Faculty of Applied Ecology and Agricultural Sciences

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# Master thesis

# 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 in Sustainable Agriculture

2016

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# Abstract

Irrigated agriculture plays a major role in food security, producing nearly 40 percent (%) of food and agricultural commodities. It uses more than 80% of the water withdrawn from the earth's rivers. This increased pressure to water as a valuable resource in agricultural food production which remains finite due to the competition of current and future events namely; rapid increase in world population, climatic change, agricultural and industrial sector activities. In order to conserve and able to produce food continuously; an efficient water use and crop yield improving agricultural practices need to be adapted and implemented. Therefore, this study is an assessment of the irrigation system efficiency based on water use and production efficiency between drip and sprinkler on three vegetable crops (cabbage, tomato, and pepper), grown at small-scale on North-central Namibia. The study assumes four hypothesis; [1)] production input costs, planted field size, types of fertilizer, stakeholder visits, and agricultural soil practices have positive effects on the production efficiency of both three crops under the two irrigation system, [2)] Socio factors; age and sex have no influence on production yield efficiency in both irrigation systems, [3)] drip irrigation to use less water cost with fewer outputs and [4)] irrigation systems and total water cost per ha expected to have an effect on the outputs. The study was contacted through data collection whereby small-scale farmers were interviewed using a structural questionnaire. Data were analyzed in R software, whereby three statistical linear regression model such as; backward selection model, Akaike information criterion and interactions were used to measure the objectives. Among production inputs costs; water and fertilizer were found to be important determinants, of production efficiency in all three vegetables under both two irrigation systems. Age of the farmer, stakeholder visit, and agricultural soil practices (only; mulching) were found to have positive effects only on tomato and cabbage production efficiency under drip irrigation. The relationship between water use and irrigation systems was not significant, neither crop yield difference was not observed between drip and sprinkler irrigation systems. However, the statistical findings contradict the findings based on opinions and observations of farmers on crop yield and water use; which concluded that drip is more efficient relative to sprinkler irrigation. Together these results highlighted no clear difference between drip and sprinkler on water use and irrigation production efficiency on North-central Namibia, however, if proper agricultural water conservation practices and inputs subsidies are implemented among drip irrigation farmers, an efficiency difference between the two irrigation systems will be seen.


**Keywords:** *sprinkler, drip, water use and vegetable production efficiency*

# Acknowledgements

Initially, I would like to thank the small-scale farmers at Etunda irrigation project and Olushandja area, for their co-operation and trust they showed to me by sharing their confidential information practical skills they have taught me during my data collection period. Further thank you to the management at Etunda and OHPA for authorized me to interview their farmers. Without them this personnel's, I could not have contacted this study.

My special gratitude goes to my main supervisor Hans Christian Endrerud at the Hedmark University of Applied Science at Blæstad Norway, together with my co-supervisors Thomas Benisiu and Cecil Togarepi at the University of Namibia for all dedications, time sacrifices, and guidance they gave me throughout my thesis project. Moreover, I would like to extend my gratitude to my statistic lecture Harry Peter Andreassen for guiding on my statistics analyses.

A very special thank you to the following people; my best Phillip Namusheshe helping in data collection as my driver, on GPS operator, and contacting interviews during data collection period, thanks to Twiihendeni Israel a farmer at Etunda who accommodated me during field work. Further thank you goes to my classmates; Leif for providing me with transport sometimes when I have an appointment with my supervisor, Nhan for many hours of discussions felt of constructive comments and criticisms regarding the thesis. My thanks go to my entire classmates Hilde, Rebbeca, Anna, & Veronica for organizing social events such; lunch and cabin trip, it was a good learning platform for sharing information regarding our thesis and was a nice opportunity to refresh our minds, you guys have been awesome towards our study time.

Thank you!

# Table of content

# Acronyms

**AIC:** Akaike information criterion

**AMTA:** Agro-marketing Agency

**ANOVA:** Analysis of variance

**CPP:** Country Pilot Partnership for Integrated Sustainable Land Management Programme (MAWF & CPP).

**CCA:** Climate Change Adaptation

**DI:** Deficit irrigation

**FAO:** Food and Agricultural Organization

**GDP:** Gross Domestic Product

**GPS:** Global Positioning System

**GRN:** Government Republic of Namibia

**MAWF:** Ministry of Agriculture, Water, and Forestry

**NCN:** Northern Central Namibia

**NSA:** Namibia Statistic Agency

**NDP:** National Development Plan

**NGO:** Non-Governmental Organization

**OHPA:** Olushandja Epalela Horticultural Producers Association

**Q-Q plot**- Quantile-Quantile plot

**WUE:** Water use efficiency

# 1. Background

Irrigated agriculture makes a major contribution to food security, producing nearly 40 percent (%) of food and agricultural commodities from approximate 270 million hectors of land (De Pascale, Dalla Costa, Vallone, Barbieri, & Maggio, 2011), equivalent to 17 percent (M. Imtiyaz, Mgadla, Manase, Chendo, & Mothobi, 2000) of agricultural land. Irrigated areas have almost doubled in recent decades and have contributed much to the growth in agricultural productivity over the last 50 years (FAO, 2002). Moreover, FAO (2014) has estimated that irrigated agriculture uses more than 70% of the water withdrawn from the earth's rivers; whereby the proportion exceeds 80% in developing countries. Water is a valuable resource in Agricultural food production while it remains a finite resource, the competition of this precious resource is highly increasing due to current and future events such; rapid increase in world population which is expected to reach 9 Billion by 2050 (FAO, 2014), climatic change, agricultural and industrial sector activities. This possesses a threat to sustainable agricultural production and global food security; due to unsustainable agricultural practices that require excessive water and other production inputs leading to inefficient production and water scarcity (Costa, Ortuño, & Chaves, 2007; Pair, Kimberly, Hinz, Reid, & Frost, 1975).

The majority of people specifically in developing countries still live under poverty line and malnourishment (Wani, Rockström, & Oweis, 2009). It is, therefore, important to consider the following; the extent agricultural practices can be manipulated and to what extent cropland water requirements can be minimized at high output through better management practices in order to meet the existing crop production demand, and continuously food production to feed both current and future growing world population without damaging the environment. To mitigate these effects, agricultural practices that make use of water efficiently and yield improving irrigation strategies should be adopted, whereby irrigation is rated as the major solution (Pair et al., 1975). Further, several literatures also revealed that by implementing irrigation techniques such as deficit irrigation (DI) (Jackson et al., 2001) system can be among solution to water problem and low crop yield at small-scale level, specifically recommended for arid and semi-arid regions (FAO, 2002; Jackson et al., 2001; Kang, Shi, & Zhang, 2000; Kirda, 2002).

There are several definitions of DI, however in this study DI is defined as regulated irrigation techniques that minimize water demand, with minimal impacts on crop yield and quality; leading to improved food security, farm revenue and ensure sustainable agricultural productivity (Kirda, 2002; Shock & Feibert, 2002). Pair et al., (1975), stated that in dry areas DI such as; the use of sprinkler and drip irrigation can improve crops quality at the same time improve their yield. Studies by (Kang et al., 2000; Kirda, 2002) also supported that drip and sprinkler irrigation systems can maximize water use efficiency for high yield per unit of water applied to crops. The two irrigation systems (drip and sprinkler) can reward farmers by giving them high or optimum crop yield if combined with good farming practices such as; good soil management, good fertilization, pests management, mechanization operations and improved seeds (Pair et al., 1975). Moreover, Pair et al., (1975) stated that the two irrigation system can reduce manmade environmental effects that involve water wastage, for example; land reclamation with sewage, water waste from the cities and factories, converting them into agricultural crop productivity.

With reference to efficiency definition by Jensen (2007), efficiency is defined as the ability to produce the desired effect, expenses, and wastes. De Pascale et al. (2011), further defined agricultural water use efficiency as the ratio of crop yield per unit of water applied. Drip and sprinkler irrigation technology have proven success on water use efficiency (WUE) and high productivity or yield in agricultural crops and adaptability to almost all crops (Pair et al., 1975). For example, success was attained in fruits production (Boland, Jerie, Mitchell, Goodwin, & Connor, 2000; Costa et al., 2007; FAO, 2002), in cotton (FAO, 2002; Kang et al., 2000), it has also proven successful by increasing grain yield in vast semi-arid area of China (Kang et al., 2000) and vegetable crops production such as; tomato, hot pepper, and potato production among others (Costa et al., 2007; De Pascale et al., 2011).

Many published research evaluated the feasibility of deficit irrigation (drip and sprinkler) and whether significant savings in irrigation water are possible without significant yield effects, whereby yield and production efficiency differences between the two irrigation systems have been observed on different field crops and vegetables (Costa et al., 2007; De Pascale et al., 2011; M. Imtiyaz et al., 2000). Most studies have individually researched the two irrigation systems (few comparison between the two were made) and most have proven success in irrigation production efficiency. M. Imtiyaz et al. (2000), published a paper that revealed success on production efficiency and a high economic return of vegetables such as; cabbage, tomato, onion, spinach, and rapeseeds; however the results was positively correlated with the amount of irrigation water. Furthermore, the efficiency is said to depend on other factors such us; time of irrigation, input costs, adopted soil management and agricultural practices are among the factors (De Pascale et al., 2011).

Different scientists revealed different efficiency findings between the two irrigation systems. Pair et al., (1975) revealed that both sprinkler and drip irrigation are all water use efficient; means they make use of little water available and good moisture control enhancing high and quality crop yield. (FAO, 2002) stated that sub-surface drip irrigation improves water use efficiency (WUE) over 95% (Postel, 1998) of various crops and vegetables, relative to sprinkler; drip cover less surface water application area, maintain moisture and water is directed to crops, simultaneously reducing farming cost. Oktem, Simsek, and Oktem (2003) revealed yield reduction in *Zea mays* production through drip irrigation, however, contradict with the study by (Stegman, 1982) that revealed no statistically yield differences observed in maize between drip and sprinkler irrigation techniques, albeit they differ in WUE. Other studies revealed no or unclear statistical yield differences obtained between drip and sprinkler irrigations, specifically on vegetable crops, hence, this created an opportunity for this study on water use and production efficiency between the drip and sprinkler irrigation systems. This study has been done strictly with respect to irrigation system at small-scale in Namibia specifically north-central Namibia. In Namibian perspective, MAWF (2013) defined small-scale farmers as the irrigation farmers utilizing a farming unit within the state agro project or farmers who entered into an agreement with a commercial farmer for service or independent enterprise or individually engaged in horticulture or crop production under irrigation.

## 1.1 Overview on Namibian perspective

With a current population of 2.1 million (NSA, 2011) which projected to rise to 3.4 million by 2040 (NSA, 2014), Namibia is among one of the developing and one of driest countries in sub-Sahara Africa; about 80% of its 842 000 Km$^2$ is made up of desert, arid and semi-arid land (Lange, 1998). Water scarcity in the country remains the critical major problem to agricultural production (specific crop farming), due to low and much variable annual average rainfall the country receive; ranging between 50mm along the coast to 350mm in the central interior and 700mm in the North-eastern region (Information, 2010-2016). Few and shared perennial rivers with the neighboring countries, limited ephemeral rivers, catchments, and failure to harvest rain water are also among the contributing factors to country water scarcity, significantly hindering national food production and global food security. In Namibia about 85% (Nekwaya,

2008) and 45% (FAO, 2005) of water is consumed by irrigation, this indicated the necessity to find and implement better resource use technology in agricultural sector whereby efficient water use irrigation techniques are among.

Besides country's water limitation challenge, the agricultural sector still plays a major role in the country's economic development, contributing 7.4% to the National Gross Development Product (GDP) in 2015 (NSA, 2015). It is therefore regarded as a fundamental and instrument for sustainable development and poverty reduction, serving the livelihood of more than 70% of the country's population (NSA, 2015). The government of Namibia through its green scheme policy have invested in Agro-irrigation projects, which was adopted in 2002 and formally approved in 2003 (Hansen & Kathora, 2013). This program is aimed to encourage farmers (commercial and communal) 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 both national and within irrigation sub-sector, which are milestones in attainment of the country's food self-sufficiency. The Irrigation Scheme accommodate both small-scale and medium-scale agri-business horticultural farmers, whereby sprinkler and drip irrigation systems are commonly used for irrigation.

Outside the green scheme are also individual small and medium-scale farmers, venturing into agri-business horticultural production through drip and sprinkler irrigation techniques. Among these are farmers; an example is the farmers located in this study area of North-central Namibia (Etunda irrigation Project surrounding and in the vicinity of Olushandja Dam near Epalela whereby most are members of Olushandja Horticultural Producers Association (OHPA)). These farmers get help through private organizations in jointly with the Ministry of Agriculture, Water and Forestry (MAWF & CPP, 2011), by offering them training and extension services on adaptable irrigation techniques adaptable to the Namibian environment and climate change (climate smart irrigation systems); which enable farmers to sustain their livelihood and community development.

## 1.2 Problem Statement

As revealed by literature, irrigation provides the opportunity to produce food in countries where crop production can be limited by environmental factors (Bannayan, Nadjafi, Azizi, Tabrizi, & Rastgoo, 2008; Postel, 1998; Sharmasarkar, Sharmasarkar, Miller, Vance, & Zhang, 2001). It is, therefore, important to use irrigation technique that suit to the local environmental condition and irrigation with capability to improve yield when complimented with good management practices, with the capacity to limit scarce resource wastage and require few inputs (M Imtiyaz, Mgadla, Chepete, & Manase, 2000).

Considering the past and current pedoclimatic features of low rainfall and poor soil of Namibia, and the current global effect of climate change which has negative effects on rainfall, water scarcity in the country remains the critical major problem to agricultural production, specifically on crop production. Vegetable crops namely; cabbage, tomato and pepper (green or red) are common among high-value crops grown by small-scale farmers in North Central Namibia. Drip and sprinkler irrigation systems are the most common and affordable method of irrigation systems for these vegetable crops by small-scale farmers in Namibia. However, there is a lack of technical and production efficiency information such as; water use, production efficiency between drip and sprinkler irrigation systems, and the ability to be easily adaptable by small-scale horticultural farmers on North-central Namibian environment which characterized by high temperature, water scarcity and unequal distribution of resources among farmers.

Hence, this study is about the assessment of the irrigation system efficiency between drip and sprinkler on three vegetable crops (cabbage, tomato, and pepper), grown on North-central Namibia. The study is based on two main objectives, whereby the first objective is to compare production efficiency between drip and sprinkler irrigation systems on three vegetable crops (tomato, cabbage, and pepper) at North-central Namibia. The second objective is to assess the efficient water use irrigation technique (drip and sprinkler) which can fit Namibia environment and easily adopted by small-scale farmers.

