YIELD CHARACTERISTICS, CARBON CAPTURE AND CHEMICAL COMPOSITION OF *MORINGA OLEIFERA* UNDER DIVERSE PLANTING POPULATION AND AGRO-ECOLOGICAL CONDITIONS OF THE LIMPOPO PROVINCE

by

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THESIS

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DECLARATION

I, Moshibudi Paulina Bopape-Mabapa, declare that **YIELD CHARACTERISTICS, CARBON CAPTURE AND CHEMICAL COMPOSITION OF *MORINGA OLEIFERA* UNDER DIVERSE PLANTING POPULATION AND AGRO-ECOLOGICAL CONDITIONS OF THE LIMPOPO PROVINCE** is my own work and that all the sources that I have used or quoted have been indicated and acknowledged by means of complete references and that this work has not been submitted before for any other degree at any other institution.

.... ……...................

Full names Date

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Risk and Vulnerability Science Centre

University of Limpopo

DEDICATION

“In memory of my late parents Maake Jerry Ramoshaba and Mapula Jermina Bopape (Pheladi)”.

This PhD study is also dedicated to my

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LIST OF ACRONYMS AND ABBREVIATIONS

A	Photosynthetic rate
ANOVA	Analysis of variance
AOAC	Association of Official Analytical Chemists
Ca	Calcium
Ci	Sub-stomatal CO_2
cm	Centimetre
CP	Crude protein
CO_2	Carbon dioxide
Cu	Copper
CV	Coefficient of variation
DAP	Days after planting
^{o}C	Degree Celsius
E	Transpiration rate
Fe	Iron
Gs	Stomatal conductance
g	Gram
ha	Hectare
ha^{-1}	per hectare
IPCC	Intergovernmental Panel on Climate Change
K	Potassium
kg	Kilogram
LSD	Least significant difference
m	Meter
mg	Milligram
Mg	Magnesium
mg/kg	Milligram per kilogram
mm	Millimetre
mmol m^{-2} s^{-1}	Millimole per square meter per second
Mn	Manganese
molm^{-2} s^{-1}	Mole per square meter per second

mmol m^{-2} s^{-1}	Micromole per square meter per second
µmol mol^{-1}	Micromole per mole
N	Nitrogen
NS	Not significant
OC	Organic carbon
P	Phosphorus
%	Percent
SD	stomatal density
SE	Standard error
Tn	Minimum temperature
Tx	Maximum temperature
vpm	Volume per million
WUE	Water use efficiency
Zn	Zinc

PUBLICATIONS DURING CANDIDATURE

Peer-reviewed articles from the thesis

1. **Mabapa, M.P**., Ayisi, K.K., Mariga, I.K., Mohlabi, R.C. and Chuene, R. S., 2017. Production and Utilization of Moringa by Farmers in Limpopo Province, South Africa. *International Journal of Agricultural Research*. 12: 160-171.
2. **Mabapa, M.P**., Ayisi, K.K. and I.K. Mariga, 2017. Effect of Planting Density and Harvest Interval on the Leaf Yield and Quality of Moringa (*Moringa oleifera*) under Diverse Agroecological Conditions of Northern South Africa. *International Journal of Agronomy.,* Vol. 2017, Article ID 2941432, 9 pages, 2017. doi:10.1155/2017/2941432.

Articles in the press and accepted for publication from the thesis

3. **Mabapa, M.P**., Ayisi, K.K. and Mariga, I.K. Seasonal Effect on *Moringa oleifera* Gaseous Exchange and Water Use Efficiency under Diverse Planting Densities. *Journal of Applied Botany and Food Quality*. Ms No. 9659
4. **Mabapa, M.P**., Ayisi, K.K. and Mariga, I.K. Comparison of Gas Exchange in *Moringa oleifera* and other Drought Tolerant Tree Species for Climate Change Mitigation under Semi-Arid Condition of Northern South Africa. *International Journal of Agriculture and Biology*: MS No. IJAB-18-0636.

Articles in preparation from the thesis

1. **Mabapa, M.P**., Ayisi, K.K. and Mariga, I.K. Biomass Production and Nutritional Composition of *Moringa oleifera* under Different Planting Spacings.

2. **Mabapa, M.P**., Ayisi, K.K. and Mariga, I.K. Seed and Oil Yield Production of *Moringa oleifera* under as affected by Planting Spacings under Semi-arid Conditions.
3. **Mabapa, M.P**., Ayisi, K.K., Mariga, I.K. and Mashao, F. *Moringa oleifera* Leaf Nutritional Composition as Influenced by Soil Physical and Chemical Properties under Diverse Agro-ecological Conditions.

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2. **Mabapa, M.P**., Ayisi, K.K and Mariga, I.K. 2018. Effect of Planting Density on Seed Yield and Oil Content of *Moringa oleifera* Grown under Dryland in Limpopo Province, South Africa. African Combined Congress. 14 – 18 January 2018. Bridgeways Conference Venue (Ratanga Junction), Cape Town.

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THESIS STRUCTURE

The subsequent chapters in this thesis are presented as follows:

CHAPTER 1 General introduction	This section addresses the background of climate change and its impact on food security. Furthermore, the section presents the problem statement, motivation, aim, objectives and hypotheses of the study.
CHAPTER 2 Literature review	This section presents a critical review of existing literature on climate change, food security and the role of moringa as a drought tolerant tree and its benefits such as high nutrition, medicine, water purification, climate change mitigation and improvement of soil fertility.
CHAPTER 3 Farmer survey	This section presents a survey on production and utilization of moringa by farmers; to generate baseline information across the five districts of the Limpopo province and also to understand how widespread moringa is in the province.
CHAPTER 4 Effect of planting density and cutting frequency on moringa nutritional quality	This section addresses the impact of planting density and cutting frequency on moringa nutritional quality under different agro-ecological conditions.
CHAPTER 5 Effect of planting density on moringa gaseous exchange	This section evaluates moringa planting densities and its effect on leaf gaseous exchange in relation to climate change mitigation and adaptation.

CHAPTER 6

Gaseous exchange comparison on moringa and other drought tolerant species

The section addresses the comparison of moringa with mopane and marula trees focusing on their gaseous exchange as drought tolerant tree species for climate change mitigation and adaptation.

CHAPTER 7

Effect of planting density on moringa biomass, seed and oil yield

This section evaluates moringa on biomass, seed and oil yield production as influenced by planting density in the semi-arid condition.

CHAPTER 8

Agro-ecological effect and leaf quality of moringa

This section investigates the changes in soil physical and chemical properties under moringa canopy and its impact on leaf nutritional composition under diverse agro ecological conditions of the Limpopo Province.

CHAPTER 9

General Conclusion

This section presents overall conclusion of the study mainly focusing on chapters 3-8 and recommendations for future research

THESIS ABSTRACT

Moringa oleifera is a multipurpose fast growing tree which is widely cultivated in tropical and subtropical regions of the world due to its numerous benefits. The benefits include medicinal use, industrial use, soil fertility, water purification, climate change mitigation as well as of nutritional value for humans and livestock. Recently, many areas globally have been rendered vulnerable to climate change as well as food insecurity. Climate change increases irregularities of rainfall and temperature patterns in semi-arid conditions. One practical way to address this challenge in the agricultural sector is to introduce more trees crop species which are found to be more tolerant than annual crops under harsh growing conditions. Moringa is one species that could be considered under variable climatic conditions for positive outcomes through climate change adaptation and mitigation as well as life sustenance against food insecurity threats. Production of moringa in South Africa is exclusively for leaf processing and consumption. To date, there is no documented information available about seed and oil yield production of moringa mainly in the Limpopo Province of South Africa. The aim of the study was to generate knowledge on moringa growth, nutritional composition, seed and oil yield production as well as its response to drought through gaseous exchange parameters, as influenced by plant density under diverse agro-ecological locations in Limpopo Province. The study was conducted in the Limpopo Province, South Africa, from November 2013 to January 2016. The study area falls within the semi-region which is characterized by low and erratic rainfall which predominately falls in summer as well as extremely low or high temperatures. A survey was conducted from November 2013 to September 2014 in five districts of the Limpopo Province. Focus group discussion, questionnaires and field observations were used for data collection. A total of 150 moringa growers formed part of the focus group and a questionnaire was administered to only thirty-one farmers, who constitute the population of farmers producing moringa within an area of 0.25 ha or more. A second study was conducted at two experimental sites in the Limpopo Province of northern part of South Africa to evaluate for the first time, the effect of plant density and cutting interval on biomass production and chemical composition of moringa grown under two diverse climatic conditions. Four different planting densities (435 000, 300 000,

200 000 and 100 000 plants/ha) were arranged in a randomized complete block design and experimental samples were replicated four times.

A third study was conducted over two years to achieve additional objectives which included evaluation of gaseous exchange, biomass, seed, and oil yield. Untreated seeds of *Moringa oleifera* were used for establishing the trial at densities of 5 000, 2 500, 1 667 and 1 250 plants ha^{-1}, with eight replicates. The same study was used to achieve the objective on gaseous exchange in comparison with other two naturally growing tree species of mopane (*Colophospermum mopane*) and marula (*Sclerocarya birrea*) trees growing within the moringa trial vicinity. The study was further used to evaluate the effect of planting density on biomass, grain, oil yield production and nutritional composition of *Moringa oleifera* trees. The last part of the study was carried out in the five districts of the Limpopo Province to determine the influence of soil physical and chemical properties on the nutritional composition of moringa leaves. The farms that were identified during the survey were also used to achieve other objectives of the study. In order to determine soil and leaf nutritional composition, soil samples were collected and analyzed for physical and chemical properties. The harvested leaves were dried at room temperature and their nutritional compositions were determined using standard methods.

Findings from the studies revealed the following: The survey indicated that there are potential moringa farmers in all the districts of the province, with the intention to commercialize the tree. Majority of farmers grow moringa on 0.25-1.0 ha and have been producing the crop for the past 2 years. The study on planting density and cutting frequency revealed satisfactory nutritional composition in the leaves across the cutting frequencies and that, an increase in the plant density led to enhanced biomass production. The study on the monthly and seasonal gaseous exchange revealed significant differences in net photosynthetic rate, transpiration, sub-stomatal CO_2 and stomatal conductance. However, planting densities of *Moringa oleifera* had no significant effect on all the gaseous exchange parameters measured. In a comparison of moringa with other tree species growing in the vicinity of moringa, the results differed significantly in gaseous exchange. The highest activity in photosynthetic rate (A), stomatal conductance (gs), transpiration rate (E) and sub-stomatal CO_2

(Ci), as well as higher stomatal density, was found in moringa. The findings from the biomass, seed yield and oil yield study showed that the increase in measured biomass, seed and oil yield increased with increasing planting density. However, seed oil concentration was non-significant. Findings from the ecology study revealed that moringa improved soil nutritional composition; mainly in areas where the trees were more than three years old as compared to control soils where moringa had not been planted. The soil nutritional composition differed with soil textural classes with the clay soils recording higher nutrient ion values. The study revealed that moringa can be produced in many locations of the Limpopo Province without negatively affecting leaf nutritional composition. Moringa leaves contain high level of nutrients even under marginal production areas irrespective of the planting density. A population of 5000 plants ha^{-1} can be used for seed and oil yield production where temperatures are favourable for improved farmers' livelihoods. The results strongly showed with no doubt, the superiority of moringa in capturing more carbon among the three species. Moringa maintained good leaf yield even under drought condition, which is an indication of its potential to act as a good sink for carbon dioxide absorption. It can, therefore, be recommended for many parts of Limpopo Province for climate change mitigation and adaptation strategies and food security.

KEY CONCEPTS: agro-ecology, biomass, climate change, commercialization, drought, food security, gas exchange, leaf chemical composition, location, *Moringa oleifera*, oil, seed, soil textural class, survey, trees, weather, yield

CHAPTER 1

GENERAL INTRODUCTION

1.1 Background of the study

Food security is deteriorating due to stressed food systems experienced globally mainly in African countries (Gregory *et al*., 2005). According to FAO (2016a), the world has committed to eradicating extreme poverty and hunger by 2030, but climate change is undermining the livelihoods and food security of almost 80% of the world's rural poor communities.

Several studies have revealed that climate change is one of the leading challenges affecting the performance of agriculture and the livelihoods of smallholder farmers and poor rural communities (Nhemachena *et al*., 2014; Mpandeli *et al*., 2015; Dhanya and Ramachandran, 2016; Rankoana, 2016). Agriculture is a major contributor to the current economy of most African countries, averaging 21% and ranging from 10% to 70% of gross domestic product (GDP) (FAO, 2016a).

Climate change directly affects agroecosystems which leads to a negative impact on agricultural production and hence food insecurity. In some areas of southern Africa, there are noticeable agricultural losses that are linked to climate change as well as changes in the length of the growing season (Kurukulasuriya *et al*., 2006; FAO, 2016a). A study by Kurukulasuriya *et al*. (2006) from 9000 farmers in 11 African countries revealed falling farm revenues as a result of climate change, particularly the negative effect of temperature on agricultural produce.

Majority of smallholder farmers produce their crops under rainfed agriculture and it is estimated that the yield production could reduce by up to 50% by the year 2020 if the issue of climate change is not properly handled. Therefore, ensuring proper food security in the midst of climate change is among the most challenging situations facing humankind. The need for urgent actions in order to mitigate the vulnerability and enhance resilience in the food systems is imminent if the desire of better access to food with good nutrition for all is to be met (FAO, 2016a). There is a close link between the environment and the development of a sustainable food system (Maroyi, 2006).

The use of tree crops and their products for food, medicine, and other purposes is common among rural communities in developing countries (Omotesho *et al*., 2013). This is done due to inadequate and unaffordability of nutritious food caused by unemployment and low-income levels. Moringa tree has been reported to be a wonder plant that is useful for human and animal nutrition. The tree has long been consumed by man due to its edible and nutritious properties (Omotesho *et al*., 2013).

Moringa oleifera belongs to the Moringaceae family (Price, 1985). The tree is native to the sub-Himalayan tracts and widely cultivated in India, Pakistan, Bangladesh and Afghanistan (Fahey, 2005), Africa, Pakistan, Central, North and South America, Philippines and Indonesia (Anwar and Bhanger, 2003). According to Pakade *et al*. (2013), the leading African countries in terms of moringa production are Ghana, Senegal, and Malawi.

Moringa is a fast growing tree species (Fahey, 2005; Pakade *et al*., 2013), which can attain a height of up to 7 m within a year (Foidl *et al*., 2001). A study by Anwar *et al*. (2007) reported that the tree can grow well in the humid tropics or hot dryland conditions and can also survive in infertile soils. This statement is supported by Foidl *et al*. (2001), indicating that the tree can survive in areas receiving a rainfall below 400 mm per annum. Furthermore, the tree grows well in the tropical and subtropical regions globally, mainly in areas where its nutritional benefits are highly required (Thurber and Fahey, 2009; Moyo *et al*., 2011).

The benefits of moringa are enormous, whereby every part of the tree is beneficial, one way or the other (Maroyi, 2006). The leaves of *Moringa oleifera* are reported by several authors to be tremendously rich in valuable essential nutrient elements required by both humans and livestock (Thurber and Fahey, 2009; Anjorin *et al*., 2010; Omotesho *et al*., 2013). It is considered to be a remedy for malnutrition for poor communities (Gopalakrishnan, 2016).

There is a large number of reports on nutritional content and benefits of moringa. A comparative study on nutrient concentration of moringa leaves with other commercially available food, revealed that moringa leaves contain ten times more vitamin A than carrots, seventeen times more calcium than milk, 25 times more iron than spinach, seven times more vitamin C than oranges, and fifteen times more potassium than bananas as well as nine times the protein quality that one could get from milk and eggs (Makkar and Becker, 1996; Foidl *et al*., 2001; Fahey, 2005; Thurber and Fahey, 2009; Anjorin *et al*., 2010; Jongrungruangchok *et al*., 2010; Omotesho *et al*., 2013; Gopalakrishnan, 2016). Nutritional properties of moringa are well recognized and hence, there is limited doubt of the substantial health benefits to be realized by consumption of moringa leaf powder in situations where starvation is imminent (Fahey, 2005).

Lekgau (2011) reported that communities and farmers in South Africa have shown an interest in growing moringa on small lands and also in the backyards. Such observation of moringa cultivation growing interest was also revealed by Pakade *et al*. (2013).

1.2 Problem statement

Climate change directly affects agroecosystem functioning which leads to a negative impact on agricultural production and enhanced food insecurity. There had been some noticeable agricultural losses in the rainfed farming systems in some areas of southern Africa in recent years especially the arid and semi-arid regions resulting from changes in the length of the growing season and instability in rainfall patterns (Kurukulasuriya et al., 2006; FAO, 2016a). These have resulted in low productivity and disruptions in farm revenue. Such an impact is also felt in many other parts of the continent. For instance, studies by Kurukulasuriya *et al*. (2006) and Hatfield and Prueger (2015) reported that the effect of accelerated temperatures and drought have negatively impacted agricultural produce.

Majority of smallholder farmers produce crops under rainfed agriculture and it is estimated that the yield production could be reduced by up to 50% by the year 2020 if the issue of climate change is not properly handled. Therefore, ensuring proper food security in the midst of climate change is among the most recent challenges facing humankind. There is a need to take urgent actions in order to mitigate the vulnerability and enhance resilience in food systems to ensure better access to food with good nutrition (FAO, 2016a). There is a close link between the environment and the development of a sustainable food system (Maroyi, 2006). This must be explored critically to address the looming climatic and environmental challenges in the agricultural sector.

1.3 Motivation of the study

Moringa oleifera is a drought tolerant tree which grows well even in areas receiving annual rainfall as little as below 250 mm and up to 1500 mm. The tree is produced for its enormous benefits for both humans and livestock. Their potential values include high nutritional quality, water purification, medicinal properties and oil production. It has also been observed that moringa is becoming famous in South Africa with several households growing the tree in their backyards. Pakade *et al*. (2013) reported that South African farmers have started showing interest to grow moringa. Despite the increasing popularity of the plant, not much is known about its response to drought. Furthermore, there is no documented information on appropriate management practices, biomass, seed and oil yield production in moringa in the Limpopo Province of South Africa.

1.4 Aim of the study

The aim of the study was to investigate and generate knowledge on moringa growth, nutritional composition, seed and oil yield production as well as its response to drought through gaseous exchange parameters, as influenced by plant density under diverse agro-ecological locations in Limpopo Province.

1.5 Objectives of the study

The objectives of this study therefore were:

i) To generate baseline information through a survey on moringa production, management practices and utilization on the tree by farmers in the Limpopo Province.
ii) To determine the effect of planting density and cutting frequency on the nutritional quality of moringa fodder under diverse agro-ecological conditions.
iii) To assess the effect of planting density on the gaseous exchange of moringa in comparison with other indigenous drought-tolerant tree species.
iv) To evaluate the effect of plant density and weather conditions on biomass, seed and oil yield production of moringa tree.
v) To determine the effect of soil physical and chemical properties on moringa nutritional composition under diverse agro-ecological conditions of the Limpopo Province.

1.6 Hypotheses

i) Farmers in the Limpopo Province grow and manage moringa in a similar manner.
ii) Planting density and cutting frequency do not have an effect on nutritional quality of moringa under diverse agro-ecological conditions.
iii) Planting density has no effect on the gaseous exchange of moringa and other indigenous drought-tolerant tree species.
iv) Plant densities and weather conditions have no effect on biomass, seed and oil yield production of moringa tree.
v) Soil physical and chemical properties have no effect on moringa nutritional composition under diverse agro-ecological conditions of the Limpopo Province.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter will focus on the review of studies relating to challenges posed by climate change on food security; the adaptation strategies implemented by other researchers; possible plants that can be used in climate change mitigation and adaptation; the potential of using *Moringa oleifera* for climate change mitigation and adaptation as well as other general benefits of moringa tree.

2.2 Climate change

Climate change is already affecting many communities globally and nationally, whereby rising temperatures and shifts in rainfall patterns are experienced as a result of an accelerated increase in atmospheric greenhouse gas concentration attributed to human activities (IPCC, 2007). Climate is defined as mean weather conditions over a long period of time and which could have a negative impact on cropping area and intensity as well as yield production. Weather is a climate-related event that occurs in any one time (IPCC, 2007; Iizumi and Ramankutty, 2015). Both climate and weather affect crop production and the agricultural sector immensely (Iizumi and Ramankutty, 2015).

The latest predictions suggest that, globally, temperatures could rise between 1.1°C and 6.4°C by 2100 (Development LE, 2016), whereby great variations can be experienced at regional level. Different regions in the world experience varied effects caused by climate change. Developed countries have the means to adapt to the effects of climate change, while the majority of the developing countries do not have mitigation strategies from such effects of climate change (Development LE, 2016). South Africa as part of the developing countries is also vulnerable to the effects of climate change. Several African countries including South Africa have been identified as being highly vulnerable to the impacts climate change (RSA, 2011).

According to Development LE (2016), South Africa is situated among the three regions of the African continent that will most likely suffer significant adverse impacts of continuous warmer and drier summers, wetter and milder winters and more frequent extreme weather, particularly heavy rainfall and heat waves. Furthermore, Maponya and Mpandeli (2013a) indicated that extreme weather patterns experienced in the Limpopo Province have led to climate diversity which impacted farming communities. There is an indication of rapid climate change that has hit many provinces of South Africa, including Limpopo province. The observations include increases in temperature, rises in sea level, inconsistent and unpredictable rainfall patterns in other areas, which lead to extreme rainfall (flooding) and drought as well as extreme weather events (RSA, 2011; Maponya and Mpandeli, 2013a).

2.3 Effect of climate change on food security

Climate change may affect food production in many ways ranging from direct effects on crop production which include changes in rainfall leading to drought or flooding, or warmer or cooler temperatures leading to changes in the length of growing season, and changes in markets, food prices and supply chain procedures (Gregory *et al*, 2005; Maponya and Mpandeli, 2013a). Studies indicated that outcomes of climate change such as heat stress, droughts, and floods, negatively affect crop yields and livestock (IPCC, 2007; Maponya and Mpandeli, 2013a). Nhemachena *et al*. (2014) added that climate change has a negative impact on the livelihoods of rural communities. Changes in frequency and severity of extreme climate events modify the risk of fires, pests and disease outbreaks, which at the end affect food security (IPCC, 2007).

In many African countries, agricultural production will be severely compromised by climate change and variability. In southern Africa, the climate is among the most frequently cited drivers of food insecurity because it acts both as an underlying, ongoing issue and as a short-lived shock. The low ability to cope with shocks and to mitigate long-term stresses means that coping strategies that might be available in other regions are unavailable or inappropriate (Gregory *et al.*, 2005). This will negatively impact food security and aggravate malnutrition (IPCC, 2007). The National Development Plan (NDP), aims to eliminate and reduce poverty by 2030 (Development LE, 2016). However, it was observed that South Africa is also contributing to greenhouse gas emission and is also vulnerable to the effects of climate change whereby women and children are more vulnerable. Therefore, the NDP has set the long-term vision for South Africa to reduce emissions in order to achieve its goal of poverty reduction.

The Limpopo provincial climate change strategy is also in the process of developing a strong foundation under the Limpopo Development Plan and the Green Economy Plan which have a listed range of priorities on how Limpopo Province could plan to actively and rapidly respond to climate change. The plans have also identified gaps that exist in the current approaches in response to climate change by smallholder farmers and are soon to come up with a long-term planning to better manage these responses for the betterment of the entire communities of the Limpopo Province (Development LE, 2016).

After realizing that climate change is disproportionately affecting the world's vulnerable countries and mainly communities that rely on natural resources for food production, the FAO has put in place some interventions to address this. The organization has invested in important areas to support food security as well as climate change mitigation and adaption to measures. With the relevant policies and actions, FAO has realized that to gain from improved capacities such as advances in science and technology and also to withstand extreme weather events, farmers need to have access to a diverse range of hardy efficient and nutritious crops (FAO, 2016a). One of the mitigation strategies is the availability and quality of groundwater for irrigation which is ranked higher than the direct effects of climate change as factors influencing food security. However, climate change affects the extent and productivity of irrigated agriculture, as water availability is expected to decrease due to rising temperatures which lead to increased crop water demand across the globe as well as increased frequency and severity of drought. While drought is difficult to forecast, its impacts can be significantly mitigated. This can be achieved through a more proactive, risk-based management approach. FAO, together with the World Meteorological Organization (WMO), United Nations Convention to Combat Desertification (UNCCD) and other partners, works with countries to implement such an approach through well-coordinated national drought policies and the implementation of related action plans which involves upscaling climate-smart agricultural practices in drought-prone areas (FAO, 2016b).

FAO further works with countries to help ensure an enabling environment for poor communities and smallholder farmers to adopt well-adapted crops, trees, livestock, and fish. This will encourage good agricultural practices; enhance the adaptation of production systems to drought, water scarcity, and other climate-related shocks. As water scarcity and water-related issues are among the leading challenges to long-term food security, FAO has developed the Global Framework on Water Scarcity, an initiative launched at the 2016 United Nations climate change conference in Morocco (COP22) (FAO, 2016b) to end hunger and reduce poverty.

2.4 Climate change adaptation strategies

A study conducted in South India on climate change adaptation strategies revealed that farmers are experiencing anomalies in climate change based on the past experience of farming in the area. Farmers realized the unbearable increasing temperatures as well as declining and unpredictable rainfall since the past twenty years (Dhanya and Ramachandran, 2016). Again farmers in many African countries have a clear memory of extreme climatic conditions which have led to the significant disturbances of agricultural activities (Nhemachena and Hassan, 2007; Mertz *et al*., 2009; Maponya and Mpandeli, 2013b; Elum *et al*., 2017).

South Africa is already experiencing extreme weather conditions such as drought and floods due to climate change. The negative impacts of climate change affect agriculture, the environment, and human livelihoods (Maponya and Mpandeli, 2013b; Ndamani and Watanabe, 2015). According to IPPC (2007) there is a slight difference from marginally reducing negative impacts into a positive one. This can be achieved by considering production practices or changing cropping systems by engaging in adaptation strategies such as changing varieties, crop diversification and planting time (Nhemachena and Hassan, 2007; IPCC, 2007; Maponya and Mpandeli, 2013b) which in most cases can reduce the yield by up to 15% (IPCC, 2007).

Farmers need to consider adaptive strategies and capacities. Adaptive capacity has been defined by Ndamani and Watanabe (2015) as the ability of a system to adjust to climate change which includes climate variability and extreme weather changes which leads to potential damages, and to take advantage of opportunities or to cope with the consequences.

According to Ndamani and Watanabe (2015), there is a need to develop proper policies which smallholder farmers can use to adjust and cope with the climate change and simultaneously be able to improve their crop and livestock production. This is also supported by Maponya and Mpandeli, (2013b), where the study indicated that there is a need to design policies that aim to improve the role of extension services in Limpopo Province since these will significantly raise farmer awareness of changing climate as well as adaptation measures to improve agricultural production at large. The extension services have a great potential to improve farmer training on adaptation to climate change. Farmers in Limpopo Province need training on adaptation strategies that are already mentioned in order to cope with the changing environment without major crop and livestock loss.

2.5 Plants for carbon sequestration

Carbon sequestration does not need to come from a particular type of plant or to be done in any particular site. However, there are requirements for carbon plants to remain viable and grow well over a long time frame, whereby careful attention to the establishment and growing management is vital. Since photosynthesis and stomatal behaviour are central to plant carbon and water metabolisms, the growth of the plant under elevated CO_2 leads to a large variety of secondary effects on plant physiology (Ehleringer and Monson, 1993).

Over 90% of plants use C_3 carbon photosynthetic system where the primary carboxylation reaction catalyzed by Rubisco produces the 3-carbon sugar 3-phosphoglyceric acid directly in the Calvin cycle (Ehleringer and Monson, 1993). Plants with such photosynthetic system stand to gain from increased ambient CO_2, due to improved supply of CO_2 from ambient sources.

2.6 *Moringa oleifera's* potential in climate change mitigation

Deng *et al*. (2015), indicated that one practical way to compensate unpreventable CO_2 emission is to plant trees since they take CO_2 out of the atmosphere and release oxygen in return. Therefore, trees have a great influence on the environmental outcome and can contribute positively towards climate change mitigation and therefore improve the livelihoods of smallholder farmers in Africa (Daba, 2016).

Moringa oleifera is a multipurpose tree that cannot be overlooked in today's battle with climate change (Deng *et al*., 2015). Due to its fast growth rate, the tree can be able to assimilate more carbon dioxide from the atmosphere. A report by Japanese researchers revealed that moringa's rate of absorption or assimilation of carbon dioxide is twenty times higher than most of the vegetations (Daba, 2016). Growing of moringa trees in many parts of the country will contribute towards the mitigation of the negative impacts caused by climate change.

2.7 Origin and distribution of moringa

Moringa oleifera belongs to the Moringaceae family. There are about 13 species distributed in India, Kenya; north-eastern and southwestern Africa, Arabia, and Madagascar (Makkar and Becker, 1996; Saini *et al*., 2016). Among this 13 species, *Moringa oleifera* has so far mostly been studied (Price, 2007; Leone, 2016).

Moringa is native to the sub-Himalayan tracts of India, Pakistan, Bangladesh, and Afghanistan (Fahey, 2005; Price, 2007). Moringa is widely cultivated in Africa, other parts of America, India, Philippines, Indonesia and Mexico (Jongrungruangchok *et al*., 2010). In Africa, moringa is mainly produced in Ghana, Senegal and Malawi while South Africa is also showing interest in producing the tree (Pakade *et al*., 2013). Currently, moringa is found in many tropical regions throughout the world (Muhl *et al*., 2011).

Moringa is called by various names from different areas of India and Africa, for example, it is commonly known as the "horseradish tree" or "drumstick tree" (Makkar and Becker, 1996; Saini *et al*., 2016). It is also called "Ben oil" or "never die" in western African countries while in the Philippines it is called "Malungai or Malungay" (Morton, 1991).

2.8 General uses of moringa and its potential role in food security

Fahey (2005) reported that the moringa tree has the potential to combat malnutrition. Moringa serves as a backbone for food security in disadvantaged communities because all parts (leaves, flowers, young pods, seed, and bark) of the plant are edible and have long been consumed by humans (Fahey, 2005; Mishra *et al*., 2012). Several studies have already shown that moringa could serve as a solution towards the duo of poverty and hunger which remains unassailable among poor rural communities who cannot afford expensive commercialized food (Makkar and Becker, 1996; Omotesho *et al*., 2013; Basra *et al*., 2015). The benefits of moringa are massive, ranging from human food, livestock forage, medicinal and water purification (Amaglo, 2006) and all parts of the tree are consumed (Fahey, 2005; Omotesho, 2013; Leone *et al*., 2016).

Many aspects of moringa uses include: alley cropping (biomass production), animal forage (leaves and treated seed-cake), biogas (from leaves), domestic cleaning agent (crushed leaves), blue dye (wood), fencing (living trees), fertilizer (seed-cake), foliar nutrient (juice expressed from the leaves), green manure (from leaves), gum (from tree trunks), honey and sugarcane juice-clarifier (powdered seeds), honey (flower nectar), medicine (all plant parts), ornamental plantings, bio-pesticide (soil incorporation of leaves to prevent seedling damping off), pulp (wood), rope (bark), tannin for tanning hides (bark and gum), and water purification (powdered seeds) (Makkar and Becker, 1996; Fuglie, 1999; Fahey, 2005).

2.8.1 Moringa as food for human consumption

Moringa can be consumed in many ways. Leaf powder can be mixed with juices, vegetables or soup after being prepared for consumption (Foidl *et al*., 2001; Lekgau, 2011). Young leaves of moringa are an exceptionally good source of provitamin A, vitamins B, and C, minerals (mainly iron), and the sulfur-containing amino acids methionine and cysteine when cooked and eaten like spinach (Foidl *et al*., 2001). Analysis of the nutritional value of moringa from different parts of the tree was analyzed by Price (1985). Table 2.1 indicates the results of the analysis based on per 100 g of edible portion.

Based on nutritional analysis, it was found that a tablespoon (8 g) of leaf powder can be able to satisfy about 14% of the protein, 40% of the calcium, 23% of the iron and nearly all the vitamin A needs for a child aged 1-3 (Mishra *et al*., 2012). About six spoonful of leaf powder will satisfy nearly all of a woman's daily iron and calcium needs during pregnancy and breastfeeding. Leaves can be consumed while still fresh, cooked, or as a dried powder. Dried powder can be stored for many months without refrigeration, and reportedly without loss of nutritional value (Mishra *et al*., 2012).

Several studies on nutritional analysis were conducted by researchers and on average their results were similar to findings by Price (1985); Foidl *et al*. (2001); Fahey (2005); Maroyi (2006); Thumber and Fahey (2009); Ashfaq *et al*. (2012); Gopalakrishnan (2016); Saini *et al*. (2016).

2.8.2 Industrial uses of moringa oil

Moringa seeds contain about 40% oil and are of excellent quality (73% oleic acid, similar to olive oil) for cooking. The oil is also used for perfume and skin lotion (Price, 1985). The meal yields about 61% protein (Ashfaq *et al*., 2012). When the seeds are de-hulled they can produce oil content of up to 42% (Foidl *et al*., 2001). The oil is brilliant yellow, sweet non-sticking, non-drying and resists rancidity. Several studies have been conducted and showed that moringa seed oil contains between 30-40% oil. The oil is used for salads, machine lubrication, making perfumes and hair care products (Price, 1985; Foidl *et al*., 2001; Fahey, 2005; Anwar *et al*., 2007).

A survey that was conducted in India using 75 indigenous plant derived non-traditional oils showed that M*oringa oleifera* has good potential for biodiesel production based on fatty acid methyl esters (FAMEs) (Azam *et al*., 2005). Biodiesel is defined as a renewable and eco-friendly alternative to conventional non-renewable fossil fuel. Biodiesel can be prepared from oil crops such as cottonseed, moringa, palm, peanut, rapeseed, soybean, and sunflower (Saini *et al*., 2016). Previous studies also indicated that crops such as jatropha, moringa, pongamia, and tobacco have received greater attention on biodiesel production (Rashid *et al*., 2008).

Table 2.1: Nutritional value of *Moringa oleifera* per 100 grams of edible portion.

Components analyzed	Pods	Fresh leaves	Leaf powder
Moisture (%)	86.9	75.0	7.5
Calories	26	92	205
Protein (g)	2.5	6.7	27.1
Fat (g)	0.1	1.7	2.3
Carbohydrate (g)	3.7	13.4	38.2
Fibre (g)	4.8	0.9	19.2
Ca (mg)	30	440	2003
Mg (mg)	24	24	368
P (mg)	110	70	204
K (mg)	259	259	1324
Cu (mg)	3.1	1.1	0.57
Fe (mg)	5.3	7	28.2
S (mg)	137	137	870
Oxalic acid (mg)	10	101	1600
Vitamin A - ß carotene (mg)	0.11	6.8	16.3
Vitamin B - choline (mg)	423	423	-
Vitamin B1 - thiamine (mg)	0.05	0.21	2.64
Vitamin B2 - riboflavin (mg)	0.07	0.05	20.5
Vitamin B3 - nicotinic acid (mg)	0.2	0.8	8.2
Vitamin C - ascorbic acid (mg)	120	220	17.3
Vitamin E - tocopherol acetate (mg)	-	-	113
Arginine (mg)	90	402	1325
Histidine (mg)	27.5	141	613
Lysine (mg)	37.5	288	1325
Tryptophan (mg)	20	127	425
Phenylalanine (mg)	108	429	1388
Methionine (mg)	35	134	350
Threonine (mg)	98	328	1188
Leucine (mg)	163	623	1950
Isoleucine (mg)	110	422	825
Valine (mg)	135	476	1063

Source: Price (1985), ECHO Technical note. The moringa Tree

Studies conducted by Rashid *et al*. (2008), da Silva *et al*. (2010) and Ashfaq *et al*. (2012), revealed that moringa seeds oil is a potential candidate for biodiesel production. The fuel properties are mainly dependent on the fatty acid (FA) composition, wherein C^{16} and C^{18} monounsaturated FAMEs are ideal components to achieve an adequate balance between oxidative stability and cold flow properties of biodiesel (Rashid *et al*., 2008). Furthermore, moringa seed oil is regarded as a sustainable biodiesel fuel and the authors concluded that *Moringa oleifera* is one of the prospective industrial crops for biodiesel production (Ashfaq *et al*., 2012).

