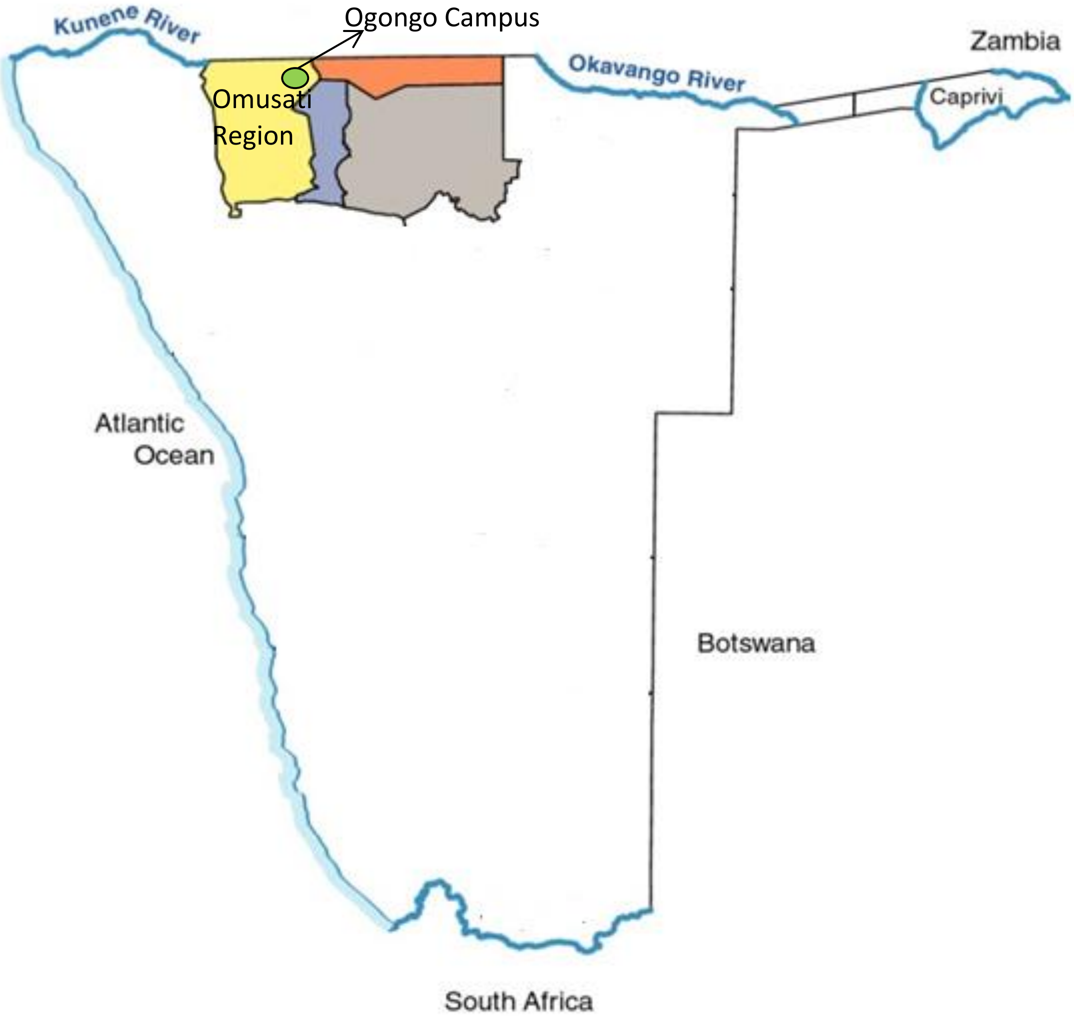

Figure 7: Map of Namibia showing the location of the study area, Ogongo campus in Northern Namibia

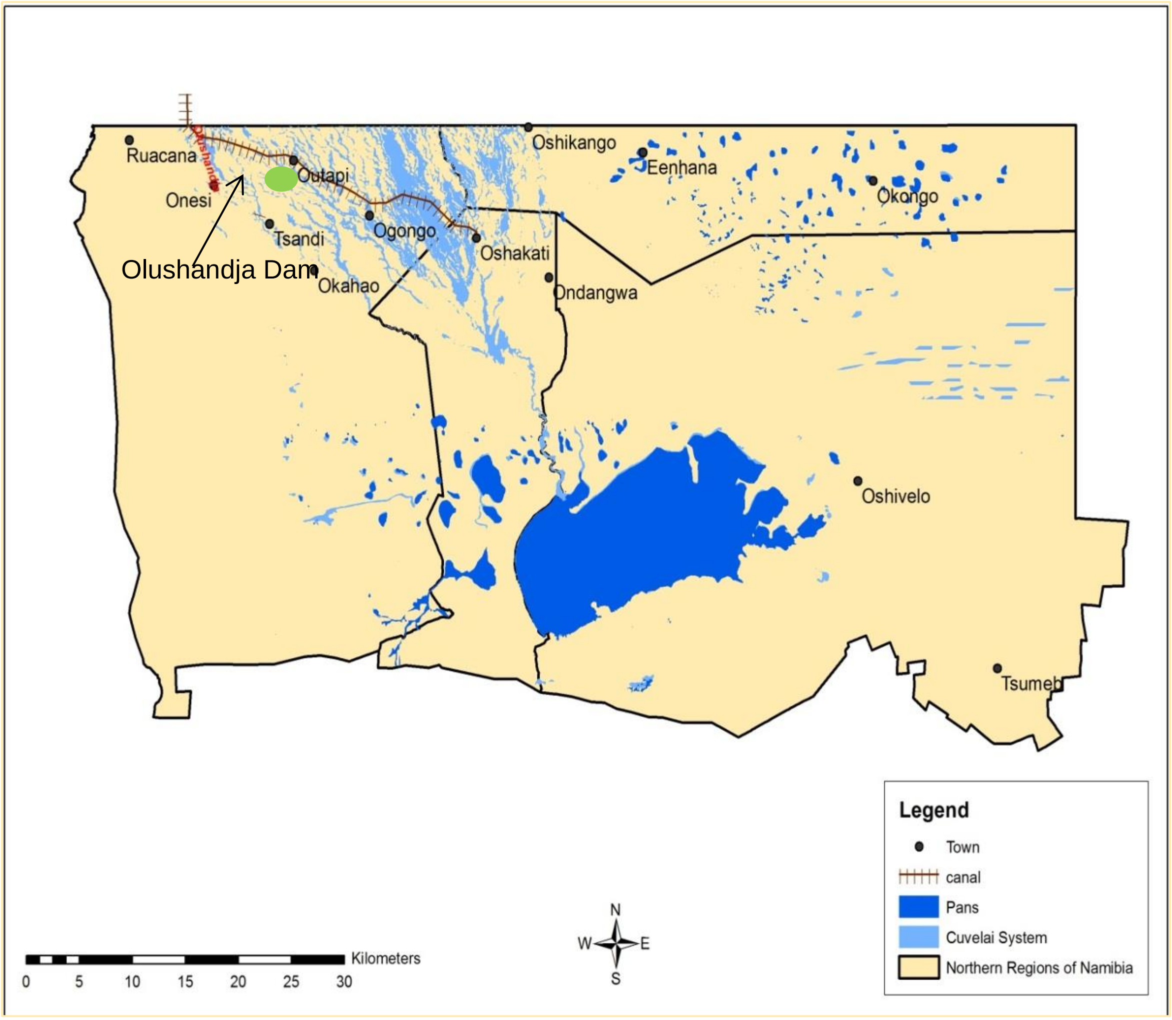

Figure 8 : The Cuvelai basin and the Olushandja dam with the Calueque-Oshakati canal in the Northern Regions of Namibia

3.3. Experimental Design

A quantitative research design was used in the study. The experiment was a 2 x 3 split plot experiment in a randomized complete block design replicated three times. The main plot factor was irrigation treatments namely flood and drip irrigation systems. The subplot factors were irrigation applied at 100% crop evapotranspiration (ET_o), 80% ET_o and 60% ET_o for both drip and flood systems. Treatments were replicated three times to give a total of 18 plots as shown in the experimental layout (Fig 10). Each plot was 10 m x 3 m. The spacing between plots and blocks were 5 m and 2 m, respectively, to avoid water infiltration effects. Each plot had 2 rows of onion plants and 29 - 30 plants in each row with a total plant population of approximately 60 in every plot. The total experimental area size was 34 m x 43 m = 1 462 m^2 or 0. 1462 ha. Treatments were randomly assigned to blocks and plots and sampling was randomly generated using the GenStat computer package (Genstat, 2003). The experiment took place between July till November. No rainfall was recorded during the experiment as it was during the dry period.

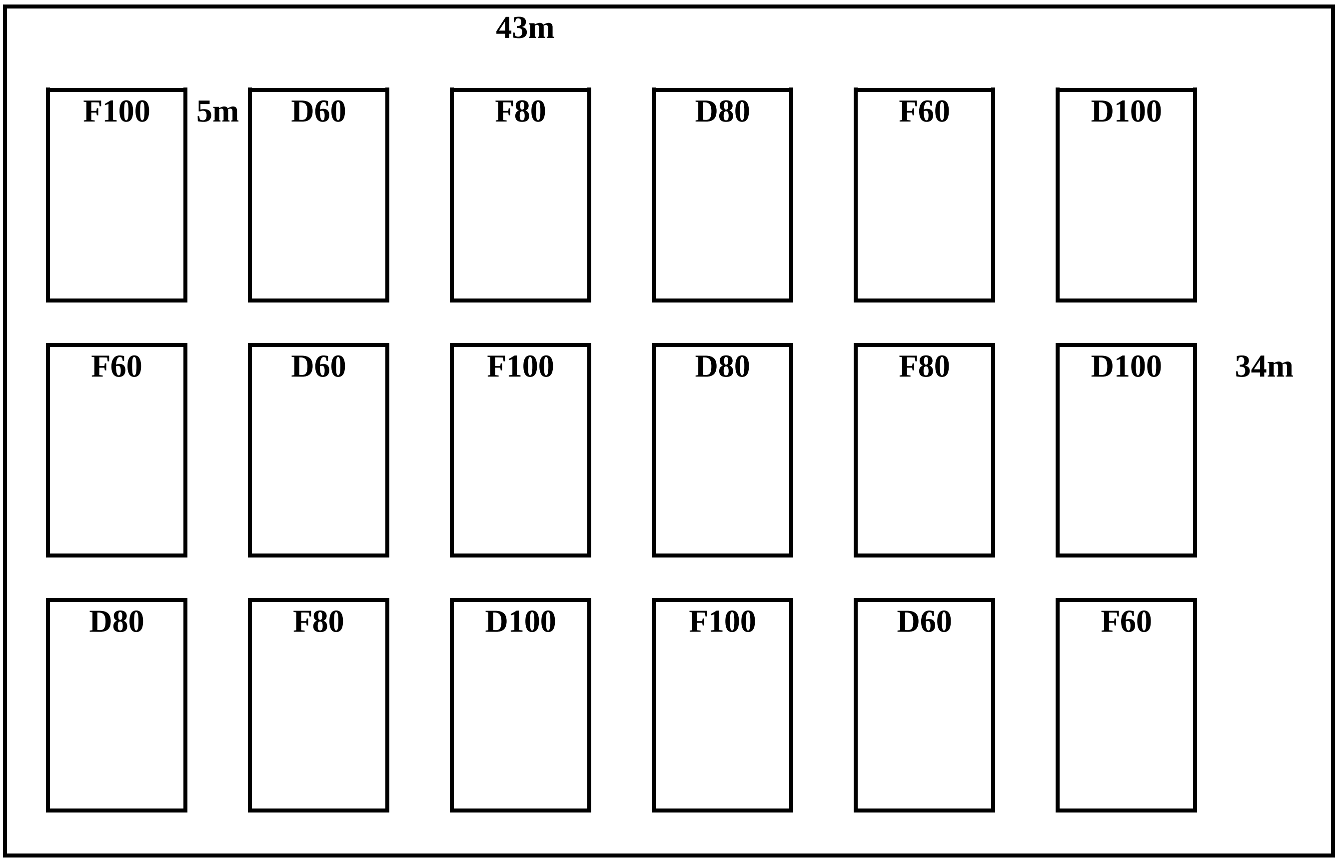

Figure 9: Field experimental layout (not to scale)

F100=Flood 100 ETo; D60 =Drip 60 ETo; F80=Flood 80 ETo; D80=Drip 80 ETo; F60=Flood 60 ETo; D100=Drip 100 ETo

3.4. Research equipment

The equipments which were used during the research include the following:

- Scale - used to measure the yield of onions in kilograms.

- 2 x 25 mm Zenner water meter - used to measure the total volumes of water used during the growing seasons under flood and drip systems.
- An HSM50 Precision Digital Soil Moisture Meter - used to measure the moisture content in the root zone of onions
- Vernier Calipers - used to measure circumference and sizes of onion bulbs.
- Hand hoe and a rake –used to cultivate the land, loosen up and level the soil.
- 50 meter measuring tape – used to measure the experimental site area.
- Ropes and sticks - used to mark the experimental site area.
- Ruler – used to measure the plant heights for all the crops.

3.5 Procedure

A site that was not cultivated for the three years previous to the start of experimentation was chosen. It was then ploughed with a disc harrow to clear the field of grass and to loosen the soil for bed preparation. After clearing, the land was cultivated by a hand hoe and a rake was used to loosen up and level the soil. Then the experimental site area was measured with a 50 meter measuring tape and marked with sticks. Row spacing was selected according to the irrigation system specifications and each row width was measured and marked. After plots were measured out correctly, drip lines were placed on the beds. Systems were installed and all connections were properly sealed to minimize water leaks and losses.

Water meters were installed at the main line to measure the total water delivered to each plot. Onions were sown on 13 trays of 25 x 12 holes on the 12 June 2015 and they were transplanted on 18 July 2015 in the morning to avoid damage to onion as it was during the dry season of the year. Based on the normal practice of local small scale farmers, fertilizer was not applied.