## 1.3 Study Hypothesis

The study hypothesized the following objectives; [1)] production input costs, planted field size, types of fertilizer, stakeholder visits, and agricultural soil practices have positive effects on the production efficiency of both three crops under the two irrigation system, [2)] Socio factors; age and sex have no influence on production yield efficiency in both irrigation systems, [3)] drip irrigation to use less water cost with fewer outputs and [4)] irrigation systems and total water cost per ha expected to have an effect on the outputs.

# 2. Methodology

## 2.1 Study area description

The study was conducted at North Central Namibia (Etunda irrigation project and at Olushandja area) located in Omusati Region. Etunda Irrigation Project is a state-owned farm, situated about 40 km North-West of Outapi town. The project was established in 1994 as a government initiative to introduce and develop agronomic production in the region and to boost economic development of the agricultural sector, through development of irrigation infrastructures. Moreover, it also aimed at improving the livelihood of communities within the vicinity, through human resources and farming skills development. Currently, the project is operating under the Government Green Scheme Policy which was adopted in 2002 in the promotion of National Development Plan (NDP) objectives; food security and country food self-sufficiency, by using cost efficient irrigation methods suitable for water scarcity environment and the long-term environmental sustainability(Hansen & Kathora, 2013).

The project covers an area of 1200 hectares of land, currently 900ha are under operation (300ha under commercial, 300 under medium-scale and 300 small-scale productions), (Leo Nuugulu (personal communication, 2013 & 2015)). In total the project has about 88 small-scale farmers, on a five years government renewable contract leased land and substantial government (GRN) support on inputs, water land preparation and free extension support (FAO, 2002). The small-scale farmers have plots ranging from 3-12 ha and a maximum farming experience of 21 years. Sprinkler irrigation is mostly used in their productivity, however, there are also few farmers starting or planning to integrate sprinkler with drip irrigation in their crop production (findings during study data collection). The crops grown at the project are maize (the main crop produced), potato, cabbages, tomatoes, groundnuts, butternuts, sweet potatoes, green peppers, watermelons and carrots.

Near to Etunda irrigation project, there are about 50 horticultural small-scale farmers in Olushandja area (along Olushandja dam) which are part of Olushandja Horticultural Producers Association (OHPA), who are also specializing in horticultural production whereby majority use drip irrigation system and few use other irrigation techniques such as; sprinkler and flood irrigation. These farmers are aiming to improve their welfare, development of their community, and also contribute to the country food self-sufficient objectives. Olushandja farmers started through improving vegetable production through the program under the

Climate Change Adaptation (CCA) project operated from 2008-2011, as a sub-project of the Country Pilot Partnership Program for Integrated Sustainable Land Management (MAWF & CPP, 2011). The project aimed at training farmers on adapting to climate change by utilizing the various traditional cropping system. The farmers were trained to adapt the use of drip irrigation in response to the shortcomings of the flood furrow irrigation system which they previously use.

Both Etunda and Olushandja farmer's source water from Kunene River via Calueque Dam in Angola by a canal which runs for about 155km through the Omusati region to Oshakati; that is what made irrigation-based agriculture possible in this study area vicinity. The soil in the study area is predominantly comprised of (deep) Kalahari sands with low water retention and to a lesser extent loams and silts. Generally, organic matter in the topsoil is low about (1 to 5%) with nutrient deficiency, low fertility and is susceptible to salinity (Angula *et al*, 2014). The climate in the region can be described as semi-arid with an average annual erratic rainfall ranging from 350 to 500 mm per annum. Moreover, Angula *et al*, (2014), stated that the temperature in this areas are characterized by hot Summers, with maximum temperatures ranging between 30°C and 35°C during the hottest months, and the coldest winter temperatures are around 2 to 6°C. The environmental characteristics similarity on the study area made it possible to compare the two irrigation systems used by small-scale farmers in Etunda and Olushandja.

**Figure 1** (a) Study area overview

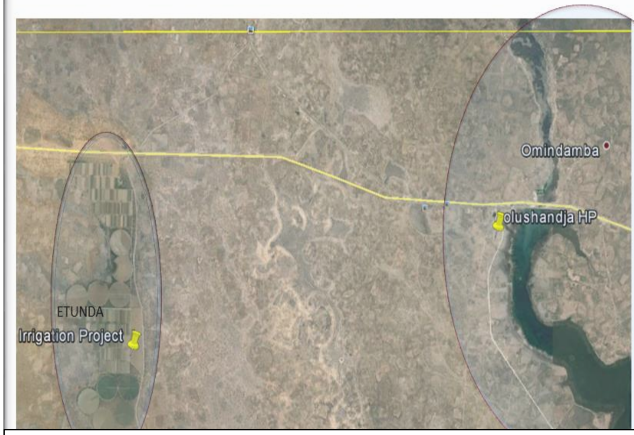



**Figure 1 (b)** Study area location on the Namibian


**Figure 1(a).** Maps of the study area; Etunda project is on the left circled and Olushandja on the right circled. Figure 1(b). Shows geographical location position on the Namibian map as indicated by an arrow .

***Source:*** *Earth Google, AfriGIS (Earth) Ltd. (2016).*

## 2.2 Data collection

To carry out this study, almost all small-scale farmers have been randomly interviewed face to face and only one telephonically interviewed (due to his absence at the farm during interview time), whereby a structural questionnaire was a tool used for an interview *(Appendix III)*. A sample size of 69 small scale-farmers composed of 48 farmers from Etunda and 21 farmers from Olushandja area was selected for an interview. Among these farmers, 48 use sprinkler, 21 use drip and one use furrow method to irrigate their vegetables. Moreover, among the interviewee seven (7) of them do not grow crops of the study interest (they specialize in growing maize and other vegetables), they all irrigate their crops with sprinkler irrigation and they are all from Etunda farm. The interview lasted for six (6) days period from 18$^{th}$ -23$^{rd}$ January 2016.

A Garmin Etrex 20x Global Positioning System (GPS) was used during data collection period, purposely for navigation, recording waypoints of interviewed farmers, and recording geographical location coordinates of their fields *(Appendix iv);* whereby this information can valuable for mapping, future studies, follow up on farmers progress assessments. Apart from Etunda , the GPS did not go tense as planned at Olushandja due to all farmers were interviewed at the same place (at their center Olushandja Horticultural Producers Association (OHPA) in Epalela, where they were gathering to select their new leadership committee for their association. Secondary information from MAWF officials (Agro-marketing Agency (AMTA), extension), including management of Etunda project and Olushandja Horticultural Association and NGO publications, was also used as additional supporting materials for the study.

## 2.3 Data analysis

A regression model Y= a +bX, in R 2.8.0 software (http://www.cran.r-project.org) was used to analyze the data. Data was initially prepared in Microsoft excel before imported into R software. The relationship between predictor variables and response variables were all analyzed following the ANOVA procedures. Since the data composed of both continuous and categorical predictor variables and this fits very well with ANOVA analysis model (Rutherford, 2001). All models were tested at 0.05 significant level, whereby these with P-value <0.05 were found to be significant otherwise, they are not significant. Different statistical linear regression model (lm) were used to test the objectives; Backward selection model (objective 1), Akaike information criterion (AIC) and interaction models (objective 2).

The statistical method selection was also influenced by the type of data contained in variables (response and predictors).

### 2.3.1 Backward selection linear regression model to measure the first objective

To measure irrigation production efficiency between drip and sprinkler irrigation systems on the three vegetables, data was manipulated, whereby production efficiency (%) was calculated to be used as a response variable; using formula *(total output (N$)/total input costs* used in the production**)***100*, of each vegetable. To compare the production efficiency per between the two irrigation systems, each crop was analyzed individually under two different irrigation system; this means data were separated into two groups, farmers producing the crops under drip irrigation and farmers producing under sprinkler irrigation. To measure objective one (1); a backward selection linear model was used to measure the significance or effects of the predictor variables *(Table 1)* on the response variable, which is irrigation production efficiency. This was done due to the following reasons; the response variable contains continuous data while predictor variables are more than 10 (AIC is limited to 3-10 models) and they are equally connected to my hypothesis. Moreover, there are many covariates predictor variables in my model, hence all the predictor effects, such confounding effects, bad distributions can be corrected under backward selection.

All linear model assumptions were checked through diagnostics plots (Residual plots, Quantile-Quantile (Q-Q) plots) and scatter plots were also used *(Appendix I (A & B)).* None of the data fulfill the assumption of homoscedasticity (larger variation in error residuals was observed), confounding and bad distribution of predictor variables toward x-axis and response variable was not normally distributed, therefore they have to be log transform by adding 1 *(Appendix I (A & B)).* Production efficiency graphs between irrigation systems were prepared on excel.

The formula used for linear regression model (lm); $Y = \alpha + \beta x_1 + \beta x_2 + ... + \beta x_n$

***m1****=(Irrigation production efficiency ~ water cost + labor cost + chemical cost + fertilizer cost + fertilizer type + planted area + stakeholders+ mulching + crop rotation or intercropping + minimum or no tillage + weeding, thinning or pruning + tillage or harrowing + farm location + pests control + age + sex)*

(m1=model,*Y=response variable (irrigation production efficiency), α = intercept, β= slope, X = predictor variables).*

***Table 1:*** *Lists of predictor variables and their expected effects on Irrigation production efficiency of the three vegetable under drip and sprinkler irrigation systems produced at North Central Namibia.*

***Response variable (Y):*** *irrigation production efficiency*

| Predictor variables | Variable type | **Eff** (T-drip) | **Eff** (T-drip) | **Eff** (P-drip) | **Eff** (C-sprinkler) | **Eff** (T-Sprinkler) | **Eff** (P-sprinkler) |
|---|---|---|---|---|---|---|---|
| Water cost | *Quantitative (N$)* | + | + | + | + | + | + |
| Labor cost | *Quantitative (N$)* | + | + | + | + | + | + |
| Chemical cost | *Quantitative (N$)* | + | + | + | + | + | + |
| Fertilizer costs | *Quantitative (N$)* | + | + | + | + | + | + |
| Fertilizer type | *Dummy; 1=if organic, 3=if norganic,2= if both* | + | + | + | + | + | + |
| Planted Field | *Quantitative (ha)* | + | + | + | + | + | + |
| Stakeholders | *Dummy; 2=visit by farmers , 3=visit officers, 1=both* | + | + | + | + | + | + |
| Mulching | *Dummy;1=if yes , 0=if not* | + | + | + | + | + | + |
| Crop rotation and intercropping | *Dummy;1=if yes , 0=if not* | + | + | + | + | + | + |
| Minimum or no tillage | *Dummy;1=if yes , 0=if not* | + | + | + | + | + | + |
| Weeding, thinning and pruning | *Dummy;1=if yes , 0=if not* | + | + | + | + | + | + |
| Tillage and harrowing | *Dummy;1=if yes , 0=if not* | + | + | + | + | + | + |
| Farm location | *Qualitative; Etunda or Olushandja* | + | + | + | + | + | + |
| Pests control | *Qualitative; mechanical & chemicals* | + | + | + | + | + | + |
| Sex | Dummy ;1= male; 0=female | No | No | No | No | No | No |
| Age | Quantitative (years) | No | No | No | No | No | No |

***Y****=response variable (irrigation production efficiency),,* ***Eff****=expected effects between predictor and response variables on crops,* ***C****=cabbage,* ***T****=tomato,* ***P****=pepper,* N**$**=Namibian Dollar, **ha**=hector, **+**=positive significance or effects expected, **No**=No effects expected.

### 2.3.2 AIC and Interaction linear regression model to measure the second objective

Water use irrigation system efficiency was measured based on the total output (N$/ha), whereby each crop output was divided by the number of ha planted to get the total output in Namibian Dollar (Bannayan et al.) per ha. Total output in NAD per ha (response variable) was first analyzed via AIC model, to select the best parsimony's models (least AIC) was selected. To measure irrigation system efficiency four linear models were used, using Boxplots and ANOVA to determine relationships. Furthermore, total water cost per ha, irrigation systems, the interaction between the two (total water cost per ha, irrigation systems) were used as predictor variables to determine the relationship towards Total output in NAD per ha (response variable) (Table 2). I tested the relationship between total water cost (N$) and irrigation system (m4=total water cost (N$) ~ irrigation system), *(refer to Appendix II)*. Statistical findings were compared with data collected on farmers perceptions on the efficient irrigation system they think can suit their environment, which also help draw up the study conclusion.

Formula used; $Y= a+b_1x_1+b_2x_2+b_3x_1*x_2$

*m1= (output per ha ~ total water cost/ha + irrigation system)*

*m2= (output per ha ~ irrigation system+ total water cost/ha*irrigation system)*

*m3= (output per ha ~ total water cost/ha + irrigation system+ total water cost/ha*irrigation system)*

***Table 2:*** *Variables used in the models to measure the efficiency of the two irrigation systems and the hypnotized effects of predictor variables on response variables (measure the effects of total water cost and irrigation systems on output per ha).*

| **Predictor variables** | **Variable type** | **Expected effect on response variable (total output per ha)** |
|---|---|---|
| Total water cost *(N$/ha)* | *Quantitative (N$)* | Significance |
| Irrigation systems | *Quantitative (N$)* | Significance |
| Total water cost *(N$/ha)* *Irrigation systems | *Interaction between total water cost/ha and irrigation systems* | Significance |

***N$****=Namibian Dollar, ha=hector,* **N$/ha** *=Namibian Dollar per hector,* *******=interaction between variables,* ***m****=model.*

# 3. Results

## 3.1 Irrigation production efficiency

### 3.1.1 Irrigation production efficiency based on data from figures compiled through Microsoft excel

On average more production input costs is spent on crops production under drip irrigation than sprinkler irrigation, whereby drip farmers invest more on water and fertilizer and their production efficiency is very high on both all three vegetable (not much difference observed *(Figure 3(b))*. In sprinkler irrigation, apart from fertilizer, farmers seems to spend less on production inputs on all three crops, however, pepper production efficiency is low compared to other two crops *(Figure 3(a))*. In overall, drip irrigation farmers spends a lot in production inputs, but their production efficiency is very high compared to sprinkler irrigation in all three vegetable crops (*refer to Figure 3 & 4 below*). Moreover, based on average, the total production efficiency of crops between drip irrigation and sprinkler irrigation is summarized by *Figure 2* below; which shows high production efficiency on sprinkler irrigation and this results is high on sprinkler due to large sample size of farmers interviewed on sprinkler relative to drip irrigation (it does not mean sprinkler is more efficient than drip).