2.8.3 Moringa as a livestock feed

Moringa shoots are cut back to encourage regrowth and the harvested materials are used for livestock feeding (Maroyi, 2006). Most of the domestic animals such as cattle, sheep, goats, pigs, and rabbits are fed on moringa leaves, mainly in areas that are experiencing shortages of grasses (Price, 1985; Foidl *et al*., 2001; Maroyi, 2006). Chicken are fed on moringa seeds.

There are many important forage tree species which are used for livestock feeding as fodder in many African countries. Forage trees such as *Acacia* spp*, Sesbian sesbane, Delbergia* spp *and Moringa oleifera* are preferred for livestock feeding since they are capable of producing more foliage with high digestible protein content and other essential mineral nutrients which most of the agricultural crops are not able to provide (Nouman *et al*., 2013). Several studies have been conducted and indicated that moringa leaves are an excellent source of protein, carotene, iron and ascorbic acid while pods are rich in amino acids (Foidl *et al*., 2001; Sánchez *et al*., 2006; Nouman *et al*., 2013).

When 30-50% of moringa leaves is constituted with feed, it was found that there was an increase of 30% of milk yields from dairy cows and daily weight gain of beef cattle (where cattle were fed at 15-17 kg of moringa daily). Milk production turned to be 10 litres /day where moringa was included as compared to 7 litres per day without moringa. Furthermore, cattle fed on moringa gained 1200 g/day as compared to 900 g/day without moringa (Price, 1985). A study by Makkar and Becker (1996) concluded that *Moringa oleifera* leaves are a good source of feed for livestock as a protein supplement.

2.8.4 Soil improvements and fertility using moringa plant

It has been discovered that moringa leaf extract contains a plant growth hormone. The results revealed that moringa can be used as a foliar spray to increase plant growth and as a green manure to improve the level of soil fertility (Price, 1985). Price, (1985) further reported that fresh moringa juice can be used to produce an effective spraying growth hormone which is capable of improving yields of crops such as onion, pepper, maize, sorghum, chili, melon and many other crops by up to 25-30%.

The extract from moringa leaves using 80% ethanol was also found to accelerate the growth rate of young plants when applied as a foliar spray. It was further observed that the use of moringa growth hormone happens to produce vigorous plants which are able to resist prevailing pests and diseases (Foidl *et al*., 2001). In a study that was conducted using *Vigna mungo*, plants treated with 80% ethanol and moringa extract produced notable results whereby nodule weight was 54 mg/plant as compared to control where the weight was 16.4 mg/plant (Foidl *et al*., 2001).

A study by Undie *et al*. (2013) indicated that the manuaral and organic matter found in moringa leaves had a positive effect on soil pH which was increased and favoured soil fertility for improved yield of garden eggplant. Leaves of moringa are rich in zeatin, a hormone from the cytokinins group. In addition with other growth-enhancing compounds such as ascorbates, a phenolic and essential mineral element makes it a marvelous plant growth enhancer substance (Price, 1985; Foidl *et al*., 2001; Ashfaq *et al*., 2012).

Moringa could serve as a source of soil organic matter and calcium and could even replace some of the inorganic fertilizers by facilitating effective plant nutrients release through controlled pH for enhanced crop production (Undie *et al*., 2013). Morton (1991) revealed that after extracting high-quality oil from moringa seeds, there is a bitter seedcake that remains which is not consumed due to its high level of saponin. This has the potential to be used for soil fertility improvement. The results concurred with findings of Pandey *et al*. (2011), where they found that the seed cake of a multipurpose tree can be used as fertilizer.

Moringa shoots are also capable of producing green manure to improve soil texture, structure as well as fertility. An intensive plant population of up to one million plants per hectare can be planted. Plants could be ploughed back once they reach 25 days to a depth of 15 cm below the soil surface and the desired crop can be planted and benefit from the decomposed organic materials (Price, 1985).

2.8.5 Use of moringa for water purification

Moringa seed powder acts as a natural flocculent; able to clarify even the most turbid water and it is considered to be a fast and easy method for cleaning dirty water (Ashfaq *et al*., 2012). After extracting the oil, the remaining cake is a by-product which contains a very high protein, and a high active ingredient, cationic polyelectrolyte (Foidl *et al*., 2001). The cationic polyelectrolyte neutralizes the colloids of dirty water. Foidl *et al*. (2001) further explained that protein can be used as a non-toxic natural polypeptide for sedimenting mineral particles and organics in the purification of drinking water, for cleaning vegetable oil, or for sedimenting fibres in the juice and beer industries.

Price (1985) reported that the seeds are prepared as a coagulant by removing the seed coats and the wings. The purification procedure was explained by Price (1985) whereby, the kernel is crushed into a powder either using a mortar or by crushing it with a stone between cloths. Two heaped teaspoons of the powder are mixed with a small amount of clean water in a bottle. This is then shaken for five minutes to form a paste. The paste is then stirred rapidly for two minutes, and then slowly for 10-15 minutes. The bucket of water is then left undisturbed for at least an hour. All the impurities will sink to the bottom of the bucket. The water is finally strained and stored in clean containers. This process removes 90 to 99% of impurities from the water by flocculation, sedimentation, and antibiosis (Price, 2007; Ashfaq *et al*., 2012).

2.8.6 Use of moringa as a medicinal plant

Several authors have reported and appreciated that different, if not all parts of moringa tree, including roots, root bark, stem bark, leaves, flowers, pods, and seeds are used to treat various diseases and body infections (Morton, 1991; Anwar *et al*., 2007; Amaglo *et al*., 2010; Saini *et al*., 2016). Extracts from different parts of moringa contain a great number of compounds with antibacterial and antioxidant activity, therefore they can be used for the treatment of several infectious diseases caused by pathogenic microorganisms which are resistant against several available drugs (Price, 1985; Charan and Gupta, 2013).

Fahey (2005) and Ashfaq *et al.* (2012) reported that moringa contains an exceptional range of phytochemicals containing the simple sugar, rhamnose, and it is rich in compounds called glucosinolates and isothiocyanates. Phytochemicals are those chemicals, which may have an impact on health, or on flavour, texture, smell, or colour of the plants, but are not required by humans as essential nutrients. However, they play an important role in inhibiting and scavenging free radicals, thus providing protection to humans against infections and degenerative diseases (Fahey, 2005; Charan and Gupta, 2013). The extracts of *M. oleifera* both mature and tender leaves have potent antioxidant activity against free radicals, prevent oxidative damage to major biomolecules and afford significant protection against oxidative damage (Price, 1985; Ashfaq *et al*., 2012).

Recently, there are numerous studies which point to the elevation of a variety of detoxication and antioxidant enzymes and biomarkers as a result of treatment with moringa, while phytochemicals isolated from moringa have shown, antiulcer effect on immune response, spasmolytic activities hypercholesterolemia effects, and antibacterial activity (Fahey, 2005; Ashfaq *et al*., 2012; Gopalakrishman *et al*., 2016).

Study by Gopalakrishman *et al*. (2016), further elaborated that the presence of phytochemicals in moringa makes the tree to be one of the good medicinal agents and is often referred to as panacea and it is believed to be used as herbal medicine in Indian and African countries and can again be able to cure more than 300 diseases which include the treatment of inflammation and infectious diseases along with cardiovascular, gastrointestinal, hematological and hepatorenal disorders (Anwar *et al*., 2007; Gopalakrishman *et al*., 2016). A study that was conducted in South Africa by Pakade *et al*. (2013) also showed that moringa leaves contain an enormous amount of flavonols, justifying the tree as a natural antioxidant.

2.9 Adaptation and management practices for increased productivity of the moringa tree

Moringa oleifera is one of the world's most important multipurpose trees. Moringa is also considered to be one of the drought-resistant and fast growing trees. The tree is grown and adapt well to tropical areas, wherein it favours hot and humid and semi-arid environmental conditions (Price, 1985; Amaglo, 2006; Muhl *et al*., 2011).

2.9.1 Botanical description of *Moringa oleifera*

Moringa is described as a deciduous perennial tree that can grow up to 12 m or at most 15 m depending on environmental conditions or climate (Morton, 1991; Pandey *et al*., 2011). The tree is characterized by tuberous roots, slender stem with drooping branches; brittle stem with corky whitish-grey bark; leaves feathery above and glabrous beneath, pale green, tripinnate, 30–60 cm long, lateral ones somewhat elliptic, terminal ones obovate and slightly larger than the lateral ones, oblique sided at base; flowers honey scented, 2.5 cm in diameter, borne in profuse axillary drooping panicles; calyx tube hairy, lobes petaloid, linear-lanceolate; petals white or rarely pink, dotted with yellow streaks at the base, anterior erect; stamens five, yellow, alternating with five staminodes; ovary oblong, style cylindrical; fruit is beaked (pointed at apex and tapering at base) capsule, drooping, brown, nine-ribbed, three-valved, three angled or nearly cylindrical on maturity, splitting lengthwise into three parts when dry, about 15–24 seeds embedded in pith, parietal placentation; seeds ivory white-brown, with three papery deciduous wings (Morton, 1991; Foidl *et al*., 2001; Pandey *et al*., 2011).

2.9.2 Climatic adaptation

Moringa grows well in areas with maximum temperatures ranging between 25 – 35^{o}C, although it can survive up to a temperature of 48^{o}C in some instances

(Price, 1985, Amaglo, 2006). A study by Muhl *et al*. (2011), concluded that higher temperatures favoured the growth and development of the moringa tree. Moringa is one of the drought-tolerant crops; it can survive in areas which receive a rainfall between 250-1500 mm per annum. However, the tree can adapt well to areas with an altitude of 600 mm but can still survive in areas of altitudes of up to 1200 m or even 2000 m in some of the tropical regions (Price, 1985; Amaglo, 2006).

It is recommended that under dry and arid conditions, irrigation be provided for good establishment and to enhance root development (Amaglo, 2006). Well rooted trees can adapt to harsh conditions and irrigation can only be applied when there are wilting signs. For good moisture conservation, mulching could also be considered to enhance yield production (Morton, 1991; Amaglo, 2006).

2.9.3 Water use efficiency of moringa

Plant water use efficiency (WUE) is becoming a key issue in semiarid areas, where crop production relies on the use of large volumes of water. Improving WUE is necessary for securing the environmental sustainability of food production in these areas (Medrano *et al*., 2015). Climate change predictions include increases in temperature and drought in semiarid regions, therefore improving crop WUE is mandatory for global food production especially in areas where smallholder farmers are actively involved in farming.

WUE can be measured at different scales, ranging from instantaneous measurements on the leaf to more integrative measurements at the plant (biomass) and crop level as indicated in Figure 2.1. However, in most cases, WUE is usually measured at the leaf level, because portable equipment for measuring leaf gas exchange rates facilitates the simultaneous measurement of photosynthesis and transpiration (Medrano *et al*., 2015).

Plant growth and productivity are adversely affected by water stress. Prolonged water stress adversely affects physiological activities, mainly photosynthetic capacity of crops (Chaves *et al*., 2009; Osakabe *et al*., 2014). Under severe environmental stresses, the stomatal activity can influence CO_2 absorption hence affect plant growth (Chaves *et al*., 2009).

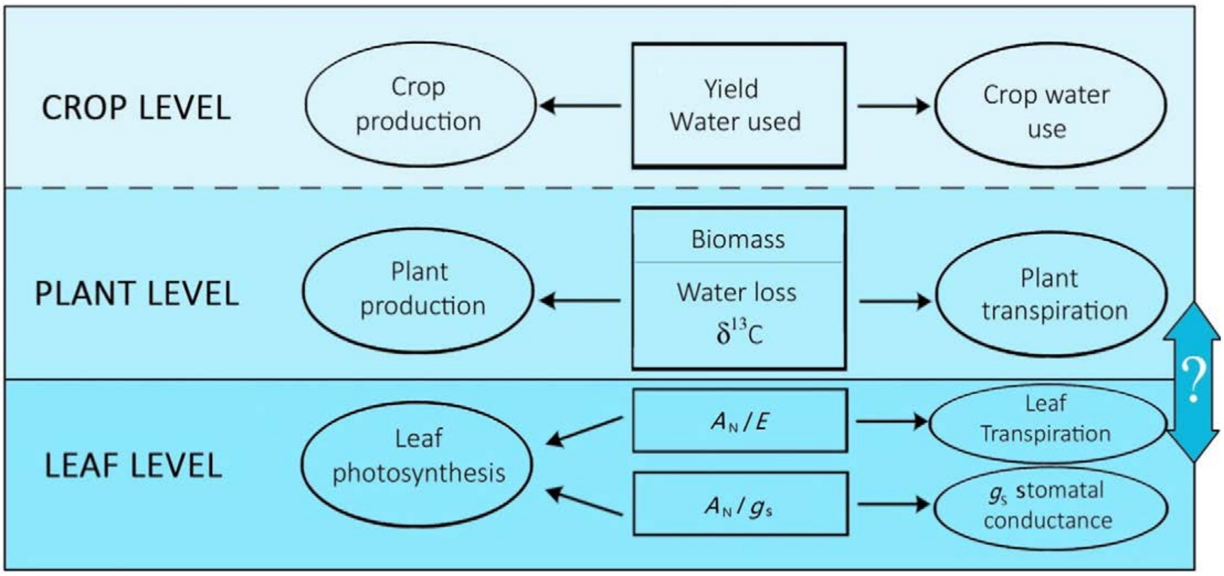


Figure 2.1: Different complexity levels for water use efficiency. Source: Medrano *et al*. (2015).

Crops with deep or dense root system which would promote soil moisture capture and water use (WU) are correlated across crop types with low WUE. Such crops produce high dry matter and known to be drought resistant under field conditions due to their high ability to maintain transpiration, which is supported by deep root systems (Blum, 2009).

Moringa is regarded as one of the drought-tolerant trees which can play an important role under semi-arid farming (Rivas *et al*., 2013). The tree has a long, tuberous tap root that grows very deep into the soil to absorb water from the deeper soil profiles and this mechanism enables the tree to survive in dry seasons where most of the other plants are unable to grow (Ndubuaku *et al*., 2014). A study by Rivas *et al*. (2013) indicated that *Moringa oleifera* can be able to maintain high leaf relative water content even under low soil moisture, which helps to maintain cellular physiological processes, high water use efficiency, and growth.

2.9.4 Soil and nutrient use

The tree has a long, tuberous tap root that grows very deep into the soil to absorb mineral salts from the subsoil (Ndubuaku *et al*., 2014). Moringa grows well on well-drained sandy and loam soils, although it can tolerate clay soils, it is sensitive to waterlogging (Price, 1985). Other studies showed that moringa grows best in dry sandy soils and it also tolerates poor soils that are prevailing in many regions where smallholder farmers are practicing agriculture (Amaglo, 2006; Ashfaq *et al*., 2012). Soils with prolonged waterlogging or poorly drained should actually be avoided. The tree adapts well to soil pH of 5.0-9.0 (Amaglo, 2006). Moringa was shown to grow best on marginal soils having poor fertility status such as desert soils (Singh *et al*., 2012). Although the tree can grow under such conditions, application of organic or inorganic fertilizers is still needed in order to maintain good productivity at appreciated level. Morton (1991) and Dania *et al*. (2014), indicated that in most cases moringa does not receive good horticultural attention and management practices, however, it can still survive, therefore mulching and fertilizer application should not be overlooked in order to achieve an optimum and quality leaf and pod yield.

Nutrient management constitute an important aspect in improving good crop management practices in order to attain optimum yields so that the increasing population's food demand can be achieved (Adegun and Ayodele, 2015). Studies on organic and inorganic fertilizers showed that both fertilizers are important in enhancing moringa growth and yield (Dania *et al*., 2014; Adegun and Ayodele, 2015).

Moringa has a low demand for soil nutrients; but continuously improved yield will only be possible through proper soil and fertilizer nutrient management (Adegun and Ayodele, 2015). Benefits of fertilizer application are not for increased utilization of nitrogen by crops but also to improve yield. Dania *et al*. (2014) conducted a study on comparative effects of nitrogen, phosphorus and potassium (NPK), poultry manure and organomineral fertilizer (OMF) on the growth and nutrient content of moringa. Some of the initial soil macronutrients results which served as a control were as follows: N = 0.40 g/kg, P = 14.5 mg/kg and K 0.17 cmol/kg. Results for poultry manure were: N = 3.4 g/kg, P = 59.53 mg/kg and K = 7.25 cmol/kg while results for OMF were: N = 44.0 g/kg, P = 11.0 mg/kg and K = 6.8 cmol/kg. The results showed that application of poultry manure significantly increased the vegetative growth of moringa as well as leaf nutrient concentration (Dania *et al*., 2014). Mohamed *et al*. (2016) also reported that under appropriate management, the use of efficient organic and biofertilizers leads to a significant increase in growth and biomass of *Moringa oleifera*.

2.9.5 Moringa plant spacing

Several studies have been conducted on moringa planting density. The selection of density depends on the objectives of the production. For example, planting population can be determined by production for fodder, human consumption, seed yield and for different production purposes. Studies on planting spacings were conducted by several researchers focusing on biomass production, cutting frequency and nutritional quality of moringa leaves (Foidl *et al*., 2001; Rajangam *et al*., 2001; Amaglo *et al*., 2006; Sánchez *et al*., 2006; Goss, 2012; Gadzirayi *et al*., 2013a; Mendieta-Araica *et al*., 2013; Basra *et al*., 2015; Zheng *et al*., 2016). The studies focused on planting spacing ranging between 2.5 cm x 2.2 cm or 16 000 000 plants ha^{-1} and 1 m x 1 m or 10 000 plants ha^{-1}. Studies showed significant differences whereby high plant densities produced higher plant biomass as compared to low densities (Amaglo *et al*., 2006; Goss, 2012, Basra *et al*., 2015). However, Gadzirayi *et al*. (2013a) indicated that planting population of 15 x 15 cm and 20 x 20 cm did not have a significant difference in growth and development of moringa.

A study by Goss (2012) showed that increasing plant density influenced dry matter weight of moringa by reducing stem diameter at high density while increasing it at low density. The highest density (197 528 plants ha^{-1}) and the second highest density (98 764 plants ha^{-1}) produced the highest leaf dry matter and leaf fresh weight. The lowest plant density (12 346 plants ha^{-1}) produced the lowest leaf fresh-weight and leaf dry matter. This plant density falls within the wide range of densities recommended for moringa. The conclusion of the study indicated that high plant densities produce higher plant biomass yields and longer stems, but smaller stem diameters, therefore higher density can be recommended for leaf biomass production.

Planting density studies were also conducted to evaluate the nutritional quality of moringa leaves as influenced by cutting frequency. Findings by Sánchez *et* *al*. (2006), showed that cutting frequency (45, 60 and 75 days after planting) and planting density (25 000, 50 000 and 75 000 plants ha^{-1}) did not have significant effect on dry matter (DM), crude protein (CP), neutral detergent fibre (NDF) and acid detergent fibre (ADF). The crude protein content was 226.3, 228.9 and 222.5 g kg^{-1} based on respective cutting frequencies and 226.3, 230.1 and 221.3 g kg^{-1} based on planting densities, respectively.

In another study where moringa was planted at a population density of 100 000 and 167 000 plants ha^{-1}, no significant differences were reported on the chemical composition of moringa leaves during the first and second year (Mendieta-Araica *et al*., 2013). Different results were reported by Basra *et al*. (2015) who found that cutting frequency influenced nutrient composition of moringa leaves under narrow and wider spacings of 15 x 30 cm and 15 x 60 cm, respectively. Nitrogen content was higher under narrow spacing and also increased with a prolonged cutting interval of up to 30 days after the first cut for uniformity (Basra *et al*., 2015).

Limited information is available on moringa seed production as influenced by planting density. Majority of the studies focus on biomass production and nutritional quality and cutting frequency as mentioned previously. No information is available on seed yield production in the African context. A study was conducted in South America on seed and oil yields of moringa as influenced by planting density under four agro-ecological conditions (Ayerza, 2012). The trees were planted at spacings of 1.2 m x 4 m or 2000 plants/ha and 1.2 m x 5 m or 1666 plants/ha. High planting population gave the highest seed yield and oil percentage was not significant (Ayerza, 2012).

2.9.6 Moringa productivity

To obtain a high productivity, a reasonable planting density should be considered as the main factor so as to establish sufficient leaf area that can be able to maximize light interception, photosynthesis and consequently improve crop growth and yield production (Zheng *et al*., 2016). One approach for increased production is to focus on the purpose of producing the tree. Moringa as a multipurpose tree can be grown for diversified products such as biomass, seed, and oil. Therefore there is a need to have background information on the production of moringa for a specific purpose under particular environmental conditions. Moringa yield production can be affected by various factors such as environment and climate (Ayerza, 2012).

2.9.6.1 Leaf yield

Several studies have been conducted globally to focus on biomass or leaf yield production of moringa tree. As indicated earlier, a number of research focused on planting densities and its effect on leaf yield production. For example a study by Patricio *et al*. (2015) was conducted to determine the leaf biomass of moringa as influenced by plant density and frequency of pruning. Moringa plants were grown at four plant spacings and densities of 1 × 1 m (10,000 plants ha^{-1}); 1 × 0.5 m (20,000 plants ha^{-1}); 0.9 × 0.37 m (30,000 plants ha^{-1}) and 0.5 × 0.5 m (40,000 plants ha^{-1}), and harvested at three frequencies; 4, 6, and 8 weeks after first pruning for all treatments. The dry biomass yield production ranged from 2.19 – 7.26 tons ha^{-1}. The highest plant population gave the highest total dry leaf biomass yield (Patricio *et al*., 2015).

A study by Zheng *et al*. (2016) showed the interactive effect between planting density and cutting height on leaf biomass yield. The highest planting density of 20 x 20 cm in combination with a cutting height of 30 cm produced the greatest total leaf dry matter yield of 8.5 tons ha^{-1}. In a study conducted by Goss (2012) results revealed that the highest plant population density produced highest leaf yield. Similar findings were reported by Foidl *et al*. (2001) where the dry matter yield was 3.33, 5.05, 8.94, 13.26, 16.56 and 44.03 metric tons ha^{-1} at a plant population of 95 000, 350 000, 900 000, 1 000 000, 4 000 000 and 16 000 000 plants ha^{-1}, respectively. These results all concur with increasing biomass production as density increases.

A population density of 167 000 plants ha^{-1} and application of nitrogen fertilizer at 521 kg ha^{-1} year $^{-1}$ gave the best results in terms of biomass production as compared to a density of 10 000 plants ha^{-1}. The total dry matter yield produced was 21.2 and 11.6 tons ha^{-1} in respect of planting density (Mendieta-Araica *et al*., 2013). Basra *et al*. (2015) reported the significant interactive effect of spacing and cutting interval on biomass yield production. Planting spacing of 15 x 30 cm with a prolonged cutting interval of 30 days gave the highest fresh matter yield of 6.40 tons ha^{-1} and dry matter yield of 1.48 tons ha^{-1} in harvest one while in harvest two the fresh biomass yield was 6.20 tons ha^{-1} and dry biomass was 1.29 tons ha^{-1}.

In a similar study on different spacings, the results showed no effect on the biomass yield of moringa. The biomass yield was 8.6, 11.1 and 7.6 tons ha^{-1} (first cutting); 7.6, 7.9 and 6.3 tons ha^{-1} (second cutting) and 6.3, 6.3 and 4.9 tons ha^{-1} (third cutting) for spacings of 40 x 20 cm; 40 x 30 cm; 40 x 40 cm, respectively (Manh *et al*., 2005).

2.9.6.2 Seed yield

In South Africa and other African regions, moringa is mainly cultivated for leaf production, since the benefits from leaf powder are well documented and farmers are familiar with the production of leaves. Therefore no information is available on seed yield production as influenced by planting density. Leone *et al*. (2016) reported that moringa can produce high seed quantity when fertilizer is applied; this was estimated after realizing improved biomass production of moringa when fertilized mainly with manure or compost. The seeds of moringa measure about 1 cm in diameter and the seed weight ranges between 270 - 300 g per 100 seeds (Omotesho *et al*., 2013).

In most cases, moringa yield is low in the first two years, whereby the tree can produce less than 90 pods year^{-1}. The yield gradually increases after two years where it can be able to produce up to 500-600 pods per year (Rajangam *et al*., 2001). In a study that was conducted on seed yield production under four ecosystems (Arid Chaco, Yungas Tropical Forest, Subhumid Chaco and Low tropical forest) of South America, the results were influenced by diversified agro-ecological conditions. The number of seeds per tree ranged between 60 and 375 seeds depending on location (Ayerza, 2012). The locations had a significant influence on seed yield production with a yield of 243.49, 749.28, 428.69 and 100.00 kg ha^{-1} at Arid Chaco, Yungas Tropical Forest, Subhumid Chaco and Low tropical forest, respectively (Ayerza, 2012). The study that was conducted in Nigeria over three years from 2007 to 2009 on moringa planted at spacing on 1 x 1 m, the yield production under semi-arid condition was 3.53 kg of seeds tree^{-1} and 16.73 tons ha^{-1} year^{-1} of dry seeds (Omotesho *et al*., 2014).

2.9.6.3 Oil yield

A study on the characterization of moringa oil from the seeds showed that moringa oil could be utilized successfully as a source of edible oil for human consumption (Lalas and Tsaknis, 2002). It contains high monounsaturated to saturated fatty acids ratio, which might be an acceptable substitute for highly monounsaturated oils from most oil crops. The production of useful oil from its seeds could be of economic benefit to the native population of the areas where the tree is cultivated (Lalas and Tsaknis, 2002). Moringa oil is also valued for cosmetic products (Foidl *et al*., 2001). The seeds contain sweet non-sticking and non-desiccating oil known commercially as Ben oil, which can yield between 30-45% oil that resists rancidity (Palada, 1996; Omotesho *et al*., 2013; Mulugeta and Fekadu, 2014). The oil is considered as a great natural cosmetic emollient which is naturally colourless and odourless as well as high in oleic concentration of less than 1% (Ayerza, 2012). The findings of the study on oil yield production under four ecosystems gave the oil yield percentage of 37.4, 37.3, 35.9 and 32.7 at Arid Chaco, Yungas Tropical Forest, Subhumid Chaco and Low tropical forest locations, respectively (Ayerza, 2012).

CHAPTER 3

PRODUCTION AND UTILIZATION OF MORINGA BY FARMERS IN LIMPOPO PROVINCE, SOUTH AFRICA

ABSTRACT

Moringa oleifera is a fast growing tree which has gained importance in the tropics because of its medicinal, industrial, human and livestock nutritional values. In the Limpopo Province of South Africa, moringa is mainly grown by a limited number of farmers in the backyards and spaces around homesteads. This study was aimed at identifying moringa growers in the province and to collate information on their perspective knowledge of production and management of the tree, as well as its commercial production potential. The survey was conducted from November 2013 to September 2014 in five districts of the Limpopo Province. Focus group discussion, questionnaires and field observations were used for data collection. A total of 150 moringa growers formed part of the focus group and a questionnaire was administered to only 31 farmers producing moringa on an area of 0.25 ha or more. Collected data were analyzed using the SPSS version 22. Results from the survey indicated that there are potential moringa farmers in all the districts of the province, with the intention of commercializing the tree. Majority of moringa growers were found in Vhembe district (38.7%) followed by the Waterberg and Sekhukhune districts which accounted for 9.7% of the growers. Male growers were dominant, with 64.5% producing mainly in the mixed farming system. The highest percentage of farmers who grow moringa on 0.25-1.0 ha of land and have been producing the crop for the past 2 years were found in Mopani and Vhembe districts. In general, most farmers grow moringa for leaf processing into powder (96.8%) that is sold locally. This study revealed that most farmers were willing to expand the moringa production, however, the major challenge of effective market access needed to be addressed. This is critical if the crop is to be effectively incorporated in the smallholder farming system for income generation and food security.

Keywords: Survey; *Moringa oleifera*; provinces; commercialization; food security

3.1 Introduction

Moringa oleifera is an important fast growing tree species which can grow up to 6-7 m within a year under a low rainfall of at least 400 mm per annum (Odee, 1998). The moringa tree is also known for its resistance to drought and diseases, as well as its adaptation to harsh growing conditions which most trees cannot withstand (Foidl *et al*., 2001). Moringa is a fairly new crop to farmers in the Limpopo Province and is mainly grown in the backyards for household purposes. There is limited information on farmers' knowledge and perceptions of management, utilization, processing and commercial production of this tree crop. Currently, many areas of South Africa, the Limpopo Province, in particular, experience significantly prolonged dry seasons which negatively impact the agricultural sector (LDA, 2010).

Limpopo Province has an average annual rainfall of 500 mm and the threshold average rainfall for agriculture is 250 mm per annum (LDA, 2010). The province also experiences extremely high temperatures with continuous records exceeding 30^{o}C during the growing season. During drought seasons, production of grain crops under dryland conditions becomes almost impossible. Food security is thus threatened, given the fact that majority of the farmers in the province produce these crops under rainfed conditions. As a result of unreliable rainfall over the past years, it is important for farmers in Limpopo Province to diversify the crops they grow in order to counteract the challenge of drought across the province (Maponya and Mpandeli, 2012). Cultivation of moringa under harsh conditions, such as experienced in the Limpopo Province, is therefore recommended since it will serve as an important contributor to food quality due to its high nutritional value in the leaves and tender green pods. Moringa products have a high commercial value thus making its cultivation a potential cash earning opportunity that can enhance the livelihoods of the smallholder farmers in the province. Moringa has been cultivated in many areas of the tropics mainly for medicinal, industrial and nutritional purposes. In many tropical areas, there are major nutritional limitations of feed for ruminants with natural feeds having poor quality and quantity, which can lead to a deficiency of energy and protein (Mannetje't, 1984; Odeyinka and Ademosun, 1993). This challenge of feed shortages for ruminants is exacerbated during the dry seasons when natural pastures are low in protein and energy. Several studies revealed that moringa has a high nutritional content and can serve as a good source of feed supplement (Dash and Gupta, 2009; Moyo *et al*., 2011). Therefore, moringa, as a source of protein, will improve the livestock performance and supplement the balance of other nutrients available (Odeyinka *et al*., 2007).

Moringa leaves contain a high concentration of crude protein and other essential elements (Gidamis *et al*., 2003). The seeds of moringa are also reported to be important for human consumption as an edible oil and seedcake for soil fertility amelioration. Seeds contain about 35 to 40% oil which can be used in many ways besides human consumption, including products for lubrication of delicate machinery, manufacture of perfumes and hairdressing products (Odeyinka *et al*., 2007). The oil has a high potential market value and could be a source of income for the producers (Maroyi, 2006). Seed cake is a good source of fertilizer, however, it is not advisable to use the seed cake for livestock feed as it contains alkaloids and saponin (CSIR, 1962).

Farmers in Limpopo Province grow moringa for various purposes under variable management strategies. The study was carried out to establish the extent of farmers' involvement in growing moringa in the five districts of the Limpopo Province; and to establish the current status of the crop in the smallholder farming sector focusing on farmers' knowledge on general production and uses, as well as the marketing of its products and its potential for income generation.

3.2 Materials and Methods

3.2.1 Study sites

A survey was conducted from November 2013 to September 2014 in all the five districts of the Limpopo Province (23.4013° S, 29.4179° E), namely Capricorn, Sekhukhune, Waterberg, Mopani and Vhembe (Figure 3.1). Limpopo Province falls within the summer rainfall region of South Africa, with the western part being semi-arid and the eastern part largely sub-tropical. Typical rainfall for the province ranges from 200 mm in the hot dry areas to more than 1500 mm in the high rainfall areas, with most of it occurring between October and April (Limpopo D.F.E.D, 2004). The province experiences the highest temperature during the months of October to March. Temperatures peak in December and January at an average of about 25°C. The lowest temperatures occur in July with an average of 15°C with the average annual temperature being about 22°C (Tshiala *et al*., 2011). Some parts of the province experience frost in June to July period.

3.2.2 Participants and data collection

The study used both the quantitative and qualitative methods. A structured questionnaire was used to gather all the information required, by interviewing both the commercial and smallholder farmers who are growing moringa in the Limpopo Province. Focus group discussions and field observations were also made to validate the data obtained from the farmers and to assess the situation on the ground. Open-ended questions were included in the questionnaire to enable discussions on production challenges that the farmers face.

Participating farmers were identified with the assistance of Limpopo Department of Agriculture and during the Moringa Development Association of South Africa (MDASA) launch, held on the 24th of February 2014 in Lebowakgomo. There were 150 farmers who attended the meeting. During that meeting, it was realized that some farmers produced moringa on very small areas as, well as in the backyards. A purposive sampling technique was used to select the farmers who produce moringa on at least 0.25 ha. A total of 31 farmers were identified and interviewed for the reporting purpose of this study. Data collected included gender, farm size, farming systems, management practices, leaf production, processing methods and marketing, as well as production constraints.

3.2.3 Statistical analysis

Data from the survey were analyzed statistically using the Statistical Package for Social Sciences (SPSS) version 22 (IBM SPSS Statistics for Windows, Version 22.0. Armonk, NY: IBM Corp, 2013). Descriptive statistics were used to achieve the study's objectives and to generate frequencies of response. The Pearson's Chi-square test was conducted to determine the significance of associations at the probability level of ≤ 0.05. The locations where farmers produce moringa on fields in excess of 2.0 ha and the mean annual rainfall experienced from the locations as indicated by Figure 3.1.

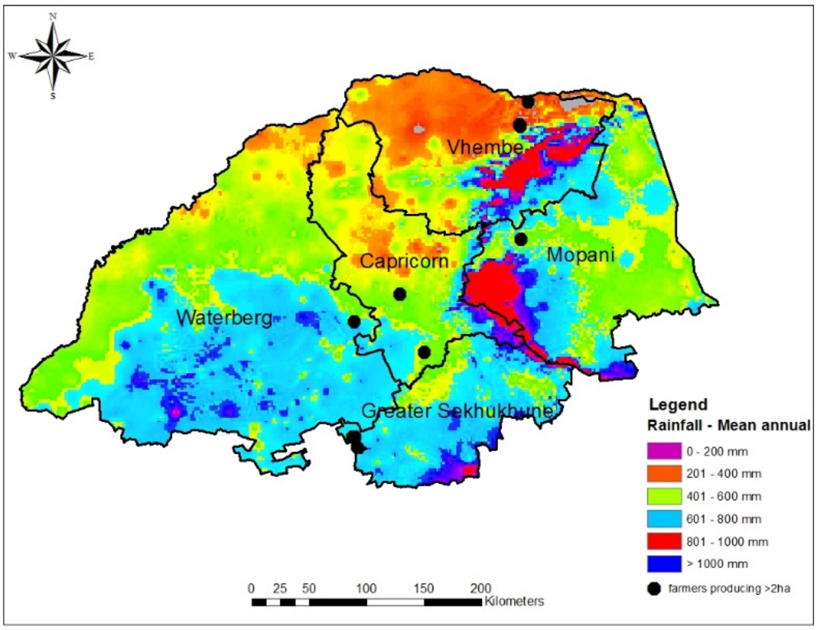


Figure 3.1: Limpopo Province map with a legend showing districts, mean annual rainfall and locations of farmers who cultivate more than 2 ha of moringa.

3.3 Results

3.3.1 Production of moringa in Limpopo Province.

The chi-square test showed significant differences (p=0.001) between the districts on the number of farmers growing moringa in the Limpopo Province. It was previously known that moringa is widely grown in Sekhukhune district but contrary to that, the results of this study (Figure 3.2) showed that most production takes place in Vhembe district with 38.7% of the smallholder farmers growing the tree on at least 0.25 ha. Mopani and Capricorn districts follow with 22.6 and 19.4%. Sekhukhune and Waterberg have the least numbers of farmers producing moringa on land areas exceeding 0.25 ha at 9.7% each. The majority of farmers in Sekhukhune produce at the household level where they have less than 5 trees in their backyards.