For all treatments, an onion plant population of 73 800 per ha was used. This is approximately in line with the 70 000 plants per hectare the farmers growing onions at Etunda Irrigation Scheme are using. In-row spacing was 15 cm and inter-row spacing was 1 m for easy use of implements.

Water for irrigation was pumped from the Ogongo Campus reservoir. For flood irrigation, water was pumped straight into the furrows. For the drip system, water was pumped first from the reservoir into the tank of the family drip system (Figure 11). Figure 12 shows the experimental plot with the onion crop in.

Figure 10: Family drip irrigation system with tank of 200 litres used by the small scale farmers

The family drip system consists of a 200 litres water tank at an elevation of 1.5 m to allow water to flow from the tank to the main liners, laterals and emitters with the help of gravity. The water tank had a 25.4 mm valve outlet installed at a height of 15 cm above tank's bottom. It consists of a drainage outlet installed at the bottom of the tank to allow sediments to be washed out and a 25.4 mm main valve installed at the tank‘s outlet. A 25.4 mm screen filter and a polythene pipe, distribution line was installed between the tank and dripper lines.

Figure 11: Experimental plots with onions at Ogongo campus field

3.6. Soil Sampling

In order to establish the soil type for the research site at Ogongo Campus, three soil samples were collected from the site. This was necessary since water use availability also depends on soil type. An auger was used to collect soil samples from three different soil depths at 0-20, 20-30 and 30-55cm. The samples were packed in a plastic bag to prevent soil water evaporation and sent to the Soils Laboratory at the Ministry of Agriculture, Water and Forestry for analysis.

3.7. Measurement of Soil Moisture Content

An HSM50 Precision Digital Soil Moisture Meter (Figure 13) was used to monitor and measure soil moisture. The meter was turned on by pressing the power button momentarily and then the moisture sensing head was inserted into the soil.

Figure 12: A HSM50 Precision Digital Soil Moisture Meter used at Ogongo experimental site

As per recommendations outlined in the operating manual, the probe head was inserted into the soil at least 10 cm deep whilst making the measurement. During the measurement, the hold button was pressed momentarily to hold the measured value. As soon as the hold button was shown on the LCD, the hold button was pressed once again to release the data hold function. The data record function was then used to record the maximum and minimum readings and these were recorded in percent moisture content.

Soil moisture contents at ten randomly selected sites per plot per row were monitored weekly starting immediately after onion was transplanted until harvesting. The moisture content were measured at the soil depths of 0 - 10 cm and 10 - 20 cm. Measurements started on the 18th August until 28 November 2015 and were taken for all treatments before each irrigation event.

3.8 Water sampling

In order to establish the quality of irrigation water used in drip and flood irrigation systems, water samples were collected before irrigating. Water was collected at 07.00 AM local time at Ogongo Canal. Sterile 500 ml sampling bottles were sourced from the Analytical Laboratory Services in Windhoek. The water was collected in the sterile bottles and all the bottles were closed tightly to avoid any contaminations. The sample bottles were labelled with the researcher's name, date of sample collected and sample location. The samples were then placed in a cooler box filled with ice. Thereafter the water samples were sent to Windhoek for analysis at the Analytical Laboratory Services and the process took two weeks.

3.9. **Method of estimating crop water requirements for onion using the Pan method**

The water requirements for onion were calculated as follows:

Step 1: Estimate the duration of the various growth stages

Step 2: Estimate ETo for Ogongo 8-9 mm/day average 8.5 mm/day

Step 3: Estimate the Kc factor for each of the 4 growth stages

Step 4: Calculate, on a monthly basis, the crop water need, using the formula:

ET crop = ETo × Kc (mm/day)

Step 5: Calculate the monthly and seasonal crop water needs.

If we estimate ETo for Ogongo 8-9 mm/day average 8.5 mm/day and assume the growing period for onion as 120 days for Ogongo then the duration estimate for this study is shown in Tables 3 to 7.

The subsequent ETo values for the growth stages are shown in Table 3. Using Table 3, the Kc factor per month are shown in Table 4.

Table 3: ETo values and the duration of the growth stages.

Crop	Total growing period (days)	Initial stage	Crop dev. stage	Mid-season stage	Late season stage
ETo estimate		8.5	8.5	8.5	8.5
Onion	120	30	40	30	20
K_C factor		0.50	0.70	1.0	1.0

Table 4: Kc factor per month for each of the 4 growth stages

Growth Stage	Month	Monthly Kc factor	Average Kc factor
Initial	July	15/31 days x .50 = 0.24	0.24
Development	August	15/31 days x.50 = 0.24	0.60
Development	August	16/31 days x.70 = 0.36 = 0.6	
Mid	September	24/30 days x .70 = 0.64	0.84
Mid	September	6/30 days x 1 = 0.2 = 0.84	
Late	October	24/31 days x 1 = 0.77	1.00
Late	October	7/31 days x 1 = 0.23 = 1. 0	
Late	November	13/30 days x 1 = 0.43	0.43

Values in Table 4 are then used to calculate onion water need on a daily basis under Ogongo conditions. This is shown in Table 5.

Table 5**:** Daily Crop water need for Onion at Ogongo

Month	Crop ET
July	ET crop = 8.5 x 0.24 = 2.04 mm/day
August	ET crop = 8.5 x 0.6 = 5.1 mm/day
September	ET crop = 8.5 x 0.84 =7.17 mm/day
October	ET crop = 8.5 x 1 =8.5 mm/day
November	ET crop = 8.5 x 0.43 = 3.66 mm/day

The daily crop ET for Onion in Ogongo in Table 5 are then used to determine the monthly crop water needs for Onion at Ogongo (Table 6)

Table 6: Monthly Crop Water Needs for Onion at Ogongo

Month	Monthly crop water need
July	2.04 x 15 days = 30.6 mm
August	5.1 x 31days = 158.1 mm
September	7.17 x 30 days = 215.1 mm
October	8.5 x 31 days = 263.5 mm
November	3.66 x 13 days =47.6mm

.

The total amount of water for successful production of onion under Ogongo conditions is therefore 715 mm per season. Since drip irrigation is highly efficient, the total amount of 715 mm was accepted as the 100% ETo value for drip irrigation, and for flood irrigation, an extra 50 % was added giving a total of 1073 mm for 100% ETo. This was done since it is recommended that irrigation water be applied at 50% water depletion. The corresponding amounts of water for different levels of irrigation are shown in Table 7.

Table 7: The total amount of water for production of onion at Ogongo

Irrigation type and level	Total amount of water per irrigation type
Flood - 100% level	1073 mm
Flood - 80% level	858 mm
Flood - 60% level	644 mm
Drip - 100% level	715 mm
Drip - 80% level	572 mm
Drip - 60% level	429 mm

3.9 Plant Height

Plant height is one of the descriptive parameters which may indicate growth, plant vigor, yield responses of onion plants to various management treatments, i.e., irrigation methods (Heady, 1957; Ashok, Sasikala & Pal, 2013). Plant heights were recorded at weekly intervals. Plant height was measured following one of the procedures described by Heady (1957). Three random plants were selected per row in a plot and the heights of the plants recorded in cm every week during the whole growing season. Plant height was measured using a ruler from the soil surface to the top of the longest mature leaf.

3.10 Crop Management and yield measurements

As the study was done during the dry season, the plants were irrigated daily to apply moisture required by the plants. Water was applied between 09.00 - 12.00 am and then from14.00 - 15.30 pm. Weeding and monitoring of water leakages was a routine for the researcher. The plots were weeded weekly to control weeds so that they would not become problematic at the end of the day. This was done before watering or sometimes after watering for easy removal or uprooting of weeds. Pests like wireworm and beetle were identified feeding on plant roots and as a result they were controlled by picking them up by hand as they were not many.

Onions were harvested on the 1st December 2015 when crops matured as indicated by the tops of onion falling over and beginning to dry. The bulbs were carefully dug out of the soil with a hoe. Thereafter onions were collected and graded according to their sizes. The best 20, 10 and 5 bulbs were selected and weighed. During harvesting onion from each plot were kept separated to simplify the recording process and also to obtain accurate results from the plots. The yields for whole plots were also measured and converted to yield per ha.

3.11 Data Analysis

3.11.1 Comparing the water use efficiency and moisture content of different treatments.

The data was recorded in Excel for data management before being transferred to the SPSS for statistical analyses. Analysis of variance (ANOVA) was used to test for any significant differences in mean values of water use efficiency and moisture content at the root zone of onion at 3 different irrigation levels (100, 80 and 60% potential evapotranspiration (ETo)) of flood and drip irrigation systems. Water use efficiency was determined using the formula

$$WUE\ (kg/m^3) = \frac{\mathrm{Pr}oduction\ (kg/ha)}{Irrigation\, water\, used\ (m^3\, ha-1)} \qquad (4)$$

3.11.2 Determining and comparing the cost and total labour requirements for growing onion under flood and drip irrigation at 3 levels.

Cost analysis was carried out using prices of the drip irrigation system from Sinclair Service cc and installation at current price levels, and onion production costs were determined based on NAB standards (NAB, 2015). Both fixed and variable costs were calculated for each irrigation system (N$ /ha/season), and the gross margin of the product under the tested irrigation systems were derived to compare these systems. The pump and engine, main control units, and lateral control units, main and sub-main lines, manifold, laterals, emitters and gathering the system were already installed for this study thus their cost were not considered. Gross margin analysis was done and profit and loss components were compared. This was done using graphs and Tables.

3.11.3 Comparing yield and plant heights of onions under flood and drip irrigation systems at 3 levels.

Parametric analysis of variance model was used to test the hypothesis of equality of mean yields and plant heights of the treatments versus that of at least one of the treatment mean is not equal. In cases where the null hypothesis of equality of means was rejected, post hoc or pairwise comparisons were performed using Duncan and Turkey's pairwise methods. The Analysis of Variance models were first validated by performing a model diagnostic test.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.0 Introduction

The chapter deals with the presentation of results in line with research objectives. Descriptive statistics, pictorial and graphical illustrations are used as appropriate to provide more insights. The results are followed with discussions in which case the results are contextualized in line with what other similar or nearly similar researches found.

4.1 Soil Analysis

The results of textural analyses of the three soil samples collected from the site at 0-20, 20-30, and 30-55 cm depth as analyzed by the Soils Laboratory of the Ministry of Agriculture Water and Forestry in Windhoek are presented in the Table 1 Table 2 shows nutrient composition and some chemical properties of Ogongo soil.

Table **1: Texture of soil samples obtained from the study site at Ogongo study site**

Soil depth (cm)	Texture			Textural Class
	Sand%	Silt%	Clay%	Overall classification
0-20	94.1	2.0	3.9	Sandy
20-30	93.4	2.5	4.1	Sandy
30-55	94.6	0.5	4.9	Sandy

Table **1: Nutrient composition and some chemical properties of Ogongo soil**

						Ppm				
Soil depth (cm)	pH w	ECw Electrical conductivity uS/cm	OM Organic matter %	P Phosphorous	K Potassium	Mg Magnesium	Mg/K Magnesium to Potassium proportion	Ca calcium	Na Sodium	Nitrogen %
0-20	6.73	59	0.32	10.6	202	123	0.61	594	84	0.01
20-30	6.85	56	0.30	10.00	235	145	0.62	724	58	0.01
30-55	6.92	53	0.22	9.20	333	215	0.65	1011	67	0.00

Arenosols (Psamments in Soil Taxonomy, FAO Soil Classification, 2006) are a feature of some soils of Botswana, Angola, Southwest DRC and spread into the North Central Namibia. The structure of the soils at the test site as was sampled was found to be mostly sandy for all the depth ranges. The Arenosols are generally known to have low nutrient contents and low water holding capacity and poor water retention capacity. This has implications in water loss during the dry hot summers of the region where evaporative loss due to hot sand combined with percolation below the plow surface layer leads to a tendency of high water deficit. Flooding may hold value only when the available soil water exceeds the rate of loss to the atmosphere and below the plow layer.

An Arenosol is a soil order characterizing the North Central Region Namibia with soils that can sometimes be saline (Watanabe et al., (2016). Table 2 shows a somewhat higher Na (sodium) in the plow surface which has an implication of reducing crop growth although to what degree was not determined in the present study. The higher concentration of salinity in upper surface soil can be explained by a precipitation into crystals as the hot sun evaporates the water. The manifestation of salinity signs is an undesirable feature for the survival of some sensitive crops (Watanabe et al., (2016).

As can be observed in Table 2, results presented confirm the common characteristic of Arenosols in terms of the low soil nutrient fertility. The nutrients assessed were extremely low in % organic matter and of % nitrogen, nearly low in phosphorus and very low in magnesium (being less than the 364.8 ppm threshold). Potassium was in the low range but was noted to have approached a medium range at the deeper depth suggesting some leaching. Flooding the soils in connection with soil K may move it to shallow depth thereby further making the plow layer of crops with shallow rooting K deficient.

The relationship between Mg and K in terms of their ratio is of further concern. For many crops, Mg level ideally should be twice as much as K (i.e. 2:1). Table 2 in the column expressed as Mg/K proportion shows values that Mg was only a fraction that was far from twice (i.e. was instead between 61 and 65% less). The micronutrients were found to be very low as well. From the above data the concentrations of micronutrients were fairly low at the deeper depth whilst Mn increased with increasing depth of sampling (Table 3).

Table **2: Physical characteristics of trace micronutrients in soil samples obtained from the study site, Ogongo before planting and flooding at the site**

Soil depth (cm)	In ppm			
	Fe	Cu	Zn	Mn
0-20	49.00	1.86	2.20	48.70
20-30	42.80	1.96	1.62	49.85
30-55	34.20	0.71	0.88	57.80

4.2. Moisture Level - Parametric Analysis of Variance (ANOVA) model diagnostic checks.

4.2.1. Normality Test

Moisture data was subjected to normality test using histogram plot and a normal probability plot. Figure 14 shows the Model Diagnostic checks: Normality test using histogram plot.