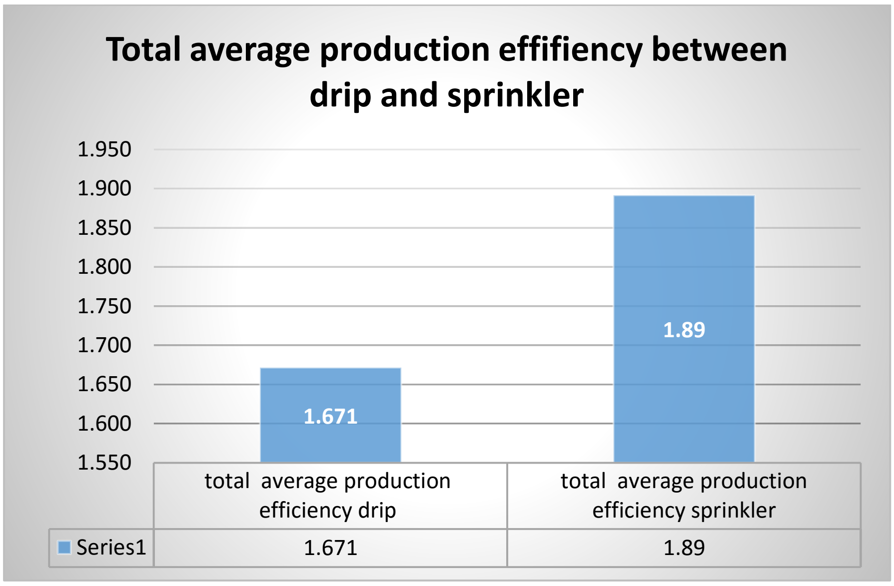
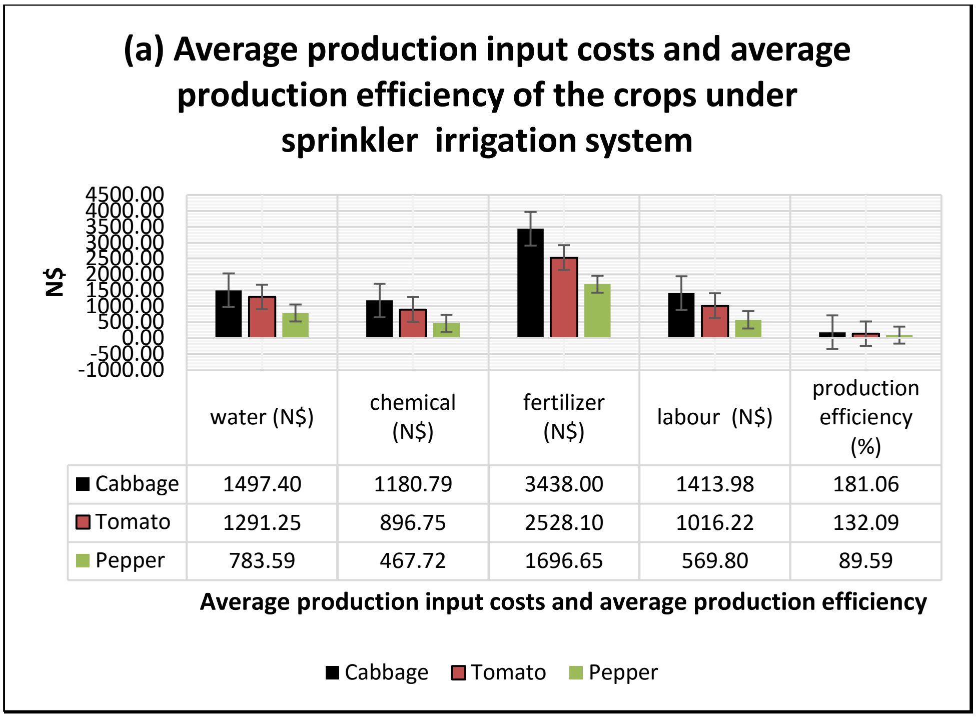
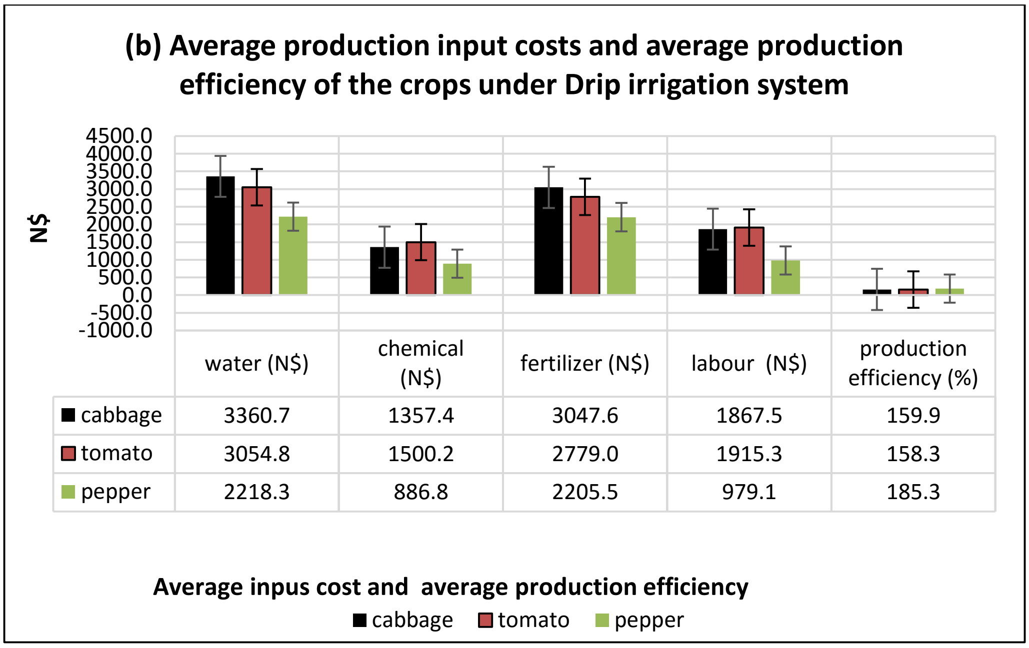



***Figure 2.*** *Total average crop production efficiency between drip and sprinkler irrigation systems.*

**Average production input costs and average irrigation production efficiency of vegetables under sprinkler and drip.**



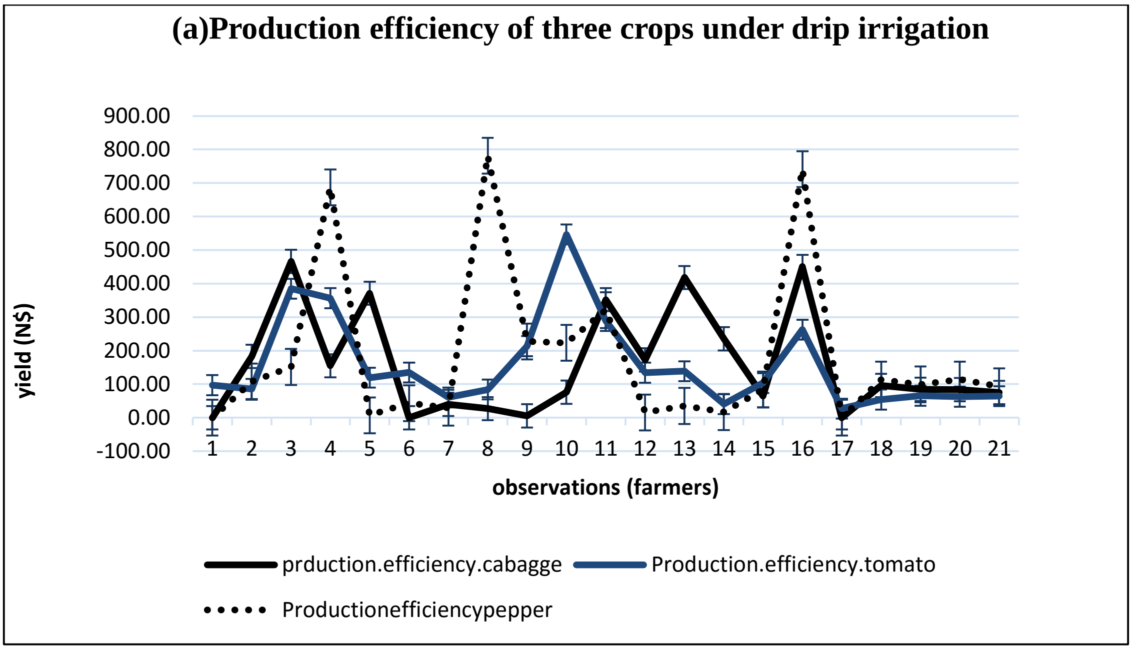

| | water (N$) | chemical (N$) | fertilizer (N$) | labour (N$) | production efficiency (%) |
|---|---|---|---|---|---|
| Cabbage | 1497.40 | 1180.79 | 3438.00 | 1413.98 | 181.06 |
| Tomato | 1291.25 | 896.75 | 2528.10 | 1016.22 | 132.09 |
| Pepper | 783.59 | 467.72 | 1696.65 | 569.80 | 89.59 |




| | water (N$) | chemical (N$) | fertilizer (N$) | labour (N$) | production efficiency (%) |
|---|---|---|---|---|---|
| cabbage | 3360.7 | 1357.4 | 3047.6 | 1867.5 | 159.9 |
| tomato | 3054.8 | 1500.2 | 2779.0 | 1915.3 | 158.3 |
| pepper | 2218.3 | 886.8 | 2205.5 | 979.1 | 185.3 |

***Figure 3 (a) & (b).*** *Compare the average production input costs and average irrigation production efficiency between the three vegetable crops under the two irrigation systems.*

*The figure below indicate the production yield obtained by interviewed farmers on individual crops under drip and sprinkler which is a good comparison of efficiency between the two irrigation systems.*



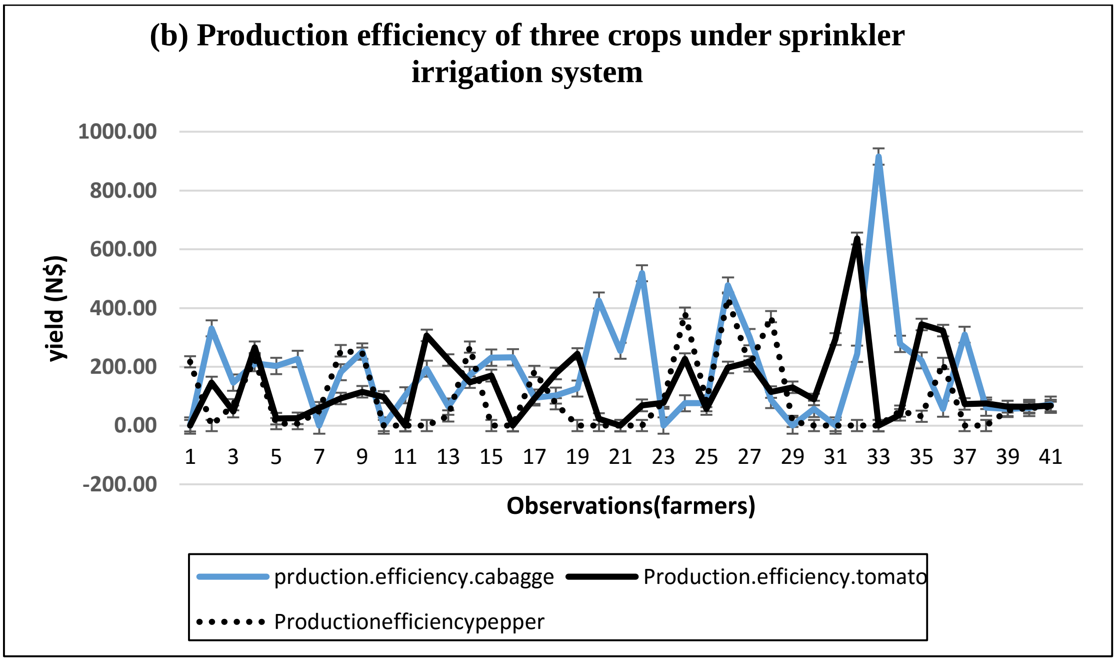




***Figure 4. (a) and (b)*** *Shows the yield production efficiency of the three vegetable crops per individual farmer interviewed under sprinkler and drip irrigation systems.*

### 3.1.2 Results from regression model

The final significant results of the backward selection regression model comparing the predictor variables effects on a response (production efficiency) variable between drip irrigation system and sprinkler on three vegetable crops (tomato, cabbage, and pepper); as shown in *Table; 3, 4 & 5.*

The fertilizer and water input costs have a positive relationship with the production efficiency of cabbage on both irrigation systems (drip and sprinkler), relative to labor costs and chemical costs which only have a significance effects on cabbage under drip irrigation system. Field area planted (ha) have a positive relationship only under cabbage grown under sprinkler and mulching is the only agricultural soil practices significant to cabbage production efficiency; however, only under drip irrigation, no effects was found on socio factors and stakeholders observed *(Table 3).*

***Table 3.*** *The effects on production efficiency of cabbage crop between drip and sprinkler irrigation systems.*

| | Cabbage under drip irrigation | | | Cabbage under sprinkler irrigation | | |
|---|---|---|---|---|---|---|
| **Coefficients** | **Estimate** | **t value** | **Pr(>\|t\|)** | **Estimates** | **t value** | **Pr(>\|t\|)** |
| *(Intercept)* | 6.395e-01 | 1.333 | 0.20110 | -4.746e-02 | -0.988 | 0.330198 |
| Fertilizer cost | -4.816e-04 | -3.080 | 0.00718** | -1.625e-04 | -5.495 | 3.91e-06 *** |
| Water cost | 6.718e-01 | 6.967 | 3.18e-06 *** | -2.372e-04 | -5.663 | 2.36e-06 *** |
| Production yield (heads) | 2.267e-04 | 3.045 | 0.00771 ** | 8.513e-01 | 48.692 | < 2e-16 *** |
| Mulching | -1.182e+00 | -2.285 | 0.03632 * | - | - | - |
| Labor cost | - | - | - | -7.884e-05 | -4.463 | 8.45e-05 *** |
| Chemical cost | - | - | - | -1.398e-04 | -4.263 | 0.000151 *** |
| Planted ha | - | - | - | 1.716e-01 | 3.686 | 0.000788 *** |

***, **and ****** *indicate the significant results or importance of predictor variables,* **-** *no observed effect of predictor variables on a crop production efficiency under irrigation system,* **<** *the significance is very close to 0.*

On tomato production efficiency relationship to predictor variables, two regression models (lm) were found significant under drip irrigation *(Table 4 & 5).* Among the predictor variables under production input costs, only water and fertilizer costs were found significant under both irrigation systems, relative to chemical and labor costs which are only significant under drip, irrigation *(Table 4).* Stakeholders and age were found to have a positive relation to tomato production efficiency under drip irrigation system *(Table 5).*