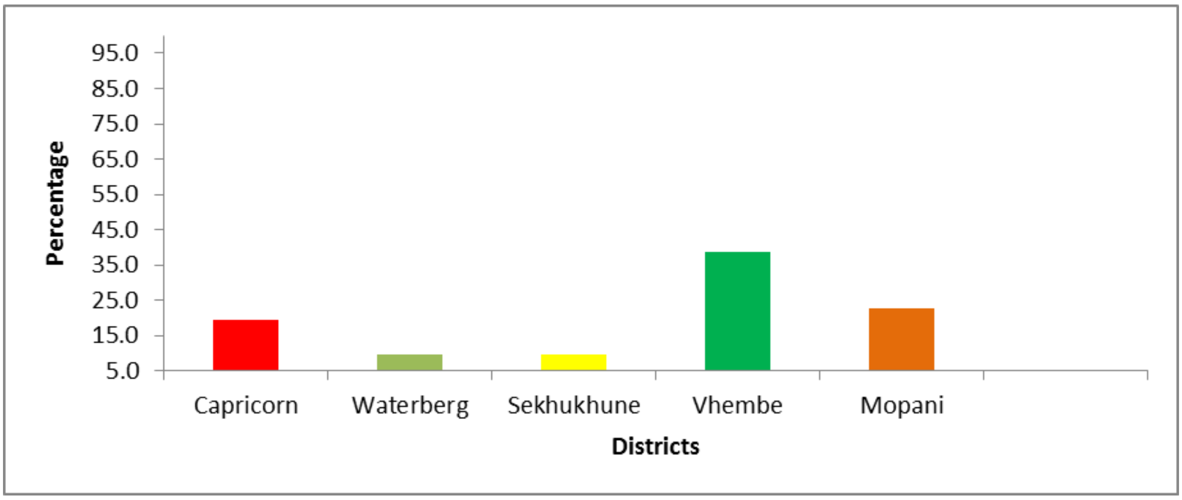


Figure 3.2: Distribution of farmers who cultivate moringa (>0.25 ha) in different districts of the Limpopo Province.

3.3.2 Gender influence on moringa production in Limpopo Province.

Amongst the producers, this survey revealed that males are the dominant producers of moringa in the Limpopo Province accounting for 64.5% of the farmers (p=0.027).

3.3.3 Farming systems

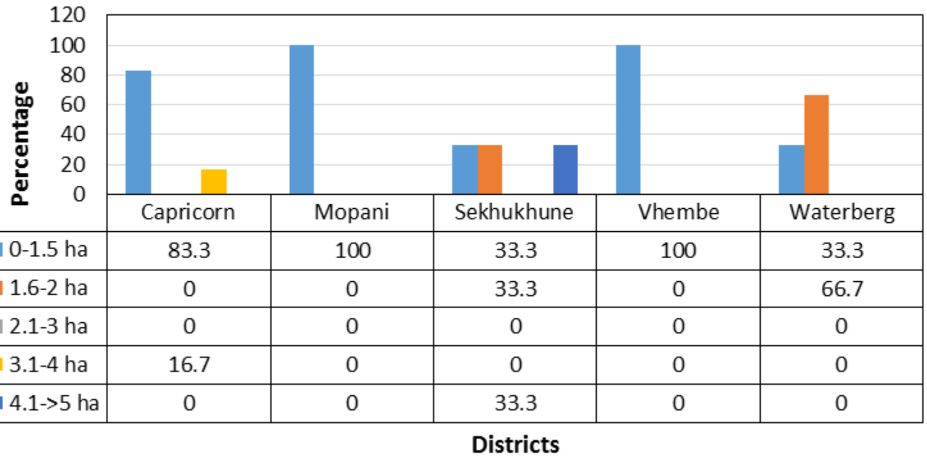
This study revealed that about 64.5% of farmers grow moringa under mixed farming systems which include moringa, other crops, and livestock. Approximately 26.0% grow the crop under polyculture, and only 9.7% of farmers were found to produce moringa in pure stands.

3.3.4 Size of landholdings of moringa farmers

The study indicated that farmers who produce moringa in the province own diverse land sizes ranging between 0.5 – 63.0 ha per farmer. There were significant differences (p=0.000) between the total farm sizes owned by farmers and between the districts. The study further revealed that 38.9% of farmers own a small land area of 0.25 to 1.0 ha, followed by 12.9% who own between 1.5- 3.0 ha, while the remaining 48.1% of farmers own bigger lands of between 3-63 ha. Among the 48.1% farmers with large lands, two farmers own 42 and 63 ha, respectively.

3.3.5 Total farm size devoted for production of moringa

Analysis from this study showed a significant difference (p=0.000) among the land devoted to moringa in the different districts. The study revealed that the land area currently allocated to moringa does not exceed 6.0 ha. Majority of farmers grow moringa at an area in the range of 0.25–1.5 ha across all the districts. However, the Capricorn, Sekhukhune, and Waterberg districts were found to have farmers who cultivate the tree in areas exceeding 1.5 ha (Figure 3.3).

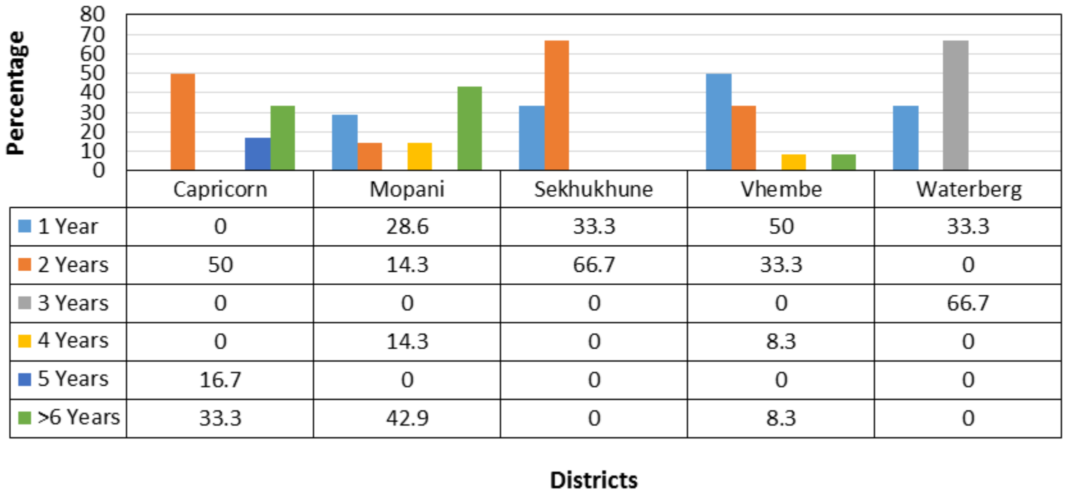


	Capricorn	Mopani	Sekhukhune	Vhembe	Waterberg
🟦 0-1.5 ha	83.3	100	33.3	100	33.3
🟧 1.6-2 ha	0	0	33.3	0	66.7
◼ 2.1-3 ha	0	0	0	0	0
🟨 3.1-4 ha	16.7	0	0	0	0
🟦 4.1->5 ha	0	0	33.3	0	0

Figure 3.3: Farmer land area devoted to moringa production in the five districts of the Limpopo Province.

3.3.6 Farming experience in moringa production

Most moringa farmers are new in the agro-enterprise having been on the production only for the last two years as shown in Figure 3.4. Majority of these are in Sekhukhune district. However, the Mopani district was found to have a large number of farmers who have been cultivating the crop for more than six years. More farmers started planting moringa after realizing its nutritional and health benefits as well as possibilities of income generation from its products. These results (Figure 3.4) show that the widespread production of moringa in the Limpopo Province is still at the developmental stage.



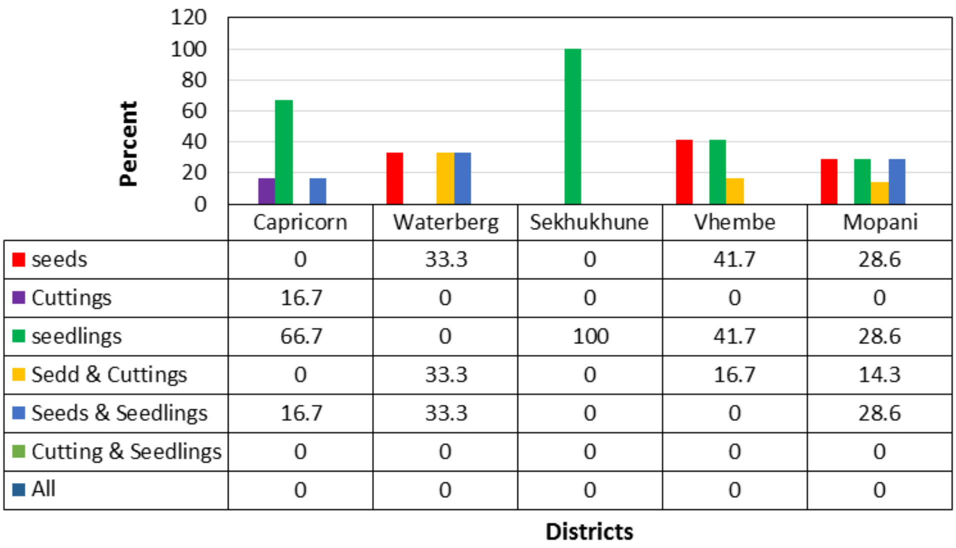
	Capricorn	Mopani	Sekhukhune	Vhembe	Waterberg
■ 1 Year	0	28.6	33.3	50	33.3
■ 2 Years	50	14.3	66.7	33.3	0
■ 3 Years	0	0	0	0	66.7
■ 4 Years	0	14.3	0	8.3	0
■ 5 Years	16.7	0	0	0	0
■ >6 Years	33.3	42.9	0	8.3	0

Figure 3.4: Farmers' experiences in moringa production in the five districts of the Limpopo Province.

3.3.7 Farmers' knowledge on management practices of moringa

The study revealed that 74.2% of farmers apply both organic and inorganic fertilizers to enhance the growth of moringa while 25.8% grow the tree under the natural conditions. Among the farmers who apply fertilizers, 61.3% use organic fertilizer particularly livestock manure, 12.9% use inorganic fertilizer while the other 25.8% of farmers allow the trees to grow naturally. Approximately 39.0% of the inorganic fertilizer users indicated that they collect the fertilizer from their own animal barn. The other group of farmers (22.6%) acquired the organic fertilizer through a donation from the surrounding villages. About 12.9% of those farmers who use the inorganic fertilizers obtain them through purchase.

Farmers in four of the districts prefer to use the only seedlings while, Waterberg district uses seeds, plus a combination of cuttings and seedlings. The results showed a significant relationship (p=0.002) between the districts and the propagation methods. Majority of farmers preferred to plant using seedlings relative to other methods (Figure 3.5).



	Capricorn	Waterberg	Sekhukhune	Vhembe	Mopani
🟥 seeds	0	33.3	0	41.7	28.6
🟪 Cuttings	16.7	0	0	0	0
🟩 seedlings	66.7	0	100	41.7	28.6
🟨 Sedd & Cuttings	0	33.3	0	16.7	14.3
🟦 Seeds & Seedlings	16.7	33.3	0	0	28.6
🟩 Cutting & Seedlings	0	0	0	0	0
🟦 All	0	0	0	0	0

Figure 3.5: Propagation methods preferred by farmers in the five districts of Limpopo Province.

Farmers' perceptions on management practices of moringa cultivation across the five districts of Limpopo are shown in Table 3.1. The study indicated that generally, 83.9% of farmers in the province preferred to plant the trees in rows whilst 16.1% of farmers plant at random without any spacing. It was observed that farmers who plant in rows used various inter-row spacings with the majority (45.2%) maintaining 1 to 2 meters between the rows (Table 3.1). Few farmers (6.5%) plant a high population of trees at a space of 0.5 m between the rows whereas 25.8% plant at low density with an inter-row spacing of 3 to 4 m.

All the farmers interviewed mentioned that they prune their trees when necessary in order to maintain a height that eases leaf harvesting. Pruning height was significant with the highest proportion of farmers (45.2%) preferring to maintain the trees at 2.0 m height followed by 25.8% of farmers who maintained their trees at a 3.0 m height. Few farmers (16.1%) prune the trees at 1 m, while a lesser proportion of 6.5% each maintained the trees at 1.5 and 2.5 m (Table 3.1).

3.3.8 Planting seasons

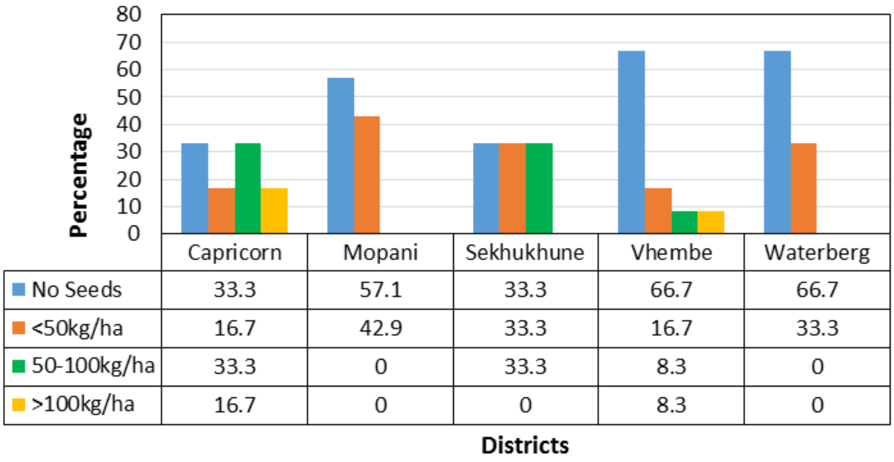
Most farmers in the Limpopo Province plant moringa throughout the year except during winter. There were significant differences (p=0.000) between the districts and planting seasons. Majority of farmers in Mopani district (71.4%) preferred to plant in spring while 75% of farmers from Capricorn district preferred to plant in summer. However, in general, the highest proportion of farmers (48.4%) plant moringa during spring and 38.7% plant the tree in summer. At least 12.9% of farmers plant the tree in autumn.

3.3.9 Harvesting duration

Farmers indicated that they harvest the tree foliage when necessary, ranging from 3-12 months after planting. The study further revealed that approximately 35.2% and 32.3% of farmers harvest the trees at 5 and 6 months after planting, respectively, whereas 26.0% of the farmers carry out harvesting when the trees are between 7-12 months after planting. A very strong relationship between the harvest duration and the districts (p=0.001) was observed, whereby half of the farmers in Vhembe district (50%) commenced harvesting within six months after planting, followed by Mopani district at five months after planting. Only a small proportion (6.4%) of farmers harvested the trees at an earlier stage of growth within 3-4 months after planting, but this occurs when favourable weather conditions prevail.

3.3.10 Seed and leaf yield production

The highest proportion of farmers preferred to harvest the leaves rather than harvesting the seeds. Overall, 55% of farmers in the Limpopo province harvest the leaves, while there are some farmers who grow the tree solely for the seeds (Figure 3.6). There was no significant difference (p=0.12) on the seed yield among the districts. Generally, the study revealed that 54.8% of farmers in the Limpopo province grow moringa with the purpose of harvesting the leaves. With this objective, the trees are maintained at a vegetative stage and pruned frequently to avoid seed production. For the farmers who grow the tree for seed production, 25.8% produce seed yield of less than 50 kg/ha, followed by 12.5 % of farmers who produce between 50-100 kg/ha. The least proportion (6.5%) of farmers produce more than 100 kg/ha. Farmers have no idea of leaf yield except harvesting from their fields. It was indicated earlier that farmers harvest the crop when necessary. This could be the reason why farmers are unable to quantify their leaf yield production. Some farmers retain bulk seeds, that they have harvested from several seasons and combine them for storage. Access to weighing balances may be a formidable challenge, for farmers who belong to these groups.



	Capricorn	Mopani	Sekhukhune	Vhembe	Waterberg
🟦 No Seeds	33.3	57.1	33.3	66.7	66.7
🟧 <50kg/ha	16.7	42.9	33.3	16.7	33.3
🟩 50-100kg/ha	33.3	0	33.3	8.3	0
🟨 >100kg/ha	16.7	0	0	8.3	0

Figure 3.6: Moringa seed yield produced by farmers in five districts of the Limpopo Province.

3.3.11 Utilization of moringa

Farmers indicated that they use moringa in several ways, such as a source of income, a high nutritional supplement for good health, food security, immune booster, livestock feeding, water purification, medicinal purposes to prevent many diseases and energy booster.

3.3.12 Moringa processing

The study indicated that there are 96.8% farmers who produce moringa in all the districts of the province with an aim of processing the leaves into powder primarily for marketing to a limited extent and other uses. A lesser proportion (3.2%) processes other parts of the tree such as the seeds. From the large proportion of farmers who process the leaves, 83.9% process them into a powder form, whilst only 16.1% of the farmers process it into different products, such as dried leaves only and tea bags.

Table 3.1: Cultural practices used by farmers in moringa production (N=31).

Management practices	Frequency	Percentage (%)	Pearson Chi-Square Value (χ^2)
Planting spacing			
Random	5	16.1	6.01**
In rows	26	83.9	
Spacing between the rows (m)			28.09**
Random	5	16.1	
0.5	2	6.5	
1.0	7	22.6	
2.0	7	22.6	
2.5	1	3.2	
3.0	4	12.9	
4.0	4	12.9	
5.0	1	3.2	
Spacing between the plants (m)			19.01*
Random	5	16.1	
0.5	2	6.5	
1.0	6	19.4	
2.0	6	19.4	
3.0	6	19.4	
4.0	5	16.1	
5.0	1	3.2	
Maintenance height			15.27**
1.0	5	16.1	
1.5	2	6.5	
2.0	14	45.2	
2.5	2	6.5	
3.0	8	25.8	
Total	**31**	**100.0**	

**Significant at 0.01 level, *Significant at 0.05 level

3.3.13 Overall marketing approaches of moringa in Limpopo Province

The marketing status of moringa in the Limpopo Province is indicated by Table 3.2. This study revealed that the majority of farmers (96.8%) produce moringa with an intention of marketing their products. From the study, it was observed that 3.2% of the farmers from Waterberg district do not sell their products, the reason being that the trees are still young but the ultimate intention is to sell the leaves at a later stage. The study further shows that 77.4% of the farmers who produce moringa, sell the leaf powder in all the five districts, while only 3.2% of these farmers sell the dried leaves only. Few farmers produce moringa and sell it in various forms including, teabags, capsules, fresh leaves, seeds and seedlings (Table 3.2).

Irrespective of the districts, it was found that farmers sell the leaf powder in diverse packaging sizes ranging from 20 g to 100 g. Majority of these farmers preferred to package the powder in 50 g while others use different packaging sizes of 30 followed by a small proportion of farmers who package the moringa powder in different sizes of 20, 60 and 100 g. In the Limpopo Province, there were about 28.9% of farmers who packed and sold the different products of moringa such as teabags, capsules, fresh leaves, seeds and seedlings (Table 3.2). Farmers who produce teabags and capsules are the ones who have established markets and managed to purchase processing machines. These farmers are located in the Capricorn, Sekhukhune, Waterberg and Mopani districts. Although a large number of farmers were found in Vhembe district, most of them preferred indigenous grinding methods to produce a powder.

Majority of the farmers sell their products within their immediate community, while only a few of well-established producers sell to the supermarkets and pharmaceutical shops. The farmers also indicated that they sell moringa products from their own produce and have not yet started sourcing from other farmers.

Due to the lack of a formal market and no price control, the selling price of moringa powder varies widely. It was observed that 29.0% of the farmers sell a 50 g powder for [‡]R50.00, followed by 22.6% and 12.9 % of farmers who sell the same quantity at R30.00 and R20.00, respectively. Other prices include R45.00, R65.00, R80.00 and R100.00 depending on the quantity. Due to the limited market access, farmers are compelled to sell their products on individual arrangements which further contribute to the inconsistency in the pricing of moringa powder.

Table 3.2: Marketing approaches of moringa in Limpopo Province (N=31).

Marketing	Frequency	Percentage	Pearson Chi-Square Value (χ^2)
Farmers sell their products			
Yes	30	96.8	9.65**
No	1	3.2	
Product marketed			
Not selling	1	3.2	15.89**
Dried leaves	1	3.2	
Powder	24	77.4	
Several products	5	16.1	
Quantity per unit (g)			
0	1	3.2	60.65**
20	2	6.5	
30	4	12.9	
50	12	38.7	
60	2	6.5	
100	1	3.2	
Different sizes	9	28.9	
Selling price (R/50g‡)			
0	1	3.2	9.64**
20	4	12.9	
30	7	22.6	
45	1	3.2	
50	9	29.0	
65	2	6.5	
80	1	3.2	
100	1	3.2	
Different products	5	16.2	
Total	**31**	**100.0**	

‡: R = South African Rand (R15.00 is approx. 1.00 US Dollars during the period of the survey)

**Significant at 0.01 level, *Significant at 0.05 level

3.3.14 Summarised representative enterprise budget from moringa farmers

An annual enterprise budget from a case study of farmers who produce and market the moringa tree is presented in Table 3.3. This information was generated from farmers who commercialize moringa in Capricorn, Waterberg and Mopani districts. Information collected from their farms in 2015 was consolidated and summarized in Table 3.3. Farmers grow moringa on an average area of 0.75 ha and assume to harvest the leaves in all the seasons. The budget shows a total income of R191 140.00 and a total production cost of R99 500.00 resulting in a gross margin of R81 690.00.

3.3.15 Challenges faced by farmers

Farmers indicated that the challenges they face in moringa production extend to: unreliable access to market, the shortage of funding to enhance production, limited land for large area production, shortage of processing infrastructure, shortage of water to irrigate the trees in times of extreme drought, theft by community members, shortage of fencing to protect the trees against free-roaming livestock and game animals, lack of training for production awareness, lack of knowledge on control of termites and formation of spider webs on the trees. Farmers further indicated that, although they have a good land suitable for the production of moringa, market access still remains the main challenge. Therefore, expansion of production is restricted by limited access to the market.

Table 3.3: Moringa enterprise budget: income and expenditure for the 2014/2015 season

MORINGA POWDER FINANCIALS				
Activity **Production of moringa/annum**	**Unit**	**Qty**	**Price or Cost/Unit (Rand)**	**Value or Cost / Ha (Rand)**
Total size of the enterprise	ha	0.75		
Gross receipts				
Spring yield of moringa/ha	kg	72		
Summer yield of moringa/ha	kg	86		
Autumn yield of moringa/ha	kg	36		
Winter yield of moringa/ha	kg	7.2		
Total Yield / 0.75 ha	**kg**	**201.2**		
Spring sales of moringa at R950 / kg	kg		950	68400
Summer sales of moringa at R950 / kg	kg		950	81700
Autumn sales of moringa at R950 / kg	kg		950	34200
Winter sales of moringa at R950 / kg	kg		950	6840
Gross Income				**191 140**
Pre-harvest				
Seed at 2 kg/ha at R600/kg	kg	0.00	65.00	0
Compost making at 3 tons/ha	tons	3.00	700.00	2100
Labour: 2 labourers at R3000.00/season	season	4	3000	12000
Total pre-harvest costs				**14100**
Marketing	month	12	400	4800
Packaging material cost	count	700	2	1400
Total harvesting costs				**6200**
Utility Cost				
Electricity	month	12	700	8400
Communication	month	12	650	7800
Transport: 70 km/day/15days/month/12 months at R5.00/km	km	12600	5	63000
Total Utility Cost				**79200**
TOTAL COST SHOWN EXCLUDING CAPITAL COST				**99500**
Contingency: Unknown (10%)				**9950**
GRAND TOTAL COST				**109450**
MARGIN ABOVE COST SHOWN				**81690**

Assumptions: Other labour comes from the company's permanent staff; the trees are established and are 2 years old; Utility cost will be lower for a smaller area than a larger one.

3.4 Discussion

3.4.1 Provincial status of moringa production

The study revealed that moringa can grow in all the districts of Limpopo Province under diverse climatic conditions. Moringa has the potential to contribute towards human and livestock dietary needs and foster rural development, due to its considerable benefits (Rebecca, 2006). A study by Lekgau (2011) indicated that, in South Africa, moringa is produced in provinces such as Kwa-Zulu Natal, Mpumalanga, as well as the Limpopo mainly for household purposes. The households have trees in their backyards for leaf and pod production (Lekgau, 2011). The leaves are dried and ground into a powder form which is sprinkled on food whereas the young pods are consumed directly as a vegetable after cooking. Packaged moringa powder is now sold by several farmer groups and industrially produced moringa juice is sold in some supermarkets.

3.4.2 Gender influence on moringa production in Limpopo Province

Moringa in the Limpopo Province is predominantly produced by male farmers. This is contrary to the general opinion that the majority of smallholder farmers in Limpopo Province are women (Thamaga-Chitja and Morojele, 2014; FAO, 2015). However, it is also known that male farmers mostly feature on the production of commercial crops. A study by Odeyinka and Ademosun (1993), on awareness and knowledge of moringa in Nigeria, also indicated a higher proportion of male farmers (59.7%) compared to females (40.3%). Furthermore, another study conducted by Thamaga-Chitja (2012), on the consumption of moringa reported that most of the respondents (69%) consuming moringa products in Nigeria were males. The possible reason for women to be less involved in moringa farming might be that large sizes of farms are owned by men while women are focusing on household activities and production in the backyards, in order to stabilize home food supplies (Thamaga-Chitja, 2012). This trend of production may also suggest a strong commercial potential of the plant, hence the clear interest of male farmers.

3.4.3 Moringa farming systems and area devoted for production in Limpopo Province

The mixed cropping system is dominant in the Limpopo Province whereby farmers produce moringa, other crops as well as raising livestock. Few farmers in the Limpopo Province plant moringa mainly as a sole crop, hence majority grow moringa under the mixed farming system because the subtropical conditions of the province make it easy for the cultivation of many tropical fruits and field crops as well as livestock farming (StatsSA, 2006). A study conducted in Zimbabwe indicated that the majority of smallholder farmers only grow moringa around homesteads instead of larger farm areas (Gadzirayi *et al*., 2013b). Such production probably caters for domestic consumption of the moringa products (Mudyiwa *et al*., 2013). In Limpopo Province, the distribution of land sizes allocated to moringa strongly suggest that either the farmers or some agencies are promoting moringa for commercial purposes. This notion can be supported by the existence of an organization called Moringa Development Association of South Africa (MDASA).

3.4.4 Management practices used by farmers for moringa production

Farmers producing moringa in Limpopo Province apply both organic and inorganic fertilizers to enhance tree growth. A study conducted by Dania *et al.* (2014) on comparative effectiveness of different fertilizer sources on growth of moringa revealed that the application of organic fertilizer such as poultry manure significantly increased the vegetative growth of moringa relative to NKP. However, this study revealed that farmers in Limpopo Province prefer to use organic fertilizer such as compost and livestock manure compared to inorganic fertilizer due to its enormous advantages as well as the minimum or no cost in acquiring it.

3.4.5 Planting time of moringa trees

This study revealed that farmers in Limpopo Province use various methods of propagation such as seeds, seedlings, and cuttings to establish moringa. Results from this study concur with the findings by Gadzirayi *et al*. (2013b), where the study indicated that seedling propagation is the most popular method for establishing moringa plantations, the reason being that most farmers plant moringa during the rainy and warm seasons to encourage establishment. Using direct planting may assist in reducing transplanting shock of seedlings, which affects the crops' performance during the early developmental stages. Utilization of stem cuttings has an advantage in terms of uniformity, however, establishment takes time and restricts the establishment period due to the slow growth rate. Therefore, the study reveals that temperature and moisture are the main factors considered for establishing the crop. In a similar study by Gadzirayi *et al*. (2013b), indicated that farmers in Zimbabwe prefer to plant the crop during rainy seasons. Such timing is likely to achieve easier plant establishment and avoid labour for manual irrigation of the seedlings. The danger of animal damage is also eliminated as all rural livestock are either paddocked or herded during the cropping season.

3.4.6 Harvesting and utilization of moringa trees

Moringa leaves can be harvested as early as three months after planting in some areas of the Limpopo Province. Factors influencing the time of harvesting vary considerably among the farmers. It was revealed that farmers only harvest the leaves when they want to sell or use them. Similar findings were reported by Maroyi (2006); Gadzirayi *et al*. (2013b) where farmers harvested the leaves with a purpose of selling or consuming them. This study indicated that farmers in Limpopo province harvest moringa at different times and this might be due to the varying temperature conditions since low temperatures slow the growth of the crop. Several studies concur with the information obtained from the farmers in the Limpopo Province on the utilization of moringa. For the majority of farmers, perceptions and knowledge on the utilization of moringa are almost similar. Besides what farmers have responded to the utilization of moringa, other uses include oil for industrial use, biogas and as an ornamental plant (Fuglie 2000; Foidl *et al.,* 2001; Fahey 2005; Maroyi 2006; Moyo *et al*., 2011; Adejumo *et al*., 2012; Animashaun *et al*., 2013; Gadzirayi *et al.,* 2013b).

3.4.7 Processing of moringa trees

The study further revealed various methods which farmers use when drying and grinding moringa leaves. Majority of the farmers use the traditional method of grinding followed by sieving to produce a fine powder. Few farmers use the grinding machine for processing the leaf powder. Drying leaves assists in the concentration of nutrients and facilitates long-term storage thus Moyo *et al*. (2011) suggested that moringa should be consumed in powder form. The high nutritional content found in the dried leaves is an important indicator of the usefulness of the plant as a likely feed source (Maroyi 2006 and Moyo *et al*. 2011).

3.4.8 Marketing of moringa products

The demand for moringa products is high in the Limpopo Province and on the South African context; however, the majority of the farmers do not meet the market requirements due to low standards of processing and storage facilities that the farmers use. This study revealed that there is a need for proper and organized market structures so that moringa farmers will be able to market their products and generate substantial income from the enterprise. This could have a positive economic contribution towards the provincial GDP, create jobs and wealth, and also improve the general livelihood of the farmers. In addition, it will contribute to the achievement of the Millennium Development Goal number 1: Eradication of extreme poverty and hunger (Williams *et al*., 2013).

The summarised enterprise budget indicated that moringa can be a good source of income and livelihood for farmers who grow the trees on a larger scale. Farmers producing moringa in the Limpopo Province also encounter production challenges such as skills in terms of good management practices for sustainable moringa production. A study by Gadzirayi *et al.* (2013b) on the other hand reported that red spider mites, aphids, caterpillars, and termites are the most troublesome pests in moringa production. The study further indicated that moringa does not have a challenge of being attacked by diseases. The issue of markets requires further probing to establish the possible demands from the organizations selling packaged moringa powder and juice. The level of local trading in moringa powder also needs further research.

3.5 Conclusion

The study concludes that moringa is produced in all the districts of Limpopo Province with its utilization being variable, although production for nutritional and medicinal purposes seems to dominate. The tree is mainly grown by male farmers and the majority of them grow on a relatively small area ranging from 0.25 ha to 1 ha, using different management practices. Farmers produce moringa with the purpose of processing the leaves into a powder that is sold in the local communities, however, due to underdeveloped market, there is wide variability on the pricing of moringa products. Moringa has strong potential to generate income in Limpopo Province but the marketing of the crop needs to be improved since this crop offers a significant opportunity for the poorest people to enhance their livelihoods without requiring large capital and sophisticated management. Therefore, there is a need to promote moringa production with the aim of sustaining its commercialization. Further research is recommended on moringa as a potential crop in agroforestry, and the conceptualization of stabilized marketing and pricing of its products.

CHAPTER 4

EFFECT OF PLANTING DENSITY AND HARVEST INTERVAL ON THE LEAF YIELD AND QUALITY OF MORINGA (*MORINGA OLEIFERA*) UNDER DIVERSE AGRO-ECOLOGICAL CONDITIONS OF NORTHERN SOUTH AFRICA

ABSTRACT

Smallholder livestock farmers who depend on natural communal grazing lands are particularly vulnerable to climate change as well as to food insecurity and should be encouraged to grow drought tolerant fodder crops. *Moringa oleifera* is a highly valued plant, due to its exceptionally high nutritional content. This study was conducted at two experimental sites in the Limpopo Province of northern South Africa to evaluate for the first time, the effect of plant density and cutting interval on biomass production and chemical composition of moringa grown under two diverse climatic conditions. Four different planting densities (435 000, 300 000, 200 000 and 100 000 plants/ha) were arranged in a randomized complete block design and experimental samples were replicated four times. Data for biomass and gravimetric soil moisture content were collected each time the plants reached a height of 50 cm. Harvested leaves were analyzed for chemical composition. An increase in the plant density led to elevated biomass production at both study locations, ranging between 527–2867 kg/ha. Moringa is capable of meeting all nutrient requirements of livestock depending on harvest time and location.

Keywords: Agroecology, biomass, chemical composition, *Moringa oleifera*, plant population and soil moisture

4.1 Introduction

Agriculture makes vital contributions to the living conditions of rural communities in South Africa as livestock and crop production are their main sources of livelihoods. Farmers rear livestock and mainly depend on natural grazing land because of their inability to purchase feed supplements or to grow fodder crops under intensive management systems where water and fertilizer inputs are unaffordable. However, the prospect of climate change poses a serious threat to food security and feed supply, whereby some farmers will lose their livestock owing to a shortage of fodder. Changes in temperature and rainfall patterns due to drought and excessive heat, with temperatures that could rise beyond 30 ^oC on three or four consecutive days as well as unpredictable rainfall and strong wind, are the major threats to the production of food by smallholder farmers in South Africa (Rankoana, 2016). More resilient food crops, therefore, need to be investigated to cope with changing weather conditions.

The Limpopo Province of northern South Africa falls largely within a semi-arid zone so that farmers should be encouraged to grow fodder crops which are drought tolerant and are also capable of producing enough yield during periods of drought. According to Maponya and Mpandeli (2012), drought and extreme temperatures are already causing serious problems in the province, forcing farmers in some areas to sell their livestock due to lack of feed. These drought conditions are not limited to Limpopo alone, but to South Africa as a whole (Maponya and Mpandeli, 2012). Lack of sufficient and high quality fodder, mainly during the dry seasons in tropical and subtropical areas, in particular, has increased the need to provide supplementary fodder to sustain farm animals (Brown *et al*., 2016).

Fodder trees such as *Acacia* spp., *Sesbania sesban, Delbergia sissoo and Moringa oleifera* are recognized throughout Africa for their ability to supplement livestock feed during times of intense drought (Nouman *et al*., 2013). These species are capable of producing more foliage with high contents of digestible and other essential nutrients as high quality forage supplement for livestock relative to other herbaceous species (Foidl *et al*., 2001). The majority of forage trees have the ability to retain their leaves even during dry seasons (Tripathi *et al*., 1992; Nouman *et al*., 2013). Relying on herbaceous plants as drought feed is particularly challenging because they become unavailable due to hot weather and associated harsh conditions including water shortage and sometimes veld fires (Nouman *et al*., 2013).

Moringa oleifera L. is a remarkably fast growing tree and highly valued plant due to its exceptional nutritional content (Foidl *et al*., 2001). It grows in many tropical and subtropical regions (Anwar *et al*., 2007; Moyo *et al*., 2011). Countries and areas such as India, the Philippines, Hawaii and throughout

Africa use the tree, mainly because it has a wide range of medicinal uses and the relatively high nutritional value of its leaves, fruit, flowers and immature pods compared with other food crops (Rebecca, 2006; Anwar *et al*., 2007; Mendieta-Araica *et al*., 2013; Asante et al., 2014). Nouman *et al*. (2014) reported that moringa can be grown under harsh conditions including in hot, humid, and dry tropical and subtropical regions. An exception is areas which experience waterlogging. The tree can produce substantial nutritional quality even under marginal conditions.

The great potential benefits mean that there is a need to critically assess harvesting practices that optimize biomass production of moringa under different agro-ecological conditions. Planting density and frequency of cutting have been identified as critical management practices that affect biomass yield and leaf quality Amaglo *et al*, 2006; Sánchez *et al*., 2006; Gadzirayi *et al*., 2013a). The main objective of the study reported here was to establish, for the first time, the effect of planting spacing and cutting interval on aboveground biomass production and nutritional quality of *Moringa oleifera,* under different climatic conditions in two study sites in northern South Africa.