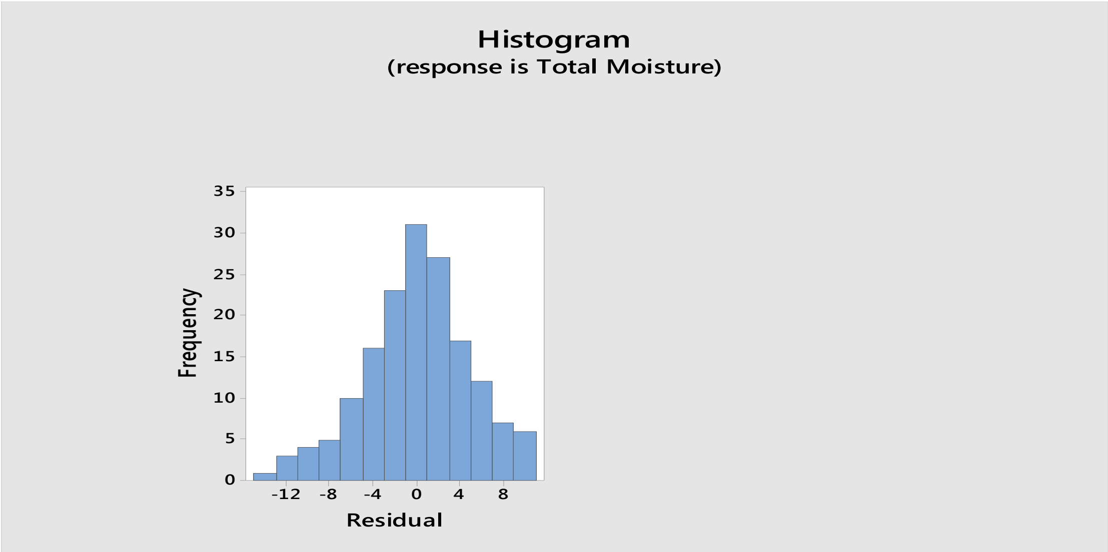

Figure 13: Model Diagnostic checks: Normality test using histogram plot

Data did not violate the normality assumption as the plot of residuals fits closely the theoretical normal/ Gaussian distribution hence there was no need to apply the Box-Cox transformations methods (see Figure 14 and Figure 15).

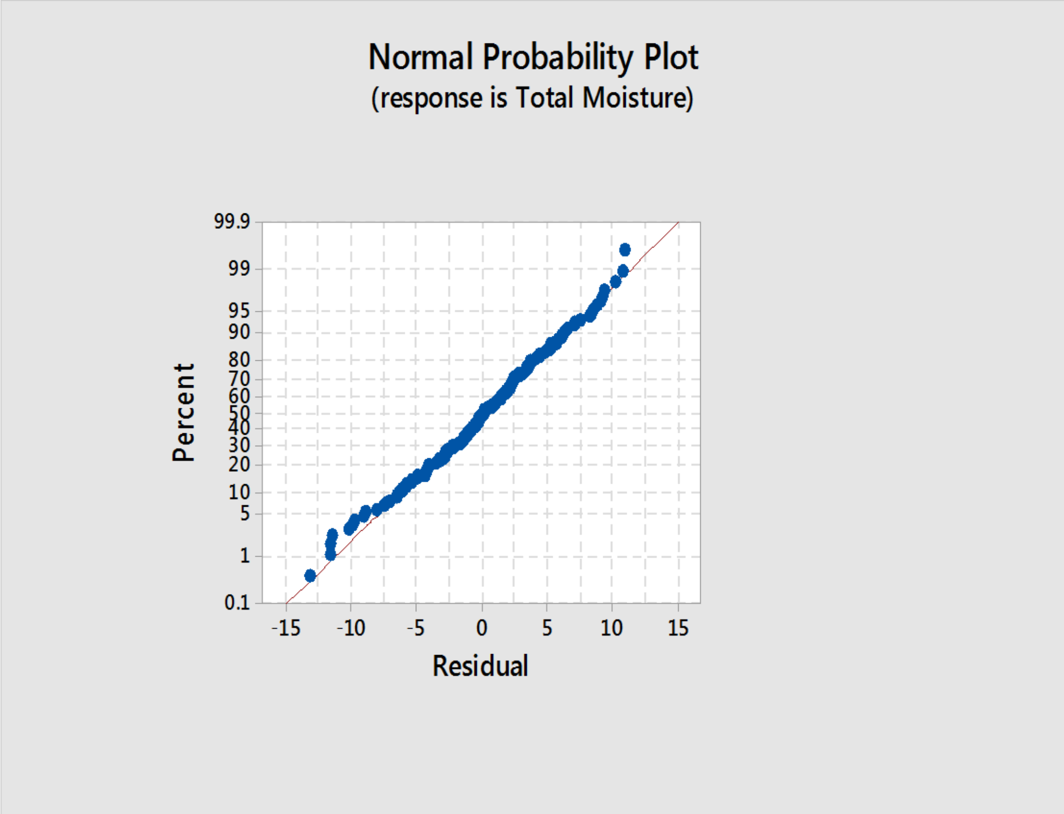

Figure 14: Normal probability plot: test for normality

The normal probability plot reflects points that lie very close to a straight line. This suggests that the assumption of normality is not violated.

4.2.2. Homoscedasticity test (Residual versus fitted value plot)

When we used ANOVA to test for differences within and between flood and drip, the assumption made was that all levels (= groups = categories) have equal variances. If our variances within a treatment are all so variable and we had to use them in comparison with variance between the two treatments, the accuracy of the test will be in jeopardy. In order to meet the assumption of homoscedasticity, the variance within the flood system treatment data set must be equal (statistically equivalent) to that of the drip system data set. The test of homoscedasticity took into account a cumulative probability distribution of a statistic that is equal to the ratio of the largest to the smallest of the two treatment sample variances in a statistic called F_{max}. Based on a Hypotheses that: Ho: $\sigma F_1 = \sigma D_2$ while H1: "Not all variances are equal". Ordinarily, s^2 is used to estimate σ^2 the Test Statistic = F_{max} = $s2_{max} / s^2_{min}$. If this value approached 1.00 it was safe to assume that the assumption of equal variances was met.

Figure 16 exhibits the rectangular pattern. The plot therefore shows that the variance is sTable hence the ANOVA assumption of homoscedasticity was not violated. We used Turkey's method that considers all possible pairwise differences of means at the same time. The Turkey method applies simultaneously to the set of all pairwise comparisons; i.e. $\{\mu i - \mu j\}$. The Confidence Interval (CI) indicated in Figure 17 is the confidence coefficient for the set. When all sample sizes are equal, it is exactly 1- α. For unequal sample sizes, the confidence coefficient is often greater than $1-\alpha$. In other words, the Turkey method is conservative when there are unequal sample sizes.

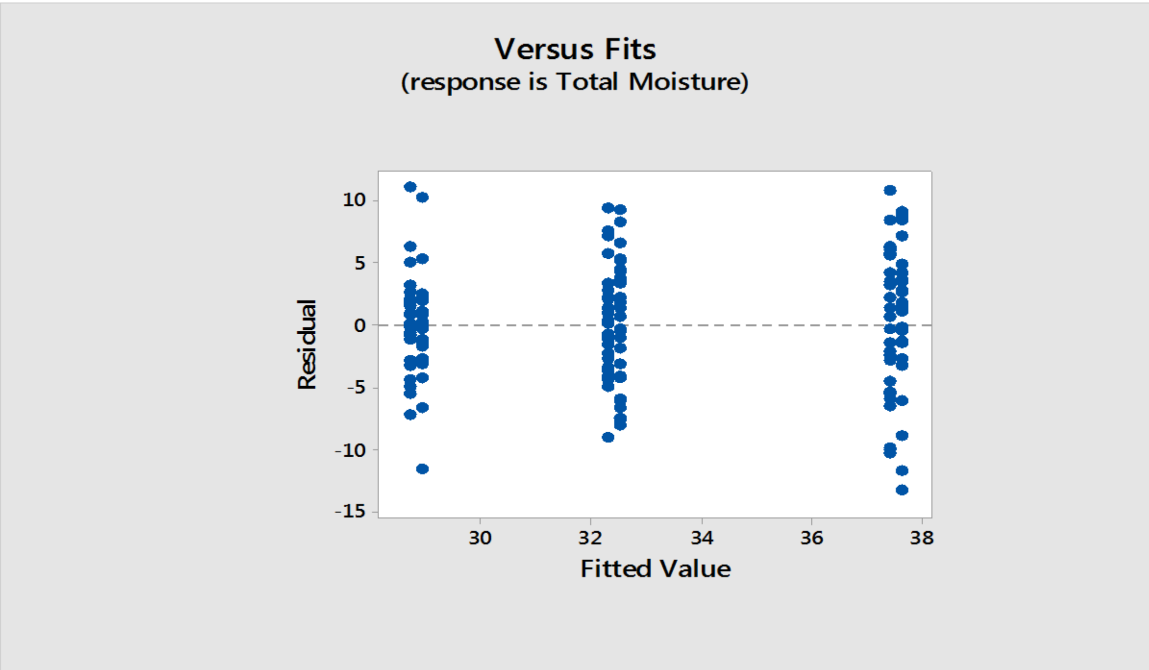

Figure 15: Homoscedasticity test (Residual versus fitted value plot)

4.3 Result of moisture level among treatments

Figure 17 and 18 show interval plot comparing the moisture level for the different levels of irrigation. Interval plot of total Moisture vs Level of irrigation do not overlap and thus suggest that they are statistically significantly different. The 100% ETo level produces the highest moisture level distinct from the rest.

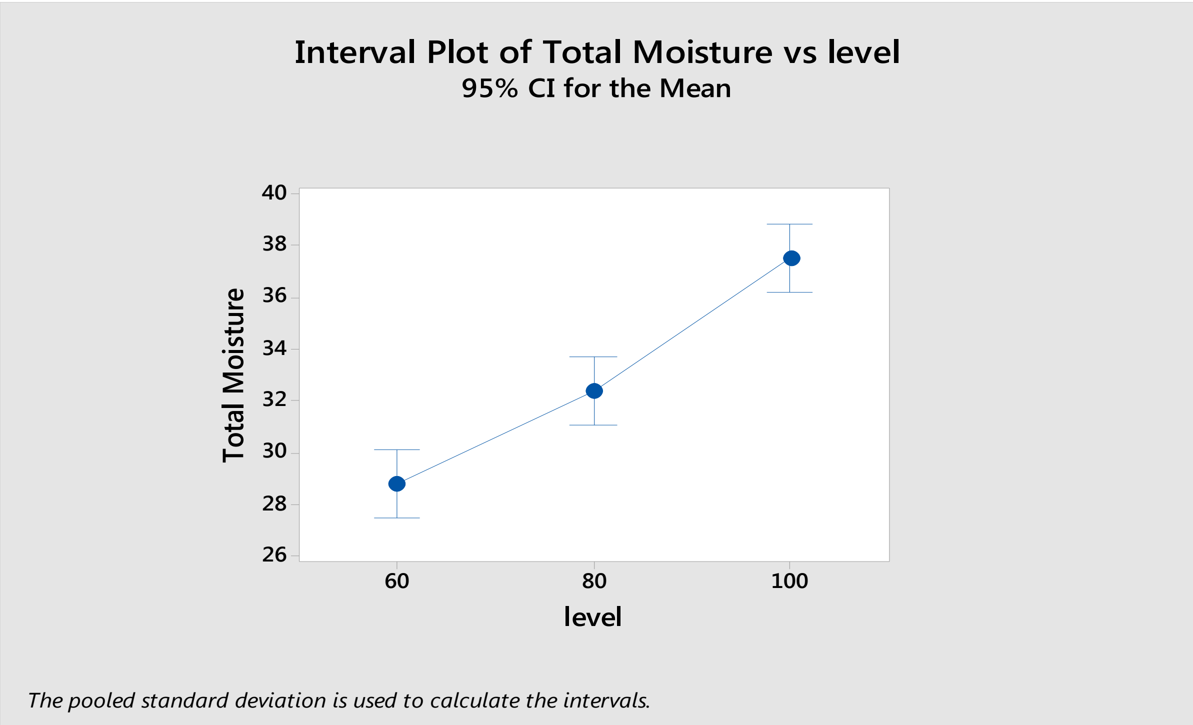

Figure 16: Interval Plot comparing the Total moisture level subject to different levels of irrigation

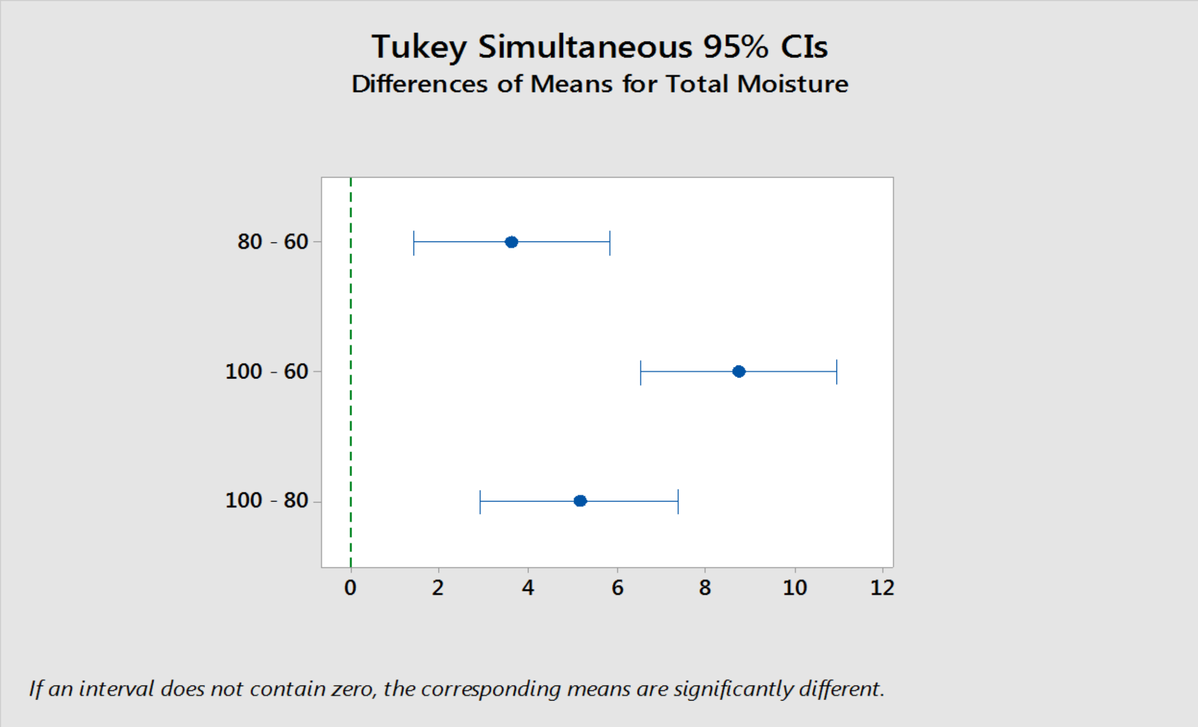

Figure 17: Interval plot of Total Moisture (vertical axis) vs Level of irrigation (Horizontal axis)

The ANOVA results shown in Table 4 reveals statistical significant difference among the irrigation level since p-value = <0.000. However irrigation type did not show statistical significance (p = 0.776).