***Table 4.*** *The effects on production efficiency of tomato crop between drip irrigation (lm (m1)) and sprinkler irrigation systems*

| | Tomato under drip irrigation; lm (1) | | | Tomato under sprinkler irrigation | | |
|---|---|---|---|---|---|---|
| **Coefficients** | **Estimate** | **t value** | **Pr(>\|t\|)** | **Estimates** | **t value** | **Pr(>\|t\|)** |
| *(Intercept)* | *2.619e+00* | *15.724* | 9.96e-11 *** | *9.187e-01* | *2.746* | *0.009259 ***** |
| Water cost | 2.673e-01 | -9.230 | 1.42e-07 *** | 8.136e-04 | 3.287 | 0.002225 ** |
| Fertilizer cost | -1.059e-04 | -9.514 | 9.59e-08 *** | 6.640e-04 | 4.192 | 0.000165 *** |
| Production yield (heads) | 9.721e-01 | 56.599 | <2e-16 *** | 2.646e-04 | 3.220 | 0.002670 ** |
| Chemical cost | -1.919e-01 | -6.505 | 9.94e-06 *** | - | - | - |
| Labor cost | -2.034e-01 | -9.968 | 5.21e-08 *** | - | - | - |

***, **and **** *indicate the significant or importance of predictor variables*, **-** *no observed effect of predictor variables on a crop production efficiency under irrigation system,* **<** *the significance is very close to 0,* ***lm*** *linear model,* ***lm (1)*** *first significant linear model of tomato under drip irrigation.*

***Table 5.*** *The effects on production (yield) efficiency of tomato crop between drips (lm (m2)).*

| | Tomato under drip irrigation; lm (2) | | |
|---|---|---|---|
| **Coefficients** | **Estimate** | **t value** | **Pr(>\|t\|)** |
| *(Intercept)* | 2.81819 | 6.092 | 9.35e-06 *** |
| Age. | 0.08722 | 3.728 | 0.00154 ** |
| Stakeholder | 0.52485 | 3.301 | 0.00397 ** |

***and **** *indicate the significant results or importance of predictor variables,* ***lm*** *represent linear regression model and lm (2) significant model 2 of tomato under drip irrigation.*

Water cost is significant on pepper which is grown under both two irrigation systems, relative to fertilizer cost which is only significant under drip irrigation system and chemical cost only significant when the pepper is grown under sprinkler irrigation *(Table 6).*

**Table 6.** The effects on production (yield) efficiency of pepper crop between drip and sprinkler irrigation systems.

| Tomato under drip irrigation | | | | Tomato under sprinkler irrigation | | |
|---|---|---|---|---|---|---|
| **Coefficients** | **Estimate** | **t value** | **Pr(>\|t\|)** | **Estimates** | **t value** | **Pr(>\|t\|)** |
| *(Intercept)* | *9.187e-01* | 2.746 | *0.009259*** | 0.3143367 | *1.413* | 0.166272 |
| Water cost | 8.136e-04 | 3.287 | 0.002225** | 0.0013987 | 4.071 | 0.000245 *** |
| Fertilizer cost | 6.640e-04 | 4.192 | 0.000165 *** | - | - | - |
| Production yield (heads) | 2.646e-04 | 3.220 | 0.002670 ** | 0.0016537 | 5.354 | 5.07e-06 *** |
| Chemical cost | - | - | - | 0.0014538 | 2.975 | 0.005201 ** |

*****and **** indicate the significant or importance of predictor variables, **-** no observed effect of predictor variables on a crop production efficiency under irrigation systems, **<** the significance is very close to 0.*

## 3.2 Results on efficient irrigation system

Model m4 composed of only one predictor variable; Total fertilizer cost per ha, is the only best parsimony models (explaining the observed variation Total outputs (N$/ha)), with the least AIC (1458.6), this means the likelihood to be better than others is 73% (according to AIC Weight, Table 7).

There were no effects found between total output per ha and irrigation; this means irrigation mean value are all the same ($F_{1, 60}$=1.07, P=0.7042, *Figure 5*), however a positive relationship between total output (N$/ha) and total water cost per ha ($F_{1, 60}$=10.053, P=0.002396 **, *figure 6).* The mean output of water and mean output of irrigation system were found to be the same; thus, the interaction irrigation system*total water cost per ha has no effects on the total output (N$/ha) of crops ($F_{1, 58}$= 0.3348, P= 0.565111, *figure 7).* Moreover, on total water cost per ha and irrigation effects, there was no significant effect found, ($F_{1, 60}$=0.9328, P=0.338, *figure 8*).

***Table 7.*** *Results from the regression model based on corrected Akaike information criterion (AIC). The model explains the effects of irrigation systems and total production inputs (water, chemical, labor and fertilizer costs) in N$/ha on the total output (N$ per ha). The regression is purposely; to compare the effects of water cost and irrigation system on crops output, and the relationship between water cost and irrigation system at the North Central Namibia.*

**Response variable:** Total output (N$ per ha)

| Model | Predictor Variables | K | AIC | Δ AIC | AIC Weight |
|---|---|---|---|---|---|
| m0 | Null | 0 | 1475.7 | 17.0 | 1.466470e-04 |
| m1 | Irrigation | 1 | 1476.6 | 18.0 | 9.316024e-05 |
| m2 | Total water cost/ha | 1 | 1471.4 | 12.8 | 1.254392e-03 |
| m3 | Total chemical cost/ha | 1 | 1473.5 | 14.8 | 4.444754e-04 |
| m4 | Total fertilizer cost/ha | 1 | **1458.6** | **0.0** | **7.370981e-01** |
| m5 | Total labor cost/ha | 1 | 1475.6 | 16.9 | 1.557095e-04 |
| m6 | irrigation*total water cost/ha | 1 | 1472.9 | 14.3 | 5.767288e-04 |
| m7 | Total water cost/ha* irrigation +total water cost/ha | 2 | 1472.9 | 14.3 | 5.767288e-04 |
| m8 | Total water cost/ha *irrigation +irrigation | 2 | 1472.9 | 14.3 | 5.767288e-04 |
| m9 | Irrigation + total water cost/ha +total chemical cost/ha+ total fertilizer cost/ha+ total labor cost/ha+ total water cost/ha* irrigation + total water cost/ha* irrigation +total water cost/ha + total water cost /ha*irrigation +irrigation | 9 | 1460.7 | 2.1 | 2.590774e-01 |

***K;*** *Number of parameters in the model,* ***AIC;*** *Akaike information criterion,* **Δ (*delta*) *AIC;*** *Akaike differences;* ***AIC Weight;*** *Indicate the likelihood of the best parsimonious model,* interactions between predictor variables.* ***Source;*** *own adopted (North Central Namibia).*

***Figure 5, 6, 7, & 8*** *below, are references to the above results which indicate predictor variables (water costs/ha, irrigation system and their interaction) relationship to the response variable (crop total output per ha), while figure 7 show total water cost /ha and irrigation system relationship which was used to measure the irrigation efficiency between drip and sprinkler.*

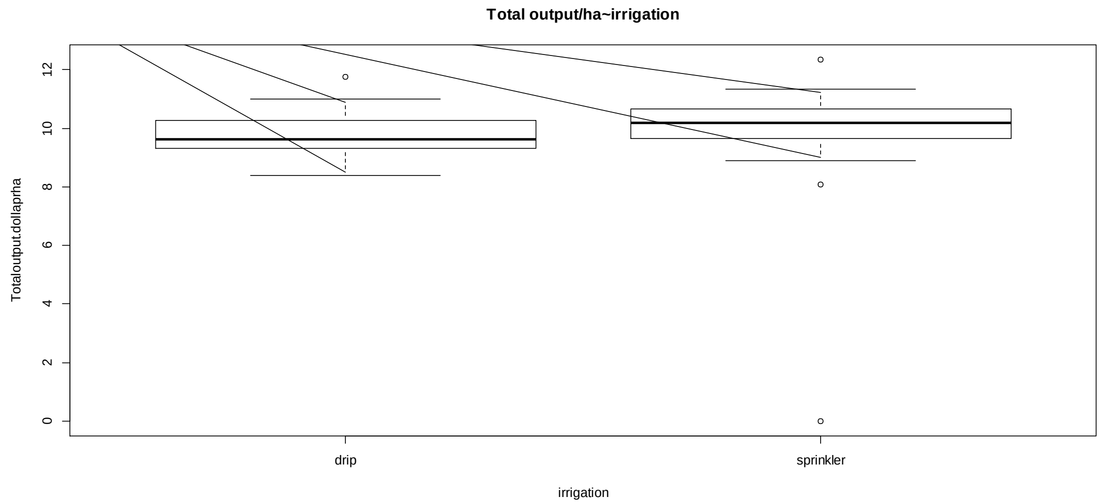



***Figure 5.*** *The relationship between Total output (N$/ha) after log transformed and irrigation system, on three vegetable crops produced relationship (North central Namibia).*

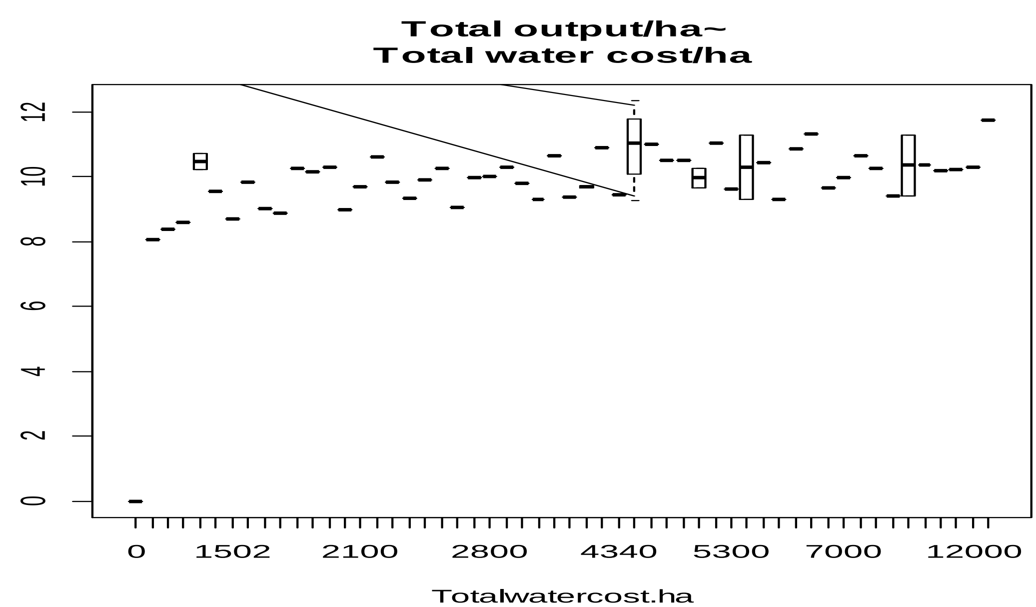



***Figure 6.*** *The relationship between Total output (N$/ha) after log transformed and total water cost per ha, on three vegetable crops produced at North Central Namibia.*

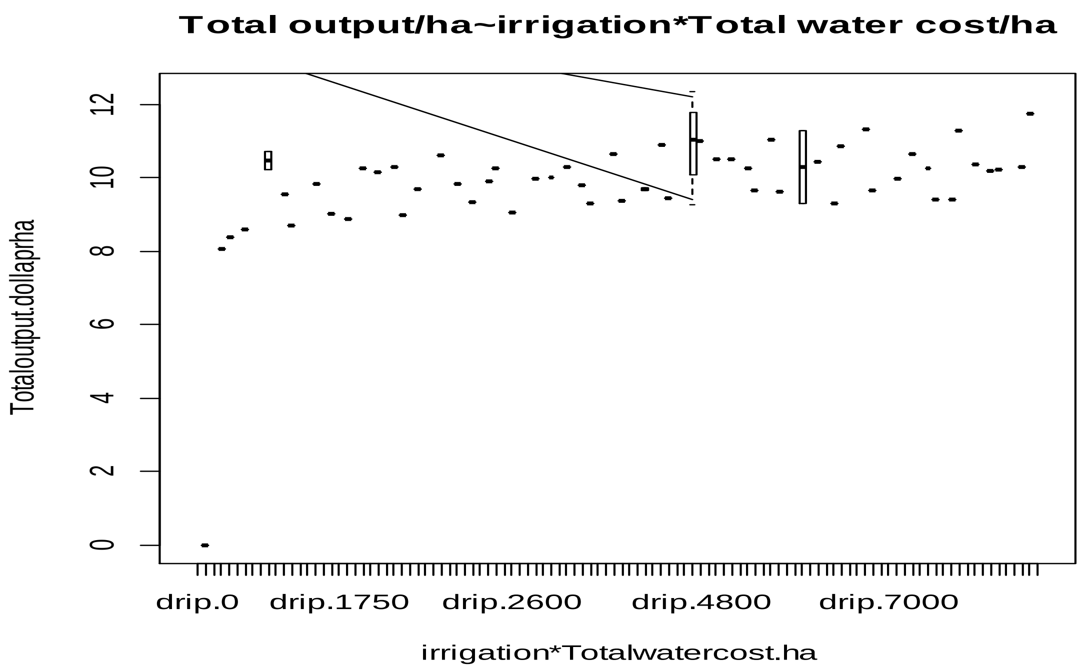



***Figure 7.*** *The interaction (irrigation*total water cost per ha) relationship with total output per ha (log transformed), of three vegetable crops produced at North central Namibia.*

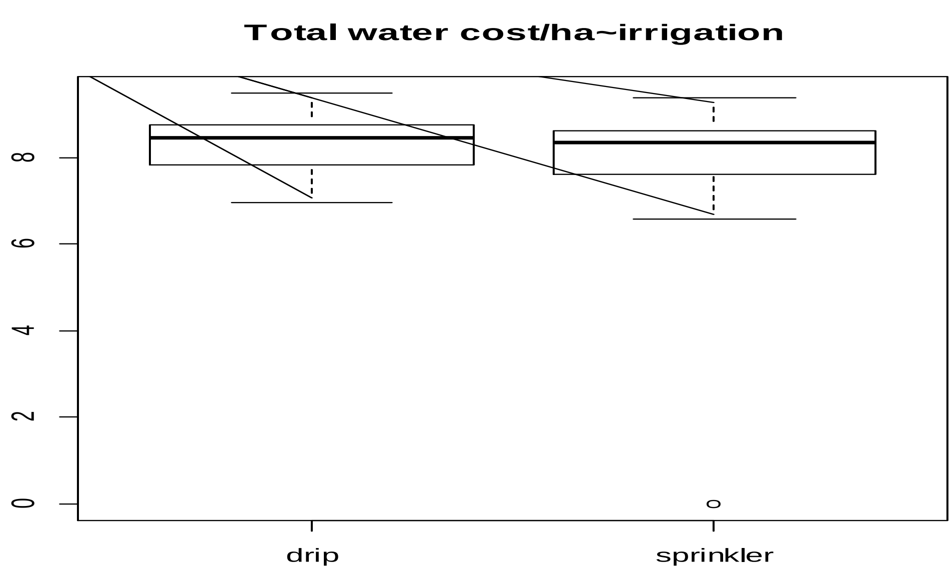



***Figure 8.*** *The relationship between irrigation system and total water cost per ha (log transformed), on three vegetable crops produced at North Central Namibia.*

## 3.3 Farmer's perceptions on efficient irrigation system

A broad question on farmers perceptive on irrigation system efficiency was included in an interview aimed at capturing farmers' ideas or opinions on the irrigation system efficiency between drip and sprinkler adaptable to Namibian environment. Efficiency questions were asked based on the ability of irrigation system to cope with water scarcity, high-temperature environment and ability to be easily adapted and give good harvest yield to farmers with unequal resources distribution. This was a tool to make farmers understand irrigation efficiency.