4.2 Materials and Methods

4.2.1. Study area

The study was conducted from December 2014 to March 2016 under two different agro-ecological conditions; namely the University of Limpopo Experimental Farm known as Syferkuil and at the Itemeleng Ba Makhutjwa Farming Cooperative known as Ofcolaco. The two sites will be referred to by their commonly known names in this chapter. Syferkuil (coordinates: 23°50’ S; 29°0’ E) is situated about 35 km south-east of Polokwane City at an elevation of 1230 m above sea level. The climate of this area is classified as semi-arid with an annual average rainfall of 400–500 mm occurring mostly in the summer months. The area experiences an average annual minimum temperature of 12.6^{o}C and maximum temperature of 25.0^{o}C during the crop growing season (Moshia et al., 2008). The soil at the study site is classified as Hutton (Soil Classification Working Group, 1991). Soil structure is granular with a good infiltration rate and has an effective depth of 90 cm (Dolo, 2016). Ofcolaco is located 43 km south-east of the town of Tzaneen (coordinates: 24°4'60" S and 30°22'0" E). The area receives an average annual rainfall of 700 mm mainly in the summer months of October to March. It experiences an average annual minimum temperature of 15^{o}C and annual average maximum temperature of 28.1^{o}C, at an elevation of 626 m above sea level (http://www.getamap.net). The soil is classified as Hutton and has good drainage characteristics, with an effective soil depth of 120 cm containing highly weathered manganese concretions at 100 cm (Dolo, 2016).

4.2.2. Experimental design and management

Prior to moringa planting, the soil was ploughed followed by disking and harrowing. Moringa seeds were soaked in cold water overnight and planted at a depth of 4 cm in the soil, with two seeds placed per hole. After six weeks, the plants were thinned to leave only one healthy tree per station. The field trial was laid out as a randomized complete block design (RCBD). Plant densities were examined at four levels, namely: 435 000, 300 000, 200 000 and 100 000 plants/ha. Experimental samples were replicated four times per treatment. Irrigation was applied for four hours, twice a week using a sprinkler irrigation system until the sixth week, to encourage good tree establishment, after which the study was allowed to run under rainfed conditions. Weather data were collected throughout the trial from Syferkuil and at a weather station located less than 10 km from the experimental area in Ofcolaco. Weather results are presented in Figure 4.1. During the course of the study, the experimental units were well maintained by removing weeds manually by hand hoe. Insect pest and plant disease incidences were not observed during the study. To reflect the financial constraints experienced by the local smallholder farmers, no fertilizer was applied in this study. The initial physical and chemical properties of the soils under test were determined at a depth of 0–30 and 30–60 cm using an auger, to identify their nutrient status (Table 4.1).

4.2.3. Plant sampling procedure

Aboveground biomass was harvested when 90% of the plants within an experimental unit reached a height of at least 50 cm measured from ground level to the tree apex. A net plot of 2.4 m^2 was used for data collection. Biomass harvesting was carried out manually using pruning shears at a uniform height of 10 cm above the ground, throughout the experiment, whenever plants had reached 50 cm cutting height. The average height of plants within an experimental unit was estimated by measuring the heights of five randomly selected plants in each net plot prior to harvesting. Measurements were made between ground level to the tip of the uppermost leaf of the plant (Amaglo *et al.,* 2006). During each harvest, soils were sampled at depths of 0–15, 15–30 and 30–45 cm to determine gravimetric soil moisture percentage. An auger was used to sample the soils according to depth; zip-lock plastic bags were used to retain soil moisture before measurement. Soil moisture was determined immediately after sampling using a battery-operated top loading weighing balance (RADWAG, W/C6/12/C1/R model). Soils were placed in aluminum drying pans and dried in an oven (Scientific oven Economy, 240 litres, Model 223) for 24 hours at a temperature of 105^{o}C. Gravimetric soil moisture percentage was determined when the soil samples had reached a constant weight, using a method described by Black (1965). The total aboveground fresh biomass was shade-dried at room temperature for 72 hours to ease separation of leaves and stems. Shoots were further oven dried for 48 hours at 65^{o}C until the samples had reached constant dry weight. The variables evaluated included total shoot dry matter yield (TSDMY); a sample of a fine fraction of leaves was taken for chemical analysis.

4.2.4. Nutrient determination

Moringa leaf samples, dried at room temperature (24^{o}C) for 72 hours, were ground to pass through a 2 mm sieve; and 10 g of a fine fraction was used to determine their chemical composition. Crude protein was determined using the Kjeldahl method (AOAC, 1990). Other minerals such as P, K, Ca, Mg, Mn and Zn were determined using atomic absorption (Gaines and Mitchel, 1979).

Table 4.1: Physical and chemical properties of soil at the experimental sites.

Soil properties	Syferkuil			Ofcolaco		
	Soil depth (cm)					
	0–30	30–60	Average	0–30	30–60	Average
pH (KCl)	6.54	6.98	6.8	5.13	5.22	5.2
Clay (%)	30	34	32	30	31	30.5
Org. C (%)	0.8	0.5	0.7	1.4	1.1	1.3
Total N (%)	0.06	0.04	0.1	<0.05	<0.05	<0.1
P (mg/L)	10	15	12.5	8	3	5.5
K (mg/L)	353	283	318	212	105	158.5
Ca (mg/L)	1139	1487	1313	646	756	701
Mg (mg/L)	868	878	873	178	153	165.5
Zn (mg/L)	1.1	1.2	1.2	1.9	0.6	1.3
Mn (mg/L)	5	3	4	41	45	43
Cu (mg/L)	5	4	4.5	6	5.4	5.7

4.2.5. Statistical analysis

Data were subjected to analysis of variance using Statistix 10.0 to determine the effect of planting density and harvest frequency on measured variables. Where significant F-values from the treatment effect were found, means were separated by the least significant difference (LSD) at a probability level of 0.05. Linear correlation and regression analyses were performed using Microsoft Excel, to determine the relationship between cutting frequency and biomass yield.

	Oct_14	Nov_14	Dec_14	Jan_15	Feb_15	Mar_15	Apr_15	May_15	Jun_15	Jul_15	Aug_15	Sep_15	Oct_15	Nov_15	Dec_15	Total Rainfall
🟥 Max Temp: Ofcolaco	28.05	28.72	29.22	30.58	31.70	31.54	27.78	29.57	24.93	25.70	28.02	27.56	31.44	31.11	34.01	
🟩 Max Temp: Syferkuil	26.35	27.04	27.44	28.37	29.88	29.00	25.68	26.97	21.75	22.85	26.38	25.93	29.60	29.55	30.57	
■ Min Temp: Ofcolaco	17.12	19.16	20.43	21.37	21.49	20.44	17.97	16.50	13.07	13.67	15.20	17.06	19.67	19.30	22.26	
■ Min Temp: Syferkuil	11.50	14.23	16.22	15.65	15.56	14.32	10.86	5.91	2.75	3.38	5.16	10.53	13.65	14.82	17.51	
▨ Rain: Ofcolaco	34.04	93.47	191.77	66.02	60.19	60.45	69.59	0.25	0.51	0.25	1.27	62.21	50.54	100.59	79.76	870.91
▨ Rain: Syferkuil	21.08	23.37	70.12	43.68	24.13	14.98	81.28	0.25	4.57	1.52	0	32.26	17.28	64.26	60.19	458.97

Figure 4.1: Weather data recorded during the 2014 and 2015 field trials at Syferkuil and Ofcolaco.

4.3 Results

4.3.1 Effect of plant density on biomass production

The results of cutting interval and plant density on biomass production at the two study sites are indicated in Figure 4.2. It was observed that the increase in planting density led to an increase in plant biomass at both locations. Planting density had a significant influence on biomass production at both Syferkuil and Ofcolaco. It took a longer time to attain the fourth harvest at Syferkuil than at Ofcolaco. At Syferkuil the time intervals between harvests 1 and 2, 2 and 3, and 3 and 4 were 92, 229, and 64 days after each harvest, respectively. At Ofcolaco, the corresponding intervals were 44, 181 and 85 days.

At Syferkuil biomass across the densities ranged from 735–1430 kg/ha; 892–1322 kg/ha; 611–943 kg/ha; and 1382–2039 kg/ha for harvests 1, 2, 3 and 4, respectively. At Ofcolaco the corresponding biomass values for the four harvests ranged between 1185–2867 kg/ha (harvest 1); 718–1557 kg/ha (harvest 2); 527–1035 kg/ha (harvest 3); and 1106–2618 kg/ha (harvest 4). At both locations, a higher planting density resulted in a greater biomass yield from all harvests (Figure 4.2).

Biomass production did not differ ($P \leq 0.05$) between locations at harvests 1 and 2, but was different at harvests 1 and 4 (Figure 4.3). Where significance was observed, the biomass production at Ofcolaco was higher than at Syferkuil.

It was observed that, at both study sites, diverse weather conditions might have affected the time to harvest the plants. Figure 4.1 shows that both temperature and rainfall at Syferkuil were correspondingly lower than at Ofcolaco.

4.3.2 Effect of moisture on biomass production of moringa

Gravimetric soil moisture percentage at the time of the four harvests at both locations is presented in Figure 4.4. Based on regression analysis, a significant quadratic relationship of over 90% between gravimetric soil moisture and harvest intervals was observed across all planting densities. At Syferkuil, the moisture percentage was higher during the first and second harvests at the relatively high planting densities of 435 000 and 300 000 plants/ha and also showed a decreasing trend with a reduction in plant density. However, at the third and fourth harvests, the moisture content dropped to a constant level at different planting densities. At Ofcolaco, an increase in the number of plants per unit area was associated with increased soil moisture content, until the third harvest. Moisture content remained similar among planting densities during the fourth harvest at both study sites.

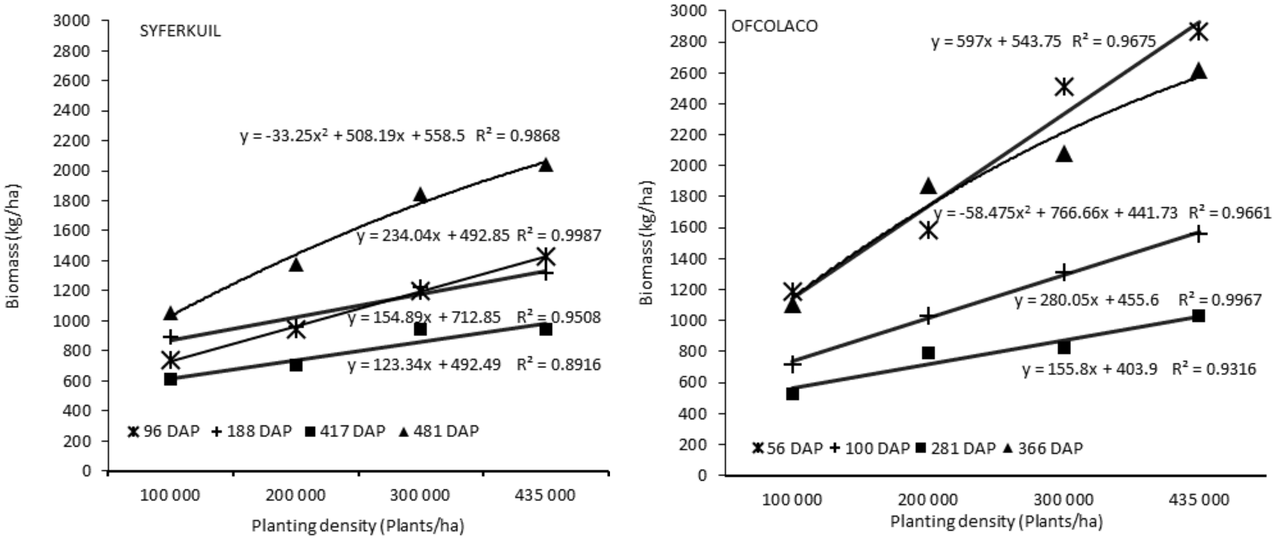
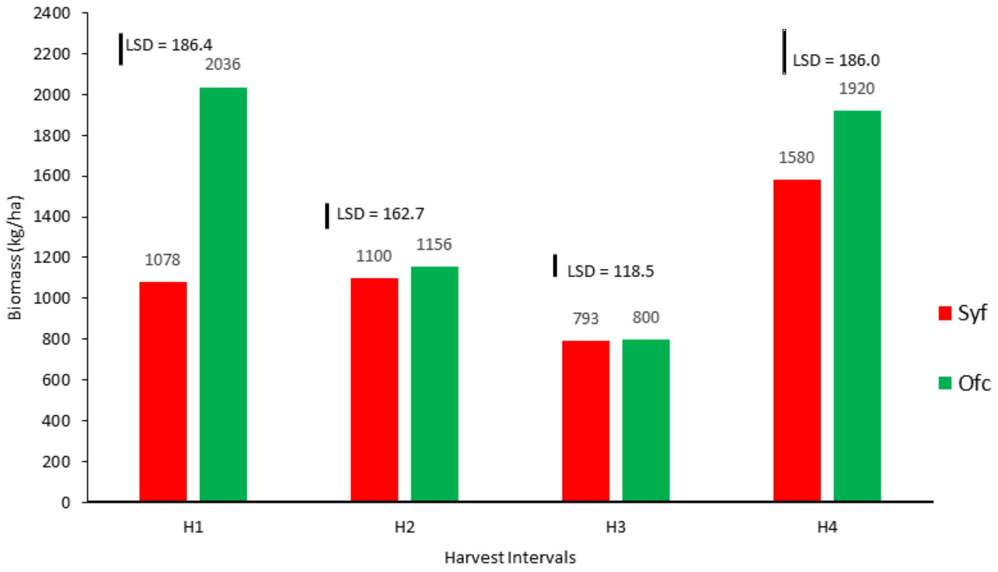


Figure 4.2: Effect of planting density on moringa biomass production at four harvest intervals at both study sites across the four seasons. DAP = days after planting.

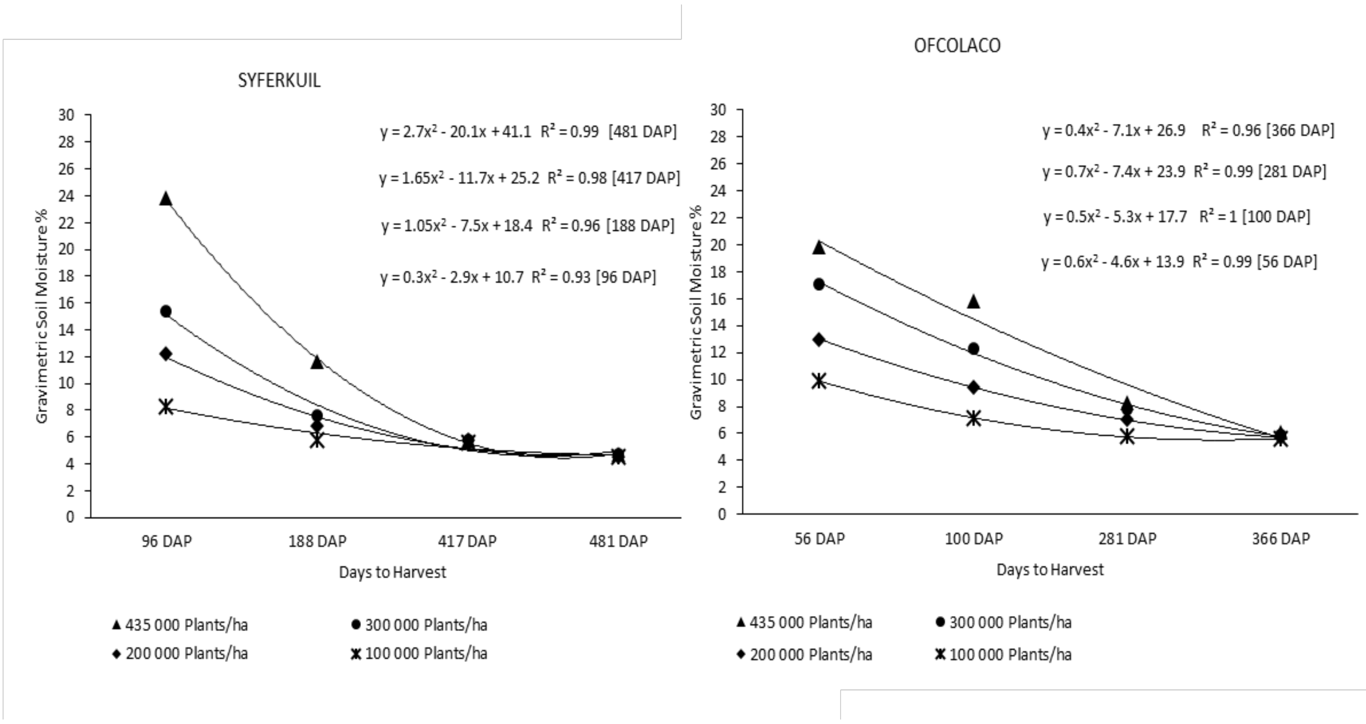


H1= harvest 1, H2 = harvest 2, H3 = harvest 3, H4 = harvest 4, Syf = Syferkuil, Ofc = Ofcolaco

Figure 4.3: Biomass production of moringa at four harvest intervals at Syferkuil and Ofcolaco, across the four seasons' irrespective of the planting density. LSD = least significant difference.

4.3.3 Effect of planting density and cutting frequency on the chemical composition of moringa leaves

The effect of planting density and harvest interval on the nutritional quality of moringa leaves at the two study sites is presented in Tables 4.2 and 4.3. At Syferkuil, plant density and cutting interval did not influence crude protein (%), Ca, Mg, K, P, and Zn content. However, a decrease in iron and an increase in manganese content were observed during the third harvest across all planting densities (Table 4.2). At Ofcolaco, cutting interval had a negative influence on the nutritional quality of moringa leaves mainly at harvests 3 and 4. The following chemical properties were affected by cutting interval: crude protein, K, P, Fe, Mn and Zn content. At harvests 1 and 2, the chemical compositions were generally higher than later, although at harvests 3 and 4 these fell markedly (Table 4.3).



*DAP = Days after planting.

Figure 4.4: Influence of planting density on gravimetric soil moisture percentage at different harvest intervals at Syferkuil and Ofcolaco across all seasons.

Table 4.2: Effect of cutting frequency and plant spacing on nutritional content of moringa at Syferkuil.

Nutrient	**100 000 plants/ha**					**200 000 plants/ha**				
	96 DAP	**188 DAP**	**417 DAP**	**481 DAP**	**LSD (0.05)**	**96 DAP**	**188 DAP**	**417 DAP**	**481 DAP**	**LSD (0.05)**
CP (%)	31.34	26.8	32.17	34.44	ns	29.08	27.06	31.86	32.65	Ns
Ca (%)	1.60	1.76	1.67	1.79	ns	1.54	1.65	1.69	1.62	Ns
Mg (%)	0.78	0.74	0.67	0.70	ns	0.82	0.64	0.78	0.83	Ns
K (%)	1.51	1.61	1.29	1.56	ns	1.55	1.78	1.70	1.37	Ns
P (%)	0.33	0.32	0.29	0.34	ns	0.31	0.35	0.3	0.35	Ns
Fe (mg/kg)	231	214	168	288	22.98	285	216	174	364	58.87
Mn (mg/kg)	53.00	57.00	94.80	74.20	15.40	57.00	57.00	87.80	67.90	7.85
Zn (mg/kg)	22.00	20.40	26.50	22.00	ns	20.00	20.20	26.40	21.80	Ns

	300 000 plants/ha					**435 000 plants/ha**				
	96 DAP	**188 DAP**	**417 DAP**	**481 DAP**	**LSD (0.05)**	**96 DAP**	**188 DAP**	**417 DAP**	**481 DAP**	**LSD (0.05)**
CP (%)	30.35	26.72	31.59	32.88	ns	32.92	27.96	32.93	33.74	ns
Ca (%)	1.57	1.65	1.67	1.71	ns	1.60	1.76	1.48	1.76	ns
Mg (%)	0.67	0.63	0.77	0.85	ns	0.67	0.63	0.65	0.82	ns
K (%)	1.75	1.83	1.68	1.67	ns	1.60	1.73	2.04	1.64	ns
P (%)	0.31	0.33	0.33	0.38	ns	0.29	0.32	0.34	0.39	ns
Fe (mg/kg)	183	207	136	328	69.95	207	166	152	323	74.45
Mn (mg/kg)	67.00	59.00	96.70	67.60	8.23	65.00	61.00	86.00	61.70	13.29
Zn (mg/kg)	22.00	24.40	28.50	24.10	ns	26.00	24.50	28.70	21.80	ns

CP = Crude protein, Ca = Calcium, Mg = Magnesium, K= Potassium, P = Phosphorus, Fe = Iron, Mn = Manganese, Zn = Zinc, ns = not significant; LSD: least significant difference (p = 0.05); DAP = days after planting.

Table 4.3: Effect of cutting frequency and plant spacing on nutritional content of moringa at Ofcolaco.

Nutrient	100 000 plants/ha					200 000 plants/ha				
	56 DAP	100 DAP	281 DAP	366 DAP	LSD (0.05)	56 DAP	100 DAP	281 DAP	366 DAP	LSD (0.05)
CP (%)	25.73	27.66	18	17.78	2.30	23.09	32.84	18.34	16.68	2.39
Ca (%)	1.48	1.71	2.1	2.28	ns	1.70	1.83	1.85	2.15	Ns
Mg (%)	0.58	0.63	0.68	0.78	ns	0.62	0.64	0.84	0.62	Ns
K (%)	2.33	2.66	1.37	0.90	0.27	2.36	2.32	0.63	0.98	0.19
P (%)	0.54	0.55	0.32	0.19	0.04	0.46	0.53	0.18	0.2	0.06
Fe (mg/kg)	194	434	69.00	85.00	124.61	190	307	78.00	91.00	70.11
Mn (mg/kg)	86.5	67.70	72.80	111	5.19	95.90	101	95.50	104	2.26
Zn (mg/kg)	23.90	28.30	11.10	10.70	3.27	26.10	27.90	11.10	13.30	3.71

	300 000 plants/ha					435 000 plants/ha				
	56 DAP	100 DAP	281 DAP	366 DAP	LSD (0.05)	56 DAP	100 DAP	281 DAP	366 DAP	LSD (0.05)
CP (%)	24.97	26.67	17.71	17.66	1.69	24.20	30.30	17.02	16.32	3.49
Ca (%)	1.67	1.71	2.21	2.18	ns	1.82	1.92	2.22	2.00	ns
Mg (%)	0.62	0.61	0.69	0.97	0.15	0.66	0.66	0.88	0.76	ns
K (%)	2.39	2.71	0.84	0.65	0.28	2.35	2.55	0.63	0.70	0.19
P (%)	0.49	0.55	0.21	0.19	0.03	0.47	0.58	0.18	0.17	0.02
Fe (mg/kg)	199	224	89.00	64.00	59.85	138	182	176	75.00	35.12
Mn (mg/kg)	94.90	79.10	109.00	110.90	8.68	95.70	82.60	100.10	98.10	2.89
Zn (mg/kg)	23.40	25.30	13.30	11.10	2.50	28.10	28.00	19.90	11.10	1.96

CP = Crude protein, Ca = Calcium, Mg = Magnesium, K= Potassium, P = Phosphorus, Fe = Iron, Mn = Manganese, Zn = Zinc, ns = not significant; LSD: least significant difference (p = 0.05); DAP = days after planting.

4.4 Discussion

4.4.1 Effect of plant density on biomass production

This study demonstrated that the greater the plant density the higher the total aboveground dry biomass production of moringa across harvests times and at both locations, although the effect on plant height at each harvest was not significant. Nouman *et al*. (2013), Amaglo *et al*. (2006) and Fadiyimu *et al*. (2011) focused their work on biomass production and cutting frequencies at a given number of days to harvest. Our study was different from theirs in the sense that, in all four treatments, the trees were cut to a uniform height of 10 cm above ground level when they had reached the same height of 50 cm. It took 481 days after planting to reach the fourth harvest at Syferkuil compared to 366 days at Ofcolaco and this was primarily due to variation in weather, particularly minimum temperature.

At both study sites, the time taken to reach the third harvest was longer than the other intervals. This could be the result of the cold weather experienced in Limpopo between May and August (Figure 4.1). The prevailing low temperature and dry conditions negatively affected the biomass yield of the plants in the period to harvest 3 at both locations. Other findings support the results of this study; for example, that drought or low rainfall conditions resulted in stunted regrowth and reduced total above-ground dry matter yield, whereas dry matter productivity was greater during the rainy season (Sánchez *et al*., 2006; Fadiyimu *et al*., 2011; Mendieta-araica *et al*., 2013). A study by Amaglo *et al*. (2006), on the effect of spacing and harvest frequency on the growth and leaf yield of moringa, indicated a significant difference ($P < 0.05$) in shoot yield per hectare due to density but not to the frequency of harvesting. Their results concurred with findings from this study in that the closest experimental spacing of 5 x 5 cm between the plants produced the greatest leaf biomass yield ranging between 10–30 t/ha; medium spacing of 5 x 10 cm and a relatively wide spacing of 5 x 15 cm resulted in the lowest yield of 3–12 t/ha.

Nouman *et al*. (2013) found that cutting frequency and height significantly affected both fresh and dry moringa biomass ($P < 0.05$); maximum fresh biomass was obtained in the hot rainy season when the plants were harvested at 30 cm above ground level. Another study, by Goss (2012), aimed at determining the effect of moringa planting density on biomass accumulation and leaf yield, indicated that increasing the density up to 197 528 plants/ha raised the plant dry matter yield. The highest value of 3.4 t/ha was achieved. These findings are in agreement with results from this study, in that increasing planting density led to increased biomass yield at both locations (Figure 4.2). This study also showed that climatic and environmental factors played a major role in biomass production of moringa. The crop produced a reasonable biomass yield, bearing in mind that the plants did not receive any supplementary growth inputs such as irrigation and fertilization. Indeed, this study was conducted to simulate smallholder farming conditions in Limpopo, which are characterized by low-resource conditions. Comparing results from this study with those of Mendieta-Araica (2013), the latter reported that under dry conditions, available P and K in the soil can maintain a relatively high biomass yield over time, when sufficient nitrogen fertilizer is supplied to cover the nutrients that are removed at harvest and are needed for regrowth.

Amaglo *et al*. (2006) revealed that relatively high shoot productivity may be maintained only by continuously replenishing the nutrient intake by plants from the soil by adequate application of fertilizer, preferably an organic fertilizer that is of less cost to smallholder farmers and does not have the adverse environmental and health impacts of mineral supplements. Abdullahi *et al*. (2013) recommended that 20 000 stands per hectare and a fertilizer application rate of 200 kg per hectare N is the optimum combination for the cultivation of *Moringa oleifera* for biomass production in the North-Central zone of Nigeria, where the area is characterised by hot summer temperatures and high rainfall of up to 1300 mm/a. Dania *et al*. (2014) further reported that the application of poultry manure significantly increased the vegetative growth of this crop.

4.4.2 Effect of moisture on biomass production of moringa

Biomass accumulation continued to increase under favourable weather conditions of temperature and rainfall, at harvests 1, 2 and 4 when the trees were pruned (Figure 4.1). This is evidence that moringa can survive and produce satisfactory yields even under conditions of water limitation such as experienced at Syferkuil. At Ofcolaco, the yield was more than 1 t/ha at a high density of 435 000 plants/ha. Soil moisture content was greater at Ofcolaco than at Syferkuil and this could be the result of higher rainfall received at the former. Greater rainfall and relatively close plant spacing, which together reduce the rate of evapotranspiration, had an added advantage for the enhanced soil moisture at Ofcolaco (Figure 4.3). This study was conducted under dry-land conditions, in which plant growth and development relied on only rainfall. During the early growth stage, the higher plant density maintained higher gravimetric soil moisture at both locations (Figure 4.4). However, with time, the gravimetric soil moisture content was reduced as a result of plant competition for light, space and dwindling moisture concentration among the plant densities. This finding concurs with those of Amaglo *et al*. (2006) and Gadzirayi *et al*. (2013a), who showed that relatively close plant spacing resulted in taller plants because of competition for growth factors especially light and space. These observations indicate that proper field management of soil moisture and fertilizer is necessary in order to supply plants with adequate levels of nutrients and moisture to overcome competition among the plants.

4.4.3 Effect of planting density and cutting frequency on the chemical composition of moringa leaves

The chemical composition of moringa leaves was not affected by cutting interval or by plant density at Syferkuil except for iron and manganese content (Table 4.2); at Ofcolaco, however, significant differences were observed mainly in terms of crude protein, phosphorus, potassium, iron, and zinc content at harvests 3 and 4 (Table 4.3). The reason for these findings might be that the plants were accumulating nutrients at a slower rate because of the low temperature and rainfall experienced at Ofcolaco before harvests 3 and 4. These results are similar to those reported by Sánchez *et al*. (2006), who observed no differences in chemical composition even at continuous harvests or in the harvesting of young leaves and tender stems. Furthermore, Nouman *et al*. (2013), Moyo *et al*. (2011) and Sánchez *et al*. (2006) reported no changes in the chemical composition of moringa leaves in respect of plant density, cutting height or cutting frequency mainly in terms of crude protein content. Relatively high temperature and rainfall were experienced at Ofcolaco during the trial, which affected the chemical composition of the moringa plant parts. A hot rainy season enhances biomass production and the plant's nutritional content. In this study, the reduction in the chemical composition of the leaves might be due to the lack of nutrients in the soil, mainly nitrogen and phosphorus at Ofcolaco relative to Syferkuil where soil nutrients were higher and might have contributed towards high leaf nutrient content. Moringa is a fast growing tree and cutting might have led to the excessive extraction of available soil nutrients for regrowth, which, without supplementation, led to a decline in chemical composition at harvests 3 and 4. However, several factors may have influenced the concentration of mineral elements in the plants, such as those in the soil, their availability to the plant, type of soil, soil pH, stage of plant growth and weather conditions (Lukhele and Van Ryssen, 2003; Sánchez *et al*., 2006). In most of the studies where no significant changes of chemical composition were found, even under high temperature and rainfall conditions, adequate initial soil nutrients were maintained prior to planting and during growth.

For example, in the study by Nouman *et al*. (2013), there was a basal fertilizer application of 90:80:90 NPK kg/ha. Sánchez *et al*. (2006) applied fertilizer at a rate of 90 kg/ha N as urea, 30 kg/ha P (P_2O_5) and 30 kg/ha K (K_2O). Further findings by Dania *et al*. (2014) revealed that the nutrient concentration of moringa leaves was significantly improved by treating the degraded soil with poultry manure. Under high rainfall and temperature conditions, application of nutrients to the soil will improve plant growth and the chemical composition of the plants. Compared with other studies, moringa plants from this study had a satisfactory chemical composition when grown at both study sites, although some of the nutrient composition was reduced at Ofcolaco at the time of harvests 3 and 4. This study revealed also that moringa, grown under the variable weather conditions of Limpopo at diverse plant densities, maintained a nutritional composition which can be utilized as potential supplementary feed for livestock, mainly as a protein source. Several studies have reported a similar range of protein content, from 11.4% up to 40% (Makkar and Becker, 1996; Gidamis *et al*., 2003; Sánchez *et al*., 2006; Oduro *et al*., 2008; Moyo *et al*., 2011; Mendieta-Araica *et al*., 2013; Nouman *et al*., 2013). Results from this study concur with findings by Nouman *et al*. (2014) who indicated that moringa is rich in nutrients like iron, potassium, calcium, and multivitamins, which are more important in weight gaining and milk production.

4.5. Conclusion

Planting moringa at a relatively high density increased biomass production. A planting density of 435 000 plants/ha resulted in enhanced biomass accumulation at all cutting intervals. Low temperature and drought had a negative impact on biomass production and the nutritional composition of moringa, mainly iron content. Moringa can be harvested at a height of 50 cm above ground level, which facilitates mechanical harvesting and while the stem is still pliable. The crop is able to supply livestock with a satisfactory amount of crude protein, and the tree is rich in other nutrients, making it a potentially valuable source of feed supplement at times when there is not enough natural fodder due to drought. Moringa is capable of producing a good yield at a relatively high density of plants. Moreover, it is desirable to consider fertilizer application to boost plant growth and the chemical composition of the above-ground plant parts in high temperature and rainfall areas. Moringa proved to be a good source of fodder for livestock, is able to survive harsh growing conditions, and can be recommended to resource-poor smallholder farmers in regions such as Limpopo. Further studies should be conducted to evaluate the use of fertilizer under diverse weather conditions and soil types on behalf of those farmers who are willing and able to grow the plant on a larger or commercial scale.

CHAPTER 5

SEASONAL EFFECT ON *MORINGA OLEIFERA* GASEOUS EXCHANGE AND WATER USE EFFICIENCY UNDER DIVERSE PLANTING DENSITIES

ABSTRACT

Moringa oleifera is a highly valued tree, identified as one of the plants with the ability to capture carbon due to its exceptionally fast growth rate. The study was conducted to evaluate the impact of growing season and varying planting densities of moringa to biomass yield and physiological attributes under dryland conditions. The study was conducted over twelve months to cater for the four seasons during 2014 – 2015. Untreated seeds of *Moringa oleifera* were used for establishing the trial at densities of 5 000, 2 500, 1 667 and 1 250 plants ha^{-1}, with eight replicates. The increase in planting density led to an increase in biomass production. The monthly and seasonal data collected showed significant differences in net photosynthetic rate, transpiration, sub-stomatal CO_2 and stomatal conductance. However, planting densities of *Moringa oleifera* had no significant effect on all the gaseous exchange parameters measured. The results further revealed that the amount of carbon dioxide assimilated by the tree is not attributable to photosynthetic and transpiration rates as well as stomatal conductance. Under water shortage condition and high temperature, moringa uses an adaptation strategy by reducing stomatal conductance and transpiration and hence increase the water use efficiency. Moringa thus has the ability to sequester carbon even under water stress conditions. The tree can, therefore, be recommended for planting at a relatively high density of 5000 plants ha^{-1} in many parts of Limpopo Province where temperatures are favourable, for improved farmers' livelihoods as well as for climate change mitigation.

Keywords: Biomass, climate change, moringa, physiological response, planting density

5.1 Introduction

Moringa (*Moringa oleifera*) is a highly valued tree that is widely distributed in many countries of the tropics and subtropics. It is considered as one of the most useful trees since almost every part of the tree is a valuable source of food, medication and industrial uses (Morton, 1991; Foidl *et al*., 2001). Moringa is fast growing and tolerant to harsh climatic and environmental conditions where many agricultural plants would not survive requiring only 400 mm of annual rainfall (Morton, 1991; Reyes-Sánchez, 2006; Pandey *et al*., 2011; Gedefaw, 2015). Moringa tree can play a significant role in climate change mitigation, due to its ability to capture carbon (Gedefaw, 2015). It also has the potential to improve the income and livelihood of smallholder farmers as well as nutritional needs of rural communities (Babu, 2000; Moyo *et al*., 2011; Gedefaw, 2015; Mabapa *et al*., 2017a).

Through observations, South Africa and other countries globally are already affected by severe negative consequences of climate change. This is particularly evident in the smallholder farming sector that relies on natural resources for production. Best practices of agriculture can contribute towards climate change mitigation and adaptation by adopting various agricultural management practices that could minimize adverse effects of unpredictable rainfall patterns as well as other extreme weather conditions (Hulme, 2005; Pareek, 2017). Pareek (2017), reported that various agricultural adaptation management practices are available to attenuate the effects of climate change on crop production. This includes broader agronomic management strategies such as altering planting densities, row spacings, planting time as well as introducing new germplasms that are resistant to heat and drought stress.

Literature revealed no information regarding carbon sequestration through moringa tree as influenced by varying plant densities in the South African context. It is known from the literature that moringa has been described as a tree that can be grown in the drier ecological zones (Seresinhe and Marapana, 2011; Asante *et al*., 2014). However, no quantitative information is available in South Africa about the moringa's gaseous exchange response such as stomatal conductance, stomatal CO_2, transpiration and photosynthetic rate to planting density over the different seasons of the year. This study was therefore established to evaluate the seasonal response of moringa in terms of biomass yield and gaseous exchange under varying planting densities as a contribution towards climate change mitigation.