Table **3: Fisher's ANOVA for testing effect of irrigation type and level on moisture content**

Source	DF	Adj SS	AdjMS	F-Value	P-Value
Irrigation	1	1.96	1.96	0.08	0.776
Level	2	2084.08	1042.04	43.35	0.000
Error	158	3798.04	24.04		
Lack- of- Fit	2	0.94	0.47	0.02	0.981
Pure Error	156	3797.10	24.34		
Total	161	5884.08			
Model Summary					
S	R-sq	R- sq (adj)	R-sq (pred)		
4.90288	35.45	34.23%	32.14%		

Figure 19 shows that 100% irrigation level produced highest moisture level as compared to 60 and 80% irrigation levels for both irrigation systems. Figure 20 shows that in most cases during the duration of the crop, drip irrigation had more moisture in the root zone than flood irrigation.

For the drip irrigation the 100% ETo irrigation level produced the highest moisture value at 37.67%, while the moisture for the 80% ETo irrigation level was 32.58 % and for 60% ETo level 28.8 %. For the flood irrigation system, the 100% ETo irrigation level produced the highest moisture value at 37.39%, while the 80% irrigation level was 32.21 % and 60% level 28.79 %. Drip irrigation at 100% was better than flood at 100% by 0.74% whist at 80% drip was better than flood by 1.14% and at 60% drip was better than flood by 0.03%. This shows than drip irrigation was better than flood on moisture content. The moisture content also decreased proportionally to the three levels most likely because water was also applied proportionally to the levels.

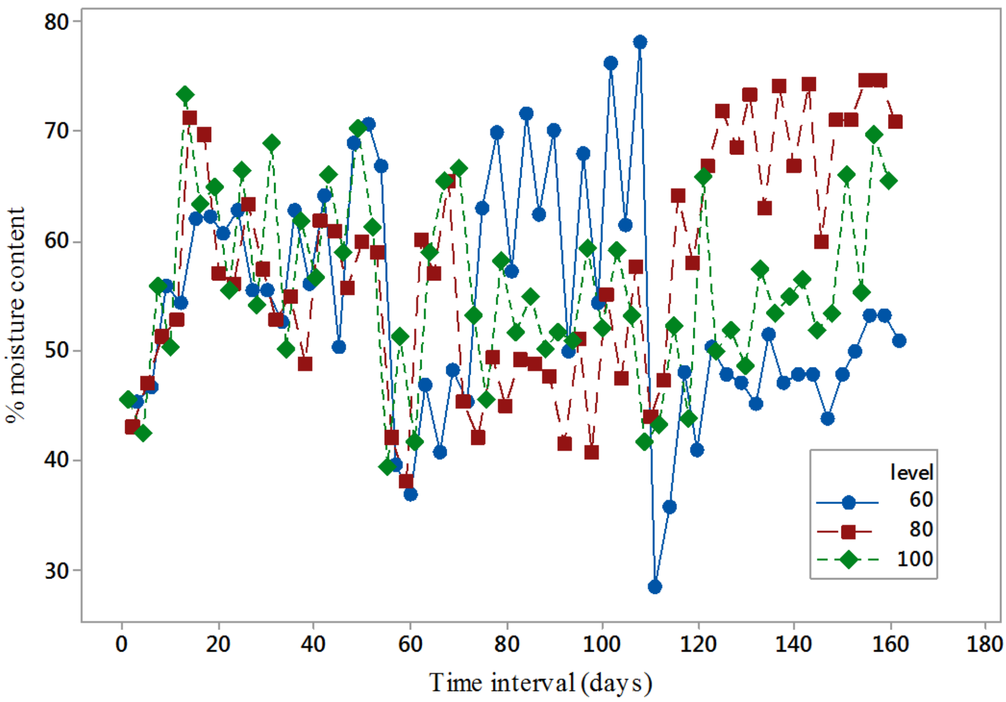

Figure 18: Comparison of total moisture across three irrigation levels (at 60, 80 & 100% ETo)

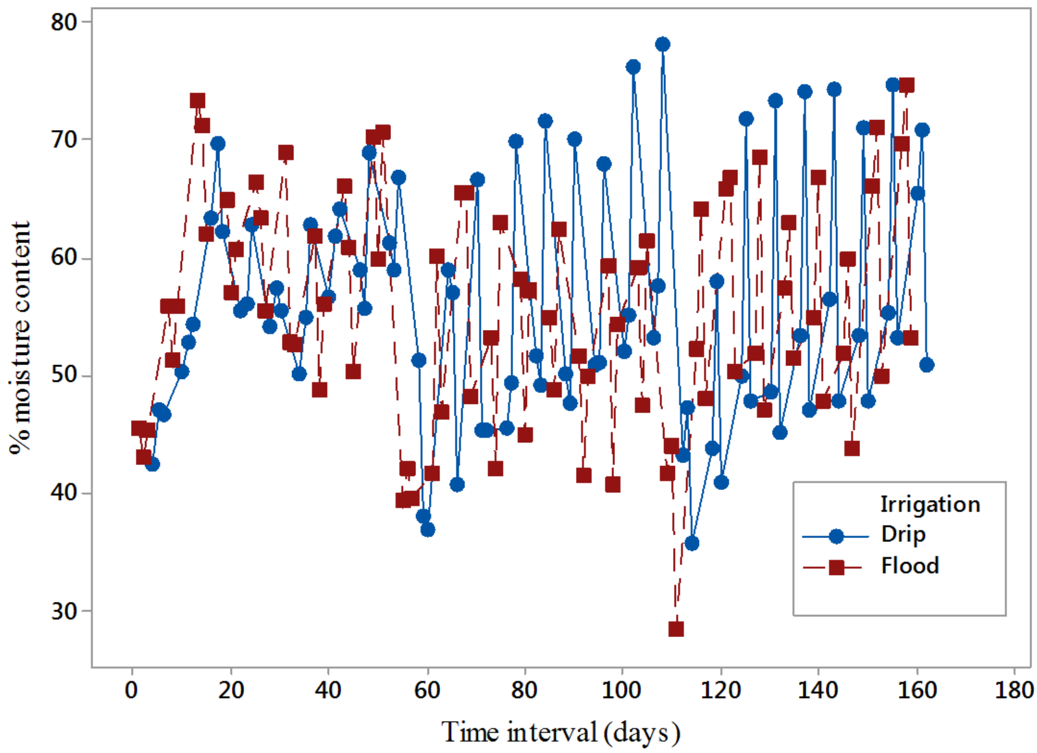

Figure 19: Comparison of total moisture between drip and flood across the experimental period

4.4. Plant Height

Table 5 shows the ANOVA for testing effect of irrigation level on plant height. Plant height are not significantly different at all the three levels of irrigation (p =0.397). Figure 21 shows a comparison of plant height for flood and drip irrigation at different levels.

Table **4: ANOVA for testing effect of irrigation level on plant height**

Source	**DF**	**AdjSS**	**AdjMS**	**F-value**	**P-value**
Irrigation level	5	1033	206.5	1.05	0.397
Error	48	9398	195.8		
Total	53	10431			
Model Summary					
S	R-sq	R-sq (adj)	R-sq (pred)		
13.9926	9.90%	0.52%	0.00%		

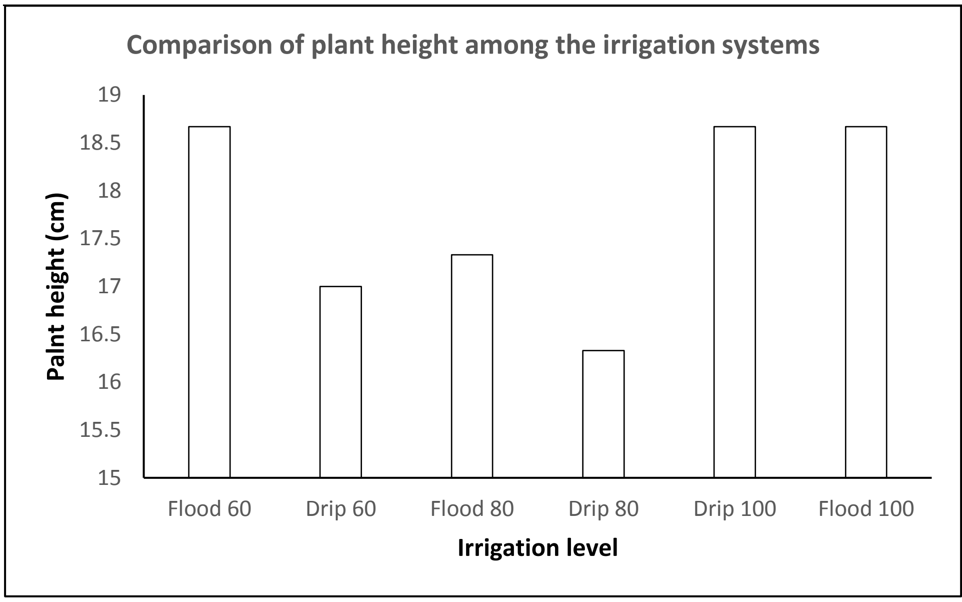

Figure 20: Comparison of plant height among the irrigation systems

Results show higher plant heights were obtained in drip irrigation by a margin of 28.36% for the 100% levels, by 3.65% for the 80 % levels and 22.38 % for the 60% levels.

Results are in line with Enchalew *et al.,* (2016) who also found that deficit irrigation did not affect much the plant height of onion. In contrast to that Srinivas and Hegde (1990) reported that the plants were 3% taller under the drip irrigation than the basin irrigation. In another study Karam *et al.,* (2002) reported that water stress caused by the deficit irrigations significantly reduced leaf number, leaf area index and dry matter accumulation of lettuce.

4.5 Yield

Following the grading and weighing of onions into the best 20, 10 and 5 bulbs, analysis of variance of a model in STATA was conducted to explore their difference at the p= 0.1. Table 12 shows a summary Analysis of Variance for comparing the effects of different irrigation type, irrigation level and their interaction on yield. Meanwhile ANOVA at eta squared value was computed to explore the magnitude of reported difference of the three levels of irrigation. According to Cohen (1988) eta squared is classified as small at 0.01, medium at 0.06 and large at 0.14.

Table **5: Summary Analysis of Variance** Table **for comparing the effects of different irrigation type, irrigation level and their interaction on yield**

Response	Treatment	P-Value	Eta Squared value
Yield (20wt)	Level of Irrigation (L)	0.008***	0.22
	Irrigation Type (I)	<0.001***	0.47
	L*I	0.415n.s	0.03
Yield (10wt)	Level of Irrigation (L)	<0.001***	0.18
	Irrigation Type (I)	<0.001***	0.29
	L*I	0.224n.s	0.02
Yield (5wt)	Level of Irrigation (L)	<0.001***	0.16
	Irrigation Type (I)	<0.001***	0.19
	L*I	0.08*	0.02

The yield productions of all treatments are highly significant at 0.47, 0.29 and 0.19 eta squared. Irrigation type is highly significant (p< 0.001). Irrigation level at 20wt is (p=0.008) irrigation level at 10 wt. is also significant at (p <0.001) and at 5wt it is also highly significant at (p<0.001). However the interaction between level of irrigation and irrigation type are not significantly different at 20wt (p=0.415) and 10wt (0.224). At 5wt, yield (p =0.08; 0.02 eta squared) is significantly different as compared to 20wt and 10wt.

Table 7 shows a post Hoc analysis performed using Turkey and Duncan's Multiple Range Test, to determine which irrigation level produces the highest 20 bulbs yield. Statistical analysis indicated that 100% ETo level of irrigation had the highest 20 bulb yield which was significantly higher than those of 80 and 60% ETo. Although the yield trend followed the level of irrigation, the results indicated no statistically difference in yield of onions at 80 and 60% irrigation level.

Table **6: Results from Turkey and Duncan Multiple Range Test**

Yield 20wt

Irrigation Level		N	Subset for alpha =0.05	
			1	2
Turkey B[a]	60	6	167.6667	
	80	6	176.9000	
	100	6		194.2667
Duncan	60	6	167.6667	
	80	6	176.9000	
	100	6		194.2667
	Sig.		.195	1.000

Treatments (irrigation level) in the same subset are not statistically different at P≤ 0.05 by Turkey B test and DMRT.

The yields for onion for the whole plots were also measured and converted to yield per hectare. Table 8 shows yields of onion for the type and level of irrigation. The highest level of yields were obtained from the 100% ETo level followed by 80% ETo level and then 60% ETo. The drip irrigation however showed higher yields than the flood irrigation at all the 3 levels.