After talking to all 69 interviewed farmers on irrigation efficient irrigation that suit the Namibian (North central) environment, 45 (65.2%) farmers chosen drip irrigation,12 (17.4%), and 12 (17.4%) indicated that both drip and sprinkler are efficient *(see figure 8 below).*

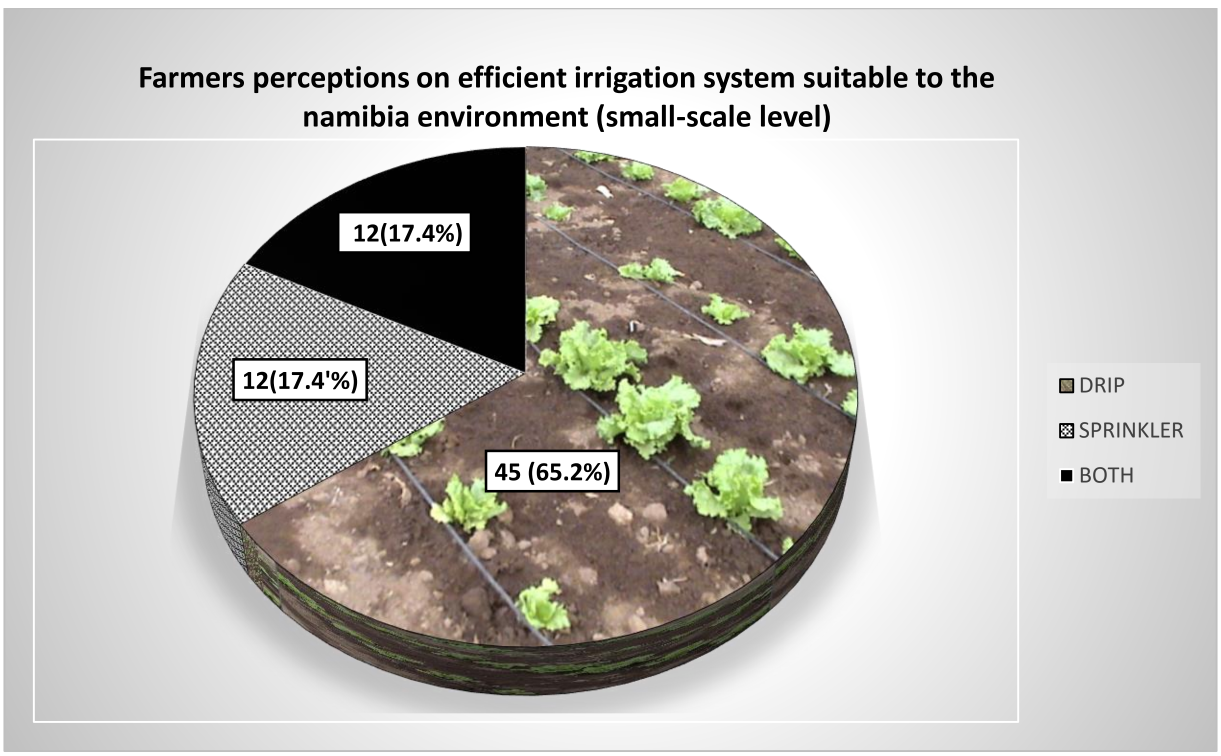



***Figure 9.*** *Pie chart showing the proportions of farmers who indicated the favorite irrigation system which suitable to the Namibian environment (North Central Namibia).*

# 4. Discussion

## 4.1 Irrigation production efficiency

Among the objectives of the study, was to compare relationship or effects of various factors, namely; farmers age, production inputs costs (water, fertilizer, labour and chemicals), types of fertilizer used (kraal manure or inorganic fertilizer), hectare size of land planted, stakeholder inputs, and agricultural soil management practices, on irrigation production efficiency on three vegetable crops (tomato, cabbage and pepper) produced under two types of deficit irrigation systems (drip and sprinkler irrigation system) at North Central Namibia. As many others stated that irrigation production yield efficiency has proven success on various crops including vegetables, produced under drip and sprinkler irrigation, whereby the production efficiency and high economic return in vegetables is enhanced through the amount of water used, input costs, agricultural soil management practices, farmers age, just to mention some, stated factors(Bergez, Garcia, & Lapasse, 2004; Costa et al., 2007; De Pascale et al., 2011; M. Imtiyaz et al., 2000; Kang et al., 2000; Miller & Hang, 1980). Moreover, (Oktem et al., 2003) revealed that efficiency is more like associated with drip relative to sprinkler irrigation, other studies contradicts these findings, that there no statistical difference between crop production efficiency between drip and sprinkler irrigation systems (Stegman, 1982).

This study has shown that, water (measured by cost the cost water used in the crops production) have shown positive effect on production efficiency of all three vegetable crops grown under both irrigation systems, high water cost means, more water irrigated to crops, the high irrigation efficiency *(Table, 3, 4 & 6).* This means that water irrigated to plants increase the production efficiency of tomatoes, cabbage, and pepper under both irrigation system. Several studies by Musik et al., 1976; Singh, 1987; Stone et al, 2000; Farah et al., 1997; Howell et al 1997; Tiwari & Reddy, 1997; cited in:M Imtiyaz et al. (2000), revealed similar findings, but stipulated that production efficiency depends on the irrigation type used, and pedoclimatic condition such as; soil and climate. On the contrary, other studies revealed that excess water can lead to poor aeration and nutrients leaching resulting in a decline in irrigation production efficiency, consequently poor economic return (M. Imtiyaz et al., 2000). Furthermore, Tiwari, Mal, Singh, and Chattopadhyay

(1998) stated that production efficiency can be attained under drip irrigation since economic wise it utilizes water to an extent of 87% without causing yield loss.

According to the study findings; fertilizer was also another important determinant factor besides water on irrigation production efficiency of all crops produced under all irrigation except no effect was found on pepper production under sprinkle irrigation *(Table 3, 4 and 6)*, means other than pepper under sprinkler irrigation fertilizer increase the production efficiency of all three vegetable crops produced under both drip and sprinkler**.** Chemical use has a positive effect only on production efficiency of tomato under drip irrigation compared cabbage and pepper under a sprinkler irrigation system. It seems the use of chemical (pesticides) can increase irrigation production efficiency more on tomato under drip irrigation with no effects on other two crops under the same irrigation system, on the contrary, it also increases efficiency only on cabbage and pepper under sprinkler irrigation.

Mulching as the type soil management practice, the age of farmer and stakeholder visit affect positively production efficiency of tomato and cabbage produced under drip irrigation, but no relationship found under sprinkler irrigation. Angula et al., (2014) also found age as a critical factor in the agribusiness study area. Regarding the age of the farmer, it shows that production efficiency increase with the age of the farmer growing tomato only under drip irrigation system *(Table 5).* Contrarily,Karagiannis, Tzouvelekas, and Xepapadeas (2003) stated that;

> *Irrigation production efficiency is expected to increase at the young age of the farmer and continue increasing, eventually will decline as the farmer approach retirement age. This is associated with technical and managerial efficient among young farmers, therefore their practical skills will keep on improving (p. 69).*

Hence, with this said, age is expected to have effect on both crops under both irrigation systems. This study have, revealed that farming advices and information from different stakeholders such as; agricultural extension officer, farmer, private and state owned organizations' (i.e. AMTA can have an influence on farmers' irrigation production efficiency of tomato production under drip irrigation. They help also in technical and input management of both farming and irrigation system (Karagiannis et al., 2003).

The study expected land size (planted ha) to have a positive significant effect on irrigation production efficiency of all three vegetables under all irrigation systems, however, it was found only to have a positive influence on cabbage grown only under sprinkler irrigation system *(Table 3).* These findings differ from a recent study conducted in the same area by (Angula, Thomas, & Ijambo, 2014) which indicated "plot size as among important factors found to encourage farmers to participate in this agri-business project". Pair et al. (1975), stated that an increase in land size does not decrease sprinkler irrigation efficiency. On the contrary; M Imtiyaz et al. (2000) wrote that a large land size might affect crop production both on production, technical and irrigation water efficiency which results due to unequal incentives and information distribution among farmers. It seems this under two irrigation system results might be due to the lack of inequality and skills in production inputs and management. For example; a farmer can have large field but due to the lack of skills or insufficient production inputs such as; money to buy fertilizer, to buy fuel for water pumping (Olushandja farmers), timing of fertilizer application and crop watering can be a contribution factors to insignificance of land size to the crops production efficiency under drip and sprinkler at NCN.

It seems that irrigation production efficiency depends on both technical, innovations and management inputs resources. This means that irrigation water source and input intensification have played a major role in efficiency. Farmers that irrigate their plants using a controlled irrigation system and better inputs management specifically in Etunda irrigation system tend to be more irrigation production efficient than farmers in Olushandja who are mostly on their own. Karagiannis et al. (2003), found a negative relationship between intensification and irrigation water efficiency which may explains their strong complementary in production.

## 4.2 Water use efficient irrigation system

The second aim of the study was to assess the efficient water use irrigation system suitable to farm with, at small-scale level in North Central Namibia. The results of this objective are based on two sections; (1) AIC model, which was measured by effects of irrigation systems have on total output per ha, and (2) farmers opinions (efficiency perceptions on irrigation system suitable to Namibian environment).

As recommended and revealed by several studies that WUE can be achieved through irrigation techniques such as deficit irrigation systems (Costa et al., 2007; Kang et al., 2000; Kirda, 2002), more specific on arid and semi-arid regions (Jackson et al., 2001). Literature by FAO (2002) revealed that via regulated technique such as deficit irrigation, it minimized crop water demand with less influence on crop yield; it further stated that water used efficiency for high crop yield can be enhanced per unit of irrigated water applied to crops.

### 4.2.1 WUE based on AIC output/ha on water cost and irrigation system

The study found that total water cost per ha have a significant effects, but no effects were found on irrigation system, neither on the interaction (total water cost*irrigation system) on vegetable crops total output (N$/ha), *(Figure 7, 6 & 7);* this means crops yield increase with water applied to crops but does not depend on any type of irrigation system. Stegman (1982), also revealed no statistical yield differences observed among drip and sprinkler irrigation system, even though they differ in WUE.

The relationship between irrigation systems was found to be not significant *(Figure 8),* means water use does not vary between drip and sprinkler irrigation based on results from farmers at north central Namibia. Both sprinkler and drip can equally apply same water to their crops; these findings differ from several findings by scientists, that stated that drip irrigation is more water efficient over 95% (Postel, 1998), 87% (Sivanappan et al., 1987; cited inTiwari et al., 1998) relative to sprinkler environment. Even though drip irrigation is expected to use less water, since water is directed to crops, and moisture is maintained, I believe the results of this study is more influenced by several factors such as; hot Namibian climatic environment, inequality in resources or incentives; purchase efficient or manage irrigation system (this apply specific to drip farmers since they are on their own, with less or no production subsidies, relative to sprinkler who are under government irrigation project), the lack of technical or managerial skills are all factors that might lead insignificance between the two irrigation system (no difference in water use efficiency between drip and sprinkler).

### 4.2.2 Farmers opinions on efficient irrigation system

Study findings on the efficient irrigation system that suit vegetable production at North-central Namibia environment revealed that; among overall interviewees farming through both drip and sprinkler, 65.2% have indicated drip irrigation as suitable and more efficient irrigation system than sprinkler irrigation. They based their opinions on the followings; comparable to sprinkler irrigation, drip uses less water (less production cost, conserve water), associated with few pests (weeds, insects and diseases such as; fungal diseases and cracking in tomato production). Based on their past and present experience they highlighted a huge difference in harvest or crop yield between the two irrigation systems; sprinkler harvest (in Etunda) is less relative to other farmers using drip in Olushandja, even though this contradicted the statistical findings from the study which has indicated no variation or difference between the two irrigation systems *(Figure 5).* Further outcomes indicated that 17.4% of farmers have different opinions that sprinkler irrigation is more favorable than drip (due to perceptions that drip does not suit poor soil quality, commonly found in Etunda), while other 17.4% of farmers indicated that both drip and sprinkler are efficient due to their ability suit different crops *(Figure 9).* Farmers with positive perceptions on both two irrigation systems are based on the suitability for farmers with cropping diversification system (i.e., field crops and vegetables), since sprinkler is more favorable with crops that require more water such as; cabbage, and maize relative to drip which is suitable for crops like tomatoes.

Results based on farmers perceptions (drip is efficient than sprinkler) go hand in hand with findings from several works of literature. Dasberg and Or (2013), revealed that field application efficiency of drip irrigation can be higher as 90% relative to 60-80% of the sprinkler. This is associated with the ability to maintain an optimal balance between soil water and aeration, reduction in evapotranspiration, runoff and nutrients leaching (Caswell & Zilberman, 1986; Dasberg & Or, 2013; Postel, 1998). Further, they revealed that drip requires less energy, and is adaptable to soil pathogens and plant pathogen incubation. The study by (Caswell & Zilberman, 1986) stated that drip conserves water and increase yield as growers become more experienced with the technology. In contrast, sprinkler lower air temperature around growing plants, reduce water stress and transpiration. Despite, both drip and sprinkler are adaptable to area with relative land quality and water scarcity (expensive water environment), (Caswell & Zilberman, 1986).

## 4.3 Study limitation

There are about 120 small-scale farmers involved in the horticultural production and only about 45% were interviewed, the sample might be not sufficient to give clear evidences between the two irrigation systems. Further, the Namibian vegetable industry is not well developed this was a major limitation in measuring water use efficiency of irrigation systems between drip and sprinkler irrigation systems, due to lack of several data and records such as; lack of evapotranspiration data for different vegetables (which also require time, I believe an experimental study is needed for accurate measurements of production irrigation efficiency between the two irrigation systems), lack rainfall records among farmers (specifically Olushandja farmers), hence, this have resulted in making use of production input costs such as; water, chemical, labour, and fertilizer among other factors as an available alternative to estimate the water use efficiency of the irrigation systems.