5.2 Materials and Methods

5.2.1 Study location

The study was conducted over twelve months to cater for four seasons which are summer (December - February), autumn (March - May), winter (June - August) and spring (September - November) during 2014 – 2015, at NTL Baraka Eco-Farming Organic Farm (23°57.691'S and 30°35.205'E), situated in Eiland. The farm is situated about 50 km East side of Tzaneen in the Limpopo Province. The area is a tropical region and receives about 429 mm of rain per annum, with most rainfall occurring during mid-summer. The annual rainfall data were derived from the total monthly values for Eiland averaged for the past 7 years. The area received the lowest average rainfall (<0.5mm) in June and July months; the highest in December and January of more than 120 mm in the past 7 years. The monthly temperature distribution shows that the average maximum monthly temperatures for Eiland could rise above 31°C while minimum temperatures could range between 7 to 25 °C, during winter and summer seasons, respectively.

5.2.2 Experimental design, planting and management

An area measuring 60 m length and 40 m breadth was demarcated and prepared by conventional tillage using disk ploughing, followed by disk harrowing and manual digging of shallow holes for planting.

The experiment was laid out in a randomized complete block design (RCBD) which was replicated eight times. The treatments consisted of four levels of intra-row spacings: D1 = 1 m, D2 = 2 m, D3 = 3 m and D4 = 4 m, with a uniform inter-row spacing of 2 m, giving total populations of 5 000, 2 500, 1 667 and 1 250 plants ha^{-1}, respectively. Untreated seeds of *Moringa oleifera* were used for planting by placing 2 seeds per hole at a depth of 2 cm during December 2013.

Each plot measured 4 m x 12 m and plots were separated from each other by 2 metre walkways. Irrigation was applied for four hours twice a week using a microjet irrigation system until the tenth week to encourage good tree establishment, after which the study was allowed to run under rainfed conditions. Eight weeks after trial establishment, plants were thinned out to the desired densities, retaining only the healthier plants during the thinning process. Prior to data collection, the whole experiment was uniformly cut at a height of 50 cm aboveground and all foliage was removed but not weighed.

5.2.3 Leaf gaseous exchange and water use efficiency measurements

Monthly leaf gaseous exchange measurements were measured on a fully-expanded leaf on the abaxial side of three selected leaves per experimental unit, using a portable photosynthesis system (ADC Bio Scientific, UK). Monthly measurements were averaged for each season to come up with seasonal data. The photosynthetic rate (A), stomatal conductance (gs), transpiration rate (E) and sub-stomatal CO_2 (Ci) were simultaneously determined for each species using a non-destructive method. All the measurements were carried out under steady-state conditions in full sun between 10:00 am and 14:00 pm (Clifford *et al*., 1997). The instantaneous water use efficiency (WUE) which is defined as the ratio of photosynthetic capacity to the rate of transpiration was calculated for each density as A/E (Field *et al.*, 1983; Rivas *et al*., 2013).

5.2.4 Plant biomass determination

Leaf biomass was collected from a net plot of 12 m^2 during harvesting in 2015. The leaf yield (kg) was determined by separating the leaves from the petiole. The fresh leaf biomass was shade-dried at room temperature for 72 hours and later weighed using a battery-operated top loading weighing balance (RADWAG, W/C6/12/C1/R Model).

5.2.5 Statistical analysis

Data were subjected to analysis of variance using Statistix 10.0 to compare the response of moringa to planting density on measured variables. Where significant F-values from treatment effects were observed, means were separated by the least significant difference (LSD) at a probability level of 0.05. Correlation and regression analyses were performed using both Statistix 10.0 and Microsoft Excel, to determine the relationship between gaseous exchange parameters irrespective of their planting densities.

5.3 Results

5.3.1 Weather parameters of the study area

Data on weather parameters measured during the study and anomaly in rainfall distribution are presented in Table 5.1 and Figure 5.1. Rainfall dropped during summer season (November - February) of 2014/15, whereby the rainfall was below 100 mm as compared to the past two years during which the amount exceeded 200 mm. The temperatures increased during the summer season with the maximum temperature exceeding 32°C (Figure 5.1). The drought that was experienced during 2015 had a significant influence on rainfall anomaly. The accelerated heat accompanied by moisture deficit led to below average rainfall anomaly mainly during the year 2015 as compared with the years 2013 and 2014, in which the rainfall anomaly was above average in many instances, mainly during the rainy season (Figure 5.2).

5.3.2 Monthly gaseous exchange and water use efficiency of moringa as influenced by planting density

The monthly data collected showed highly significant differences in all gaseous exchange parameters and water use efficiency (Table 5.1). However, planting density of *Moringa oleifera* had no effect on photosynthetic rate, transpiration rate, sub-stomatal CO_2 and stomatal conductance (Figure 5.3).

5.3.3 Seasonal effect on moringa gaseous exchange

The seasonal effect significantly influenced all the measured gaseous exchange parameters (Figure 5.4). Photosynthetic rate, stomatal conductance, and transpiration rate were reduced during the summer season, whilst the sub-stomatal CO_2 concentration increased during the same season. Furthermore, the photosynthetic rate and stomatal conductance were higher during the winter season when temperatures were low. No significant differences in transpiration were found during winter, autumn and spring seasons, while sub-stomatal CO_2 was found not to change during the three seasons except in the winter season.

Table 5.1: Weather, gaseous exchange parameters and instantaneous water use efficiency of moringa as influenced by month irrespective of density

Month/Year	Weather parameters			Transpiration rate (E) mmol m^{-2} s^{-1}	Stomatal conductance (gs) molm^{-2} s^{-1}	Photosynthetic rate (A) µmol m^{-2} s^{-1}	Sub-stomatal CO$_2$ (Ci) vpm	WUEinst µmol mol^{-1}
	Min Temp (°C)	Max Temp (°C)	Tot Monthly Rainfall (mm)					
May'14	10.29	28.06	0.00	2.88^{abc}	0.15^{b}	6.73^{bc}	276.91^{ab}	2.33^{cde}
June'14	6.29	26.23	0.00	3.49^{a}	0.09^{d}	6.73^{bc}	220.75^{bcd}	1.91^{de}
July'14	6.19	24.79	0.51	2.53^{bc}	0.07^{de}	10.65^{a}	133.38^{f}	4.37^{a}
August'14	8.31	26.41	8.38	2.46^{bc}	0.07^{de}	9.04^{ab}	152.12^{ef}	3.72^{ab}
September'14	12.37	30.15	0.51	3.14^{ab}	0.05^{fg}	4.31^{cde}	246.22^{abcd}	1.29^{e}
October'14	15.26	29.48	25.91	2.10^{cd}	0.19^{a}	8.96^{ab}	270.41^{abc}	4.29^{a}
November'14	18.99	30.39	13.97	2.19^{cd}	0.05^{ef}	5.54^{cd}	190.81^{def}	2.68^{bcd}
December'14	20.40	30.94	95.49	2.65^{abc}	0.07^{de}	5.85^{cd}	207.31^{cde}	2.38^{bcde}
January'15	21.39	31.91	17.26	1.47^{de}	0.03^{g}	3.46^{de}	195.53^{def}	3.40^{abc}
February'15	21.06	32.41	99.31	1.06^{e}	0.04^{fg}	1.76^{e}	297.03^{a}	2.16^{cde}
March'15	19.37	32.47	12.18	3.28^{ab}	0.13^{c}	8.98^{ab}	229.03^{bcd}	2.55^{bcde}
April'15	16.65	29.42	41.15	1.39^{de}	0.06^{ef}	4.667^{cde}	215.50^{bcde}	4.2659^{a}
Significance				***	***	***	***	***
Interaction (Month x Density)				ns	ns	Ns	Ns	ns

Significance levels: *P<0.05, ** P<0.01, *** P<0.05, ns: not significant. Means with different letters are statistically significant.

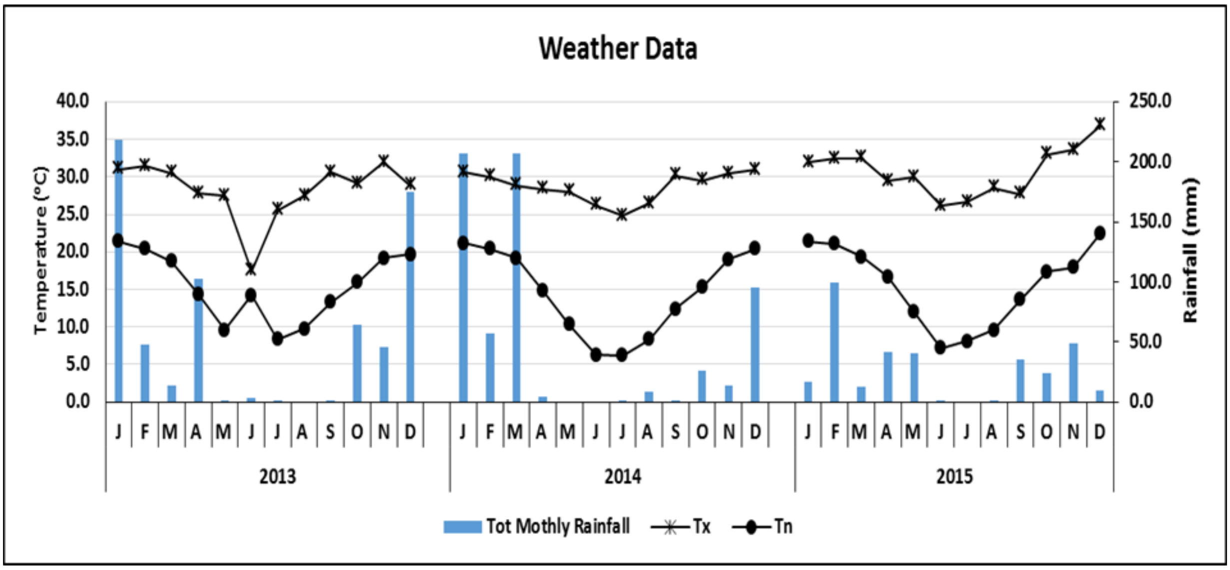


Figure 5.1: Total monthly rainfall (mm), average maximum (Tx) and minimum (Tn) temperatures collected at Eiland from during the production seasons.

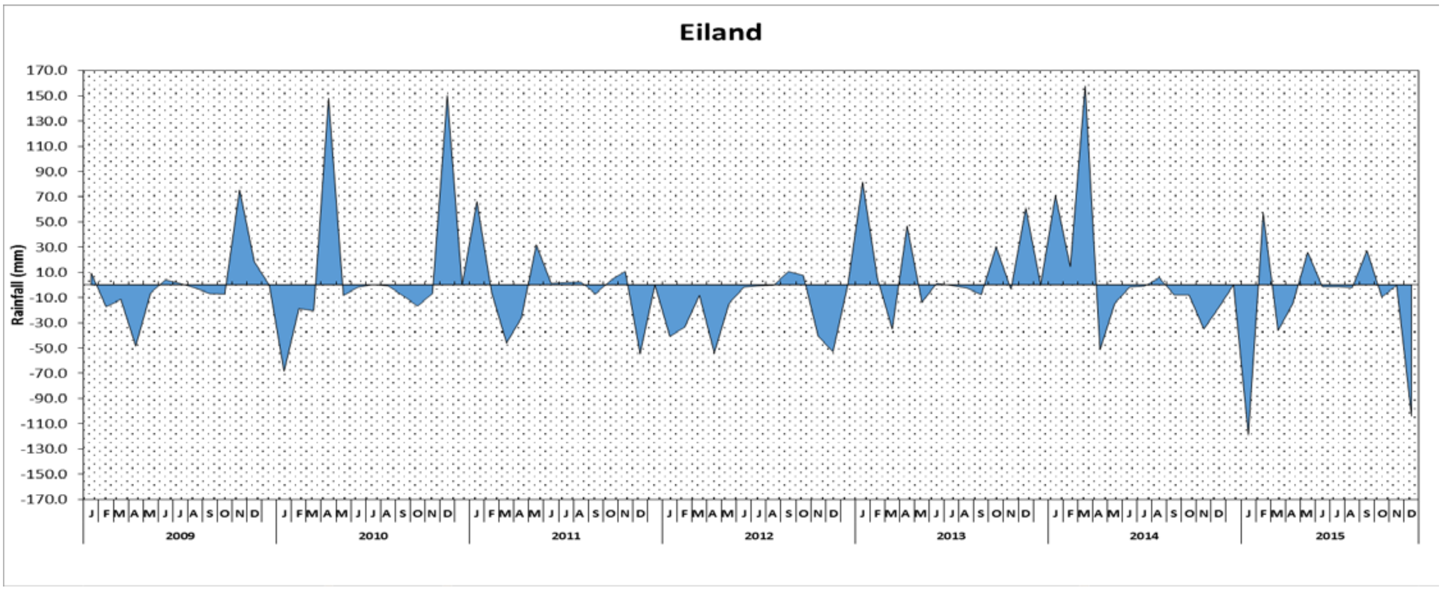


Figure 5.2: Rainfall (mm) anomaly at Eiland as compared to long-term average rainfall from 2009 to 2015.

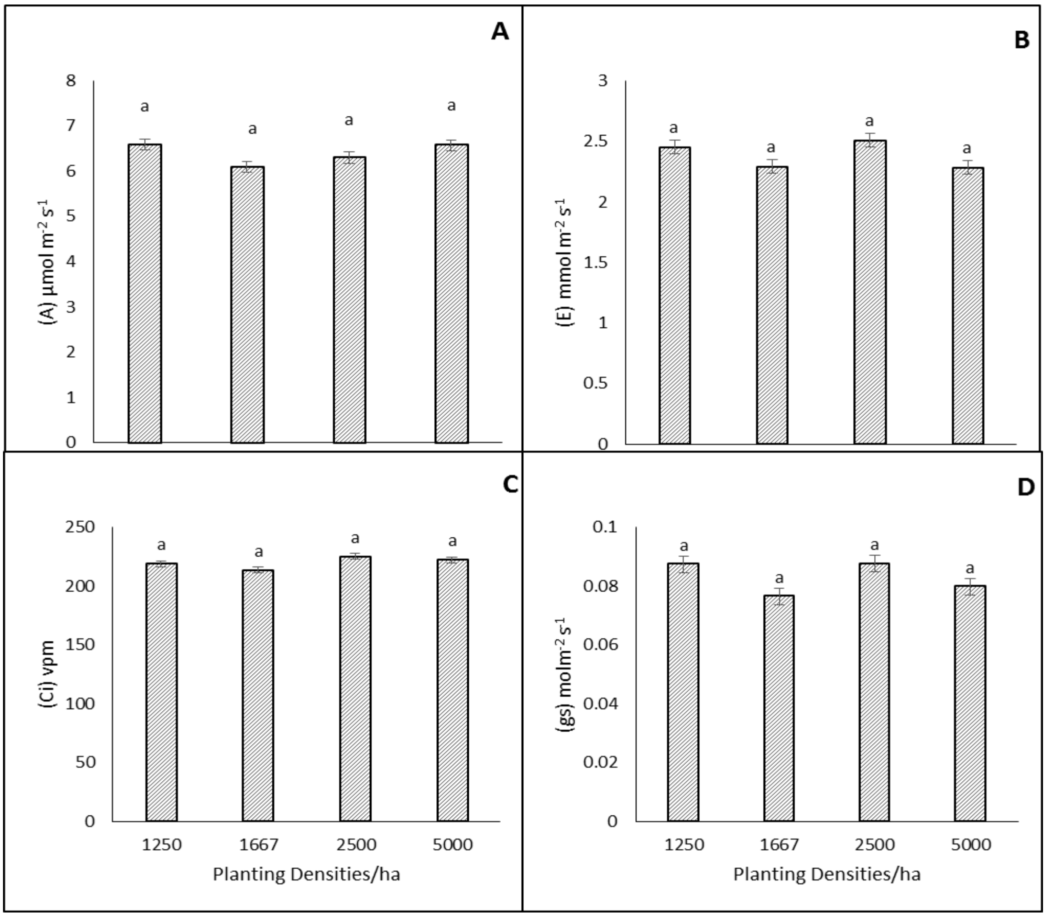


Figure 5.3: (A) Photosynthetic rate (A), (B) transpiration rate (E), (C) sub-stomatal CO_2 (Ci) and (D) stomatal conductance (gs) as affected by planting densities. Means with different letters are statistically significant.

5.3.4 Correlations and regression of moringa gaseous exchange parameters

Seasonal relationships between gaseous exchange parameters are presented in Figure 5.5. Transpiration rate and photosynthetic rate showed a strong positive relationship. A similar relationship was observed between stomatal conductance and photosynthetic rate as well as between stomatal conductance and transpiration rate (Figure 5.5). However, substomatal CO_2 had a negative relationship with photosynthetic rate, transpiration rate, and stomatal conductance.

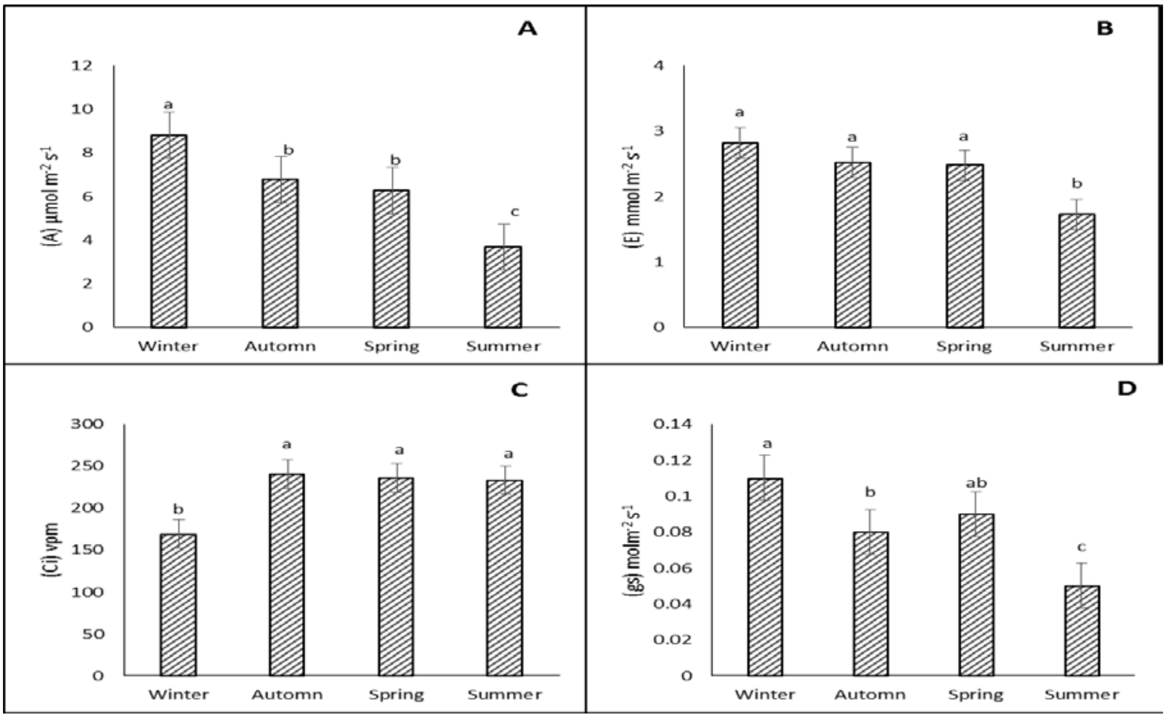


Figure 5.4: (A) Photosynthetic rate (A), (B) transpiration rate (E), (C) sub-stomatal CO_2 (Ci) and (D) stomatal conductance (gs) as affected by season, irrespective of planting density. Means with different letters are statistically significant.

5.3.5 Biomass production of moringa as influenced by planting density

Table 5.2 shows the effect of planting density on biomass production at harvest in April 2015. The planting density had a significant influence on both total and leaf biomass yields, where increasing planting density led to an increase in biomass yield. Leaf and total biomass yields had no significant differences at the densities of 1 667 and 1250 plants ha^{-1}. Leaf biomass yield increased by 118.1 and 63.0 kg ha^{-1} at densities of 5 000 and 2 500 plants ha^{-1}, respectively relative to a population of 1250 plants ha^{-1}. On the other hand, total biomass yield increased by 93.2 and 55.5

kg ha^{-1} at densities of 5 000 and 2 500 plants ha^{-1}, respectively relative to a population of 1250 plants ha^{-1}.

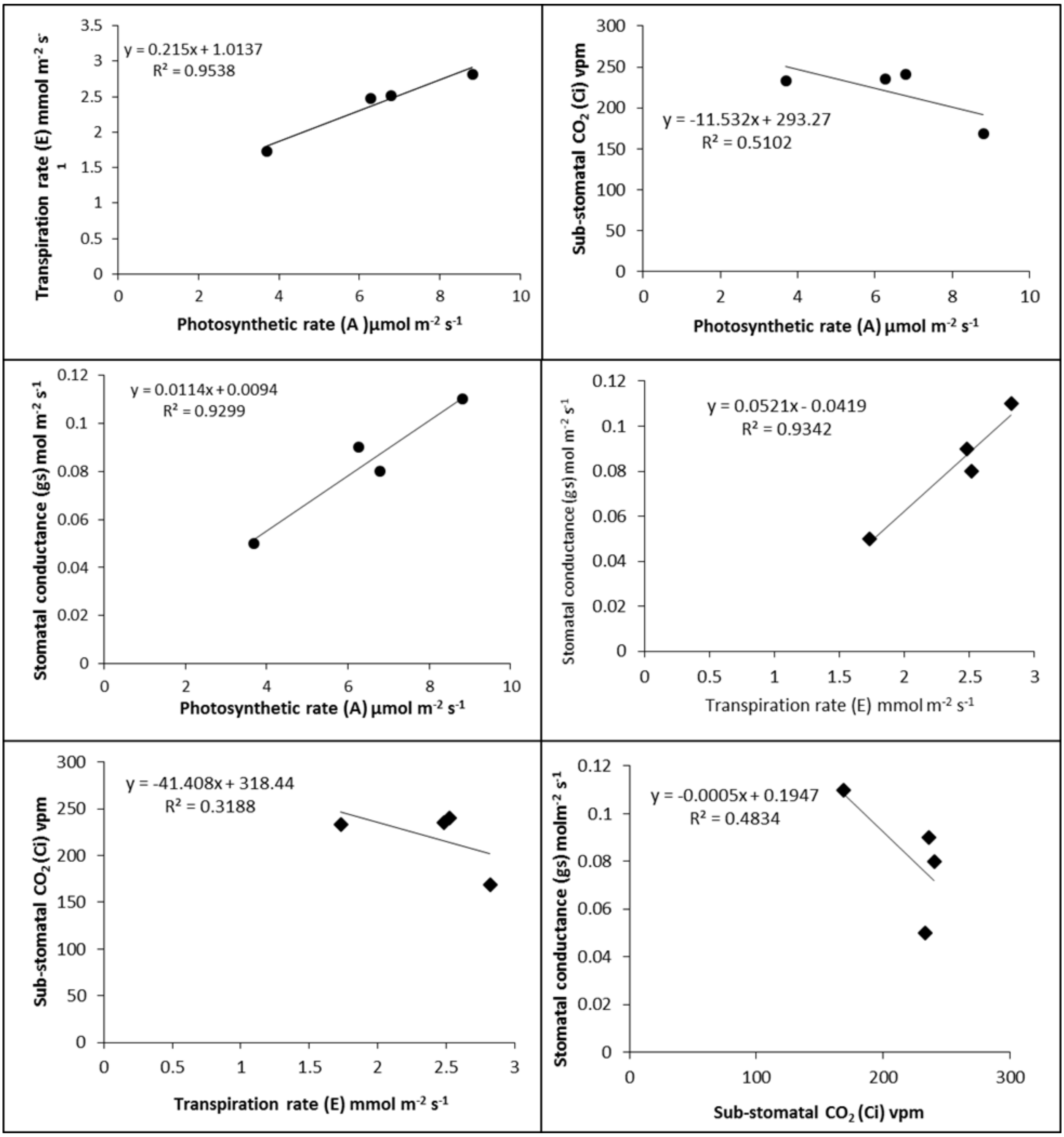


Figure 5.5: Seasonal linear regression for moringa gaseous exchanges.

Table 5.2: Biomass yield (kg/ha) production of moringa under different densities at Eiland during the harvest in April 2015.

Density (Plants ha^{-1})	Dry leaf yield (kg ha^{-1})	Total dry biomass yield (kg ha^{-1})
5000	447.91^{a}	1250.6^{a}
2500	338.80^{b}	1006.6^{ab}
1667	263.13b^{c}	805.2^{bc}
1250	205.33^{c}	647.3^{c}
P value	0.000	0.001
CV%	23.79	28.18
Significance (0.05)	**	**

Significance levels: *P<0.05, ** P<0.01, *** P<0.05, ns: not significant. Means with different letters are statistically significant.

5.4 Discussion

5.4.1 Weather parameters of the study area

During data collection between 2014 and 2015, the study area experienced extreme drought and high temperatures. A total rainfall of 432 mm was received during this period. It was observed from the 2014 and 2015 summer season, that Eiland received below average rainfall with the situation worsening during 2015 where the rainfall anomaly was greater than 100 mm below average. These data show the magnitude of abiotic stress experienced in the study area. A study by Anjum *et al*. (2011) reported that environmental abiotic stresses mainly drought, salinity, and extreme temperatures, could impair plant growth and development and as such limit the productivity of many agricultural crops. The weather conditions reported at Eiland during the current study are typical of the semi-arid conditions experienced in north-eastern South Africa. Such conditions make dryland crop production highly unstable and characteristically of low yields.

5.4.2 Monthly gaseous exchange and water use efficiency of moringa as influenced by planting density

The effect of planting density on the gaseous exchange was not significant during the study period. However, there was the noticeable significant effect on monthly gaseous exchange parameters. This might be due to variable monthly temperatures and rainfall which influenced the response of moringa trees. Findings from this study revealed the survival mechanism utilized by moringa to tolerate harsh environmental and climatic conditions. It was observed that moringa tree does not rely on moisture from immediate rainfall; instead, the tree absorbs and stores moisture within the roots and other succulent tissues to utilize when there is moisture deficit in the soil. This was evident because, when rainfall was low or in deficit, moringa still exhibited a high transpiration rate which was influenced by high temperature. However, when temperature continued to rise under moisture shortage, moringa adapted to the stressed condition by also reducing the rate of transpiration. These results concur with findings by Rivas *et al*. (2013) who reported that *Moringa oleifera* can maintain a high leaf relative water content (RWC), under low soil moisture which helps to maintain cellular physiological processes and growth. Another study conducted on drought-resistant bread wheat cultivars showed that under drought stress conditions the cultivars had more relative water content (Keyvan, 2010).

Plants use several physiological mechanisms that contribute to their drought tolerance. The first mechanism utilized by most plants is through decreased stomatal conductance. When the resistance to H_2O is greater than that of CO_2, there is an increase in the water use efficiency (Galle *et al*., 2011; Rivas *et al*., 2013). The photosynthetic rate was reduced when there was moisture deficit in the soil and the plant itself, where these responses negatively affected water use efficiency (Table 5.1). Low moisture experienced until November 2014 and in January 2015 with increased temperature decreased stomatal conductance, photosynthetic rate and the extent of sub-stomatal CO_2. Gaseous exchange activities, mainly photosynthetic rate, are among the primary processes to be negatively affected by drought and higher temperatures (Chaves, 1991). Similar findings were reported by Frosi *et al*. (2017), on response of two tropical evergreen species to drought stress, who found that all gaseous exchanges under severe drought stress showed a significant decrease with the average values of 0.01 (mol $m^{-2}s^{-1}$), 0.66 (mmol $m^{-2}s^{-1}$) and 0.4 (mmol $m^{-2}s^{-1}$) for stomatal conductance, photosynthetic rate and transpiration rate, respectively. Rivas *et al*. (2013) also reported a drop in gaseous exchange due to water stress as compared to irrigated moringa plants. When plants encounter water deficit, they respond by lowering stomatal conductance in order to reduce water loss which eventually results in decreased photosynthetic rate (Munjonji *et al*., 2016).

5.4.3 Seasonal effect on gaseous exchange in moringa

The current study revealed a significant influence of season on the gaseous exchange of moringa. The higher temperatures that were experienced during summer led to a decrease in photosynthetic rate, stomatal conductance, transpiration rate, while lower temperatures decreased the concentration of sub-stomatal CO_2. Chaves et al. (2009) reported that under mild water stress, plants showed a small decline in stomatal conductance which is a protective mechanism against stress, by allowing water saving and improving plant water use efficiency. Water use efficiency has been reported to increase in stressed plants compared to irrigated moringa plants. However, over time, a rapid recovery from stress was observed on rehydrated plants through increased stomatal conductance (gs), net CO_2 assimilation (Pn) and transpiration (E) and decreased water use efficiency (Rivas *et al*., 2013).

A nursery study on irrigation interval revealed that irrigating moringa seedlings at 8 day intervals had a negative effect on the gaseous exchange; however, the internal CO_2 concentration displayed significantly higher values as compared to shorter intervals (Wafa, 2015). The long taproot of moringa and its succulent tubers enhances the drought resistance properties of the tree (Jagadheesan *et al*., 2011; Gedefaw, 2015). Jagadheesan *et al*. (2011) also reported that succulent plants often resist moderate water stress by storing water in their succulent tissues and utilizing it during the drought stress period.

Findings from this study showed that higher temperature favoured assimilation of carbon dioxide by the moringa tree (Table 5.1). Gedefaw (2015) reported that the aboveground biomass of moringa can store carbon stock of between 4.89 and 98.74 tons/ha while below ground carbon stock storage can be between 1.95 and 39.49 tons/ha. Results from the current study concur with findings from other researchers who reported that the higher rate of sub-stomatal CO_2 concentration is an indication that moringa is able to partition carbon into different parts of the plants (Ndubuaku *et al*., 2014; Gedefaw, 2015).

No literature is available on the seasonal effect of moringa on the gaseous exchange. The results from this study showed that the higher temperatures which prevail mainly in summer months had a negative effect on transpiration, photosynthetic rate, and stomatal conductance, but favoured the accumulation of carbon dioxide in three out of four seasons of the year. During the winter season, there was an excessive leaf fall and less soil moisture and this significantly affected carbon assimilation and plant growth. Under water stress conditions, plants generally produce a lesser number of leaves, with a general reduction in their size (Jagadheesan *et al*., 2011). Muhl *et al*. (2011) concluded that higher temperatures favour the growth of *Moringa oleifera*, while low temperature leads to thickening of leaves which is symptomatic of an adaptation against temperature stress, resulting in reduced growth. Furthermore, Jagadheesan *et al*. (2011) reported that moringa is sensitive to prolonged water stress which may result in a prominent decrease in cellular growth. Nevertheless, the tree is still able to produce satisfactory yields and high nutritional content from the leaves under such conditions.

5.4.4 Correlation of moringa gaseous exchange parameters

The findings from this study showed a strong positive relationship between photosynthetic rate and transpiration rate as well as between photosynthetic rate and stomatal conductance. Sub-stomatal CO_2 showed a moderate to weak negative relationship with photosynthetic and transpiration rates as well as stomatal conductance. Therefore, the amount of carbon dioxide assimilated by the tree cannot be determined by photosynthetic rate and transpiration rate as well as its stomatal conductance. The results from this study are in line with findings by Araújo *et al*. (2016), who reported that the impairment of net CO_2 assimilation rate cannot be attributed to stomatal effects since stresses did not reduce the intercellular CO_2 availability. This study further showed a positive relationship between measured stomatal conductance and photosynthetic rate, whereby, an increase in stomatal conductance led to an increase in photosynthetic rate. This relation was mainly influenced by higher temperature and stored moisture in the plant. Similar results were reported by Muhl *et al*. (2011) who found out that the reduction in leaf stomatal conductance lowers photosynthesis in moringa. A study by Rivas *et al*. (2013) further reported that *Moringa oleifera* can maintain high leaf relative water content even under deficit soil moisture and this helps the plant to maintain physiological processes and growth.

5.4.5 Leaf biomass production of moringa as influenced by planting density

The effect of planting density on biomass was evident whereby the highest planting density of 5000 plants ha^{-1} produced the highest total leaf dry biomass yield of 1251 kg ha^{-1}, with the leaf biomass yield of 448 kg ha^{-1}, relative to lower planting densities of 2 500, 1 667 and 1250 plants ha^{-1}. Several authors have reported similar findings, where an increase in planting density led to an increase in dry matter yield (Foidl *et al*., 2001; Sánchez *et al*., 2006; Abdullahi *et al.*, 2013; Basra *et al*., 2015).

Planting density of 250 000 and 500 000 plants ha^{-1}, established under dryland conditions, had a total dry matter yield of 7.6 and 8.1 tons ha^{-1}, with leaf yield of 4.6 and 4.9 tons ha^{-1} (Sánchez *et al*., 2006). Results by Abdullahi *et al.* (2013) showed that moringa grown at a stand of 20 000 plants ha^{-1} was the best in terms of leafproduction relative to 10 000 plants ha^{-1}. In the current study, leaf yield accounted for about a third of the total biomass whereas the study by Sánchez *et al*. (2006) reported leaf yields that accounted for about 60% of the total biomass of the moringa tree.

5.5 Conclusion

In conclusion, this study showed that moringa can survive harsh climatic and environmental conditions such as high temperatures and moisture deficit which commonly occur under tropical climates. The study further revealed that planting density has no influence on various gaseous exchange parameters of the moringa tree. Under soil water deficit and high temperature, moringa uses adaptation strategy by reducing stomatal conductance and transpiration thereby increasing water use efficiency. The results also revealed that the plant has the ability to sequester more carbon probably by sustaining photosynthesis through storage of water in its succulent parts. Moringa can, therefore, be recommended for planting at a higher density of 5000 plants ha^{-1} in many parts of Limpopo Province that experiences high temperatures, as the potential crop to contribute to climate change mitigation and nutritional security given its many nutritional attributes.

CHAPTER 6

COMPARISON OF GASEOUS EXCHANGE IN *MORINGA OLEIFERA* AND OTHER DROUGHT TOLERANT TREE SPECIES FOR CLIMATE CHANGE MITIGATION UNDER SEMI-ARID CONDITIONS OF NORTHERN SOUTH AFRICA

ABSTRACT

Climate change increases irregularities of rainfall and temperature patterns, especially in semi-arid regions. One practical way to compensate for this challenge is to plant trees that could have a great influence on environmental outcomes. Plants act as a carbon sink which is a process or mechanism that removes carbon dioxide from the atmosphere during photosynthesis and stores excess carbon as biomass in their parts, thus mitigating climate change. This study was conducted under semi-arid conditions of northern South Africa, to evaluate the physiological parameters of three drought tolerant tree species to assess their relative contributions to climate change mitigation. An existing moringa (*Moringa oleifera*) trial, planted at a population of 5000 plants ha^{-1} was used in this study. The other two naturally growing tree species, mopane (*Colophospermum mopane*) and marula (*Sclerocarya birrea*) trees growing within the moringa trial vicinity were included in the study as a control. Eight trees from each species were sampled for data collection in the study. The photosynthetic rate (A), stomatal conductance (gs), transpiration rate (E) and sub-stomatal CO_2 (Ci) measurements were performed using a fully-expanded leaf on the abaxial side of each selected leaf using a non-destructive method. Furthermore, three fully expanded leaves were sampled from one tree per species to determine leaf stomatal density from each replication. The tree species differed significantly in gaseous exchange. Moringa showed the highest activity in all the parameters measured. Stomatal density was also different among the three tree species, being 281.8, 355.2 and 930.6 per unit area of 0.09 mm^2 for marula, mopane and moringa species, respectively. Moringa maintained good leaf yield even under drought conditions, which is an indication of its potential to act as a good sink for carbon dioxide absorption. The results strongly showed, without a doubt, the superiority of moringa in capturing more carbon among the three tree species. Moringa can, therefore, be recommended for many parts of Limpopo Province for climate change mitigation where semi-arid conditions prevail.

Keywords: climate change, gaseous exchange, marula, mopane, moringa, stomatal density.

6.1 Introduction

Climate change is negatively affecting smallholder farmers in the developing countries (Daba, 2016). The effect of the change on food security is difficult to predict at present and research is needed to deepen the understanding of this issue. Gedefaw (2015) indicated that a single step to compensate for the several unpreventable carbon dioxide emissions is to plant trees, due to their ability for high carbon dioxide uptake and the released oxygen in return. Plants act as a carbon sink in a process or mechanism that removes carbon dioxide from the atmosphere (IPCC, 2007) during photosynthesis and storing excess carbon as biomass in their parts (Johnson and Coburn, 2010).