Table **7: Total yields of onion per ha for the type and level of irrigation**

Irrigation type and level	Production/(kg ha^{-1})
Drip irrigation at 60 ETo	19 780.1
Drip irrigation 80 ETo	20 350.2
Drip irrigation 100 ETo	20 790.7
Flood irrigation 60 ETo	17 900.4
Flood irrigation 80 ETo	18 430.7
Flood irrigation 100 ETo	19 770

Results show that more yields were obtained in drip irrigation by a margin of 5% for the 100% levels, by 9.4% for the 80 % levels and 9.5 % for the 60% levels.

Results also show that yields for drip at 60% ETo were better than flood at 60% ETo by 9.5%. Drip 80% ETo was better than flood 80% ETo by 9.429%. Drip 100% ETo was better than flood 100% ETo by 4.9%. Drip 60% ETo was better than flood 100% ETo by 0.05%. Drip 80% ETo was better than flood 100 % ETo by 2.85%. Drip 100% ETo was better than Drip 60% ETo by 5.11%. 100% drip ETo was better than Drip 80% ETo by 2.12%.

The results of this study have shown that the yield of onion crop was higher under drip irrigated plots as shown above. The moisture content also showed higher values under drip irrigation than flood irrigation. These results are in line with Maisiri *et al*., (2005) who cited that water saving can be as high as 50% and crop yield can be increased by up to 40% with drip irrigation. Postel, *et al.,* (2001), Holzapfell *et al., (*2009), Prajapati *et al.,* (2013) also mentioned that drip irrigation can prove to be very useful in dry and semi dry areas. Sammis, (1980) also reported that tomato yields under Drip were twice more over flood irrigation method. Enciso *et al.,* (2012) found that drip irrigation systems more than doubled yields and increased onion size while using at least 44% less water.

Ramalan *et al.,* (2010) reported yields of 37.2 tons per hectare with no irrigation deficit, compared to where there was a deficit level of 75% of total available water, the yield dropped to 24.32 tons per hectare for onions. However Kumar et al., (2007) reported that applying 80 and 60% of crop water requirements resulted in yield decreases of 14 and 38% and saved 18 and 33% of irrigation water compared to full irrigation in 2 years, respectively.

Nagaz et al., (2012) also found that the onion bulb fresh yields of deficit-irrigated treatment (deficit irrigation-60) were significantly lower than those in full irrigation treatment (full irrigation-100). They concluded that the full irrigation (full irrigation-100) and continuous and regulated deficit-irrigation (deficit irrigation-80 and full irrigation100) strategies offered significant advantage for both onion yields and WUE compared to the deficit irrigation-60 in onion production under arid conditions. Al Jamal et al., (2001) reported that most economical deficit irrigation level depends on the uniformity of application of irrigation water, cost of irrigation water and the value of a unit of the crop.

4.6 Crop water requirements and irrigation water used

4.6.1 Irrigation water used and water use efficiency

The total volume of water applied in m^3 ha^{-1} for the two irrigations systems and levels is shown in Table 9. These results reveal that total volume of water used under drip irrigation system was less as compared to flood irrigation system by 32.3%. Results show that there was saving of water in drip irrigation by a margin of 30.7% for the 100% levels, by 33.3% for the 80 % levels and 33.3 % also for the 60% levels.

Table **8: Irrigation water used and water use efficiency**

Irrigation system and level	Production/(kg ha^{-1})	Irrigation water used (mm ha^{-1})	Irrigation water used (m^3 ha^{-1})	Production / Irrigation water used (kg m^{-3})
Drip 60 ETo	19 780.1	429	4 290	4.6
Drip 80 ETo	20 350.2	572	5 720	3.6
Drip 100 ETo	20 790.7	715	7 150	2.9
Flood 60 ETo	17 900.4	643	6 430	2.8
Flood 80 ETo	18 430.7	858	8 580	2.1
Flood 100 ETo	19 770	1 073	10 730	1.84

Table 10 shows the ANOVA for testing effect of irrigation type and level on water use efficiency. WUE is significantly different at all the three levels of irrigation (p =0.0.008) and also significantly different for the irrigation type (p = <.001)

Table **9: ANOVA for testing effect of irrigation type and level on Water Use Efficiency**

Variate: Water use Efficiency_kg/m^3

Source of variation	**D.F.**	**S.S.**	**M.S.**	**V.R.**	**F pr.**
Irrigation_Level	2	5.20671	2.60336	112.79	<.001
Irrigation_type	1	9.36002	9.36002	405.49	<.001
Irrigation_Level* Irrigation_type	2	0.34138	0.17069	7.39	0.008
Residual	12	0.27700	0.02308		
Total	17	15.18511			

The highest water use efficiency of 4.6 was obtained in drip 60% level compared to 2.8% for flood at the same level; Drip at 80% level was 3.6 kg m^{-3} compared to 2.1% for flood at the same level. At 100% levels WUE was 2.9 kg m^{-3} for drip compared to 1.84 kg m^{-3} for flood irrigation method. The results suggest that farmers could choose the 60% level of irrigation as there were higher water use efficiencies for both systems without much loss in yield.

These results are in line with Maisiri *et al.,* (2005), who cited that water saving can be as high as 50% on English Giant rape. Tagar *et al.,* (2012) also revealed that the drip irrigation method saves 56.4% of water and gave 22% more yield of tomatoes as compared to that of furrow irrigation method. They further reported that a higher water use efficiency of about 4.87 kg m^{-3} was obtained in drip irrigation method, whereas lower water use efficiency of about 1.66 kg m^{-3} was obtained in furrow irrigation method.

Also in line is Enciso et al., (2012) who reported that the irrigation water use efficiency obtained with the drip irrigation system ranged from 17.5 to 25.2 kg $m\text{-}^{3}$ and from 4.2 to 6.2 kg $m\text{-}^{3}$ for the furrow system in two locations whilst growing onions. Drip irrigation systems more than doubled yields and increased onion size while using at least 44% less water. Tagar *et al.*, (2012) also reported a higher water use efficiency of about 4.87 units in drip irrigation method, whereas lower water use efficiency of about 1.66 kg m^{-3} was obtained in furrow irrigation method whilst growing tomatoes. With a high water use efficiency of 4.6 kg m^{-3}, the 60% ETo drip system is the best for the farmer as it only results in less than 5% reduction in yield compared to 100% ETo drip.

4.7 Cost of various equipment

The total installation cost of the drip irrigation was N$ 10 710 (Table 11). The system was connected to the main pump station. This is the fixed cost of the drip irrigation system.

Table **10: The infrastructural equipment to facilitate the transition to the drip irrigation system**

Equipment	Quantity	Unit value N$	Total
Electrical pump	1	4,012.99	4, 012.99
Water drum 200Litre	1	518.99	518.99
25mm filters	2	837.00	1674.00
20mm LDPE pipes	2	637.00	1274.00
Installation			3230.00
Cost of electricity			
Total cost			10710.00

The flood irrigation system's total installation cost was N$8 479.98 (Table 12). This constituted the fixed cost of the flood irrigation system. The total cost of drip irrigation was more than the flood irrigation.

Table **11: The infrastructural equipment to facilitate the transition to the flood irrigation system**

Equipment	Quantity	Unit value (N$)	Total (N$)
Electrical pump	1	4,012.99	4, 012.99
Water drum 200Liter	1	518.99	518.99
25mm filters	2	837.00	1 674.000
20mm pipes	2	637.00	1 274.00
Installation			1 000
Total Cost			8 479.98

The gross margin analysis for drip irrigation 60% ETo indicated that the drip irrigation system generated N$ 72 990.60/ha using the current prices of onions as per NAB gazetted prices NAB, (2015). The total variable costs amounted to N$45 690 /ha (Table 13).

Table **12: Gross margin for drip irrigation at 60 ETo**

	Amount	Unit Cost / Price/kg (N$)	Total (N$)
Revenue (Yield / kg/ha)	19 780.1	6	118 680.6
Variable costs			
-Water (N$/m^3)	4 290	10	42 900
-Labour - person days			
-Watering days	75	30	2 250
-Weeding days	11	30	330
-Harvesting days	7	30	210
Total cost			45 690
Gross margin			72 990.60

The gross margin analysis for drip irrigation 80% ETo indicated that the drip irrigation system generated N$ 62 111.20/ha using the current prices of onions as per NAB gazetted prices NAB, (2015). The total variable costs amounted to N$ 59 990/ha (Table 14).

Table **13: Gross margin for drip irrigation at 80ETo**

	Amount	Unit Cost / Price/kg (N$)	Total (N$)
Revenue (Yield / kg/ha)	20 350.2	6	122 101.2
Variable costs			
-Water (N$/m^3)	5 720	10	57 200
-Labour days			
-Watering days	75	30	2 250
-Weeding days	11	30	330
-Harvesting days	7	30	210
Total cost			59 990
Gross margin			62 111.20

The gross margin analysis for drip irrigation 100% ETo indicated that the drip irrigation system generated N$ 50 454.2/ha using the current prices of onions as per NAB gazetted prices NAB, (2015). The total variable costs amounted to N$ 74 290/ha (Table 15).

Table **14: Gross margin for drip at 100 ETo**

	Amount	Unit Cost / Price/kg (N$)	Total (N$)
Revenue (Yield / kg/ha)	20 790.7	6	124 744.2
Variable costs			
-Water (N$/m^3)	7150	10	71 500
-Labour days			
-Watering days	75	30	2 250
-Weeding days	11	30	330
-Harvesting days	7	30	210
Total cost			74 290
Gross margin			50 454.2

The gross margin analysis for flood irrigation 60% ETo indicated that the drip irrigation system generated N$ 40 312.4/ha using the current prices of onions as per NAB gazetted prices NAB, (2015). The total variable costs amounted to N$ 67 090/ha (Table 16).

Table **15: Gross margin for flood irrigation at 60 ETo**

	Amount	Unit Cost / Price/kg (N$)	Total (N$)
Revenue (Yield / kg/ha)	17 900.4	6	107 402.4
Variable costs			
Water (N$/m^3)	6430	10	64 300
Labour days			
watering days	75	30	2 250
weeding days	11	30	330
harvesting days	7	30	210
Total cost			67 090
Gross margin			40 312.4

The gross margin analysis for flood irrigation 80% ETo indicated that the drip irrigation system generated N$ 21 994.2/ha using the current prices of onions as per NAB gazetted prices NAB, (2015). The total variable costs amounted to N$ 88 590/ha (Table 17).

Table **16: Gross margin for flood irrigation at 80 ETo**

	Amount	Unit Cost / Price/kg (N$)	Total (N$)
Revenue (Yield / kg/ha)	18 430.7	6	110 584.2
Variable costs			
-Water (N$/m^3)	8580	10	85 800
-Labour days			
-Watering days	75	30	2 250
-Weeding days	11	30	330
-Harvesting days	7	30	210
Total cost			88 590
Gross margin			21 994.2

The gross margin analysis for flood irrigation 100% ETo indicated that the drip irrigation system generated N$ 12 630.00/ha using the current prices of onions as per NAB gazetted prices NAB, (2015). The total variable costs amounted to N$ 105 990/ha (Table 18). Table 19 shows all the treatments in one.

Table **17: Gross margin for flood at 100 ETo**

	Amount	Unit Cost / Price/kg (N$)	Total (N$)
Revenue(Yield/ kg/ha)	19 770	6	118 620
Variable costs			
-Water (N$/m^3)	10320	10	103 200
Labour days			
-Watering days	75	30	2 250
-Weeding days	11	30	330
-Harvesting days	7	30	210
Total cost			105 990
Gross margin			12 630.00

The results showed that the gross margin for drip at 60% % ETo performed significantly higher than for 60% flood by 81%. This shows that drip performed better than flood.

Table **18: Total cost and gross margin for all treatments**

Treatment	Total cost (N$)	Gross margin (N$)
Drip 60 ETo	45 690	72 990.60
Drip 80 ETo	59 990	62 111.20
Drip 100 ETo	74 290	50 454.2
Flood 60 ETo	67 090	40 312.4
Flood 80 ETo	88 590	21 994.2
Flood 100 ETo	105 990	12 630.00

Table 20 shows the ANOVA for testing effect of irrigation type and level on Gross Margin. Gross margin is highly significantly different at all the three levels of irrigation (p =0.001) and also significantly different for the irrigation type (p = <.001)

Table **19: ANOVA for testing effect of irrigation type and level on gross margin**

Variate: Gross_Margin_

Source of variation	**D.F.**	**S.S.**	**M.S.**	**V.R.**	**F pr**.
Irrigation_Level	2	7.607E+09	3.803E+09		
Irrigation_type	1	6.794E+07	6.794E+07	5.826E+07	<.001
Irrigation_Level*.Irrigation_type	2	3.954E+08	1.977E+08	1.695E+08	<.001
Residual	12	1.400E+01	1.166E+00		
Total	17	8.070E+09			

The 60% levels for both flood and drip showed highest gross margin followed by 80% and lastly 100%. This is in line with Zimmermann (1999); Prajapati et al., (2013) who also reported that net profit under irrigated banana under drip irrigation resulted in higher net profit to the extent of 12 to 20 % realized over surface irrigation. The main advantages of drip irrigation compared to other methods as highlighted by Michael (2008) include, saving in water, reduced labor cost, higher crop yields, increased fertilizer use efficiency and reduced energy consumption. Kadigi *et al*., (2012) also highlighted that irrigation has the potential to enhance food security and economic growth and to achieve this, investment must be profiTable for the farmer. It’s also in line with Mc Gulkin *et al.*, (1987) changing from flood to drip irrigation can increase irrigation efficiency and irrigation water use efficiency and is economical for high value crop.

Sirvastava *et al*., (2003) did an investment decision model for drip irrigation system and reported that shifting of drip irrigation depends on many factors like cost of cultivation, electricity cost, productivity, yield gain factor and irrigation requirement. These parameters differ from place to place, crop to crop as well as farmers to farmers.

The gross margin analysis for drip irrigation at 60 % ETo indicated that the drip irrigation system generated N$ 72 990.60/ha using the current prices of onions as per NAB gazetted prices, whilst the gross margin analysis for flood irrigation 60 % ETo generated N$ 40 312.4/ha.