# 5. Conclusion and recommentations

## 5.1 Conclusion

The study concluded that production input costs; fertilizer and water are very important determinant of irrigation production efficiency of all three vegetables on both irrigation systems. Irrigation production efficiency of vegetables under drip irrigation is high than vegetables under sprinkler irrigation, however drip farmers spend much in buying inputs than sprinkler irrigation farmers. Statistical results on total output per ha and irrigation system the relationship was not significant, neither the interaction between water and irrigation system was found to be significant. Furthermore relationship between water cost and irrigation system was not significant, and this leads to conclude that efficiency between the two irrigation system was found equal. Based on farmers perceptions, 65.2% interviewed have indicated drip irrigation as their prefarred efficient irrigation system suitable to the Namibian environment, whereby their perceptions are based on the advantages associated with drip; such as; good harvest, fewer pests, water conserving among others. Apart from mulching other agroecological soil practices were not found signifcant in this study. In conclusion; most findings of this studies are not inline with the expected findings.

## 5.2 Study Recommendations

With reference to this study statistical findings; which have revealed no difference on irrigation production efficiency of the crops between the two irrigation systems, and by considering the facts that input intensification and irrigation water source can play a major role in efficiency of resources use; I therefore concur with farmers perceptions that drip irrigation is or can be able to an efficient irrigation system favourable to Northern Central Namibia if these Olushandja small-scale farmers get assisted with input subsidies such as; fertilizer, land preparation and water, which other small-scale farmers in Etunda are getting from the government.

Agroecological soil practices are not commonly practiced by the small-scale farmers, the study also discovered that farmers make use of excessive chemicals (fertilizer and pesticide) which are very dangerous to the environment and exhaust their soil; therefore, the study, recommend relevant authorities such as; project management, extension officers, and farmers representatives to give practical skills to farmers on the importance of using agroecological practices for sustainable farming. As recommend by Pair et al., (1975) these practices be as can be easily used together with drip and sprinkler irrigation systems, make use of minimum water, help to maintain soil moisture and organic matter which eventually leads to efficient production.

This study also recommended further studies to focus on exploring further technology that can be integrated with the current deficit irrigation system or shift it to affordable precision agricultural technology such as; the use of automatic sensor to measure soil moisture and soil nutrients requirements, or and make utilizations of solar power as a cheap renewable energy source, these techniques have the ability to increase the production efficiency among small-scale farming, enhance food self-sufficient, and promote sustainable agriculture in Namibia.

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# 7. Appendices

## 7.1 Appendix I

### 7.1.1 Appendix I (A)

**R-script which Represent cabbage data under drip irrigation system (one of the example I used to test my hypothesis for irrigation production efficiency)**

```
library(gdata)
setwd("C:/A/THESIS DATA/DATA WITH BINOMIAL")
list.files()
irri=read.xls("DRIP WITH BINOMIAL.xlsx")
head(irri)
names(irri)
edit(irri)
attach(irri)
str(irri)
##########################################################################
irri$Age.=as.numeric(Age.) # since age is a factor variable i change it to numeric
attach(irri)
hist(prduction.efficiency.cabagge)# to check for normality assumption which is not fulfilled
irri$cabbage.production.efficiency=log(prduction.efficiency.cabagge+1)
attach(irri)
hist(cabbage.production.efficiency)#normality assumption is fullfiled
#####################################################################
m1=lm(cabbage.production.efficiency~Age.+sex+X.fertilizer.+Planted.haC+Fert.cost.C.+C.water.cost+productionyield.headsC +labourcost.C
+chemical.cost.+stakeholders.+pestscontrol+tillageandharrow+mulching+minimumandnotill+weeding.thinning.prunning.+Crotationandintercrop
)
#################
par(mfrow=c(2,2))
plot(m1)
install.packages("car",dependencies=TRUE)
library(car)
qqPlot(m1)     #linearly distribution assumption not fullfilled
spreadLevelPlot(m1)
###################################################################################################
par(mfrow=c(3,6))
plot(cabbage.production.efficiency~Age.,pch=16)
plot(cabbage.production.efficiency~sex,pch=16)
plot(cabbage.production.efficiency~X.fertilizer.,pch=16)
plot(cabbage.production.efficiency~Planted.haC,pch=16)
plot(cabbage.production.efficiency~Fert.cost.C.,pch=16)
plot(cabbage.production.efficiency~C.water.cost,pch=16)
```

```
plot(cabbage.production.efficiency~labourcost.C,pch=16)
plot(cabbage.production.efficiency~chemical.cost.,pch=16)
plot(cabbage.production.efficiency~productionyield.headsC,pch=16)
plot(cabbage.production.efficiency~stakeholders.,pch=16)
plot(cabbage.production.efficiency~pestscontrol,pch=16)
plot(cabbage.production.efficiency~tillageandharrow,pch=16)
plot(cabbage.production.efficiency~mulching,pch=16)
plot(cabbage.production.efficiency~minimumandnotill,pch=16)
plot(cabbage.production.efficiency~weeding.thinning.prunning.,pch=16)
plot(cabbage.production.efficiency~Crotationandintercrop,pch=16)
########################################################################
panel.cor <- function(x, y, digits=2, prefix="",cex.cor)  #check correlation plot
{
 usr <- par("usr"); on.exit(par(usr))
 par(usr = c(0, 1, 0, 1))
 r <- abs(cor(x, y))
 txt <- format(c(r, 0.123456789), digits=digits)[1]
 txt <- paste(prefix, txt, sep="")
 if(missing(cex.cor)) cex <- 0.8/strwidth(txt)
 text(0.5, 0.5, txt, cex = cex * r)
}
panel.hist <- function(x, ...)
{
  usr <- par("usr"); on.exit(par(usr))
  par(usr = c(usr[1:2], 0, 1.5) )
  h <- hist(x, plot = FALSE)
  breaks <- h$breaks; nB <- length(breaks)
  y <- h$counts; y <- y/max(y)
  rect(breaks[-nB], 0, breaks[-1], y, col="cyan", ...)
}
###########################################################Pairplot to test correlation among variables
pairs(cabbage.production.efficiency~Age.+sex+X.fertilizer.+Planted.haC+        Fert.cost.C.+C.water.cost+productionyield.headsC+labourcost
+chemical.cost.+stakeholders.+pestscontrol+tillageandharrow+mulching+minimumandnotill+weeding.thinning.prunning.+Crotationandintercrop,
lower.panel=panel.smooth,upper.panel=panel.cor,diag.panel=panel.hist)
#########################################################started to log transform variables with bad distribution and out layers
(water cost, labour cost, and chemical costs)
par(mfrow=c(2,2))
hist(C.water.cost)
irri$Cabbage.watercost=log(C.water.cost+1)
attach(irri)
hist(Cabbage.watercost)
#####################################################
hist(labourcost.C)
irri$labourcost.Cabbabe=log(labourcost.C+1)
attach(irri)
hist(labourcost.Cabbabe)
##########
```

irri$chemicalcost.cabbage=log(chemical.cost.+1)

attach(irri)

hist(chemical.cost.)

hist(chemicalcost.cabbage)

###########################################################

m1=lm(cabbage.production.efficiency~Age.+sex+X.fertilizer.+Planted.haC+Fert.cost.C. +Cabbage.watercost+productionyield.headsC +labourcost.Cabbabe+chemicalcost.cabbage+stakeholders.+pestscontrol+tillageandharrow+mulching+minimumandnotill+weeding.thinning.prunning.+Crotationandintercrop)

influencePlot(m1)

qqPlot(m1)

spreadLevelPlot(m1)

vif(m1)

#########removed aliased variables(weeding.thinning.prunning.pestscontrol++tillageandharrow+minimumandnotill) to get a vif(m1)

**m1**=lm(cabbage.production.efficiency~Age.+sex+X.fertilizer.+Planted.haC+Fert.cost.C.+Cabbage.watercost+productionyield.headsC +labourcost.Cabbabe+chemicalcost.cabbage+stakeholders.+mulching+Crotationandintercrop)

################################################################ checked for value inflation factors of predictor variables

vif(m1)#was bad have to remove chemicalcost.cabbage due to high vif(195.645187)

| Age. | sex | X.fertilizer. | Planted.haC | Fert.cost.C. | Cabbage.watercost |
|---|---|---|---|---|---|
| 3.553284 | 1.279821 | 2.898388 | 5.671494 | 6.665773 | 92.052295 |

| productionyield.headsC | labourcost.Cabbabe | chemicalcost.cabbage | stakeholders. | mulching | Crotationandintercrop |
|---|---|---|---|---|---|
| 2.830389 | 80.320853 | 195.645187 | 2.652549 | 3.321018 | 1.355567 |

**m1**=lm(cabbage.production.efficiency~Age.+sex+X.fertilizer.+Planted.haC+Fert.cost.C.+Cabbage.watercost+productionyield.headsC +labourcost.Cabbabe+stakeholders.+mulching+Crotationandintercrop)

vif(m1)#still bad labourcost.Cabbabe(39.341591 ) have to been removed

| Age. | sex | X.fertilizer. | Planted.haC | Fert.cost.C. | Cabbage.watercost |
|---|---|---|---|---|---|
| 2.006447 | 1.279758 | 2.886015 | 2. 903893 | 5.062325 | 36.655166 |

| productionyield.headsC | labourcost.Cabbabe | stakeholders. | mulching | Crotationandintercrop |
|---|---|---|---|---|
| 2.043882 | 39.341591 | 2.079080 | 2.895667 | 1.203122 |

m1=lm(cabbage.production.efficiency~Age.+sex+X.fertilizer.+Planted.haC+Fert.cost.C.+Cabbage.watercost+productionyield.headsC +stakeholders.+mulching+Crotationandintercrop)

**vif(m1)#ok now see below**

| Age. | sex | X.fertilizer. | Planted.haC | Fert.cost.C. | Cabbage.watercost |
|---|---|---|---|---|---|
| 1.777992 | 1.279692 | 2.656808 | 2.899219 | 4.866918 | 4.354389 |

| productionyield.headsC | stakeholders. | mulching | Crotationandintercrop |
|---|---|---|---|
| 1.658045 | 2.073970 | 2.895583 | 1.189536 |

m1=lm(cabbage.production.efficiency~Age.+sex+X.fertilizer.+Planted.haC+Fert.cost.C.+Cabbage.watercost+productionyield.headsC +stakeholders.+mulching+Crotationandintercrop)

**drop1(m1,test="F")**

#drop Age. with P value= 0.5349368

**m2**=lm(cabbage.production.efficiency~sex+X.fertilizer.+Planted.haC+Fert.cost.C.+Cabbage.watercost+productionyield.headsC +stakeholders.+mulching+Crotationandintercrop)

**drop1(m2,test="F")**

#drop **X.fertilizer.** with P value= 0.521363

**m3**=lm(cabbage.production.efficiency~sex +Planted.haC+Fert.cost.C.+Cabbage.watercost+productionyield.headsC+stakeholders.+mulching +Crotationandintercrop)

**drop1(m3,test="F")**

#drop Planted.haC with P value= 0.329683

**m4**=lm(cabbage.production.efficiency~sex+Fert.cost.C.+Cabbage.watercost+productionyield.headsC +stakeholders.+mulching+Crotationandintercrop)

**drop1(m4,test="F")**

#drop sex with P value= 0.29747

m5=lm(cabbage.production.efficiency~Fert.cost.C.+Cabbage.watercost+productionyield.headsC +stakeholders.+mulching+Crotationandintercrop)

**drop1(m5,test="F")**

#drop stakeholders. with P value= 0.102879

**m6**=lm(cabbage.production.efficiency~Fert.cost.C.+Cabbage.watercost+productionyield.headsC+mulching+Crotationandintercrop)

drop1(m6,test="F")

#drop Crotationandintercrop with P value=0.144933

m7=lm(cabbage.production.efficiency~Fert.cost.C.+Cabbage.watercost+productionyield.headsC+mulching)

**drop1(m7,test="F") #MODEL BECAME SIGNIFICANT**

Model:7= lm(cabbage.production.efficiency ~ +Fert.cost.C. + Cabbage.watercost + productionyield.headsC + mulching)

| | Df | Sum of Sq | RSS | AIC | F value | Pr(>F) |
|---|---|---|---|---|---|---|
| <none> | | | 10.101 | -5.3693 | | |
| Fert.cost.C. | 1 | 5.9887 | 16.090 | 2.4070 | 9.4860 | 0.007175 ** |
| Cabbage.watercost | 1 | 30.6408 | 40.742 | 21.9175 | 48.5344 | 3.176e-06 *** |
| productionyield.headsC | 1 | 5.8551 | 15.956 | 2.2319 | 9.2744 | 0.007713 ** |
| mulching | 1 | 3.2954 | 13.397 | -1.4400 | 5.2199 | 0.036320 * |

---Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

**summary(m7)**

Call:

lm(formula = cabbage.production.efficiency ~ Fert.cost.C. + Cabbage.watercost + productionyield.headsC + mulching)

Residuals:

| Min | 1Q | Median | 3Q | Max |
|---|---|---|---|---|
| -1.7215 | -0.5852 | 0.2537 | 0.5323 | 0.9842 |

Coefficients:

| | Estimate | Std. Error | t value | Pr(>\|t\|) |
|---|---|---|---|---|
| (Intercept) | 6.395e-01 | 4.796e-01 | 1.333 | 0.20110 |
| Fert.cost.C. | -4.816e-04 | 1.564e-04 | -3.080 | 0.00718 ** |
| Cabbage.watercost | 6.718e-01 | 9.643e-02 | 6.967 | 3.18e-06 *** |
| productionyield.headsC | 2.267e-04 | 7.445e-05 | 3.045 | 0.00771 ** |
| mulching | -1.182e+00 | 5.174e-01 | -2.285 | 0.03632 * |

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 0.7946 on 16 degrees of freedom

Multiple R-squared: 0.8742, Adjusted R-squared: 0.8428

F-statistic: 27.8 on 4 and 16 DF, p-value: 5.013e-07

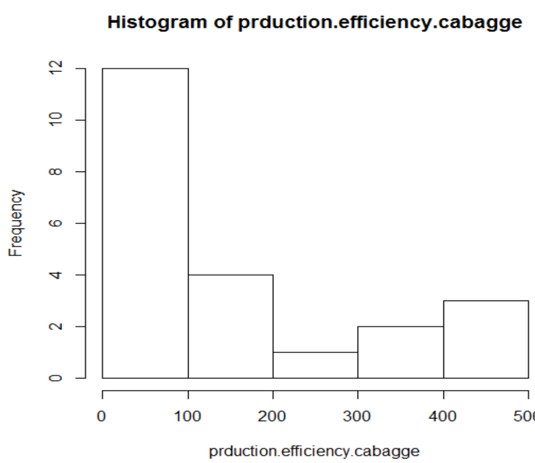
##########################################################################################

aDD BACH OTHER EARILER REMOVED VARIABLES(chemicalcost.cabbage, labourcost.Cabbabe# the model become insignificance#

7.1.2 Appendix I (B)

OUTPUTS FROM R- SRIPT (APPENDIX I) SHOWING HOW ASSUMPTIONS WAS TESTED UNDER AND DECICIONS TO TRANSFORM VARIABLES

**Normal distribution Assumption** which was tested through plotting a Histogram of a response variable **(irrigation production efficiency of all three vegetable crops in all irrigation systems),** which was not fulfilled there was bad distribution along x-axis, which therefore lead to be log-transform of the response variable in order to meet the Normality assumption.