Trees source a huge carbon quantity and regulate the carbon cycle by exchange of CO_2 from the atmosphere (Johnson and Coburn, 2010; Suryawanshi *et al.,* 2014). It is, therefore, important to identify different plants species which can remove concentrated carbon dioxide from the atmosphere through the natural process of photosynthesis and store carbon in their leaves, branches, stem, bark, and roots as part of the climate change mitigation process.

Trees used or targeted for carbon sequestration do not need to be of a particular kind or to be located at a particular site (Johnson and Coburn, 2010; Hof *et al.,* 2017). However, one of the main essential characteristic to consider is their adaptability to drought conditions. In semi-arid regions, such as prevails in the Limpopo Province, the rainfall is seasonal and highly unpredictable (Clifford *et al.,* 1997). Moringa (*Moringa oleifera)* is a fairly new crop in the Limpopo Province while mopane (*Colophospermum mopane)* and marula (*Sclerocarya birrea)* trees are known to be dominant in the far northern parts of South Africa and can survive harsh conditions better than many tree species. They also have the potential to contribute to food security for either livestock or humans (Mashabane *et al*., 2001, Muok *et al*., 2009; Mabapa *et al*., 2017b).

According to Mabapa *et al.* (2017b), *Moringa oleifera* has proven to be a good source of fodder for livestock, is able to survive harsh growing conditions and can be recommended to resource-poor farmers in regions such as the Limpopo Province of South Africa. The nutritional benefits of *Moringa oleifera* are reported by several authors to be tremendous with the leaves being rich in valuable essential nutrient elements that are required by both humans and livestock (Thurber and Fahey, 2009; Anjorin *et al*., 2010, Omotesho *et al*., 2013).

Several studies have been conducted on the physiological activity of plants, some of which reveal that salinity and soil water stress affect some physiological characteristics of plants (Chaves *et al*., 2009; Rivas *et al*., 2013; Wafa, 2015). However, there is no documented information on stomatal activity or gaseous exchange in moringa, marula, and mopane tree species under semi-arid conditions of northern South Africa, even though these species are known to survive harsh conditions. The aim of this study, therefore, was to evaluate the photosynthetic rate (A), stomatal conductance (gs), transpiration rate (E) and sub-stomatal CO_2 (Ci) of three drought tolerant tree species as well as their stomatal density for planning climate change mitigation and adaptation strategies.

6.2 Materials and Methods

6.2.1 Study location

The study was conducted over a twelve month period in 2014 to 2015 to cater for the four seasons which are Summer (December - February), Autumn (March - May), Winter (June - August) and Spring (September - November). The trial was established at a farmer’s field, NTL Baraka Eco-Farming Organic Farm located at Eiland, Limpopo Province of South Africa with central geographical coordinates of 23°57.691'S and 30°35.205'E. The farm is situated approximately 50 km east of a major town, Tzaneen, in the province. The area is a tropical region and receives approximately 429 mm of rain per annum, with most rainfall occurring mainly during mid-summer. The annual rainfall data were derived from the total monthly values for Eiland averaged over the past 7 years. The area received the lowest average rainfall (<0.5 mm) in June and July months; the highest in December and January of more than 120 mm in the past 7 years. The monthly temperature distribution shows that the average maximum monthly temperatures for Eiland could rise above 31°C while minimum temperatures could range between 7 to 25°C, during winter and summer seasons, respectively.

6.2.2 Experimental design

An existing moringa trial which was planted during December 2013 at a population of 5000 plants ha^{-1} was used in this study. Another two naturally growing tree species, mopane (*Colophospermum mopane*) and marula (*Sclerocarya birrea*) trees were included in the study. The naturally growing trees were used as a control within the vicinity of the moringa trial (Figure 6.1). The marula species were scattered across the farm, while the mopane species which is dominant, occurs in pure stand with an estimated population of 1300 plants ha^{-1}. Eight trees from the three species were used as replications and five leaves from each species were randomly measured for data collection.

6.2.3 Leaf gaseous exchange measurements

Leaf gaseous exchange measurements were recorded on a selected fully-expanded leaf on the abaxial side using a portable photosynthesis system (ADC Bio Scientific, UK). The photosynthetic rate (A), stomatal conductance (gs), transpiration rate (E) and sub-stomatal CO_2 (Ci) were simultaneously determined for each species using a non-destructive method. All the measurements were carried out under steady-state conditions in full sun between 10:00 am and 14:00 pm (Clifford *et al.*, 1997).

6.2.4 Leaf stomatal density

During harvesting, three fully expanded leaves were sampled from each tree species to determine leaf stomatal density, which was expressed as number of stomata per unit area of a leaf (Radoglou and Jarvis, 1990). The leaves were cleaned using cotton and slightly smeared with clear glue in the mid area between the central vein and the leaf edge at approximately 5 x 10 mm. A film was applied three times on each leaf and allowed to dry for about thirty minutes and become thin. A drop of glycerol was applied on a glass slide and the film was peeled off from the leaf surface using a fine point tweezer, mounted on a glass slide and immediately covered with a coverslip. A number of stomata for each film strip was counted under a photomicroscope system (CH-9435, Leica Microsystems, Heerbrugg, Germany) with a computer attachment.

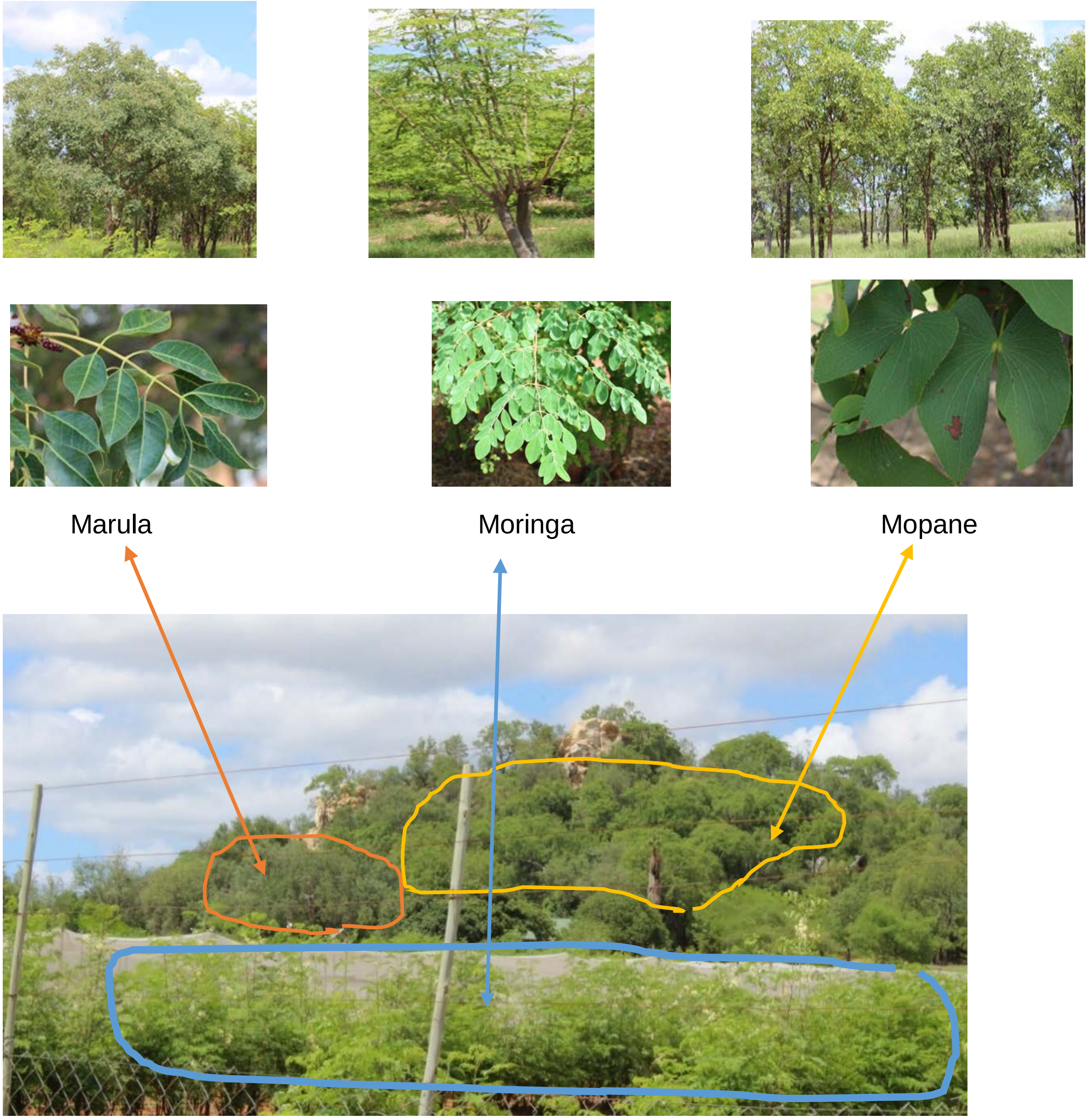


Figure 6.1. Marula and mopane trees growing within the vicinity of *Moringa oleifera* trial at Eiland.

6.2.5 Statistical analysis

Data were subjected to analysis of variance using the software, Statistix 10.0, to compare the response of tree species on measured variables. Where significant F-values from treatment effects were observed, means were separated by least significant difference (LSD) at a probability level of 0.05. Correlation and regression analyses were performed on the sampled data using Microsoft Excel to determine the relationship between stomatal density and gaseous exchange.

6.3 Results

6.3.1 Weather parameters of the study area

Data on weather parameters measured during the study and anomaly in rainfall distribution are presented in Figures 6.2 and 6.3, respectively. A reduced rainfall amount of less than 100 mm was recorded during summer season (November to January) of 2014/15 growing season, compared to the previous two years where the amount exceeded 200 mm. The temperatures were elevated during the summer season of experimentation with the maximum in excess of 35^{o}C (Figure 6.2). The drought that was experienced during 2015 had a significant influence on rainfall anomaly (Fig. 6.3). The accelerated heat, accompanied by moisture deficit led to below average rainfall anomaly mainly during the year 2015 as compared to 2013 and 2014 where the rainfall anomaly was above average in many instances, mainly during the rainy season.

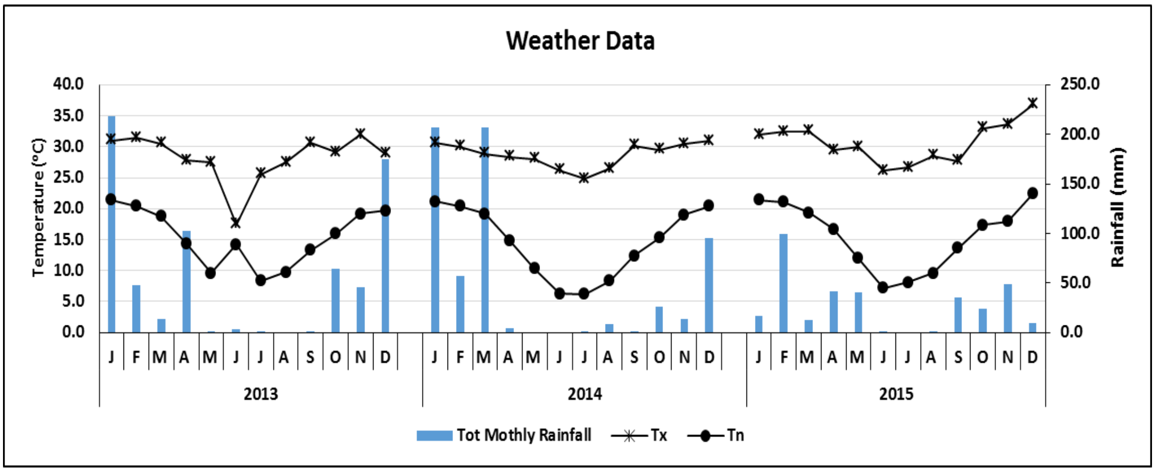


Figure 6.2. Total monthly rainfall (mm), average maximum (Tx) and minimum (Tn) temperatures collected at Eiland during the production seasons.

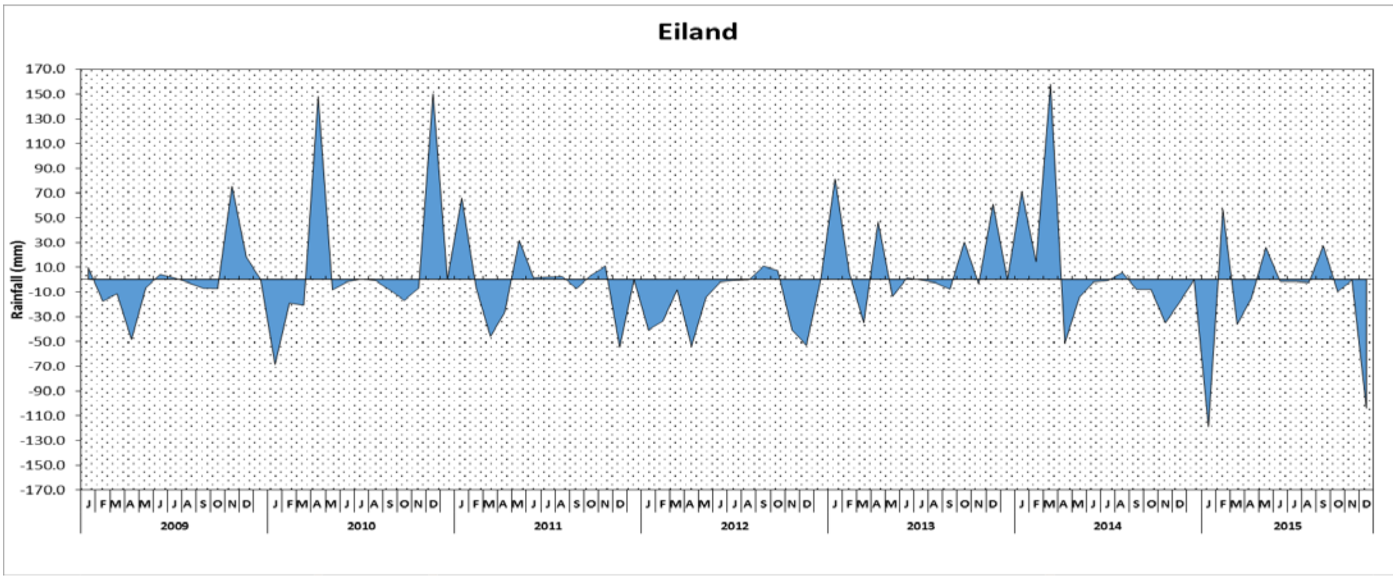


Figure 6.3. Rainfall (mm) anomaly at Eiland as compared to long-term average rainfall from 2009 to 2015.

6.3.2 Stomatal density of moringa, mopane and marula tree species

Measurement of stomatal density showed significant differences among the three tree species. The stomatal density per unit area of 0.09 mm^2 ranged from 281.8 to 930.6 with the highest occurring in moringa, followed by mopane and then marula (Figure 6.4).

The relationships between stomatal density and gaseous exchange across the species are presented in Figure 6.5. Photosynthetic rate and stomatal conductance were positively and linearly related to stomatal density (Figure 6.5). The transpiration rate and sub-stomatal CO_2 were also positively and linearly related to stomatal density but with reduced associations.

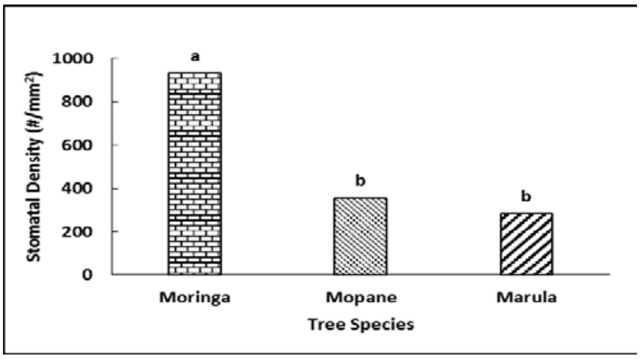


Figure 6.4. Stomatal density of the measured tree species recorded from an area of 0.09 mm^2.

6.3.3 Gaseous exchange of moringa, mopane and marula tree species

Comparing gaseous exchange among the three tree species, moringa was found to exhibit the highest in all gaseous exchange parameters measured, among the three species. No significant difference in sub-stomatal CO_2 and stomatal conductance were found between mopane and marula tree species, but mopane had higher photosynthetic rate and transpiration relative to marula tree (Figure 6.6).

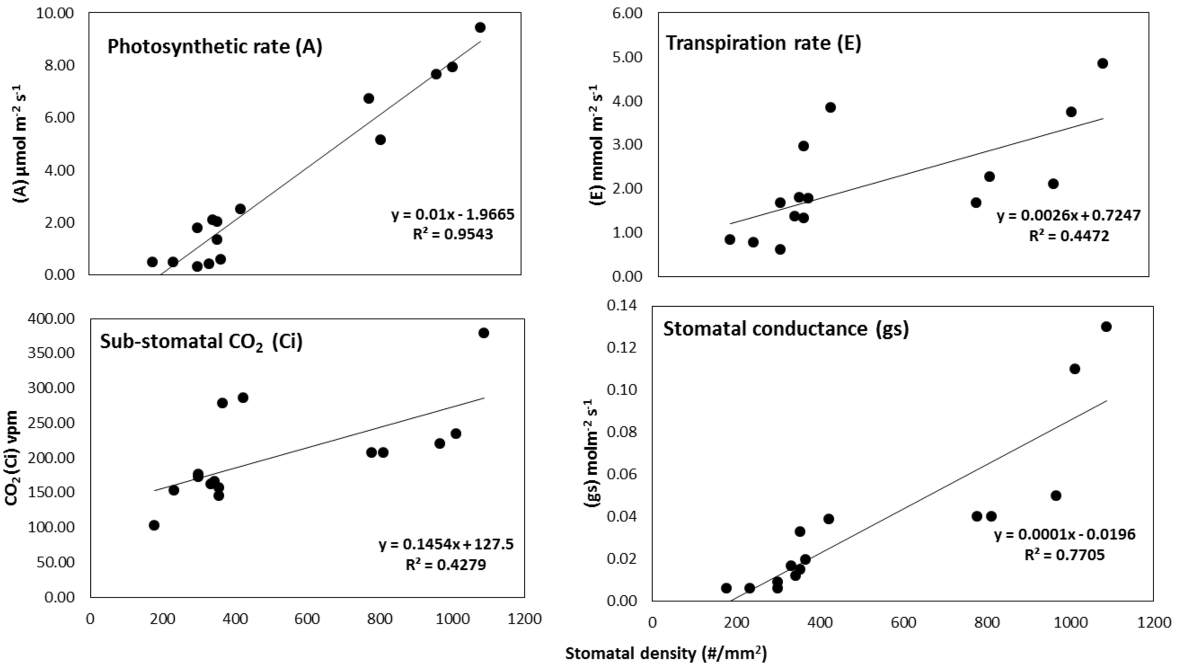


Figure 6.5 Correlation and linear relationship effect of stomatal density with gaseous exchange across the tree species.

Comparison of the monthly influence on gaseous exchanges among the tree species showed moringa to exhibit the highest among the three species (Figure 6.7). The photosynthetic rate for moringa was observed to be considerably higher relative to the other species throughout the data collection period except in September 2014 and February 2015 months, where the differences were not significant (Figure 6.7A).

Furthermore, transpiration in moringa and mopane tree species was higher compared to marula species. However, a drastic drop was measured in all tree species between January and February 2015 (Figure 6.7B). Once again, the highest sub-stomatal CO_2 concentration was recorded in moringa compared to the other two species which were similar (Figure 6.7C). Stomatal conductance was again higher in moringa during May, October 2014 and March 2015 months compared to the other species during the same period (Figure 6.7D).

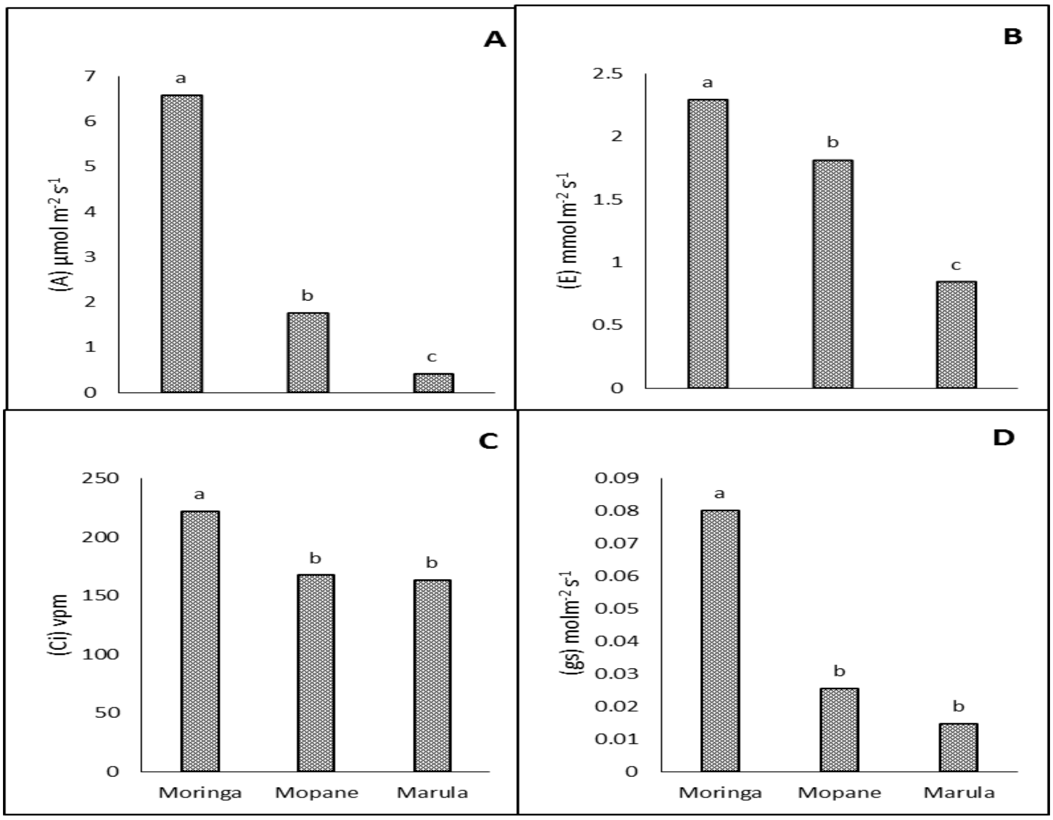


Figure 6.6. Gaseous exchange parameters of moringa, mopane, and marula tree species. (A) Photosynthetic rate, (B) transpiration rate, (C) sub-stomatal CO_2 and (D) stomatal conductance. Means with different letters are statistically significant.

Photosynthesis was significantly correlated with transpiration rate, sub-stomatal CO_2 and stomatal conductance (Table 6.1). A strongly positive correlation was found between the transpiration rate and stomatal conductance. However, transpiration and stomatal conductance did not correlate with sub-stomatal CO_2.

Table 6.1. Pearson correlation coefficients between measured gaseous exchanges of *Moringa oleifera.*

	Photosynthesis	Transpiration	Sub-stomatal CO_2
Transpiration	0.48***		
Sub-stomatal CO_2	-0.45***	-0.09^{ns}	
Stomatal Conductance	0.46***	0.70***	0.16^{ns}

Significance levels: *P<0.05, ** P<0.01, *** P<0.001, ns: not significant.

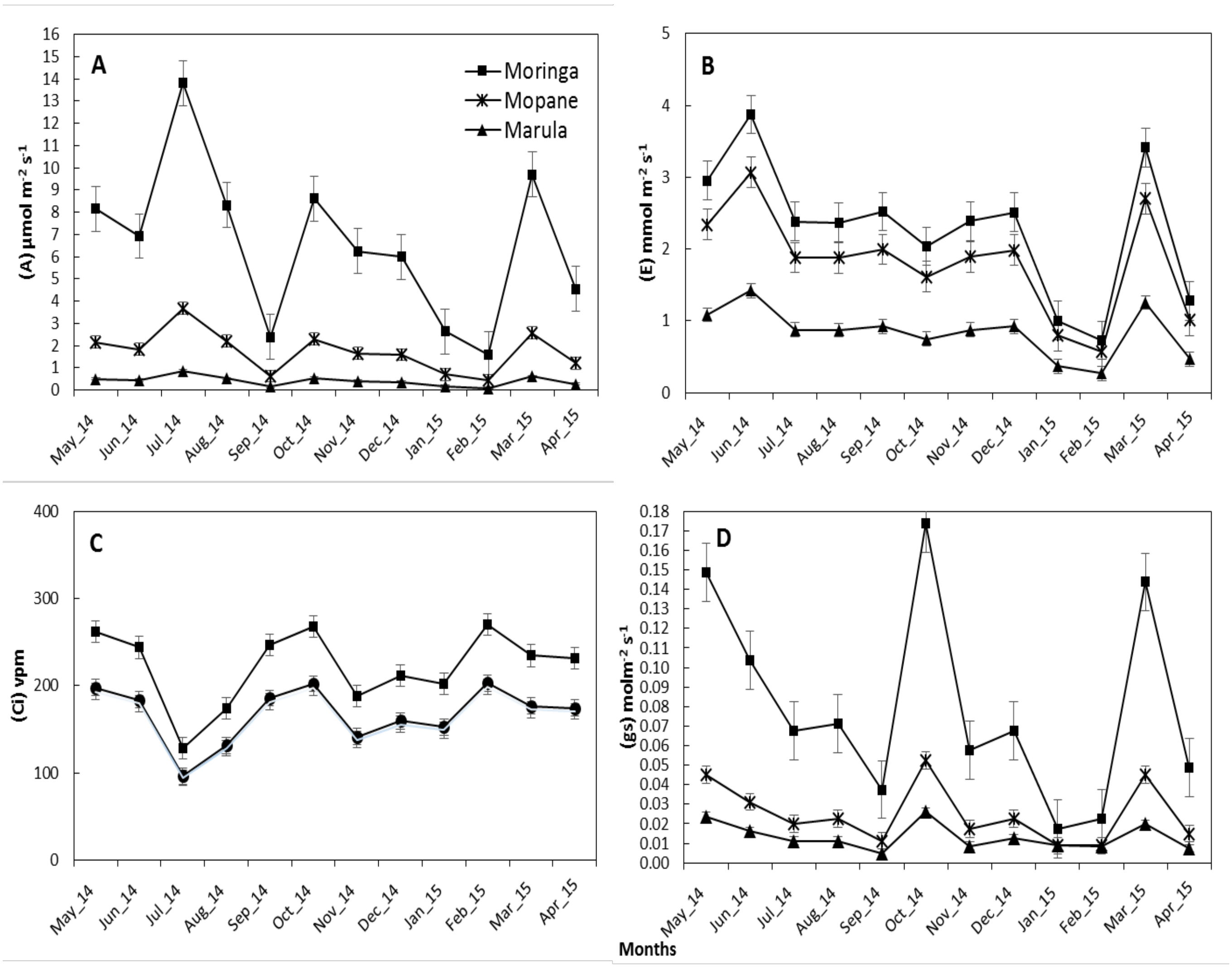


Figure 6.7. Monthly gaseous exchange parameters of moringa, mopane, and marula tree species. (A) Photosynthetic rate, (B) transpiration rate, (C) sub-stomatal CO_2 and (D) stomatal conductance.

6.4 Discussion

6.4.1 Weather parameters in the study area

During the study between 2014 and 2015, the study site at Eiland experienced extreme drought and high temperatures. A total rainfall of 432 mm was received during this period. A study by Anjum *et al.* (2011) reported that environmental abiotic stresses mainly drought, salinity, and extreme temperatures, could impair plant growth and development and as such limit the productivity. During the summer season (December 2014 to February 2015), Eiland received below average rainfall with the situation worsening during 2015 when the rainfall anomaly was greater than 100 mm below average. This situation affected many agricultural crops and the impact of climate change on this region was evident. Frosi *et al.* (2017) reported that increased irregularities of rainfall and temperature mainly in the semi-arid conditions are a major climate concern for agricultural productivity. Low rainfall and prolonged dry spells affect crop production through disrupted physiological activities (Reddy *et al*., 2003; Chaves *et al*., 2009; Behrouzyar and Yarnia, 2014).

6.4.2 Stomatal density of moringa, mopane and marula tree species

The stomatal density of moringa was significantly higher compared to that of mopane and marula trees. This presented an added advantage to moringa in gaseous exchange. According to Xu and Zhou (2008), an increase in leaf stomatal density leads to a significant increase in stomatal conductance and net CO_2 assimilation rate. Camargo and Marenco (2011) reported that stomata are turgor-operated valves that control water loss and CO_2 uptake during the process of photosynthesis. From our results, moringa was again superior in stomatal conductance in addition to possessing the highest stomatal density. These two morphological and physiological traits could partly explain the relatively highest photosynthetic activity recorded in moringa.

The reduction in leaf conductance due to lower stomatal density resulted in lowered photosynthesis as it is positively related to stomatal conductance (Figure 6.5). Similar results were observed in this study whereby, moringa had a significantly higher stomatal conductance and consequently, higher photosynthetic rate (Figures 6.4 and 6.5) compared to the other two tree species. This could be due to moringa’s ability to survive in all types of soils and various climatic conditions in the semi-arid tropics as reported by Kumar *et al*. (2017).

6.4.3 Gaseous exchange of moringa, mopane and marula tree species

The superiority of moringa in terms of gaseous exchange, compared to the other tree species could be due to adaptation strategies utilized by the plant under harsh conditions. As indicated earlier, moringa uses various survival mechanisms against drought and temperature effects. From this study, it was revealed that moringa does not use the surrounding soil moisture within the root zone immediately after a rainfall event, but rather stores the absorbed water in its succulent root tissues and utilizes it at a later stage when there is a moisture deficit. This improves gaseous exchange including transpiration; hence the tree was not severely affected by water deficit. The sub-stomatal CO_2 of marula and mopane were not statistically different from each other but that of moringa was significantly higher than those of the other two species, showing that moringa has the potential to sequester more carbon dioxide from the atmosphere. The sub-stomatal conductance allows diffusion of carbon dioxide and other gases in and out of the plant cells (Farooq *et al*., 2009).

From this study, it was evident that prolonged drought had a more severe impact on the gaseous exchange of mopane and marula trees relative to moringa. The two species kept the stomata closed during the time of drought and high temperatures. These findings are in agreement with Anjum *et al*. (2011) and Frosi *et al*. (2017), who revealed that drought leads to progressive stomatal closure with a parallel decline in gaseous exchange. Farooq *et al*. (2009) further reported that stomata close progressively as drought progresses with a consequent decline in photosynthesis. When water is severely limiting, the first strategy of plants to avoid drought is to close the stomata (Chaves *et al*., 2009; Farooq *et al*., 2009; Hussein *et al*., 2014).

Clifford *et al*. (1997) reported that, under drought conditions, photosynthetic rate and stomatal conductance decreased but sub-stomatal CO_2 tended to increase. The implication is that stomatal conductance was not a limiting factor for changes in sub-stomatal conductance. Furthermore, Rivas *et al*. 2013 reported that, as drought prolongs with time, moringa species drops in gaseous exchange. This was evident in this study mainly on photosynthetic rate and stomatal conductance.

It was observed that moringa maintained good leaf yield even under drought conditions and this gives an added advantage of the plant to act as a good sink for carbon dioxide absorption. Thus, given the nutritional benefits of moringa both for humans and livestock (Maroyi, 2006; Thurber and Fahey, 2009; Anjorin *et al*., 2010; Omotesho *et al*., 2013; Mabapa *et al*., 2017b), the plant can be considered for national climate change mitigation and adaptation plans in South Africa. A study by Jagadheesan *et al*. (2011) indicated that moringa can maintain continuous growth even under severe drought conditions and still be able to produce satisfactory yields. The plant survives harsh conditions and its growth is not easily hampered by the restricted availability of water in the soil. It has the capability of modifying the internal structure to resist drought conditions through maintenance of higher water levels (Jagadheesan *et al*., 2011). After a period of drought, the tree experiences faster recovery and fast growth which provides a competitive advantage under semiarid conditions (Frosi *et al*., 2017).

Based on the prevailing weather conditions during the study period, many plant species were affected by the negative impact of drought. Marula and mopane trees showed symptoms of heat and drought stress, but the tolerance of moringa to this condition was evidenced by the maintenance of satisfactorily gas exchange. This might be due to the ability of the tree to store water in the bloated trunk, as well as its tuber roots during periods of soil moisture availability for later use (Yamato *et al*., 2009). Improved nutrient status of a plant is an important attribute towards adaptation to stressed conditions.   It is reported that most terrestrial plants have a symbiosis with arbuscular mycorrhizal (AM) fungi and such colonization has been reported in moringa (Yamato *et al*., 2009). The AM fungal association contributes to soil nutrients uptake, disease resistance and improved drought tolerance of the host plant (McGonigle *et al*., 1990; Jeffries *et al*., 2003; Yamato *et al*., 2009). This could have also contributed to the drought tolerance abilities of moringa relative to the other species studied.

6.5 Conclusion

In conclusion, this study revealed that moringa can better survive harsh conditions such as high temperatures and moisture deficit which occur under semi-arid climates, relative to mopane and marula trees. Moringa was superior in terms of controlling gaseous exchange for adaptation to harsh environmental conditions compared to the other two tree species. The tree has a higher number of stomata which is advantageous for maintaining high photosynthetic rate, stomatal conductance, transpiration rate and sub-stomatal CO_2. These results showed without any doubt that moringa can be a good crop for the semi-arid conditions of Limpopo province, where a high frequency of drought periods prevails. Furthermore, the superiority of the moringa plant to capture carbon even under harsh growing conditions is a good attribute for climate change mitigation. It can, therefore, be recommended for cultivation in many parts of Limpopo Province for contribution to national climate change adaptation and mitigation plans.

CHAPTER 7

BIOMASS, GRAIN, OIL YIELD PRODUCTION AND NUTRITIONAL COMPOSITION OF *MORINGA OLEIFERA* UNDER DIFFERENT PLANTING DENSITIES IN LIMPOPO PROVINCE, SOUTH AFRICA

ABSTRACT

Production of moringa in South Africa is exclusively for leaf processing and consumption. To date, there is no documented information on seed and oil yield production of moringa, including in the Limpopo Province of South Africa. This study was conducted to evaluate the effect of planting density on biomass, grain, oil yield production and nutritional composition of *Moringa oleifera* planted under the semi-arid condition of the Limpopo Province. Initially, the study was planned for two diverse agro-ecological conditions in the province, namely: a farmer's field at Eiland (NBef Organic Farm) and the University of Limpopo Experimental Farm at Syferkuil. However, the plants at the experimental farm suffered severe mortality and poor growth owing to very low temperatures coupled with severe frost injury during the season resulting in excessive injuries that prevented the plants to grow to the level of grain yield production. This location was therefore excluded from the study. The Eiland study was conducted over two consecutive years of 2014–15 and 2015–16. The initial and post planting physical and chemical properties of the soil at the site were carried out at depths of 0 to 30 and 30 to 60 cm using a soil auger. The experiment was established as a randomized complete block design and replicated eight times. The treatments included planting densities of 5 000, 2 500, 1 667 and 1 250 plants ha^{-1}. Data collection included total dry matter yield (kgha^{-1}), leaf yield (kgha^{-1}), seed yield (kgha^{-1}), yield components, crude oil % and leaf nutritional composition. Results from the analysis revealed slightly acidity and very low nitrogen content (0.08%) at all sampling depths before moringa establishment. In addition, excessive magnesium, manganese and copper contents in the soil were recorded. Soil properties such as phosphorus, potassium, zinc, copper, organic carbon and nitrogen were reduced after the first harvest. However, during the second harvest similar soil nutrient reductions followed the same trend as compared to the first harvest except for phosphorus which showed an increase as compared to initial soil sampling at the second harvest. During harvests 1 and 2, the increase in planting density resulted in increased biomass production as well as seed and oil yields. The seed oil percentage was however not responsive to planting density. Planting densities also did not affect moringa leaf nutritional composition. The study showed that a population of 5000 plants ha^{-1} produced the highest biomass and seed yield of moringa. This study also revealed that moringa contains a high level of leaf nutrients even under marginal production conditions, irrespective of the planting density.