Gross margin for drip irrigation were significantly higher than for the flood irrigation at all levels of ETo. Farmers who can afford drip irrigation systems will earn higher margins with lower yield than farmers who would use drip and get higher yields. This is caused by cost of water which increases significantly from 60ETo to 100 % ETo. In the event that flood irrigation is chosen to be used then 60 % ETo flood level would be recommended.

When gross margin for drip and flood irrigation are compared at 80 % ETo, drip irrigation gross margin out performed flood irrigation by 182.4% which is almost 3 fold. Thus 80 % ETo irrigation has higher gross margin which can contribute to income as the cost of water is lower. More-over, at 100 % ETo, drip irrigation gross margin was 299% higher than flood irrigation gross margin which was four fold. This indicates that drip irrigation has higher returns than flood irrigation at any level of ETo as it uses less water resulting in demand costs as well.

Under flood irrigation, the 60 % ETo Gross margin was 219% higher than 100ET_o Gross margin which is more than 3 fold higher. Thus the higher the flood ETo the lower the returns as cost of water increases exponentially and although yield increases, the increase is much smaller than the cost increase and gross margin thus declines.

When 60 % ETo flood is compared to 80 % ETo flood, the gross margin increased by 83% from 80 % ETo to 60 % ETo. This shows that increasing ETo is not a viable option when irrigating either using drip or flood. Irrigation at 60 % ETo performed significantly higher in both treatments and this could be attributed to the cost of water that increases with increase in ETo.

The gross margin analysis for drip irrigation 100 % ETo indicated that the drip irrigation system generated N$ 50 454.2/ha using the current prices of onions as per NAB gazetted prices and the gross margin analysis for flood irrigation 100 ETo indicated that the drip irrigation system generated N$ 12 630.00/ha using the current prices of onions as per NAB gazetted prices. Overall all drip irrigation systems were better that flood on gross margin showing that farmers should choose drip over flood.

4.7 Summary

The results indicated that WUE is significantly different at all the three levels of irrigation (p =0.008) and also significantly different for the irrigation type (p = <.001). They also show that 60% ETo had a higher water use efficiency of 4.6 kg m^{-3}in drip irrigation compared to 2.8 kg

$m^{-3}$for the flood. At 80% level, water use efficiency of drip was 3.6 kg m^{-3}compared to 2.1 kg $m^{-3}$for flood. At 100% levels the water use efficiency was 2.9 kg $m^{-3}$for drip compared to 1.84 kg m^{-3} for flood irrigation method. The total volume of water used under drip irrigation system was less as compared to flood irrigation system by 32.3%. Results also show that there was saving of water in drip irrigation by a margin of 30.7% for the 100% levels, by 33.3% for the 80 % levels and 33.3 % also for the 60% levels.

However, plant height were not significantly different at all the three levels (p =0.397) of irrigation. Moreover, a higher growth rate was obtained in drip irrigation treatment by a margin of 28.36% for the 100% levels, by 3.65% for the 80 % levels and 22.38 % for the 60% levels.

Results also show that more yields were obtained in drip irrigation by a margin of 5% for the 100% levels, by 9.4% for the 80 % levels and 9.5 % for the 60% levels. In addition, the results showed that the gross margin for drip at 60 ETo was higher than for flood by 44.7% while at 80 ETo the gross margin for drip was more than for flood by 64.6%.

CHAPTER FIVE

5. CONCLUSIONS AND RECOMMENDATIONS

5.1. Introduction

This study was initiated with overall objectives of comparing the water use efficiency, yield, plant height and gross margins of different levels of drip and flood irrigation systems on onion production and to develop a best technical system for high onion yield for small scale farmers. The chapter concludes by summarizing on major findings of the study and possible recommendation based on findings of the study.

5.2. Conclusions

- Objective 1 was to compare at 3 different irrigation levels (100, 80, and 60% potential evapotranspiration (ETo)) the water use efficiency (also termed productivity of water) as well as the moisture content in the root zone of onion between flood and drip irrigation systems at Ogongo in Namibia. Results lead to the conclusion that levels of irrigation were more important than the two irrigation types. Levels were assessed in terms of % moisture values and were highest for drip irrigation compared to flood levels.
- Objective 2 was to compare the plant height and yield of onion under flood and drip irrigation systems at 3 levels of irrigation at Ogongo in Namibia. The results for the yield of onion in this study showed that the crop yield was higher under drip irrigated plots than flood.

- The third objective was to determine and compare the cost of growing onion under flood and drip irrigation at 3 levels of irrigation at Ogongo in Namibia. Again gross margins for drip irrigation at 100% ETo was 299% higher than flood irrigation. This indicates that drip irrigation has higher returns than flood irrigation at any level of ETo as it uses less water resulting in demand costs as well. On the other hand, increasing ETo is not a viable option when irrigating the onion crop whether by drip or flood as the cost of water will tend to increase with any increases in ETo.

5.3 Recommendations and Future Research Needs

- The agriculture sector is very important to the livelihood of the Namibian people. For the small scale farmers to flourish there is a need to upgrade the irrigation infrastructure to accommodate drip irrigation. Results show that progress should be made towards improving the water use efficiencies of drip and flood irrigation systems as well as yield. The management of water in Omusati region is crucial at all levels.
- Flood irrigation system should be phased out in a country like Namibia because the system uses large volumes of water and makes it difficult for farmers to pay their bills. It is also advisable that small scale farmers should make use of the system that is most efficient and which will save water and increase yield. Countries that adopted drip irrigation technologies are those that suffered most of the water scarcity and poor water quality. In this case, Namibia is an example of a country with water shortage. The government of Namibia should encourage small scale farmers to adopt drip irrigation system for them to produce quality and high yield products.

- Drip irrigation has proved to save water, improved water use efficiencies as compared to flood irrigation system which is wasting a lot of water. In drip irrigation water can be controlled while fertilizer can also be easily applied and weed growth can also be reduced. It is hereby recommended that in order for drip irrigation to become more profiTable than other irrigation systems, the cost of watering with agricultural input must be less than the total income.

The recommended future research along similar lines are:

• To test the drip irrigation system for producing other vegeTable crops.

• Promotion of drip irrigation system among growers and stakeholders through demonstration and extension services.

• To develop the best management guidelines for different vegeTables crops.

• Designing and installing different types of a family drip system for some high value crops.

To compare the Leaf Area Index of onions under flood and drip irrigation systems at 3 levels of irrigation at Ogongo or elsewhere in Namibia

REFERENCES

Adeniran, K.A., Amodu, M.F., Amodu, M.O., &. Adeniji, F.A. (2010). Water requirements of some selected crops in Kampe dam irrigation project. *Australian Journal of Agricultural* Engineering. Retrieved September, 2017 at the University of Namibia. Ogongo Campus from: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.623.6363&rep=rep1&type=pdf).

Agrawal, N., & Agrawal, S. (2007). Effect of different levels of drip irrigation on the growth and yield of pomegranate under Chhattisgarh Region. Orissa. J. *Hort. 35:38-46.*

AGRI Views, (2010).Newsletter Edition 1. Ministry of Agriculture, Water and Forestry Retrieved on 1st May 2013 from: http://www.mawf.gov.na/Documents/AgriViews_Newsletter_new.pdf.

AGRIBUSDEV, (2015). Strategic Business and Financial Plan 2015 – 2019.

Ahmad, H.K. (1990). Studies on biological intercrop relationship and water use technique in wheat. Ph.D. Thesis, Dept. Agron. Univ. Agric. Faisalabad. pp. 64-65.

Ahmadi, S.H., Andersen, M.N., Plauborg, F., Poulsen, R.T., Jensen, C.R., Sepaskhah, A.R. & Hansen. S. (2010). Effects of irrigation strategies and soils on field grown potatoes: Yield and water productivity. *Agricultural Water Management 97: 1923- 1930.*

Allen, R.G., Pereira, L.S., Raes, D., & Smith, M. (1998).Crop evapotranspiration: guidelines for computing crop requirements. FAO: Irrigation and Drainage Paper 56. FAO, Rome, 1998.

Al-Omran, A. M., Sheta, A.S., Falatah, A. M., & Al-Harbi, A. R. (2005). Effect of drip irrigation on squash (Cucurbita pepo) yield and water-use efficiency in sandy calcareous soils amended with clay deposits. *Agricultural Water Management. (73) 43-55.*

Ashwini, M., & Sathishkumar, R. (2014).Onion (Allium cepa) –Ethno medicinal and therapeutic properties. Editor: Nidhi Gupta. Handbook of Medicinal Plants and their Bioactive Compounds, 2014: 27-34. ISBN: 978-81-308-0548-1.

Ashok, P., Sasikala, K., & Pal, N. (2013). Growth Analysis on Onions (*Allium Cepa L*), *International Journal of Farm Sciences, Vol 3, pp 30-46.*

Aujla, M.S., Thind, H. S., & Buttar, G. S. (2007). Fruit yield and water use efficiency of eggplant (Solanum melongema L.) as influenced by different quantities of nitrogen and water applied through drip and furrow irrigation. *Scientia Horticulturae. (112): 142–148.*

Bajracharya, R., & Sharma, S. (2005).Influence of drip irrigation method on performance and yield of cucumber and tomato. *Kathmandu University J. Engineering and Technology, 1; 1-7.*

Yohannes, F., & Tadesse, T. (1998). Agricultural Water Management, 1998, vol. 35, issue 3, 201-207

Basal, H., N. Dagdelen, N., Unay, A., & Yilmaz, E. (2009). Effects of deficit drip irrigation ratios on Cotton (Gossypium hirsutum L.) Yield and Fibre Quality. Journal of *Agronomy and Crop Science. (195):19-29.*

Bharambe, P.R., Shelke, O.K., Oza, S.R., & Vaishanava, V.G. (2002). Effect of irrigation levels .on spatial moisture distribution, soil-plant-water relations and water use efficiency of .cotton under drip irrigation. *Journal of the Indian Society of Soil Science 50: 303-305.*

Batchelor, C.H., Lovell, C., & Murata, M. (1996).Simple micro irrigation techniques for improving irrigation efficiency on vegeTable gardens. *Agricultural Water Management 32, 37-48.*

Bilal, H., (2009). Need for drip irrigation DAWN.COM. Retrieved on February 24, 2018 at the University of Namibia. Ogongo Campus from: http://archives.dawn.com/archives/153763.

Bogle, C.R., Hartz, T.K., & Nunez, C. (1989). Comparison of subsurface trickle and furrow irrigation on plastic mulched and bare soil for *Horticulture Science, 114(1): 40-43.*

Brewster, J.L. (1994) Onion and other vegeTable Alliums. CABI, Wallingford, Oxom, UK.

Brouwer, C., Prins, K., & Heibloem, M. (1989).Irrigation Water Management: Irrigation Scheduling Training manual no. 4, a manual prepared jointly for FAO - Food and Agriculture Organization of the United Nations © FAO 1989. Retrieved February 24, 2016 at the University of Namibia. Ogongo Campus from: http://www.fao.org/docrep/t7202e/t7202e08.htm.

Brouwer, C., Prins, K., Kay, M., & Heibloem, M. (2001).Irrigation Water Management: Irrigation Methods. Training manual no5.Provisional edition. A manual prepared jointly for FAO - Food and Agriculture Organization of the United Nations (2001). Retrieved on 1st May 2013 at the University of Namibia. Ogongo Campus from: http://www.fao.org/docrep/s8684e/s8684e06.htm.

Burt, C.M. & Styles, W.S. (1994).Drip and micro irrigation for trees, vines and row crops. Irrigation Training and Research Centre, California State University, California.

Camp, C.R., Garrett, J. T., Sadler, E. J., & Busscher, W.J. (1993). Micro irrigation management for double –cropped vegeTable in a humid area. *Transactions of the ASAE 36(6): pp. 1639-1644.*

Caprivi Freedom- News, (2001). Kalimbeza Rice Project needs Govt injection. http://www.caprivifreedom.com/news.i?cmd=view&nid=1137

Caswell, M.F., & Zilberman D. (1985). The Choices of Irrigation Technologies in California. *American Journal of Agricultural Economics 67(2): 223–234.*

Christelis, G., & Struckmeier, W. (2001). Groundwater in Namibia an explanation to the Hydrogeological Map. Prepared by Germany technical Cooperation project of the Department of Water Affairs, Ministry of Agriculture, Water and Rural Development; the Geological Survey of Namibia, Ministry of Mines and Energy, the Namibia Water Cooperation and the Federal Institute for Geoscience and Natural Resources on behalf of the Germany Ministry of Economic Cooperation and Development.

Clemens, A.J., & Solomon K.H. (1997). Estimation of global irrigation distribution uniformity. J. *Irrigation Drainage Eng. 123(6) pp. 454-461.*

Cohen, J. (1988). Statistical power analysis for the behavioral sciences (2nd ed.).Hillsdale, NJ: Lawrence Earlbaum Associates.

Collaizzi, P. D., Lamm, F.R., Howell, T.A., & Evett, S.R. (2006). Crop production comparison under various irrigation systems. IN: Proc. Central Plain Irrigation Conference, Colby, KS, Feb. 21-22.Available from CPLA, 760N. Thompson Colby, KS.pp.189-207.

Dagdelen, N., Basal, H., Yılmaz, E., Gurbuz, T., & Akcay, S. (2009). Different drip irrigation regimes affect cotton yield, water use efficiency and fiber quality in western Turkey. *Agricultural Water Management. (96): 111-120*.

Dastorani, M.T., Heshmati, M., & Sadeghzadeh, M.A. (2010). Evaluation of the Efficiency Of surface and subsurface irrigation dryland environments. *Irrigation and Drainage, 59, 129-137.*

De Lange, M. (2006). Experiences with Micro Agricultural Water Management Technologies: Namibia. Report submitted to the International Water Management Institute (IWMI)

Southern Africa Sub-regional Office, Pretoria, South Africa January 2006. An input to the Study on Agricultural Water Management Technologies for Small Scale Farmers in Southern Africa: An Inventory and Assessment of Experiences.