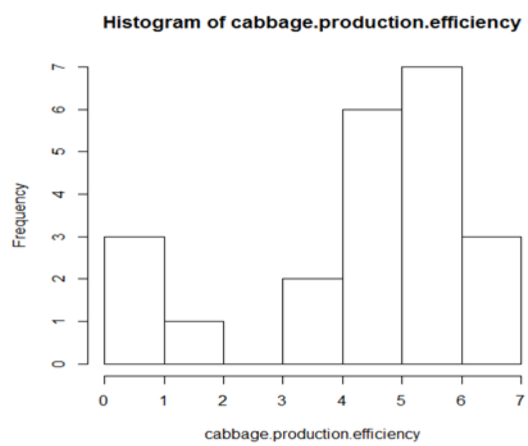
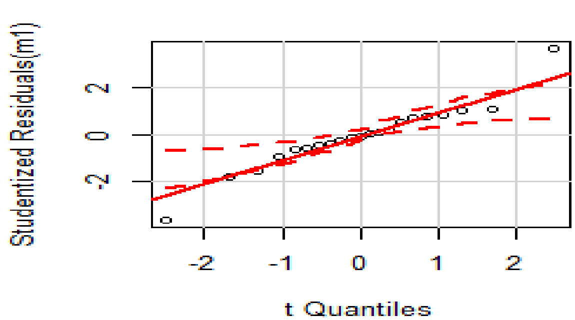




***Figure 1.*** *Histogram of production efficiency of cabbage under drip irrigation which does not fullfill normal distribution*

***Figure 2.*** *Normal distribution of a response variable after log transformed*



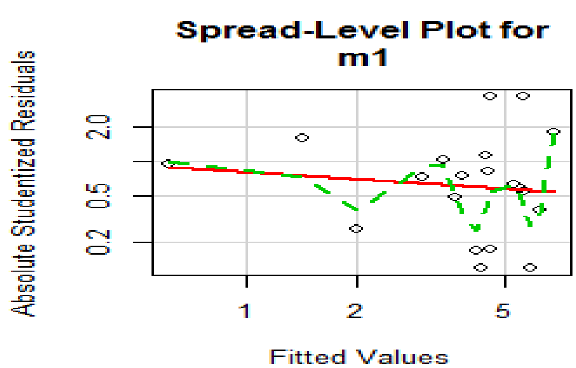




***Figure 3. (Left)*** *Q-Q plot showing the violation of normality and equal variance of the model m1 , and right shows spread level plot to test equal variance (for cabbage under drip irrigation).*

## Linearity assumption

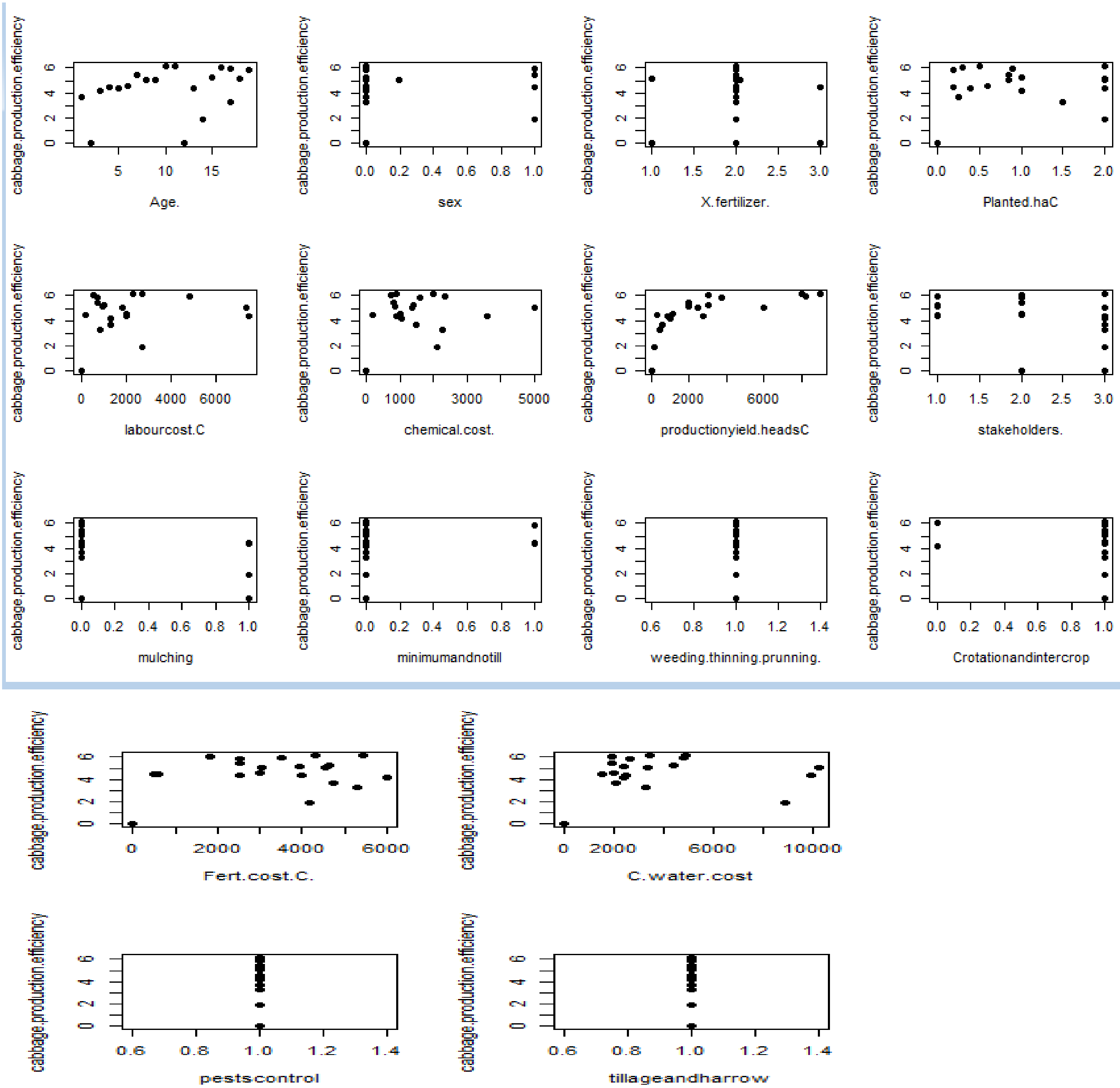



***Figure 4.*** *The linearity among predictor variables, three variables namely; labourcost.C, chemical.costT. and C.water.cost, does not fulfill the linearity assumption, (showing bad distribution along x-axis) therefore they were transformed due to they have big influential on a model.*

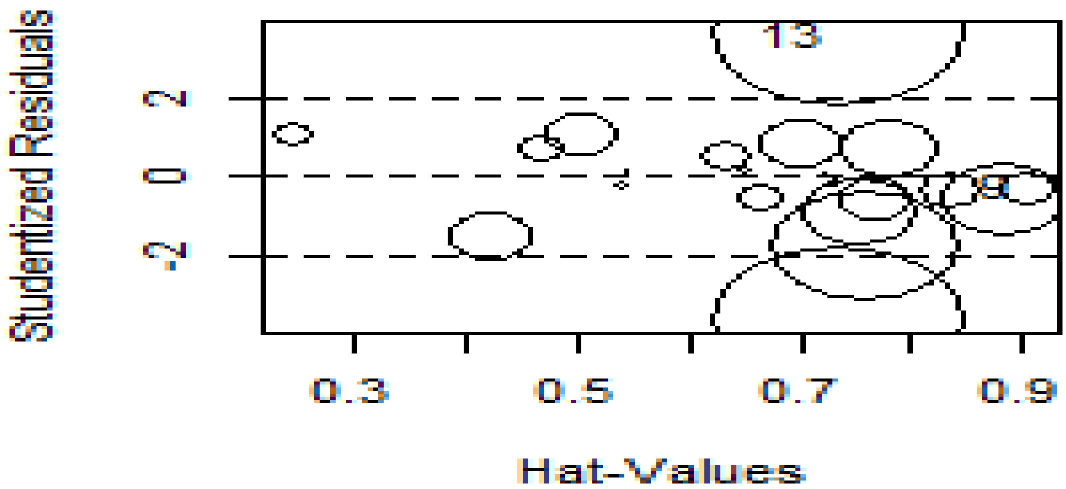



***Figure 5.*** *Influential plot for model (m1), before transformations of labourcost.C, chemical.costT. and C.water.cost.*

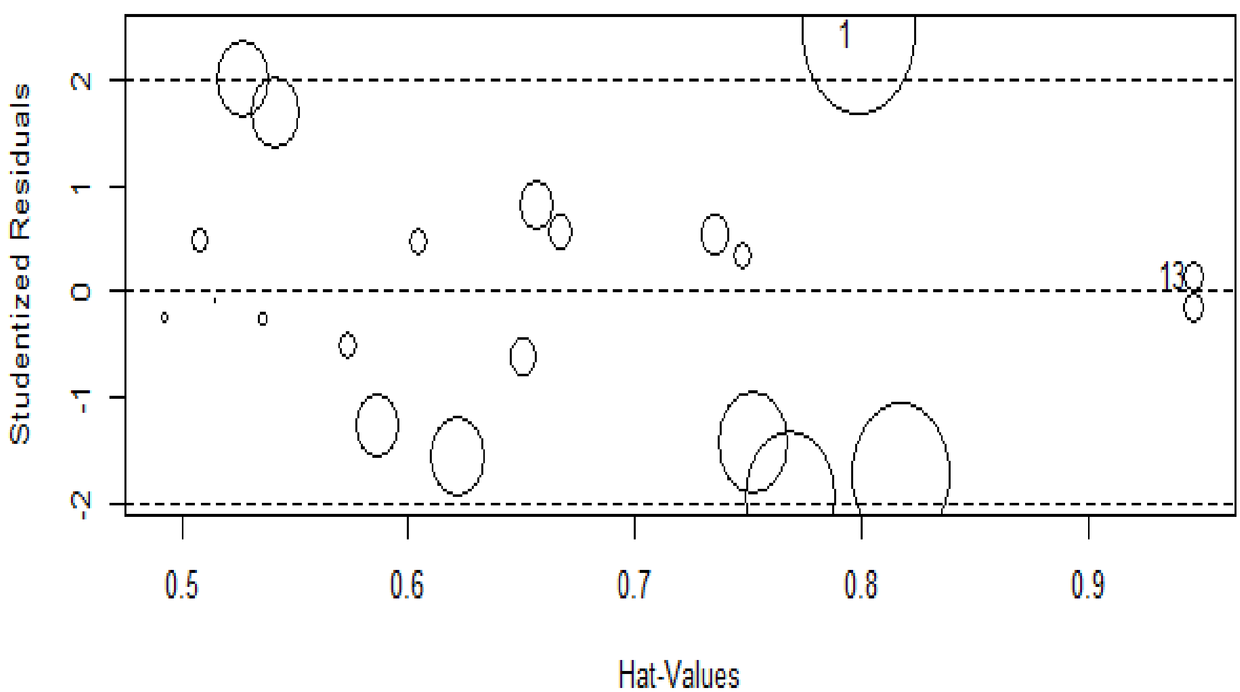



***Figure 6.*** *Influential plot for model (m1), before after transformations of labourcost.C, chemical.costT. and C.water.cost*

### 7.1.3 Appendix II

R script used to *measure the effects of total water cost and irrigation systems on output per ha* using AIC and Interactions

**SECTION ONE**

```
library(gdata)
setwd("C:/A/THESIS DATA/AIC 2 OBJECTIVE")
list.files()
eff=read.xls("WATER EFFICIENCY OBJECTIVE TWO.xlsx")
edit(eff)
names(eff)
attach(eff)
head(eff)
####################################################
m0=lm(Totaloutput.dollaprha~1)
m1=lm(Totaloutput.dollaprha~irrigation)
m2=lm(Totaloutput.dollaprha~Totalwatercost.ha)
m3=lm(Totaloutput.dollaprha~Totalchemcostprha)
m4=lm(Totaloutput.dollaprha~Totalfercost.ha)
m5=lm(Totaloutput.dollaprha~totallaboucst.prha)
m6=lm(Totaloutput.dollaprha~irrigation*Totalwatercost.ha)
m7=lm(Totaloutput.dollaprha~Totalwatercost.ha*irrigation+Totalwatercost.ha)
m8=lm(Totaloutput.dollaprha~Totalwatercost.ha*irrigation+irrigation)
m9=lm(Totaloutput.dollaprha~irrigation+Totalwatercost.ha+Totalchemcostprha+Totalfercost.ha+totallaboucst.prha+Totalwatercost.ha*i
rrigation+Totalwatercost.ha*irrigation+Totalwatercost.ha+Totalwatercost.ha*irrigation+irrigation)
AIC(m0)
AIC(m1)
AIC(m2)
AIC(m3)
AIC(m4)
AIC(m5)
AIC(m6)
AIC(m7)
AIC(m8)
AIC(m9)
ALLAIC=c(AIC(m0),AIC (m1),AIC(m2),AIC(m3),AIC(m4),AIC(m5),AIC(m6),AIC(m7),AIC(m8),AIC(m9))
ALLAIC
deltaAIC=ALLAIC-min(ALLAIC)
deltaAIC
B=exp(-0.5*deltaAIC)
AICweight=B/sum(B)
AICweight
#######################################################> # My BEST MODEL m4# WITH LOW AIC
 m4=lm(Totaloutput.dollaprha~Totalfercost.ha)
 library(lsmeans)
Loading required package: estimability
 lsmeans(m4,~Totalfercost.ha)
 Totalfercost.ha  lsmean         SE            df        lower.CL       upper.CL
                  7434.928       31987.63 3822.86 60 24340.78     39634.49
Confidence level used: 0.95
par(mfrow=c(2,2))
plot(m4)


#######################################################
```

**SECTION TWO**

```
hist(Totaloutput.dollaprha)# NORMALITY ASSUMPTION
Totaloutput.dollaprha=log(Totaloutput.dollaprha+1)
hist(Totaloutput.dollaprha)
m1=lm(Totaloutput.dollaprha~irrigation)
library(lsmeans)
lsmeans(m1,~irrigation)
 irrigation     lsmean     SE            df     lower.CL     upper.CL
```

| | | | | | |
|---|---|---|---|---|---|
| drip | 9.767380 | 0.3336060 | 60 | 9.100069 | 10.43469 |
| sprinkler | 9.923856 | 0.2387545 | 60 | 9.446276 | 10.40144 |