Keywords: biomass, oil, planting population, seed, weather, yields

7.1 Introduction

Moringa oleifera is the most cultivated species belonging to the Moringaceae family (Makkar and Becker, 1996; Fahey, 2005). The tree is native to sub-Himalayan tracts of India, Pakistan, Bangladesh and Afghanistan and some western parts of Africa (Makkar and Becker, 1996; Leone *et al*., 2016). The main producing counties in Africa are Ghana, Senegal, and Malawi (Pakade *et al*., 2013). In South Africa, moringa is grown by a few farmers. However, the majority of farmers know about moringa, but grow it in very small areas and in their backyards for household purposes.

Moringa thrives under harsh conditions where the majority of agricultural crops cannot survive, especially in tropical and subtropical areas (Leone *et al*., 2016). Besides being tolerant to various environmental and climatic conditions, it is a fast growing tree species which can reach a height of 6 to 7 m within 12 months of establishment in areas receiving a rainfall of less than 400 and up to 1500 mm/annum (Odee, 1998; Amaglo, 2006). The tree grows best at temperatures ranging between 25 to 35^{o}C, but can still survive extreme temperatures of up to 48 ^{o}C and tolerate a soil pH of 5.0–9.0 (Amaglo, 2006; Saini *et al*., 2016).

Moringa (*Moringa* spp.) is one of the world’s most useful plants and promising food sources because its high nutritional leaf can survive during dry seasons and therefore be able to feed communities when other foods are typically scarce (Fahey, 2005). The tree is used mainly for human food, livestock forage, medicine, dye, and water purification (Palada and Chang, 2003; Amaglo, 2006). *Moringa* *oleifera* can be a suitable crop for climate change mitigation in areas that are already experiencing the effect of climate change, given its high level of adaptability and abundant nutritional, medicinal, industrial, domestic as well as agricultural values (Ndubuaku *et al.*, 2014; Nouman *et al*., 2014).

A large volume of literature is available on the nutritional quality of moringa (Fahey, 2005). Moringa leaves are concentrated with different nutrients that can alleviate malnutrition. For example, the leaves mainly in powder form contain more vitamin A and C, calcium, iron, potassium, protein and other nutrients compared to other food crops (Makkar and Bekker, 1996; Fahey, 2005; Jongrungruangchok *et al*., 2010; Mendieta–Araica *et al*., 2013; Nouman *et al*., 2013; Asante *et al*., 2014; Gopalakrishman *et al*., 2016; Zheng *et al*., 2016).

Different studies conducted on moringa had recognized with little doubt on the tree’s nutritional value and the substantial health benefit derived through the consumption of moringa leaf powder, especially in situations where starvation is a threat (Fahey, 2005; Pakade *et al*., 2013). Majority of moringa consumers prefer the leaves over the other products from the tree. Studies have been conducted mainly in India and other countries on the characterization of the oil from the seeds of *Moringa oleifera* (Anwar *et al*., 2006; Ayerza, 2011; Adejumo *et al*., 2013; Azad *et al*., 2015).

Moringa seed contains between 35 to 45% oil depending on climatic and environmental conditions (Lalas and Tsatskins, 2002; Amaglo, 2006; Ayerza, 2011; Adejumo *et al*., 2013). The oil can be utilized successfully as a source of edible oil for human consumption. It contains high monounsaturated to saturated fatty acids ratio and might be an acceptable substitute for highly monounsaturated oils such as olive oil in diets (Lalas and Tsaknis, 2002). Adejumo *et al*. (2013) indicated that moringa oil can be used for various purposes including, cooking, cosmetics and as a lubricant. The study further concluded that moringa seed oil has a longer shelf life of up to five years due to its low peroxide level.

Production of moringa in South Africa is exclusively for leaf processing and consumption. To date, there is no documented information available about seed and oil yield production of moringa including in the Limpopo Province of South Africa. The cultivation of moringa trees needs to be expanded to achieve economies of scale in the production of its moringa leaves and seeds for both commercial and smallholder farmers. Therefore, this study was conducted to evaluate the effect of planting density on biomass, grain, oil yield production and nutritional composition of *Moringa oleifera* planted under the semi-arid condition of the Limpopo Province.

7.2 Materials and Methods

7.2.1 Study location

The study was conducted during two consecutive years of 2014–15 and 2015–16 at NBef Organic Farm, Eiland (Tzaneen) on a farmer’s field. Initially, the study was planned to be conducted under two diverse agro-ecological conditions including University of Limpopo Experimental Farm. However, plants at that site suffered severe mortality and poor growth owing to low temperature coupled with severe frost injury and as a consequence of which it did not manage to grow to the level of grain yield production. Therefore the location was excluded from the study.

Nbef Organics Farm (23°57.691'S and 30°35.205'E) is situated 50 km from Tzaneen town. The area lies in the tropical region of the Limpopo Province and the area receives about 429 mm of rain per year, with most rainfall occurring mainly during mid-summer. The rainfall data were derived from the monthly average rainfall values for Eiland in the past 7 years. The area received the lowest average rainfall (<0.5 mm) in June and July months, the highest in December and January of more than 120 mm in the past 7 years. The monthly distribution of average daily maximum temperatures shows that the average maximum monthly temperatures for Eiland could rise above 31°C while minimum temperatures could range between 7 to 25°C.

7.2.2 Soil sampling, preparation, and planting

Prior to land preparation, the land was demarcated within an area of 60 m length and 40 m breadth. The initial physical and chemical properties of the soil under test were randomly sampled 15 times within the demarcated area at a depth of 0 to 30 cm and 30 to 60 cm using a soil auger. The soils were bulked according to depth, thoroughly mixed and a composite sample was taken for analysis. Soil preparation was carried out by conventional tillage using a tractor and by disk ploughing followed by disk harrowing and making shallow holes for planting. Untreated seeds of *Moringa oleifera* were used for planting by placing 2 seeds per hole at a depth of 2 cm.

7.2.3 Experimental design and management

The experiment was arranged in a randomized complete block design (RCBD) which was replicated eight times. The blocks were divided into four plots where treatments were placed. Four spacing levels were used as a treatments (D1 = 1 m x 2 m, D2 = 2 m x 2 m, D3 = 3 m x 2 m and D4 = 4 m x 2 m), giving total populations of 5 000, 2 500, 1 667 and 1 250 plants ha^{-1}, respectively.

The four treatments were randomly assigned within each of the eight blocks. The experiment was set up in a field that covered an area of 1620 m^{2}. The size of each plot was 4 m x 12 m and blocks were separated from each other by 2 metre walkways with a tree remaining as a border created around the treatment plots. Eight weeks after planting, plants were thinned and one healthy plant was retained. Prior to data collection, all plants within each experimental unit were uniformly pruned at a height of 50 cm aboveground and the foliage removed.

The plants were initially irrigated uniformly for 12 weeks at a rate of 30 mm per week to encourage good plant establishment, after which the experiment was left to run under rainfed condition. During planting, compost was applied at 1.5 ton ha^{-1}, thereafter no additional fertilizer was applied until the experiment was terminated after two years. There were no pest and disease incidences observed during the experiment.

7.2.4 Soil properties analysis

In order to compare soil nutrients utilization by moringa tree, the soils were sampled during each harvest and compared with initial soil sample results. The soils at the two depths (0-30 and 30-60 cm) were collected within a sampling area (12 m^{2}) and 30 cm away from the base of the plant. The sampling was done for each treatment in the experimental unit. Soils were analyzed for P, K, Ca, Mg, Zn, Mn, Cu (mg/L), pH (KCl), organic carbon, total N (%), using standard analytical methods (Manson and Roberts, 2000).

7.2.5 Data collection

During the experiment, year one traversed the period from December 2013 to March 2015, while year two ran from April 2015 to February 2016. In those two years, data were collected from a net plot of 12 m^2 at harvest. During year 1 and 2, the data for biomass, grain yield, and yield components were collected according to treatments. The new soft branches toward the tip of the tree and the leaf petioles attached to the hard branches were harvested and determined as total dry matter yield ($kgha^{-1}$). The leaf yield ($kgha^{-1}$) was determined by separating the leaves from the petiole. The total aboveground fresh biomass was shade-dried at room temperature for 72 hours to ease separation of leaves and stem. Shoots were further oven dried for 48 hours at 65^oC until the samples had reached constant dry weight. Mature pods were manually harvested from the sampling area and allowed to dry for 2 weeks, then weighed to determine total grain yield ($kgha^{-1}$). Pod circumference (mm) was measured as part of yield components. Pods were threshed to determine seed yield ($kgha^{-1}$), number of seeds/pod and 100 seed weight (g). Seeds from the four treatments were weighed and analyzed to determine the oil content percentage at SGS Agri-food laboratory using AOAC method Ai3-75 (1990). Oil yield in $kgha^{-1}$ was also determined.

7.2.6 Leaf nutritional composition analysis

After observing discrepancies in soil nutrients, sampled leaves from year two were analyzed for nutritional composition. This was done to evaluate whether moringa stored nutrients in the leaves or used it for growth. Leaf samples harvested according to treatments were dried at room temperature (24 ^oC) for 72 hours then ground to pass through a 2 mm sieve and 10 g of the fine fraction was used to determine the chemical composition of moringa leaves. Crude protein was determined using the Kjeldahl method (AOAC, 1990). Other minerals such as P, K, Ca, Mg, Mn and Zn were determined using atomic sorption (Gaines and Mitchel, 1979).

7.2.7 Gravimetric soil moisture determination

Soils were sampled every month using an auger for a period of 12 months at depths of 0 to 15, 13 to 30 and 30 to 45 cm to determine gravimetric soil moisture percentage. The soils were immediately placed in zip-lock plastic bags after sampling to keep the soil moisture intact before measurement and then using a battery-operated top loading weighing balance (RADWAG, W/C6/12/C1/R Model) to determine fresh weight. The soils were then placed in size six brown bags and dried in an oven (Scientific oven Economy, 240 litres, Model 223) for 24 hours at a temperature of 105^{o}C until constant weight. Gravimetric soil moisture percentage was determined when the soil samples had reached a constant weight, using a method described by Black (1965) as Fresh soil x Dry soil/Dry soil x 100.

7.2.8 Data analysis

Data were subjected to analysis of variance using Statistix 10.0 to determine the effect of planting density on measured variables. Where significant F-values from treatment effects were found, means were separated by least significant difference (LSD) at a probability level of 0.05.

7.3 Results

7.3.1 Weather parameters

A cold temperature, accompanied by frost was experienced at the Syferkuil location during the two consecutive years of production resulting in a slow growth rate. Hence, the data that was supposed to be collected when the crop reaches 1.5 m, tall could not be taken (Figure 7.1) and as such, the location was excluded from the study. Results on weather parameters recorded at the two locations are presented in Figures 7.2, 7.3. The minimum temperature at Syferkuil went below 2 ^{o}C in June and July of each production year (Figure 7.2).

Figure 7.1: Moringa trial injured by winter chilling frost at Syferkuil during the growing seasons.

Figures 7.2 and 7.3 indicate data on total monthly rainfall, average monthly minimum and maximum temperatures recorded during the study period at Syferkuil and Eiland.

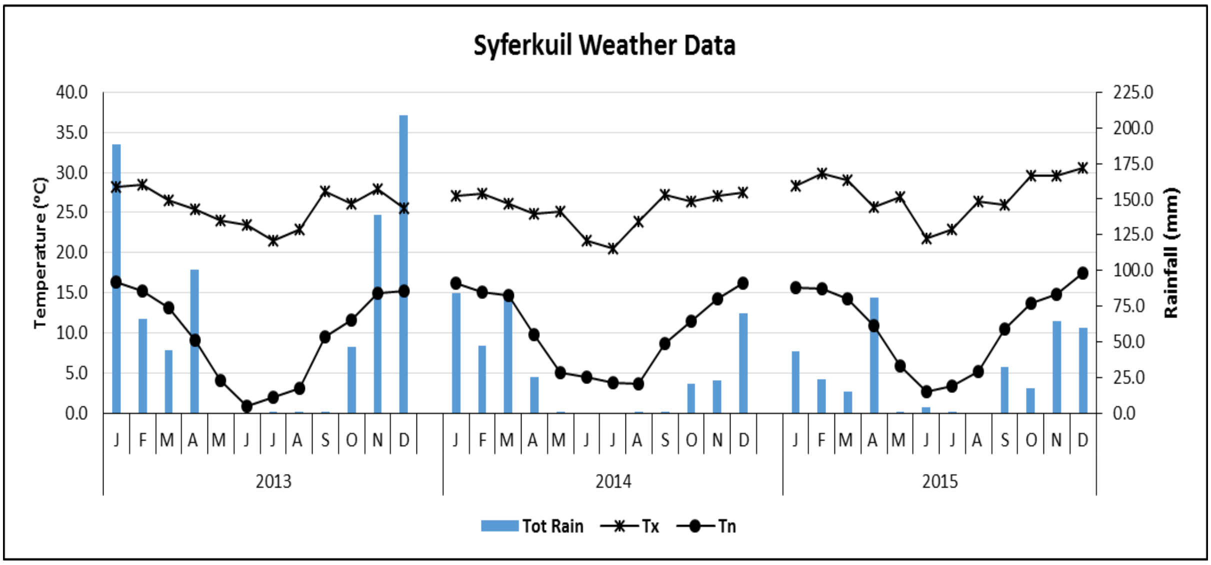


Figure 7.2: Total monthly rainfall (mm), average maximum (Tx) and minimum (Tn) temperatures collected at Syferkuil during the growing season.

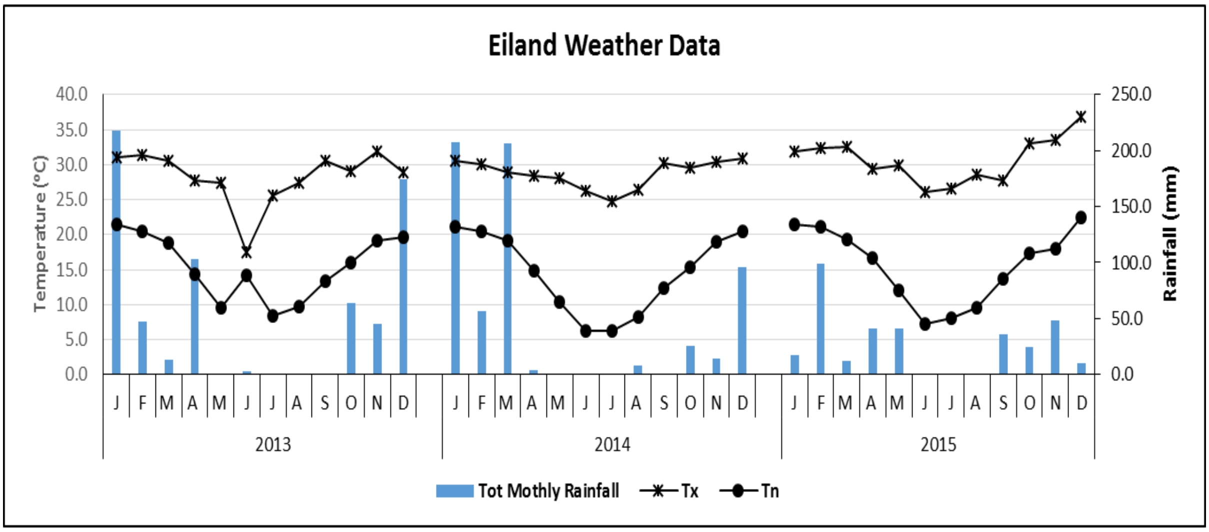


Figure 7.3: Total monthly rainfall (mm), average maximum (Tx) and minimum (Tn) temperatures collected at Eiland during the production seasons.

Figure 7.4 indicates the average long-term monthly rainfall, the minimum and maximum temperature recorded in the previous 7 years from the two study locations.

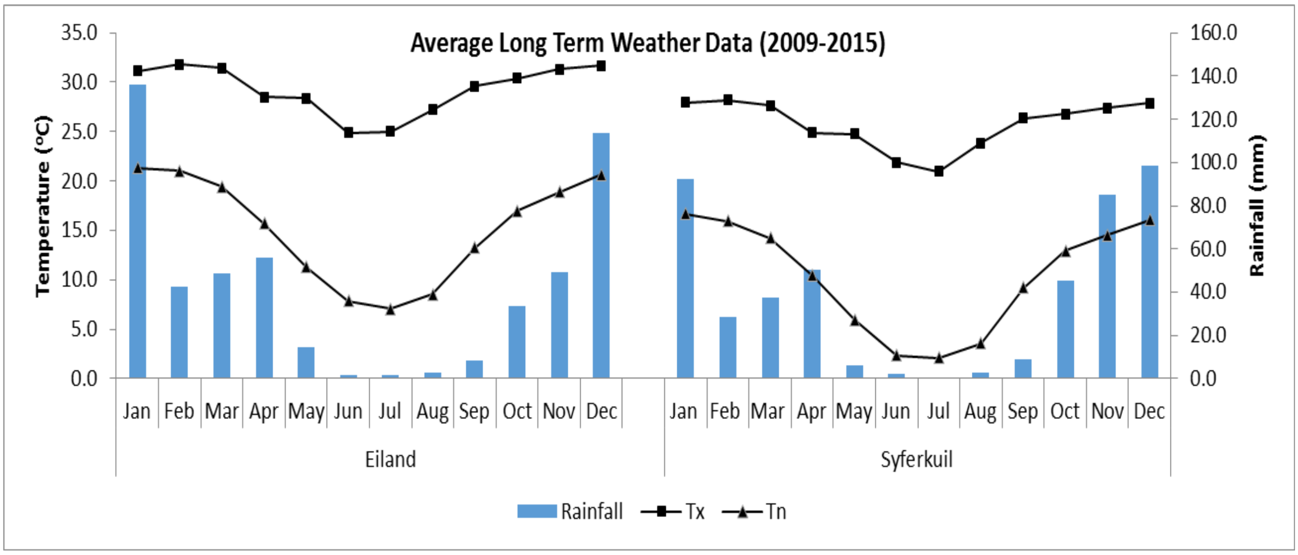


Figure 7.4: Average long-term weather data collected at Eiland and Syferkuil locations from 2009 to 2015.

Total annual rainfall received from the two study locations is presented in Figure 7.5. In many years from the long-term total annual rainfall, Eiland received more cumulative rainfall as compared to Syferkuil with the long-term total rainfall of 3529.75 mm and 3210.68 mm, respectively (Figure 7.5).

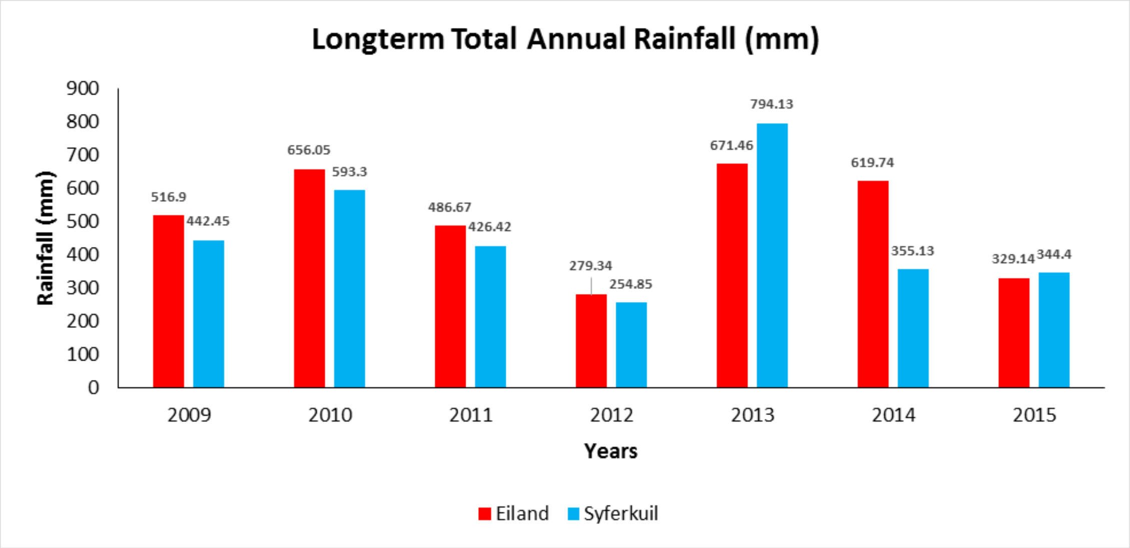


Figure 7.5: Long-term total rainfall data collected at Eiland and Syferkuil locations from 2009 to 2015.

Anomalies from recorded temperature and rainfall data at the two locations in the previous 7 years are indicated in Figures 7.6, 7.7, 7.8, 7.9 and 7.10. Rainfall and temperature affected the soil moisture level during year 2 compared to year 1. Gravimetric soil moisture showed a drastic drop across all plating densities from April 2015. Drought continued throughout the growing season of harvest 2, which led to a decrease in gravimetric soil moisture (Figure 7.11).

7.3.2 Effect of planting density on soil physical and chemical properties

The results of physical and chemical properties of the soil prior to planting are indicated in Table 7.1. The soil pH was slightly acidic before moringa establishment. Very low nitrogen content was observed at all sampling depths with a value of 0.08%. The soil nutrient profiles revealed excessive concentrations of magnesium, manganese, and copper at all sampling depths with values of more than 550 mg/l, 10 mg/l and 5.5 mg/l, respectively.

The soil analysis further showed adequate concentrations of phosphorus, potassium, calcium, zinc and organic carbon for all the depths except for phosphorous at the 30 to 60 cm depths which was slightly lower. These soils thus contained satisfactory amounts of macro nutrient elements for crop growth except for nitrogen (Table 7.1).

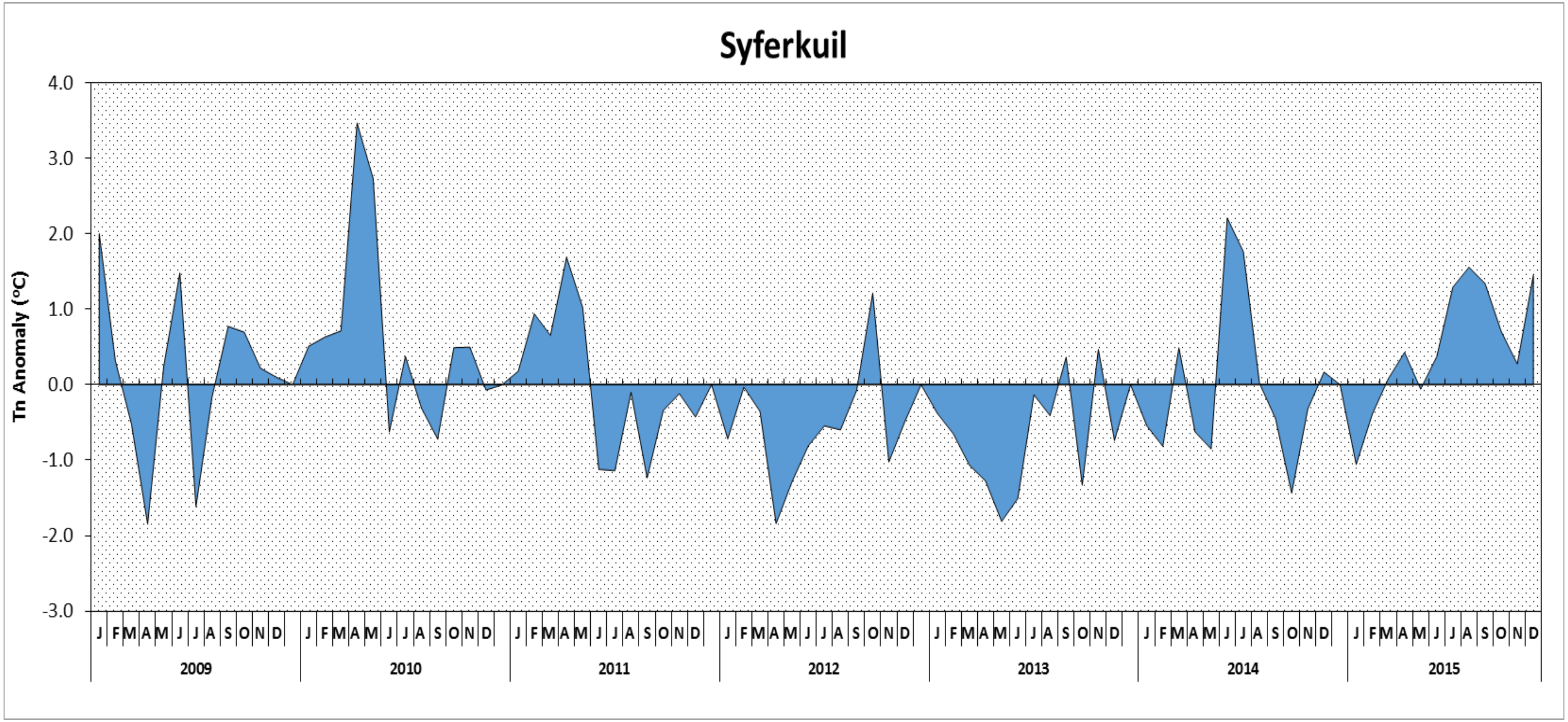


Figure 7.6: Minimum temperature (^{O}C) anomaly at Syferkuil as compared to long-term average monthly temperature.

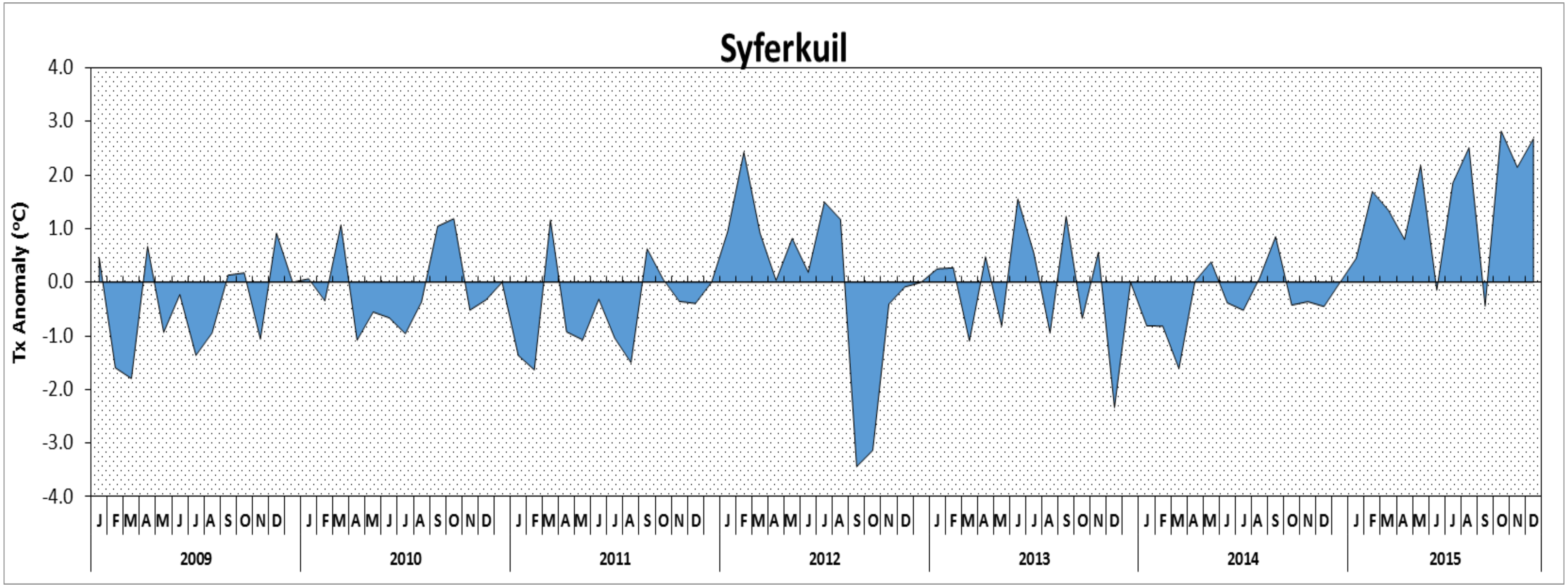


Figure 7.7: Maximum temperature (^{O}C) anomaly at Syferkuil as compared to long-term average monthly temperature.

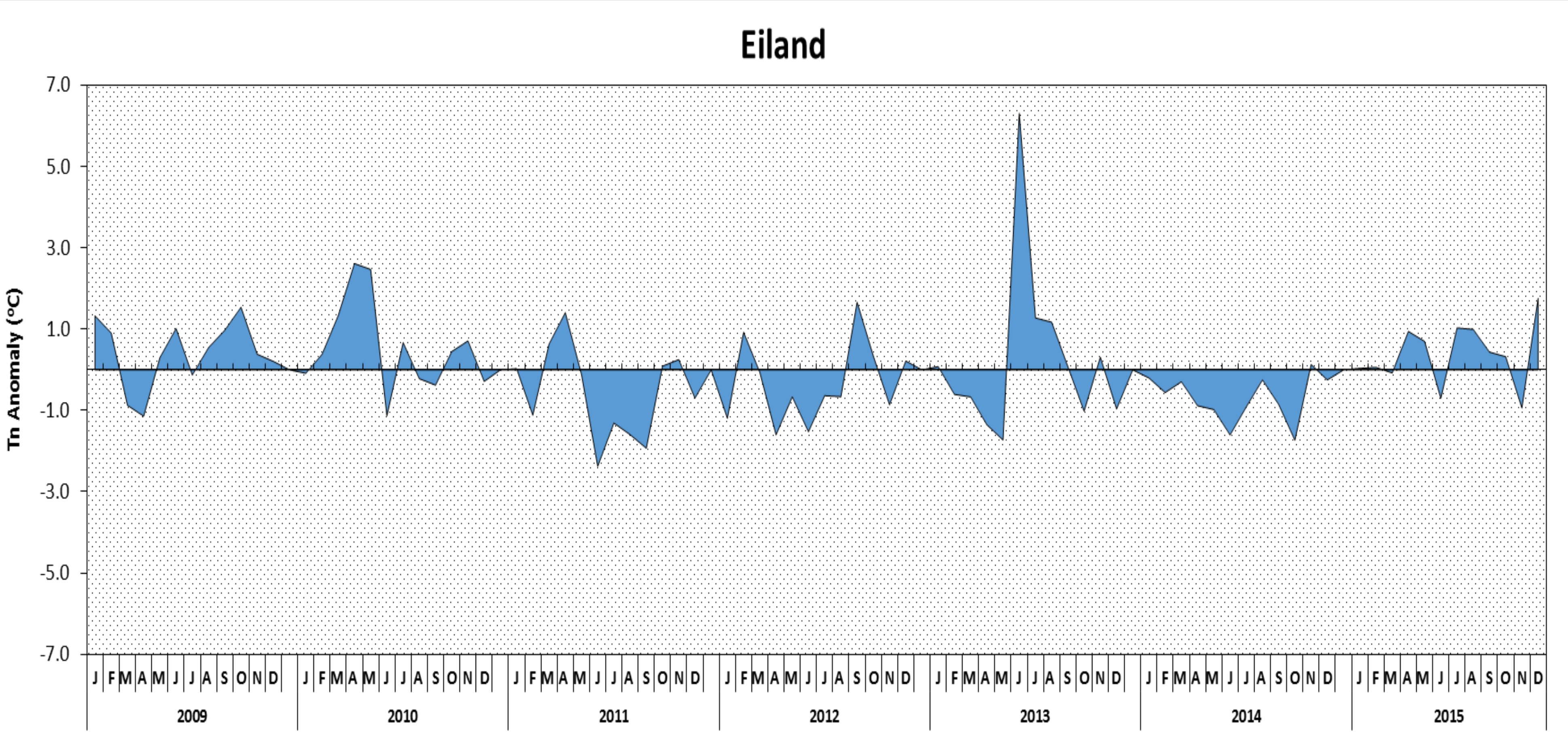


Figure 7.8: Minimum temperature (^{O}C) anomaly at Eiland as compared to long-term average monthly temperature.

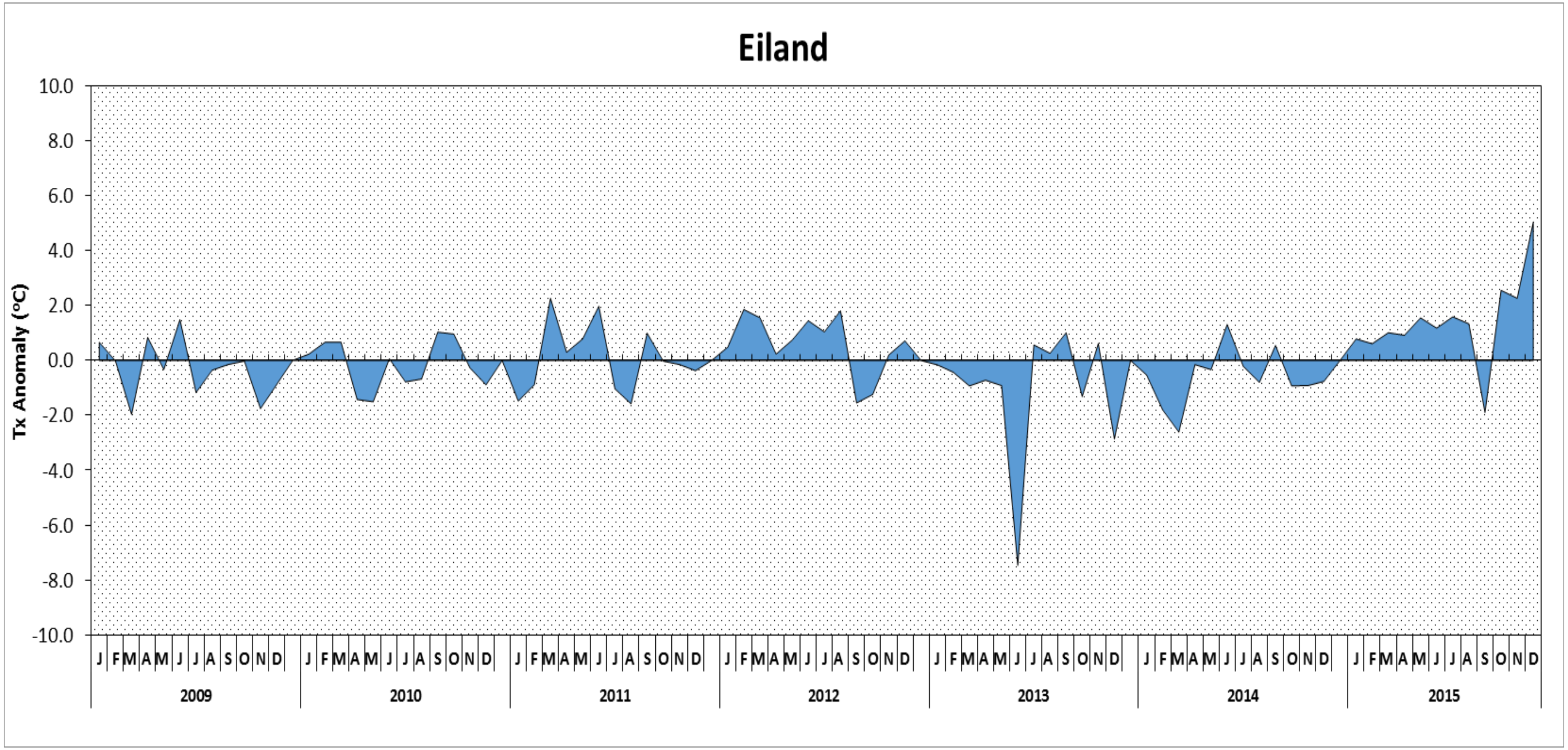


Figure 7.9: Maximum temperature (^OC) anomaly at Eiland as compared to long-term average monthly temperature.