De Pascale, S., Dalla Costa, L., Vallone, S., Barbieri, G., & Maggio, A. (2011). Increasing water use efficiency in vegeTable crop production: from plant to irrigation systems efficiency. *Hort. Technology, 21(3), 301-308.*

Elfvig, D.C. (1982). Crop response to trickle irrigation Horticulture Reviews (pp.1-48): John Wiley& Sons, Inc.

El-Boraie, F.M., Abo-El-Ela, H. K., & Gaber, A. M. (2009). Water requirements of peanut grown in sandy soil under drip irrigation and Bio fertilization. *Australian Journal of Basic and Applied Sciences. 3(1): 55-65.*

Ellis, J., E. Kruse, A. McSay, C. N., & Horn, R. (1986). A comparison of five irrigation methods on Onions. *Hort. Sci. 21(6):1349-1351*.

Elobeid, A.M. (2006). Hydraulic aspects on the design and performance of drip irrigation system, M.Sc. Thesis, University of Khartoum, Khartoum Sudan.

Emongor, R., & Kirsten, J (2009). The impact of South African supermarkets on agricultural development in the SADC: A case study in Zambia, Namibia and Botswana.

Enchalew, B., Gebre S.L., Rabo, M., Hindaye, B., & Kedir, M. (2016). Effect of Deficit Irrigation on Water Productivity of Onion (Allium cepa.) under Drip Irrigation. *Irrigation Drainage System Eng 5: 172*. doi: 10.4172/2168-9768.1000172.

Enciso, J. Jifon, J., Anciso, J., & Ribera, L. (2012). Productivity of Onions Using Subsurface Drip Irrigation versus Furrow Irrigation Systems with an Internet Based Irrigation Scheduling Program. International Scholarly Research Network. ISRN Agronomy. Volume 2012, Article ID 562315, 8 pages. doi:10.5402/2012/562315.

Eviatar, I.T., & Offenbach, R. (September, 2003)**.** Onion lecture*.* Course offered to Ogongo lecturers at Ogongo Campus. Oshakati, Namibia.

Evans, Robert G., & Sadler, John E. (2008). Methods and technologies to improve efficiency of water use. Water Resources Research, 44.

FAO, (1999). Crop Evapotranspiration, FAO *Irrigation and Drainage Paper No. 56*, Food and Agriculture Organization of the United Nations (FAO), Rome, 1999.

FAO, (2005). Aquastat Namibia: Regional report: Water Report 29, 2005. Retrieved from 11 June 2016.

FAO, 2001. Lecture notes on the major soils of the world. In Driessen, P., Deckers, J., Nachtergaele, F., eds., World Soil Resources Reports #94, Rome: FAO.

FAO, (2005). Country Fact Sheet- Namibia. Available at http://www.fao.org/nr/aquastat. Accessed on 10 May 2017.

FAO. (2006). World reference base for soil resources: Framework for International classification, correlation, and communication. Rome: Food and Agriculture Organization of the United Nations. 128 pp.

FAO, (2014). The State of Food Insecurity in the World. Retrieved from http://www.fao.org/3/a-i4030e.pdf on…..

Gijón, M.C., Guerrero, J., Couceiro, J.F., & Moriana, A. (2007). Deficit irrigation without reducing yield or nut splitting in pistachio. *Agricultural Water Management, 96 p. 12-22.*

Government of the Republic of Namibia, Ministry of Agriculture, Water and Forestry (2008): Green Scheme Policy. Windhoek.

Fereres, E., & Soriano, M.A. (2007). Deficit irrigation for reducing agricultural water use. *Journal of Experimental Botany 58: 147-159.*

Fiebiger, M. (2002): Evaluation of Crop Cultivation Potentials at the Brim of Rain Fed Agriculture by Means of an Agro-Ecological Crop-Simulation Model. A Method and its Application at the Example of the Central and Western Omusati Region, North-Central Namibia. University of Trier. Trier.

Fiebiger, M., Behmanesh, S., Dreuβe, M., Huhn, N., Schnabel, S., Weber, A.K., Diez, G., Hamutenya, L., Kanyangela, S., & Kaufilua, L. (2010). The Small scale- irrigation farming sector in the communal areas of Northern Namibia: An Assessment of constraints and potential. SLE Publication Series – S 242. SLE – Postgraduate Studies on International Cooperation. Study commissioned by Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) and Kreditanstalt für Wiederaufbau (KfW) Entwicklungsbank. In cooperation with the Polytechnic of Namibia: Gomiz Diez, Latoya Hamutenya, Sergius Kanyangela, Linda Kaufilua. Windhoek/Berlin, December 2010. Distribution SLE. Hessische Str. 1-2, 10115 Berlin. 1. Edition 2010 1-200. Copyright 2010 by SLE. ISSN 1433-4585. ISBN 3-936602-46-8.

Gencoglan, C., Altunbey, H., & Gencoglan, S. (2006).Response of green bean to subsurface drip irrigation and partial root-zone drying irrigation. *Agric.Water Manag. 84: 274-280.*

Haidula, S. (2016). Irrigation water use and vegeTable production efficiency assessment between sprinkler and drip irrigation systems at North Central Namibia (NCN) (Study on three vegeTable crops: tomato, cabbage, and pepper. Master thesis Master in Sustainable Agriculture. Faculty of Applied Ecology and Agricultural Sciences. Headmark University of Applies Sciences. Blæstad, Norway.

Hansen, B.R., Schwanki, L.J. Schulbach, K.F., & Pettygrove, G.S. (1997). A comparison of furrow, surface drip and subsurface drip irrigation on lettuce yield and applied water. *Agricultural Water Management 33, 139-157.*

Hanson, B., Schwakl, L., Schulbach, K., & Pettygrove, G. (1997). A comparison of furrow, surface and drip and subsurface drip irrigation on lettuce yield and applied water. Agric.*Water Manag. J. 33: 139-157.*

Hanson, B.R., & May, D.M. (2006). Crop coefficients for drip irrigated processing tomato. *Agricultural Water Management, 81: 381-399.*

Hatibu, N., & Mahoo, H, F. (2000). Rainwater harvesting for natural resources management: a planning guide for Tanzania. RELMA Technical Paper No. 22.

Hillel, D. (2004). Introduction to Soil Environmental Physics, University of Massachusetts, Elsevier Academic press, New York.

Heady, F.H. (1957). The measurement and value of plant height in the study of herbaceous vegetation, *Ecology, Vol.38 pp 313-320*

Holzapfell, E. A., Pannunzio, A., Lorite, I, Silva de Oliveira A. S., & Farkas, I. (2009).*Chilean Journal of Agricultural Research 69 (suppl. 1):17-25* (December 2009).

Huang, Z., QI, X., Fan, X., Hu, C., Zhu, D., Li, P., & Qiao, D. (2010). Effects of alternate partial root-zone subsurface drip irrigation on potato yield and water use efficiency. *Ying Yong Sheng Tai Xue Bao. 21: 79-83.*

Hugo, L. (2009). Report on irrigation activities along the Olushandja dam and the possibility of improving water supply for irrigation, Windhoek. (FAO, 2005).

http://www.mawf.gov.na/etunda. Retrieved February 24, 2018 at the University of Namibia. Ogongo Campus.

Hutmacher, R.B., Ayars J.E., Vail S.S., Bravo A.D., Dettinger D., & Schoneman, R.A. (1996). Uptake of shallow groundwater by cotton: growth stage, groundwater salinity effects in column lysimeters. *Agricultural Water Management 31: 205–223.*

Ibragimov, N., Evett, S.R. Esanbekov, Y., Kamilov, B.S., Mirzaev, L., & Lamers, J.P.A. (2007). "Water Use Efficiency of Irrigated Cotton in Uzbekistan under Drip and Furrow Irrigation", Agricultural *Water Management, Vol. 90, No.1/2, pp. 335-238*.

IWRM, (2010). Integrated Water Resources Management Plan for Namibia Prepared for: Ministry of Agriculture, Water and Forestry in August 2010 by IWRM Plan Joint Venture Namibia and funded by: African Water Facility.

Jacobs, C. (2009). Horticultural sector makes significant achievements. The Namibia Economist. Friday 14 August 2009. 8:48. http://www.economist.com.na/index.php. Retrieved February 24, 2011 at the University of Namibia. Ogongo Campus.

Kadigi, M.J., Tesfay, G., Bizoza, A., & Zinabou, G. (2012). (2012) Agriculture Policy Series. Briefing Paper Number 4 | (2012). Briefing Paper Number 4 Irrigation and water use efficiency in Sub-Saharan Africa. GDN Agriculture Policy Series. New Delhi | Cairo | Washington DC. www.gdn.int.

Khalid, M. M. (1999). A Comparison study between drip and furrow irrigation system for producing okra. (Hibiscus Esculentus). Msc. (Agric.). Thesis, University of Khartoun, Sudan.

Karam, F., Mounzer, O., Sarkis, F., & Lahoud, R. (2002). Yield and nitrogen recovery of lettuce under different irrigation regimes. *Journal of Applied Horticulture. 4(2):70-76.*

Karasu, A., Kuşcu, H, Öz. M., & Bayram, G. (2015). The Effect of Different Irrigation Water Levels on Grain Yield, Yield Components and Some Quality Parameters of Silage Maize (Zea mays indentata Sturt.) in Marmara Region of Turkey Karasu A et al. / Not Bot Horti Agrobo, 2015, 43(1):138-145.

Kumar, B. (2010). Indian Horticulture Database-2009, National Horticulture Board, Ministry of Agriculture, Govt. of India, Guragaon, pp. 267.

Kumar, S., Imtiyaz, M., Kumar, A., & Singh, R. (2007).Response of onion (Allium cepa L.) to different levels of irrigation water," *Agricultural Water Management, vol. 89, no. 1-2, pp. 161–166, 2007.*

Letey, J., Vaux, H.J., & Feinerman, N. (1984). Optimum crop water applications as affected by uniformity of water infiltration. *Agron. J. 76: pp.435-441*.

Letey, (1985). Irrigation uniformity as related to optimum crop production-Additional research needed. Irrigation Sci. (6) pp. 253-263.

Lincoln Environmental (LE). (2005).Irrigation in the Ida Valley– 2002/2004. Investigation, Report No 4590/1, prepared for the Ida Valley Irrigation Focus Group, Lincoln Environmental, a division of Lincoln Ventures Ltd.

Liao, L., .Zhang, L., & Bengtsson, L. (2008).Soil moisture variation and water consumption of spring wheat and their effects on crop yield under drip irrigation. *Irrigation Drainage System 22:253-270.*

Mahmoud, Husam. H. (2006). Studies on the effect of fertigation, water requirement and plant density on yield and quality of banana cv. Grand Naine (Musa AAA) Ph.D. (Agric). Thesis, Department of Horticulture, Post graduate institute, Mahatma Phule Krishi Vidyapeeth, Rahuri-413722, Dist. Ahmednagar Maharashtra, India.

Malakouti, M.J. (2004). The Iranian experiences in fertigation and use of Potash fertilizers. IPI regional workshop on Potassium and Fertigation development in West Asia and North Africa. Rabat. Morocco.

Malash, N. M., Flowers, T.J, & Ragab, R. (2008). Effect of irrigation methods, Management and Salinity of irrigation water on tomato yield, Soil Moisture and salinity distribution. *Irrig. Sci.26: 313-323.*

Maisiri, N., A. Senzanje, Rockstrom, J., & Twomlow, S.J. (2005).On farm evaluation of the effect of low cost drip irrigation on water and crop productivity compared to conventional surface irrigation system. *Phys. Chem. Earth 30:783-791.*

McIndoe, I. (2000). Irrigation Efficiency Enhancement- Stage 1.Report No 4452/16a, prepared for Land wise Hawke's Bay, Lincoln Environmental, a division of Lincoln Ventures Ltd.

McIndoe, I. (2002). Efficient Irrigation. Report No 4521/1 Prepared for Environment Canterbury, Lincoln Environmental, a division of Lincoln Ventures Ltd.

Mendelsohn J., Shixwameni, L., & Nakamhela, U. (2011).An overview of communal land tenure in Namibia: Unlocking its economic potential. Windhoek: RAISON, 2011.

Mendelsohn, J.M. (2008). Customary and legislative aspects of land registration and management on communal land in Namibia. Report for Ministry of Lands & Resettlement, Windhoek.

Mendelsohn, J. (2006). Farming Systems in Namibia, Windhoek, RAISON (Research & Information Services of Namibia).

Mendelsohn, J. Jaris, A., & T. Robertson (2013). A profile and Atlas of the Cuvelai Etosha Basin, John Meinert Printing, Windhoek.

Mendelsohn, J., Jarvis, A., Roberts, C. (2002). Atlas of Namibia. A Portrait of the Land and Its People. Cape Town, New Africa Books (Pty) Ltd.

Mendelsohn, J., Jarvis, A., Roberts, C. & Robertson, T., (2002). Atlas of Namibia. David Phillips Publishers, Cape Town.

Mendelsohn, J.; El Obeid, S., & Roberts, C. (2000). A profile of north-central Namibia. Gamsberg Macmillan Publishers for the Directorate of Environmental Affairs, Namibia.

Mendelsohn, R., Schlesinger, M., & Williams, L. (2000b)."Comparing Impacts Across Climate Models" Integrated Assessment, 1:37-48.

Mendelsohn, R., Morrison, W., Schlesinger, M., & Adronova, N. (2000a). "Country Specific Market Impacts from Climate Change", Climatic Change 45: 553-569.

MET. (2011). Namibia Second National Communication to the United Nations Framework Convention on Climate Change. Windhoek: Ministry of Environment and Tourism.

Michael, A.M. (2008). Irrigation: Theory and Practice, 2nd ed.; Vikas Publishing House PVT. Ltd: Delhi, India, 2008; p. 768.

Muhammad, D., Raza, I., Ahmad, S., Afzal, M.N., & Mian, M.A. (2006). Efficiency of Drip vs furrow irrigation system with variable plant density on cotton under southern Punjab climatic conditions. J. SCI. Agric. (Piracicaba, Braz.), 63 (3): 226-231.