Confidence level used: 0.95

OR

m1=lm(Totaloutput.dollaprha~irrigation)

boxplot(Totaloutput.dollaprha~irrigation,xlab="irrigation",+ ylab="Totaloutput.dollaprha",main="Total output/ha~irrigation")

anova(m1)

Analysis of Variance Table

Response: Totaloutput.dollaprha

| | Df | Sum Sq Mean | Sq | F value | Pr(>F) |
|---|---|---|---|---|---|
| irrigation | 1 | 0.34 | 0.34002 | 0.1455 | 0.7042 |
| Residuals | 60 | 140.23 | 2.33715 | | |

##########################################################################################################

**m2=lm(Totaloutput.dollaprha~Totalwatercost.ha)**

library(lsmeans)

lsmeans(m2,~Totalwatercost.ha)

| Totalwatercost.ha | lsmean | SE | df | lower.CL | upper.CL |
|---|---|---|---|---|---|
| 4614.01 | 9.870856 | 0.1799021 | 60 9.510999 | 10.23071 | |

**Confidence level used:** 0.95

> plot(m2)

> m2=lm(Totaloutput.dollaprha~Totalwatercost.ha)

> boxplot(Totaloutput.dollaprha~Totalwatercost.ha, xlab="Totalwatercost.ha",main="Total output/ha~ Total water cost/ha") ,ylab="Totaloutput.dollaprha")

OR

anova(m2)# a positive significant effect between total output per ha and water

Analysis of Variance Table

**Response:** Totaloutput.dollaprha

| | Df | Sum Sq Mean | Sq | F value | Pr(>F) |
|---|---|---|---|---|---|
| Totalwatercost.ha | 1 | 20.172 | 20.1723 | 10.053 | 0.002396 ** |
| Residuals | 60 | 120.397 | 2.0066 | | |

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

> #######################################################################################################

> m6=lm(Totaloutput.dollaprha~irrigation*Totalwatercost.ha) #####TEST FOR INTERACTION

> boxplot(Totaloutput.dollaprha~irrigation*Totalwatercost.ha,xlab="irrigation*Totalwatercost.ha"+ ,ylab="Totaloutput.dollaprha",main="Total output/ha~irrigation*Total water cost/ha")

**anova(m6)**

**Analysis of Variance Table**

Response: Totaloutput.dollaprha

| | **Df** | **Sum Sq** | **Mean Sq** | **F value** | **Pr(>F)** |
|---|---|---|---|---|---|
| irrigation | 1 | 0.340 | 0.3400 | 0.1665 | 0.684744 |
| Totalwatercost.ha | 1 | 21.099 | 21.0992 | 10.3317 | 0.002138 ** |
| irrigation:Totalwatercost.ha | 1 | 0.684 | 0.6836 | 0.3348 | 0.565111 |
| Residuals | 58 | 118.446 | 2.0422 | | |

---Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

##############################################################################

**<u>SECTION THREE</u>**

hist(Totalwatercost.ha) **# TO TEST THE NORMALITY ASSUMPTION**

Totalwatercost.ha=log(Totalwatercost.ha+1)**# response variable transformed to fit normality assumption**

m10=lm(Totalwatercost.ha~irrigation) **#** Test relationship between irrigation system and total water cost/ha (hypothesis test for **objective 2)**

boxplot(Totalwatercost.ha~irrigation,main="Total water cost/ha~irrigation")

**anova(m10)**

**Analysis of Variance Table #** showing no significant relationship

Response: **Totalwatercost.ha**

| | Df | SuSq Mean | Sq | F value | Pr(>F) |
|---|---|---|---|---|---|
| **irrigation** | 1 | 1.449 | 1.4488 | 0.9328 | 0.338 |
| Residuals | 60 | 93.194 | 1.5532 | | |

## 7.2 Appendix III

***STRUCTURED QUESTIONNAIRE***

***Hedmark University of Applied Sciences (****Høgskolen i Hedmark****,*** *Campus Blæstad****), Norway***

Faculty of Applied Ecology and Agricultural Sciences

***DISCIPLINE: Master (MSc) in Sustainable Agriculture***

**Questionnaire on Irrigation Systems**

*I 'am Simon Haidula, a 2nd (final) year MSc. student in Sustainable Agricultural, from Hedmark University College (Campus Blæstad) in Norway. The aim is to fulfil my MSc. Thesis program, my topic of focus is;* ***"Water use efficiency and crop yield assessment on Sprinkler and Drip irrigation system at North Central Namibia"*** *(Etunda irrigation project and Olushandja area). I would appreciate your answering these questions as the information you provide will be much useful to my study, and i assure you, all information will be treated confidential, will only be used for the study purpose. I would like to emphasize that your responses will be extremely valuable to me and my Hedmark University at large, hence i would greatly appreciate your inputs by answering all questions.*

**INSTRUCTION**

PLEASE ANSWER THE FOLLOWING QUESTIONS BY CROSSING THE RELEVANT BLOCK OR WRITING DOWN YOUR ANSWER IN THE SPACE PROVIDED.

**EXAMPLE of how to complete this questionnaire:**

Your Irrigation system? Drip ☒
If you are using Drip irrigation:
Sprinkler ☐

**Name of the Interviewer: ________________________________________**

**Questionnaire number: ________**

**Survey date: ___________________________**

## SECTION1: INFORMATION OF THE FARMER & FARMING AREA DESCRIPTION

1. **Respondent name** ______________________

2. **Sex:** Male [0] female [1]
3. **Age** …………………………….

4. **Farming (Field) area**

| | |
|---|---|
| Etunda irrigation project | 0 |
| Olushandja area | 1 |

5. **Irrigation type**

| | |
|---|---|
| Drip | 0 |
| Sprinkler | 1 |
| **Others** | **2** |

6. **Farming crops**

| | |
|---|---|
| Tomato | 0 |
| pepper (green and red), | 1 |
| Cabbage | 2 |

Others (specify)
_____________________________________________________________________________

7. **Size of farm land** ……………………… **ha**

**SECTION 2 PRODUCTION INPUTS & OUTPUTS**
**2.1)** a) **Production inputs**

| Crop | Water cost | | Fertilizer cost (N$/ha) | | Chemical cost (N$/ha) | Labour cost (N$ per $m^3$ or liter ) |
|---|---|---|---|---|---|---|
| | $M^3$ or Liters/ha | N$/ha | Organic | inorganic | | |
| Tomato | | | | | | |
| Pepper | | | | | | |
| cabbage | | | | | | |
| other | | | | | | |

b) **What is the water pump capacity?** ………………………………….

**2.2) a) Production market yield (outputs)**

| Outputs | | Kg/ha | Heads/ha | Production income (N$) | |
|---|---|---|---|---|---|
| Tomato | | | | | |
| Pepper | | | | | |
| Cabbage | | | | | |
| Others | | | | | |

**b) How long does it take to harvest your crops?**

| Months | < 4 months | 4 months | ➢ 4 months |
|---|---|---|---|
| Tomato | 0 | 1 | 2 |

| | | | |
|---|---|---|---|
| Pepper | 0 | 1 | 2 |
| Cabbage | 0 | 1 | 2 |
| Others | 0 | 1 | 2 |

**SECTION 3: INTERNAL AND EXTERNAL FACTOR INFLUENCE**

**3.1** a) **Agricultural practices**

| Tillage | minimum tillage | No tillage | Mulching | Crop rotation | Weeding | monoculture | Others………………… |
|---|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |

b) **Pests experienced?**

| Diseases | Weeds | Insects |
|---|---|---|
| 0 | 1 | 2 |

c) **Does the irrigation system used increase pest attack on crops?** *(Farmer opinions)*

| Yes | No |
|---|---|
| 1 | 0 |

d) **Pests' control**

| Chemical | Biological |
|---|---|
| 1 | 2 |

**3.2** a) **Do you receive assistance from the following stakeholders?**

| STAKEHOLDER NAME | Extension officer | Project manager /Farmer association coordinator | NGO (name) | Others………………….. |
|---|---|---|---|---|
| | 1 | 2 | 3 | 4 |

b) **Number of Visit per year?**

| 1-2 times | 3-4 times | ➢ 4 times |
|---|---|---|
| 1 | 2 | 3 |

c) **During their visit, do they provide you with any, information advice or assistance regarding irrigation system?**

| Yes | NO |
|---|---|
| 1 | 2 |

d) **How satisfied are you with the stakeholder's assistance on irrigation system?**

| Very satisfactory | Satisfactory | Not satisfactory |
|---|---|---|
| 1 | 2 | 3 |

**SECTION 4: GENERAL QUESTIONS**

4.1) **Does the irrigation system improve your vegetable production yield time to time** (every production season)?

| | |
|---|---|
| Yes | 1 |
| No | 2 |

4.2) **Farmer satisfaction on the irrigation system he or she uses** (inputs vs. outputs)

| 0 | 1 | 2 |
|---|---|---|
| Not satisfied | Satisfied | Very satisfied |

4.3) **If not satisfactory, reasons why compared to other**

**…………………………………………………………………………………………………………………………………………………………**
**……………………………………………………………………………………………………………………………………………………………………**
**……………………………………………………………………………………………………………………………………………………**

4.4) **Farmer opinions on irrigation system water use efficiency?** *(Explain to the farmer the meaning of efficiency)*

| Efficient | Not efficient |
|---|---|
| 1 | 2 |

4.7) Namibia is one of the driest country in the world, characterized by water scarcity (low rainfall and very hot temperature); **which irrigation system you think is suitable to the Namibian environment** (farmers opinions on irrigation system)? *(Brief farmer on advantages of the two irrigation systems)*

| Drip | sprinkler |
|---|---|
| 0 | 1 |

Reasons on irrigation efficiency (why one is efficient than the other)
……………………………………………………………………………………………………………………………………………………………………
……………………………………………………………………………………………………………………………………………………………………
……………………………………………………………………………………………………………………………………………………………………

4.5) Farmer future optimistic on- likely to install **drip irrigation**

| yes | No |
|---|---|
| 1 | 0 |

4.6**) If yes, when in future?**

| < 5 years | 5 years | ➢ 5 years |
|---|---|---|
| 0 | 1 | 2 |
| | | |

## 7.3 Appendix IV

### Small-scale farmer’s location the project and GPS

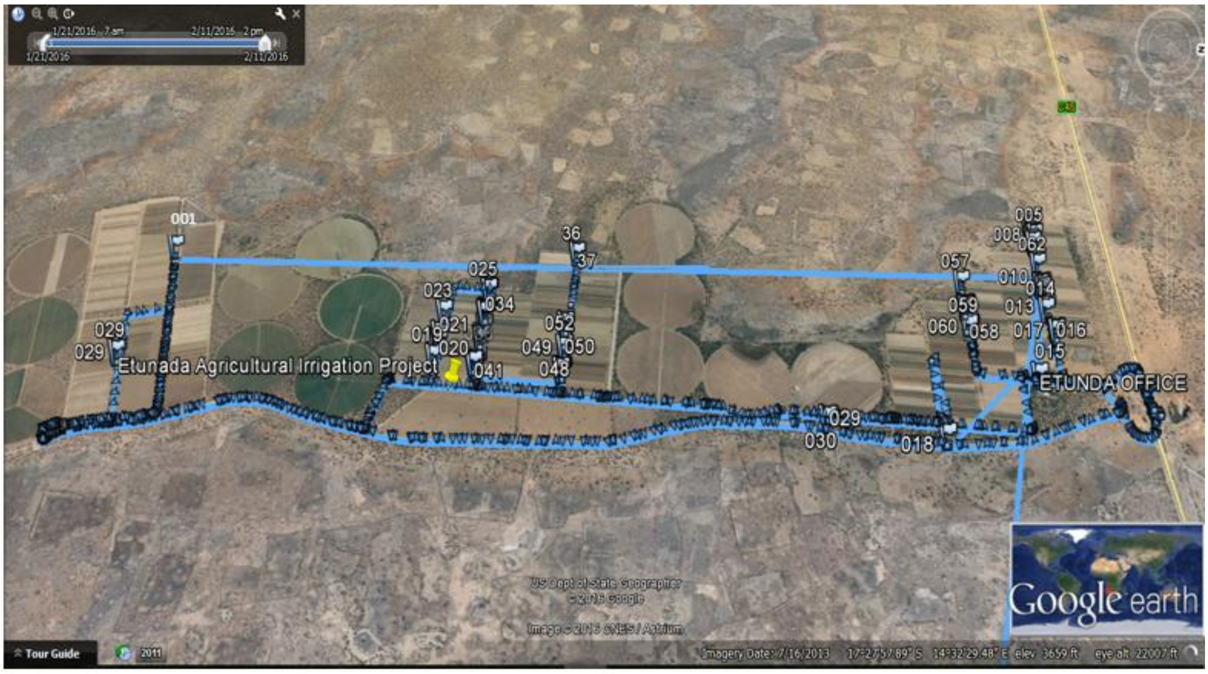



***Figure IV (a)*** *showing waypoints of small-scale farmers who were interviewed in Etunda Irrigation Project, waypoints was imported into google earth mapping softwar .*

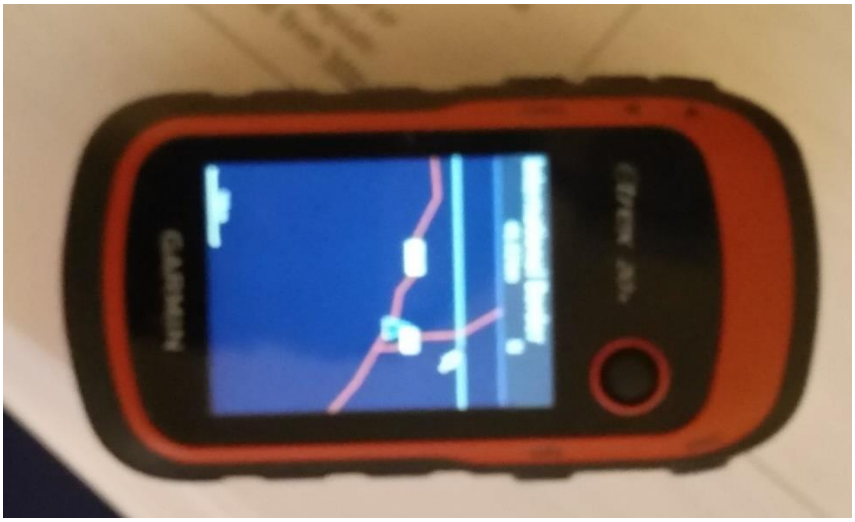



***Figure IV (b)*** *A Garmin Etrex 20x Global Positioning System (GPS) used in recording waypoints of farmers during data collection.*