NAB, (2015) *ANNUAL REPORT No. 28 -2014/2015*

Nagaz, K, Masmoudi, M. M., & Mechlia, N. (2012). International Scholarly Research Network, *ISRN Agronomy. Volume 2012, Article ID 562315, 8 pages*. doi:10.5402/2012/562315.

Nagaz, K., Toumi, I., Masmoudi, M., & Mechlia, N. (2008). Comparative effects of drip and furrow irrigation with saline water on the yield and water use efficiency of potato in arid conditions in *Tunisia. Agric. J. 3(4):272-277*.

Namibia Statistics Agency. (2012). Namibia Household Income & Expenditure Survey (NHIES). 2009/2010. Namibia Statistics Agency. Windhoek.

Namibia Vision 2030, (2003).Policy framework for long term National Development, second draft, April2003.

Namibian Agronomic Board (NAB), (2008). *NAB Annual Report, No 21.*

Namibian Agronomic Board (NAB), (2012). *NAB Annual Report, No 25.*

Narayanamoorthy, A. (2003). Averting water crisis by drip method of irrigation: A study of two water intensive crops. *Indian Journal of Agricultural Economics. 58(3): 427-437.*

Ndeutapo, P T., & Shivute. A N. (2003). Omusati region baseline survey of the impact of Agricultural Extension Services. Directorate of Extension and Engineering Services. Outie, October 2003. Republic of Namibia. Ministry of Agriculture, Water and Rural Development

NDP5, Namibia's 5th National Development Plan (2017/18 – 2021/22). Working together towards prosperity. *National Development Plan 5 (NDP5) also (NDO5) (2017/18 - 2021/22).*

NETAFIM, (2017). http://www.netafimusa.com/agriculture/crop-applications/subsurface-drip-irrigation-resource-center/. Retrieved on February 24, 2018 at the University of Namibia. Ogongo Campus

New Era, 18 August, (2010). Eat more local fruit and veggies-NAB. http:// allafrica.com/stories/201008190305;html. Retrieved February 24, 2011 at the University of Namibia, Ogongo Campus.

(New Era, 2015). Potato Onion Scheme Gaining Momentum. Retrieved February 24, 2018 at the University of Namibia. Ogongo Campus from:

https://neweralive.na/2015/02/24/potato-onion-scheme-gaining-momentum/.

Ngouajio, M., Wang, G., & Goldy, R. (2007). Withholding of drip irrigation between transplanting and flowering increases the yield of field-grown tomato under plastic mulch. *Agricultural Water Management 87:285-291.*

Niipele, J. N., & Klintenberg, P. (2006). Assessing abundance of surface water and biomass in the Cuvelai Etosha basin, central northern Namibia using Landsat TM and AATSR data. The Desert Research Foundation of Namibia, Windhoek, Namibia at http://www.drfn.org.na/TM%20vs%20AATSR.pdf. (18/02/2008).

NPC, (2004). Namibia Vision 2030 Policy framework for long –term National development, second draft, April 2003.

NPC, (2004). Namibia Vision 2030 Policy framework for long –term National development, second draft, April 2003.

NPC, (2008). NDP3, Republic of Namibia. Third national development plan. (NDP3)2007/2008 - 2011/2012.Volume I. Executive Summary. National Planning Commission. Windhoek 2008. ISBN: 978-0-86976-778-8. EAN: 9780869767788

NPC, (2008) NDP3, Republic of Namibia. Third national development plan (NDP3)2007/2008 - 2011/2012.Volume I. Executive Summary. National Planning Commission. Windhoek 2008. ISBN: 978-0-86976-778-8. EAN: 9780869767788.

NPC, (2017).National Planning Commission in partnership with the United Nations (UN) System in Namibia hosted the 2017 Development Partners (DP's) on the Fifth National Development Plan (NDP5) Implementation Plan.

NPC, (2012). National Planning Commission (NPC) (2012). Republic of Namibia Namibia's Fourth National Development Plan 2012/13 to 2016/17.

NSA, (2015). GROSS DOMESTIC PRODUCT; SECOND QUARTER 2015. Retrieved from http://cms.my.na/assets/documents/GDP_Second_Quarter_20151.pdf on 21st May 2017.

Nisar, A. M. (1995). Comparative study of trickle and furrow irrigation methods on growth and water use efficiency of mango orchard. *Mehran University Research Journal, 15 (2): 243-48.*

Ogunmokun, A. A., & Kanyomeka, L. (2003). Evaluation of pumping units for small-scale irrigation farmers in the communal areas of Namibia. Report prepared by Department of Crop Science, University of Namibia, for the Namibian Agronomic Board (NAB) and the National Horticultural Development Initiative (NHDI).June 2003.

Oktem, A., Simsek, M., & Oktem, A. G. (2003). Deficit irrigation effects on sweet corn (Zea mays saccharata Sturt) with drip irrigation system in a semi-arid region: I. Water-yield relationship. *Agricultural water management, 61(1), 63-74.*

Olalla, F.S., Padilla, A.D., & Lopez, R. (2004). Production and quality of the onion crop (Allium cepa L.) cultivated under controlled deficit irrigation conditions in a semi-arid climate. *Agric. Water Mgmt., 68: 77-89.*

Polak, P., & Yoder, R. (2006). Creating wealth from groundwater for dollar-a-day farmers: Where the silent revolution and the four revolutions to end rural poverty meet. *Hydrogeology Journal 14: 424−432.*

Postel, S., Polak, P., Gonzales, F., & Keller, J. (2001). Drip Irrigation for Small Farmers A New Initiative to Alleviate Hunger and Poverty. *International Water Resources Association. Water International, Volume 26, Number 1, Pages 3–13,* March 2001.

Prajapati, G, Khasiya R. B., & Agnihotri, P. G. (2013). A Comparative Studies between Drip Irrigation and Furrow Irrigation for Sugarcane and Banana in a Region Navsari. *Global Research Analysis International, vol 2:141-144*

Price Waterhouse Coopers, (2005). Irrigation in Namibia: Green Scheme and Horticulture Initiative for Namibia cost-benefit analysis. Price Waterhouse Coopers. Windhoek.

Quezada, C., Fischer, S., Campos, J., & Ardiles, D. (2006). Water Requirements and Water Use Efficiency of Carrot under Drip Irrigation in a Haploxer and Soil.

Raina, A.N., Thakur, B.C., & Bhournal, A. R. (1998). Effect of drip irrigation and plastic mulch on yield, water use efficiency and benefit cost ratio of pea cultivation. *Journal of Indian Society of Soil Science, 46(4): 562-567.*

Ramalan, A. A., Nega, H., & Oyebode, M. A. (2010). Sustainable Irrigation Management, Technologies and Policies IIIWIT Transactions on Ecology and the Environment, Vol 134, ©2010 WIT Press www.witpress.com, ISSN 1743-3541 (on-line). doi: 10.2495/SI100041

Rashid, A. (1992). Effect of irrigation levels and tillage practices on crop and soil parameters Msc. Thesis Dept. Agric. Eng. Univ. Agric. Faisalabas, pp 53-60.

Sakellariou, M., Kalfountzos, D., & Vyrlans, P. (2002). Water saving and yield increase of sugar beet with subsurface drip irrigation, Global Nest: the Int. J. 4(2-3):85-91.

Salokhea, H., Babel, M. S., & Tantauc, H. J. (2005). Water requirement of drip irrigated tomatoes grown in greenhouse in tropical environment. Agric. *Water Manage. 71, 225–242.*

Salvin, S., Baruah, K., & Bordoloi, S. K. (2000). Drip irrigation studies in banana cv. Barjahaji (Musa AAA group, Cavendish sub- group). *Crop Res. (Hissar). 20(3): 489-493.*

Sammis, T. W. (1980). Comparison of sprinkler, trickle subsurface and furrow irrigation methods for row crops. *Agronomy Journal. (72): 701-704.*

Sammis T.W. (1981). *Yield of alfalfa and cotton as influenced by irrigation. Agron. J. 73: 323-329.*

Sharmasarkar, F., Sharmasarkar, S., Miller, S. D., Vance, G. F., & Zhang, R. (2001). Assessment of drip and flood irrigation on water and fertilizer use efficiency for sugar beets. *Agricultural Water Management. (46): 241-251.*

Sirvastana, R.C., Verma, H.C., Mohanty, S., & Pattnaik, S. K., (2003). Investment decision model for drip irrigation system. *Irrigation Science, 22(2): 79-85.*

Shifeta, P. (2015). Statement by Minister of Environment and Tourism, Hon. Pohamba Shifeta On behalf of His Excellency, President of the Republic of Namibia, Dr. Hage Geingob. On the occasion of the world day to combat desertification. Global observance event. “No such thing as a free lunch – Invest in healthy soils” Wednesday 17th June 2015 Conference Center, Expo Milano, Italy.

Srinivas, K. & Hegde, D. M. (1990). Drip irrigation studies in banana. Proceeding of the 11th international congress. New Delhi. Page. 151- 157.

Solomon, K.H. (1983). Irrigation uniformity and Yield Theory. Ph.D. Thesis, Utah State University, Utah State University. Logan, USA.

Solomon, K. H. (1984). Yield related interpretations of irrigation uniformity and efficiency measures Irrigation uniformity and efficiency measures. *Irrigation Sci. (5) pp.161-172.*

Solomon, K.H. (1990). Sprinkler irrigation uniformity [Internet] Centre for Irrigation Technology, California State University, Fresno. USA.

Soomro, A., Mirjat, M.S., Soomro, H., & Bukhari, K.H. (1999). Effect of different irrigation frequencies on water use efficiency growth and cotton yield. *Pakistan Journal of Agricultural Engineering and Veterinary Sciences, 15 (2): 33-37.*

Soussa, H. (2010). Effect of drip irrigation water amount on crop yield, productivity and efficiency of water use in desert region of Egypt. *Nile Basin Water and Science and Engineering J., 3(2): 96-109.*

Stewart, W.M. (2001). Balanced Fertilization Increases Water Use Efficiency. In News and Views. A regional newsletter published by the Potash & Phosphate Institute (PPI) and the Potash & Phosphate Institute of Canada (PPIC).

Tagar, A., Chandio, F. A., Mari, I. A., & Wagan. B. (2012). Comparative Study of Drip and Furrow Irrigation Methods at Farmer's Field in Umarkot. *World Academy of Science, Engineering and Technology Vol: 6* pg 765=789.

Teferi, G.M. (2015). Effects of deficit irrigation on water productivity and yield of drip-irrigated onion (Allium cepa L.) in central Tigray, Northern Ethiopia. MSc. Thesis. Department of Irrigation Engineering, Haramaya University, Haramaya, Ethiopia.

Tolk, J. A., & Howell, T. A, (2002).*Water use efficiencies of grain sorghum grown in three USA southern Great Plain soils.* USDA-ARS, Conservation and Production Research Laboratory.

UNAM, (2017). http://www.unam.edu.na/ogongo-campus

Van der Merwe B, editor. (1999). IUCN report on Water Demand Management country study for Namibia. Ministry of Agriculture, Water and Rural Development Department of Water Affairs Directorate of Resource Management and City Engineer (Water Services) City of Windhoek.

Van der Merwe, F.P. J. (2008). *A method of evaluating and irrigation water use in terms of "Efficient, Sustainable and Beneficial of water in the Public interest*. A thesis submitted in partial fulfillment of the requirements for the degree Master of Engineering (Water

Resources Engineering) in the Faculty of Engineering. University of Pretoria. February 2008.

Vaughn, E. H., Israelsen, O. W., & Stringham, G E. (1980). Irrigation principles and practices. - 4th ed. New York; Chichester: Wiley, 1980.

Vigne P., & Whiteside, M. (1997). Encouraging sustainable smallholder agriculture in Namibia, Agric Services reform in Southern Africa. Phase 2 Report.

Namibia, Water Resources Management Act, (2004). Government of Namibia. Government Gazette of Namibia No. 3357 of 23 December 2004, pp. 1-67.

Watanabe, Y., Itanna, F., Fujioka, Y., Petrus, A., & Iijima, M. (2016). Characteristics of soils under seasonally flooded wetlands (oshanas) in north-central Namibia. *Afr. J. Agric. Res. 11(46):4786-4795.*

Walker, W.R. (2003). Surface irrigation simulation evaluation and design. Guide and technical Documentation. Biological and Irrigation Engineering. Utah State University.

Werner, W. (2009). Controlling access water and land: De jure and de facto powers of Water Point Committees. Werner, Wolfgang, (2009): CuveWaters Papers, No. 5.

Windhoek Consulting Engineers, (WCE). (2000). Analysis of Present and Future Water Demand in Namibia. http://www.fao.org/docrep/t7202e/t7202e08.htm.

World Atlas, (2018). Which Countries Border South Africa? https://www.worldatlas.com/articles/what-countries-border-south-africa.html. Retrieved on 24th February 2018.

World Bank. (2009). Namibia: Country Brief. World Bank. © World Bank. https://openknowledge.worldbank.org/handle/10986/2630 License: CC BY 3.0 IGO.

WWC, (2010-2016). Average Weather and Climate in Namibia. Retrieved from https://weather-and-climate.com/average-monthly-Rainfall-Temperature-Sunshine-in-Namibia.

Wu, P., Gitlin, H.M., Solomon, K.H., & Saruwatari, C.A. (1986). Design principles Trickle irrigation for crop production. Eds. Nakayama, F.S.M and Bucks, D.A. *Elsevier, pp.53-92.*

Yang, X., Cheng, F., Gong F., & Song, D. (2000). Physiological and ecological characteristics of winter wheat under sprinkler irrigation condition. *Transactions of Chinese Society Agricultural Engineering, 16(3): 35-37.*

Zimmermann, I. (1999). An evaluation trial of four small scale irrigation methods for Lucerne. *Paper presented at the National Annual Agricultural Research Reporting and Planning Conference 6-10 Sept 1999.*

APPENDICES

Appendix 1: Experimental plot at Ogongo Campus

Appendix 2: Layout of the field at Ogongo

Appendix 3: The family Drip system used in the project at Ogongo Campus

Appendix 4: the Family Drip system used in the project at Ogongo Campus