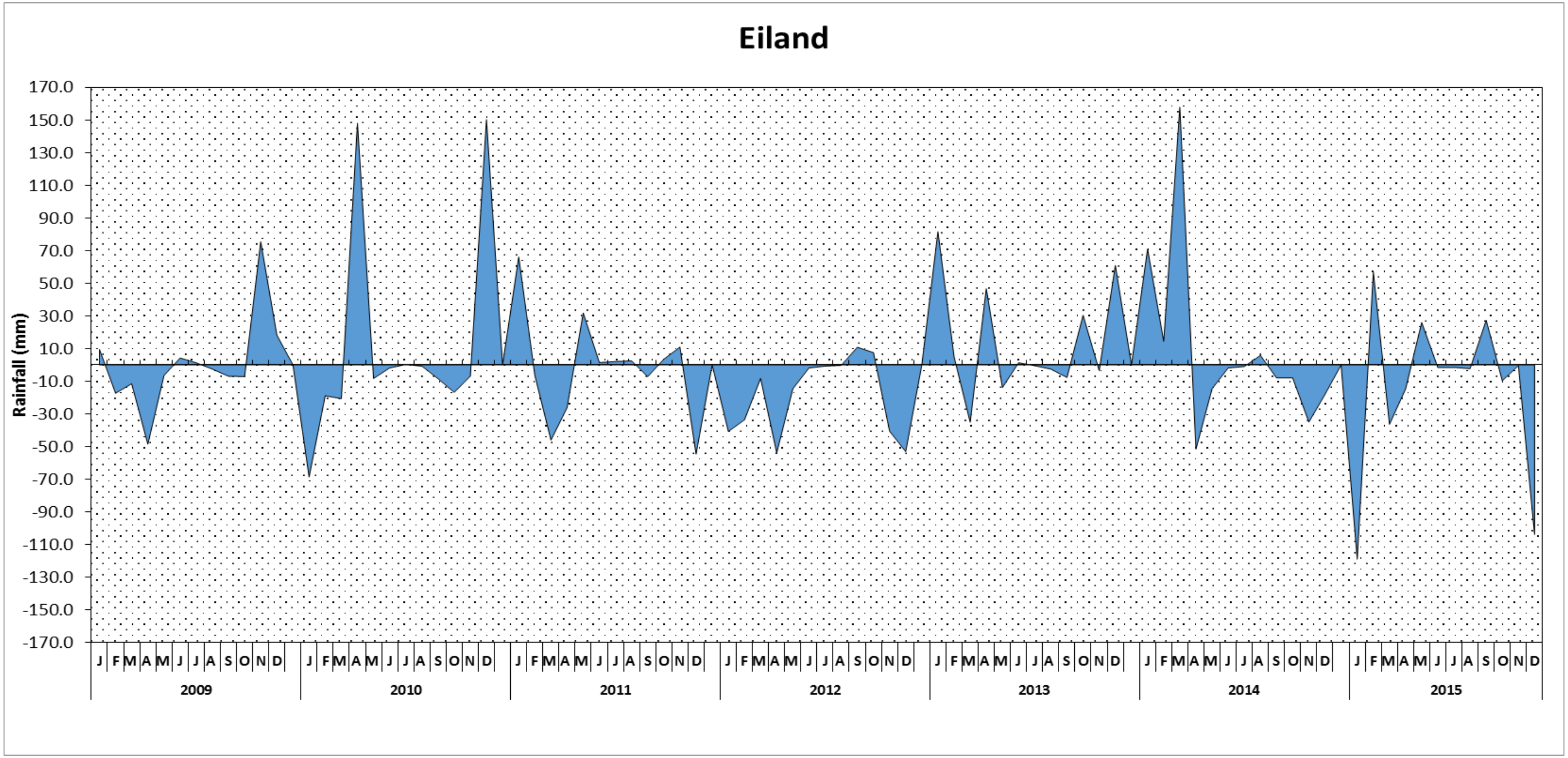


Figure 7.10: Rainfall (mm) anomaly at Eiland as compared to long-term average rainfall from 2009 to 2015.

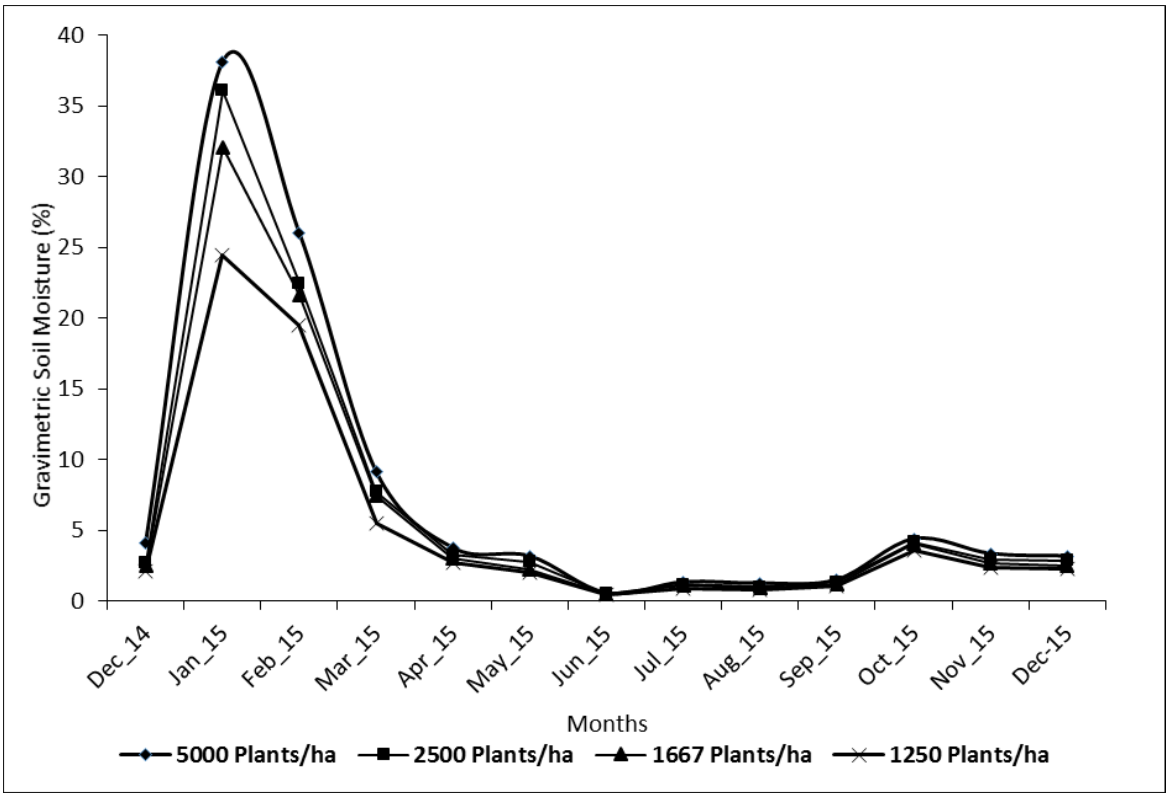


Figure 7.11: Monthly gravimetric soil moisture content recorded for different planting densities.

Table 7.1: Initial soil physical and chemical properties prior to planting.

Soil Depth (cm)	Soil properties									
	P (mg/L)	K (mg/L)	Ca (mg/L)	Mg (mg/L)	pH (KCl)	Zn (mg/L)	Mn (mg/L)	Cu (mg/L)	Org C (%)	N (%)
0-30	23	184.5	1821	580	5.7	5.9	11.5	5.9	1.3	0.08
30-60	10.5	107.5	2177	675.5	5.5	2.5	13	5.8	1.3	0.08

The soil nutrient ion concentrations after the first and second harvests are indicated in Tables 7.2 and 7.3. Significant differences in potassium and calcium concentrations in terms of nutrients utilization by moringa plants were evident under varying densities. All other measured nutrient ion concentrations were not significantly affected by planting density except for manganese at 30-60 cm depth during the first harvest.

The results showed an increase in calcium, magnesium, pH and manganese during harvest 1. During harvest 2 there was an increase in phosphorus as compared to harvest 1, while increases in calcium, pH, and manganese during the second harvest were also observed. The increases were mainly observed from plants established at a higher density at both depths of 0 to 30 and 30 to 60 cm. Some of the properties such as potassium were mainly affected at the surface soils as compared to deeper soil profile. The densities further showed great variability with the population of 5000 plants/ha showing higher nutrient recycling.

Soil nutrients such as phosphorus, potassium, zinc, copper, organic carbon and nitrogen were reduced after the first harvest. However, during the second harvest, the same soil nutrients followed the same reduction trend as observed in the first harvest except for phosphorus which showed increased levels as compared to initial soil sampling at the second harvest (Tables 7.2 and 7.3). In many cases, moringa utilized more soil nutrients to enhance growth. However, some nutrients such as P, Ca, and Mn were recycled by showing an increase in the soil nutrient content (Tables 7.2 and 7.3).

7.3.3 Effect of planting density on biomass production

The effect of total biomass and leaf yield were significantly affected by planting density in both harvests (Table 7.4). During harvests 1 and 2, the increase in planting density resulted in increased biomass production. Total dry biomass accumulation was higher during the second harvest while the leaf biomass was drastically reduced to less than 255 kgha^{-1} (Table 7.4). Plants grown under the highest planting density produced higher total biomass yield of more than 1.6 tons ha^{-1} as compared to the other planting densities. During harvest 1 the yield was slightly lower at about 1.2 tons ha^{-1}.

7.3.4 Effect of planting density on seed and oil yield

Planting densities significantly influenced total seed yield (pods + seeds), seed yield and oil yield of moringa in both years. The increase in both seed and oil yields followed the same trend with the increase in planting density (Table 7.4). Harvest 1 had lower total seed yield of fewer than 800 kgha^{-1} while in harvest 2, the total seed yield was just above 1 tonha^{-1} at a higher population density of 50000 plants ha^{-1}. Seed yield ranged between 157.60 and 435.53 kgha^{-1} in both harvests. The highest seed yield was again observed at the higher planting density during harvest 2. The increase in seed yield led to an increase in oil yield at the highest population density, giving the highest oil yield of up to 12 279.00 kgha^{-1} of oil (Table 7.4).

Table 7.2: Soil physical and chemical properties after harvest 1 during 2015 season.

Soil Depth (cm)	Plant density (Plantha^{-1})	P (mg/L)	K (mg/L)	Ca (mg/L)	Mg (mg/L)	pH (KCl)	Zn (mg/L)	Mn (mg/L)	Cu (mg/L)	Org C (%)	N (%)
0-30	5000	17.5^{a}	96.2^{b}	2741.3^{a}	610.7^{a}	6.3^{a}	2.0^{a}	26.5^{a}	5.4^{a}	0.9^{a}	0.06^{a}
	2500	12.2^{a}	90.0^{b}	2436.7^{ab}	593.5^{a}	5.8^{a}	1.6^{a}	22.5^{a}	4.6^{a}	0.7^{a}	0.05^{a}
	1667	21.7^{a}	134.2^{a}	1903.1^{b}	534.0^{a}	6.3^{a}	2.5^{a}	24.7^{a}	6.0^{a}	0.6^{a}	0.05^{a}
	1250	15.3^{a}	104.5^{b}	1887.5^{b}	581.0^{a}	6.2^{a}	2.4^{a}	23.5^{a}	5.2^{a}	0.8^{a}	0.04^{a}
	P value	0.34	0.01	0.00	0.09	0.88	0.30	0.22	0.34	0.08	0.51
	CV%	62.5	25.5	23.8	16.9	22.4	44.9	31.6	28.4	44.6	43.8
	Significance (0.05)	ns	**	**	ns	ns	ns	ns	ns	ns	ns
30-60	5000	18.7^{a}	101.5^{a}	3102.5^{a}	520.5^{a}	6.7^{a}	2.3^{a}	19.0^{b}	4.8^{a}	0.6^{a}	0.03^{a}
	2500	18.3^{a}	110.5^{ab}	1683.8^{b}	505.3^{a}	6.1^{a}	1.4^{a}	33.2^{a}	4.6^{a}	0.6^{a}	0.04^{a}
	1667	18.5^{a}	98.50^{b}	2066.5^{b}	512.8^{a}	5.8^{a}	2.3^{a}	18.2^{b}	4.6^{a}	0.6^{a}	0.04^{a}
	1250	18.5^{a}	135.1^{a}	1829.3^{b}	486.0^{a}	6.1^{a}	1.4^{a}	23.2^{b}	4.1^{a}	0.6^{a}	0.04^{a}
	P value	0.26	0.05	0.00	0.06	0.53	0.26	0.00	0.79	0.94	0.88
	CV%	104.2	25.3	26.8	26.5	20.8	64.6	32.0	33.3	28.8	61.8
	Significance (0.05)	ns	*	**	ns	ns	ns	**	ns	ns	ns

Table 7.3: Soil physical and chemical properties after harvest 2 during 2016 season.

Soil Depth (cm)	**Plant density (Plantha^{-1})**	**P (mg/L)**	**K (mg/L)**	**Ca (mg/L)**	**Mg (mg/L)**	**pH (KCl)**	**Zn (mg/L)**	**Mn (mg/L)**	**Cu (mg/L)**	**Org C (%)**	**N (%)**
0-30	5000	24.2^{b}	125.0^{b}	2078.0^{a}	503.5^{a}	6.7^{a}	2.0^{a}	21.7^{a}	4.8^{a}	0.8^{a}	0.04^{a}
	2500	24.0^{b}	100.2^{b}	1452.0^{a}	482.0^{a}	6.6^{a}	2.5^{a}	19.5^{a}	5.0^{a}	0.6^{a}	0.04^{a}
	1667	40.5^{b}	160.7^{a}	1903.8^{a}	480.2^{a}	6.9^{a}	2.8^{a}	20.0^{a}	4.6^{a}	0.8^{a}	0.04^{a}
	1250	61.5^{a}	165.1^{a}	1652.0^{a}	374.0^{a}	7.0^{a}	3.3^{a}	19.0^{a}	4.3^{a}	0.6^{a}	0.04^{a}
	P value	0.00	0.00	0.21	0.16	0.86	0.53	0.83	0.64	0.45	0.86
	CV%	50.6	17.9	34.6	26.2	15.4	62.0	31.3	23.5	45.2	51.4
	Significance (0.05)	**	**	ns	ns	ns	ns	ns	ns	ns	ns
30-60	5000	19.7^{b}	132.7^{a}	2072.5^{a}	456.0^{a}	6.5^{a}	1.9^{a}	22.3^{a}	4.7^{a}	0.7^{a}	0.03^{a}
	2500	13.7^{b}	83.2^{b}	1636.0^{a}	427.7^{a}	6.1^{a}	1.8^{a}	30.0^{a}	4.7^{a}	0.7^{a}	0.04^{a}
	1667	36.7^{a}	142.5^{a}	1959.5^{a}	419.0^{a}	6.6^{a}	2.3^{a}	24.5^{a}	4.7^{a}	0.9^{a}	0.04^{a}
	1250	41.5^{a}	163.7^{a}	1620.0^{a}	409.5^{a}	6.7^{a}	2.5^{a}	27.2^{a}	4.1^{a}	0.7^{a}	0.04^{a}
	P value	0.00	0.00	0.43	0.44	0.64	0.06	0.12	0.42	0.58	0.92
	CV%	32.7	27.2	36.4	28.8	16.9	51.3	24.7	19.6	51.0	51.9
	Significance (0.05)	**	**	ns	ns	ns	ns	ns	ns	ns	ns

7.3.5 Effect of planting density on oil percentage

Planting densities of moringa did not influence seed oil concentration (Table 7.4). The oil percentage ranged from 25.5 to 28.15 at all densities during harvests 1 and 2.

Table 7.4: Biomass, seed and oil yield and oil % (kg/ha) production of moringa under different densities at Nbef organics during 1st and 2nd harvests.

Year of Harvest	Density (Plants ha^{-1})	Dry leaf yield (kg ha^{-1})	Total Dry Biomass yield (kg ha^{-1})	Total Grain Yield (kg ha^{-1})	Seed Yield (kg ha^{-1})	Oil Yield (kg ha^{-1})	Oil %
1st Harvest (2015)	5000	447.91^{a}	1250.6^{a}	787.83^{a}	290.35^{a}	7550.9^{a}	26.05^{a}
	2500	338.80^{b}	1006.6^{ab}	646.61^{a}	238.30^{b}	6365.9^{b}	26.67^{a}
	1667	263.13b^{c}	805.2^{bc}	472.24^{b}	191.42^{c}	4843.0^{c}	25.55^{a}
	1250	205.33^{c}	647.3^{c}	268.63^{c}	157.60^{d}	4184.0^{c}	26.57^{a}
	P value	0.000	0.001	0.000	0.000	0.000	0.33
	CV%	23.79	28.18	25.15	10.62	12.04	5.15
	Significance (0.05)	**	**	**	**	**	ns
2nd Harvest (2016)	5000	252.31^{a}	1658.4^{a}	1253.0^{a}	435.53^{a}	12279^{a}	28.15^{a}
	2500	223.81^{a}	1218.9^{b}	932.3^{b}	316.89^{b}	8701^{b}	27.45^{a}
	1667	209.16^{ab}	1065.3^{bc}	930.7^{b}	291.99^{b}	7998^{b}	27.25^{a}
	1250	160.06^{b}	889.8^{c}	602.3^{c}	217.93^{c}	5999^{c}	27.57^{a}
	P value	0.012	0.000	0.000	0.000	0.000	0.47
	CV%	24.00	23.72	16.64	18.43	19.78	4.26
	Significance (0.05)	**	**	**	**	**	ns

7.3.6 Effect of planting density on yield components of moringa

The yield components of moringa under different densities are presented in Table 7.5. The results showed no significant differences on pod circumference, number of seeds per pod and 100 seed weight during harvest 1. During harvest 2, pod circumference and number of seeds per pod did not respond to planting density, whereas 100 seed weight was significantly influenced by planting density ($P<0.05$) (Table 7.5). One hundred seed weight was less during harvest 2 ranging between 18.56 and 22.93 g, while during harvest 1 the 100 seed weight ranged between 23.52 and 26.07 g (Table 7.5).

Table 7.5: Yield components of moringa under different densities at Nbef Organics during 1st and 2nd harvests

Year of Harvest	Density (Plants ha^{-1})	Pod circumference (mm)	# of seeds/pod	100 seed weight (g)
1st Harvest (2015)	5000	16.47^{a}	15.75^{a}	23.54^{a}
	2500	16.20^{a}	13.87^{a}	23.52^{a}
	1667	16.82^{a}	14.75^{a}	24.99^{a}
	1250	17.95^{a}	15.50^{a}	26.07^{a}
	P value	0.41	0.29	0.29
	CV%	12.85	13.88	12.43
	Significance (0.05)	ns	ns	ns
2nd Harvest (2016)	5000	16.80^{a}	12.50^{a}	18.56^{b}
	2500	17.76^{a}	12.12^{a}	21.56a^{b}
	1667	17.59^{a}	12.37^{a}	22.93^{a}
	1250	17.35^{a}	13.62^{a}	20.56^{ab}
	P value	0.78	0.77	0.05
	CV%	11.54	24.18	14.53
	Significance (0.05)	ns	ns	*

7.3.7 Pearson's correlation between moringa seed yield and other yield components

Correlation coefficients of *Moringa oleifera* yield parameters measured during the first year are shown in Table 7.6. Positive and highly significant relationships were found between seed yield and dry leaves (0.558***), total dry biomass (0.604***) and oil yield (0.987***). Dry leaves were also found to significantly correlate with total dry biomass (0.804***) and oil yield (0.590***). Similarly, total dry biomass significantly correlated with oil yield (0.615***). The relationships between seed yield and oil %, pod circumference, number of seed per pod and 100 seed weight were not significant.

The results presented in Table 7.7 show the correlations among *Moringa oleifera* yield parameters collected during year 2. The results revealed that there were significant positive correlations between seed yield and dry leaves (0.363***), total dry biomass (0.414***) and oil yield (0.995***). Dry leaves significantly correlated with total dry biomass (0.704**) and oil yield (0.356*), while a negative correlation between dry leaves and number of seeds per pod (-0.376*) was observed. Oil yield and oil percentage were significantly correlated but with a weak relationship of 0.364*. Similar to harvest 1, the relationship between seed yield and oil percentage, pod circumference, number of seed per pod and 100 seed weight were not significant.

Table 7.6: Pearson's correlation coefficients of *Moringa oleifera* yield parameters during 1st harvest.

Yield Parameters	Seed Yield (kg)	Dry Leaves (kg)	Total dry biomass (kg)	Oil (%)	Oil yield (kg)	Pod circumference (mm)	# of seed/pod	100 seed weight (g)
Dry Leaves	0.558***							
Total dry biomass	0.604***	0.804***						
Oil%	-0.1636	0.139	-0.001					
Oil yield	0.987***	0.590***	0.615***	-0.012				
Pod circumference	-0.158	0.102	0.1710	-0.146	-0.187			
# of seed/pod	0.047	-0.012	-0.120	-0.048	0.033	0.373		
100 seed weight	-0.212	-0.230	-0.156	0.170	-0.181	-0.073	-0.189	

Correlation Significance levels: *P<0.05; **P<0.01; ***P<0.001

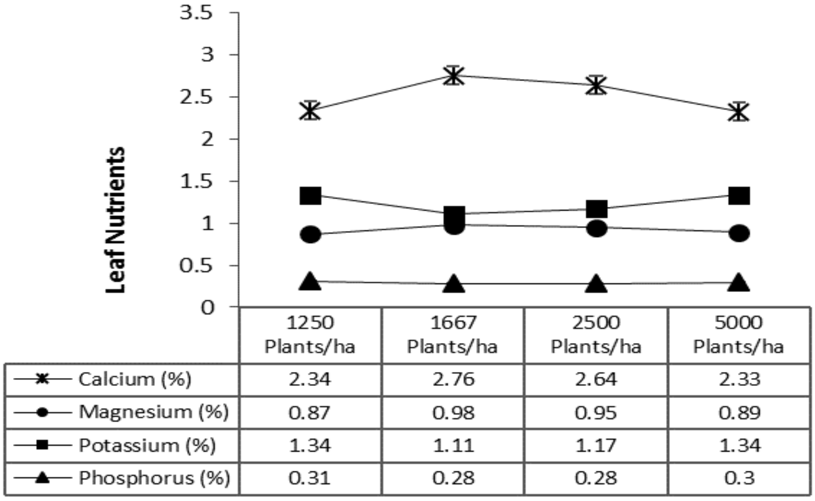
Table 7.7: Pearson's correlation coefficients of *Moringa oleifera* yield parameters during the 2nd harvest.

Yield Parameters	Seed Yield (kg)	Dry Leaves (kg)	Total dry biomass (kg)	Oil (%)	Oil yield (kg)	Pod circumference (mm)	# of seed/pod	100 seed weight (g)
Dry Leaves	0.363*							
Total dry biomass	0.414**	0.704***						
Oil%	0.277	0.051	0.244					
Oil yield	0.995***	0.356*	0.429**	0.364*				
Pod circumference	-0.138	0.1260	-0.102	-0.127	-0.144			
# of seed/pod	-0.014	-0.376*	-0.230	-0.019	-0.008	-0.0100		
100 seed weight	-0.138	0.091	-0.124	-0.143	-0.147	0.495**	0.030	

Correlation Significance levels: *P<0.05; **P<0.01; ***P<0.001

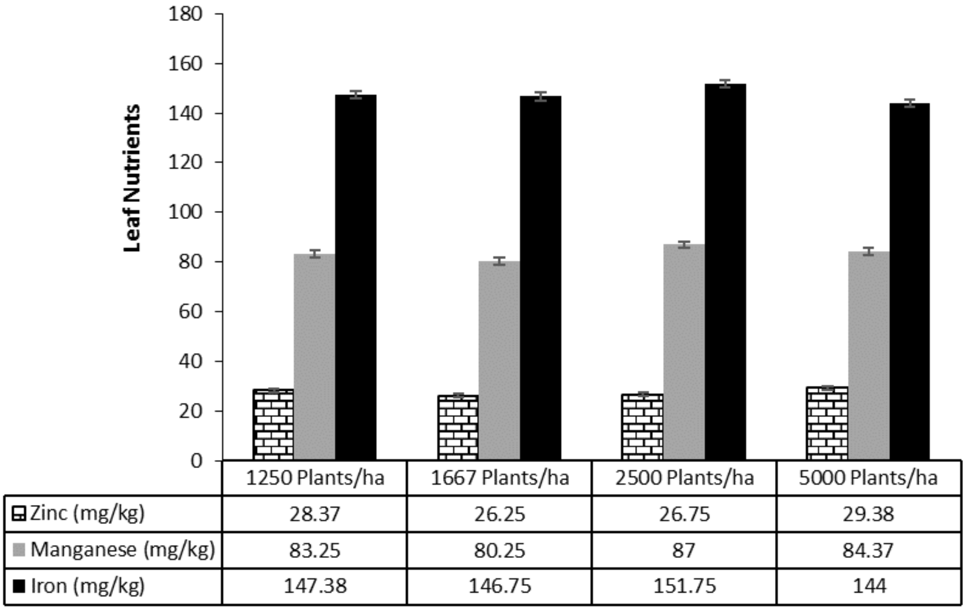
7.3.8 Nutritional composition of moringa leaves under different planting population

The data collected on the nutritional composition of *Moringa oleifera* as influenced by planting densities are indicated in Figures 7.12, 7.13 and 7.14. No significant differences were found between planting densities and nutritional composition as well as for protein content of the crop. Only zinc concentration was found to be significant ($P<0.05$), with high planting density having a high zinc level of 29.4 mg/kg. The protein content was found to be satisfactory at a value above 33 percent (Figure 7.14).



	1250 Plants/ha	1667 Plants/ha	2500 Plants/ha	5000 Plants/ha
—✱— Calcium (%)	2.34	2.76	2.64	2.33
—●— Magnesium (%)	0.87	0.98	0.95	0.89
—■— Potassium (%)	1.34	1.11	1.17	1.34
—▲— Phosphorus (%)	0.31	0.28	0.28	0.3

Figure 7.12: Some mineral composition of *Moringa oleifera* at different planting densities.



	1250 Plants/ha	1667 Plants/ha	2500 Plants/ha	5000 Plants/ha
▦ Zinc (mg/kg)	28.37	26.25	26.75	29.38
■ Manganese (mg/kg)	83.25	80.25	87	84.37
■ Iron (mg/kg)	147.38	146.75	151.75	144

Figure 7.13: Zinc, manganese, and iron (mg/kg) composition of *Moringa oleifera* at different planting densities.

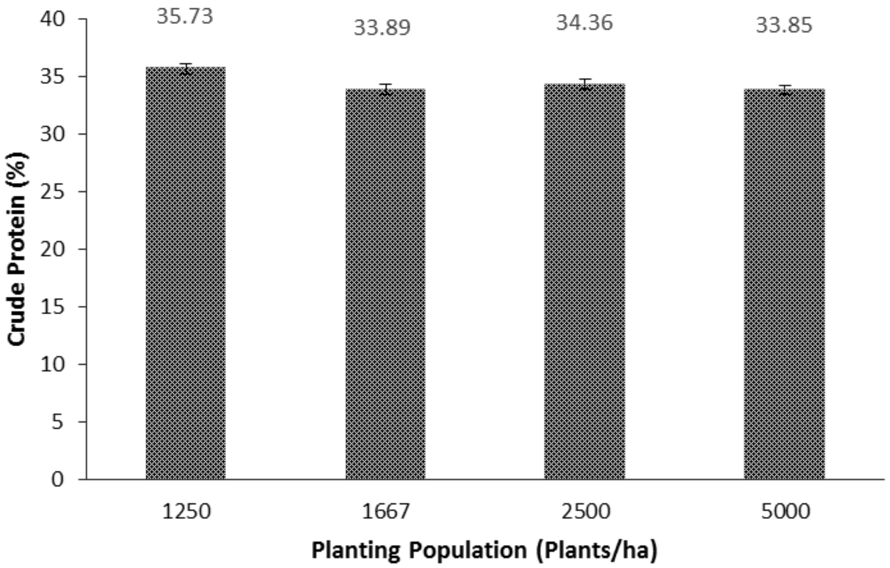


Figure 7.14: Protein content of *Moringa oleifera* at different planting densities.

7.4 Discussion

7.4.1 Weather parameters

Results from this study showed that moringa is sensitive to prevailing frost conditions and care must be taken when selecting sites for increasing production of the plant. Such as occurred at the Syferkuil location in this study, the drop in temperatures to 2 °C around June and July resulted in chilling injury and leaf drop during winter months. Moringa can, however, survive slight frost conditions (Muhl, *et al*., 2011) during vegetative growth but severe frost is generally detrimental to the plant. Therefore, farmers who are targeting seed yield production should avoid production areas in which frost prevails. A study by Muhl *et al*. (2011) reported that higher growing temperatures of above 25°C favour growth of moringa while lower temperatures below 15°C lead to thickening of the leaves due to cold temperature stress resulting into reduced growth. Furthermore, Amaglo *et al*. (2006) reported that the moringa tree grows best in the temperature range from 25 to 35°C although it can tolerate excess temperatures of up to 48°C.

7.4.2 Effect of moringa planting density on soil nutritional properties

The study showed that maintaining adequate soil nutrients is an important management consideration in moringa growth and development due to the observed reduction in some of the soil nutrients during the study. Moringa was established under rainfed condition and with the addition of 1.5 ton/ha of compost to the field which might not have been adequate for full growth and development of the plant. A study by Lamb *et al*. (2014) showed that loss of nutrients from the soil system could be greatly affected by soil type and climate of the area.

Soil nutrients can be lost in many forms, such as through leaching, crop removal or soil erosion and runoff. From this study, it was observed that nutrient loss was through biomass removal since moringa is a fast growing crop. Looking at the number of nutrients available in the leaves as indicated in Figures 7.12 to 7.14, it is evident that moringa requires enough soil nutrients in order to accumulate enough nutrients that are available in the leaves, except K and P which showed to be recycled even without the further addition of nutrients in the soil.

In 2014, the production site received higher rainfall which might have contributed to rapid decomposition of fallen leaves on the ground thereby enhancing nutrients cycling in the soil. Hence, there was an increase in calcium, magnesium, manganese, and pH during the first harvest at the depth of 0-30 cm. During the second harvest, phosphorus and manganese were relatively higher compared to the results from the initial soil test (Tables 7.1, 7.2 and 7.3). Several studies have reported that moringa can survive harsh conditions including less fertile soils (Amaglo, 2006; Ashfaq *et al*., 2012; Elayaraja, *et al*., 2017). This study proved that indeed moringa can survive harsh conditions such as that prevailing in Limpopo province. However, the crop can perform better if adequate soil fertility and soil moisture could be maintained during growth. It was observed that production of moringa under drought in low rainfall conditions could negatively affect the soil fertility status.

Warm temperatures which are accompanied by low precipitation have an impact on soil organic carbon (USDA-NRCS, 2009). Warm temperatures decrease the soil organic carbon by increasing the microbial activities and decomposition rate whilst high mean annual rainfall increases accumulation by stimulating the production of organic matter and associated organic carbon (USDA-NRCS, 2009). This was evident in this study whereby low rainfall was experienced together with high temperatures which might have affected the microbial activities hence reduced or negatively affected the soil chemical properties, mainly nitrogen and soil organic carbon.

The study site received a total annual rainfall of 619.74 mm and 329.14 mm during the years 2014 and 2015, respectively as indicated in Figure 7.5. The influence of moisture on the soil chemical properties was evident in both years. A study by Lee *et al*. (2009) showed that soil organic carbon plays a major role in crop production since it improves physical and chemical properties of the soil through the increase in cation exchange capacity. That study further showed that continuous application of compost increased soil organic carbon which contributed towards improved soil physical conditions such as bulk density, porosity, and aggregate stability while no fertilizer application can negatively affect soil organic carbon and result into deteriorating physical properties (Lee *et al*., 2009; Singh *et al*., 2012).

7.4.3 Effect of planting density on biomass production

The effect of planting density on biomass was evident during the second harvest whereby higher planting density of 5000 plants ha^{-1} produced the highest total dry biomass yield of 1658.4 kg ha^{-1}. The lower densities produced lower biomass yield in both harvests 1 and 2. The effect of planting density on biomass production which is in agreement with this study has been reported by several authors. In a study that was conducted with a population of 95 000, 350 000, 900000, 1000 000, 4000 000 and 16 000 000 plants ha^{-1}, the respective total dry matter production of 3.33, 5.05, 8.94, 13.26, 16.56 and 44.03 tons ha^{-1} were reported (Foidl *et al*., 2001). Basra *et al*. (2015) reported total dry matter yield of 1.10 and 1.12 tons ha^{-1} at a spacing of 15 x 30 cm during harvest 1 and 2 in 2009 and 2010, whereas at the spacing of 15 x 60 cm, the total dry biomass was 0.9 and 1.01 tha^{-1} during the 1st and 2nd harvests, respectively. However, in another study, Sánchez *et al*. (2006), reported a total dry matter yield of 17.6, 16.9 and 18.9 tonsha^{-1} during the year 2002 while the yield for the year 2003 was reported to be 7.6, 8.1 and 6.2 tons ha^{-1} at planting densities of 250 000, 500 000 and 750 000 plants ha^{-1}, respectively. Furthermore, the effect of planting density on biomass production was reported by Abdullahi *et al*. (2013), where an increase in planting density led to an increase in dry matter yield. A similar finding was observed in this study.

Rainfall and temperature, as well as soil nutrients, played a significant role on biomass production of the moringa plant. It was observed that leaf yield was low in harvest 2 or year 2 as compared to year 1. This might have been due to low rainfall accompanied by high temperatures during the second harvest which affected leaf production of moringa. A study by Zheng *et al.* (2016), reported similar findings by indicating that, dry or low rainfall conditions resulted in stunted growth and led to lower biomass production of less than 1 ton ha^{-1}, whereas during the time when the rainfall was higher the total biomass was also reported to be higher at about 3.1 tons ha^{-1}. Furthermore, similar findings were reported on total dry biomass, whereby all planting densities produced highest yields in year two as compared to year 1 (Zheng, 2016).

Dry leaf yield was higher during harvest 1 at all densities compared to harvest 2. This might be due to the drought that was experienced during 2015 as evidenced by rainfall anomalies (Fig. 7.10) and low gravimetric soil moisture content from Eiland. It was observed that in January 2015, the rainfall was far below average by almost -110 mm (Figure 7.10), which might have affected the leaf growth of moringa crop. Zheng *et al*. (2016) and Sánchez *et al*. (2006) showed that biomass production of moringa is greatly influenced by the amount of rainfall, particularly during the dry seasons. Sánchez *et al*. (2006) reported that harvesting in months followed by dry or low rainfall conditions resulted in stunted regrowth and lower total DM yield. However, when plants are allowed to grow during the rainy season and are harvested in the wet season or the start of the dry season they gave higher total DM yield. It was observed from the current study that the rainfall received after the first harvest influenced the vegetative growth and the reproductive stage of moringa, leading to an increase in total dry biomass yield as compared to leaf yield. Eiland experienced extreme drought from December 2015 at the podding stage of moringa was already having pods that were at the physiological maturity and leaves were also available for photosynthesis but were reduced due to high temperature and drought, hence the seed yield was higher with reduced biomass yield. Price (1985) reported that one of the strategies that moringa uses to avoid drought is to lose some of its leaves and this was evident from this study.

Although leaf yield was low while the total biomass yield was higher in the second harvest, this might be positively influenced by ratooning that enhanced branching after the first harvest. Similar findings were reported where tillering density and forage yields were generally influenced by shorter cutting heights maintained at harvesting (Zheng *et al.*, 2016). Their results further suggested that the cutting height of moringa is dependent on the degree of rainfall and that lower cutting height could be recommended in low rainfall areas in order to obtain the highest potential biomass yield.

7.4.4 Effect of planting density on seed and oil yield

No studies are available in South Africa on moringa seed yield production in response to planting density which can be used to compare the findings of this study. However, other countries had few studies on the effect of planting density on seed and oil yield production of moringa. One such example is the study conducted by Ayerza (2012) in the Arid Chaco of southern America which is characterized by low rainfall of less than 400 mm/annum and an average temperature of approximately 15 ^{o}C. The study was conducted for two years at a planting population of 1666 plants ha^{-1}. The seed yield differed between the two years producing amount of 243.49 and 926.50 kg ha^{-1} in year 1 and 2, respectively. Relating to the current study, the observed increase in seed yield during harvest 2 might have been influenced by pruning after the first harvest. It was observed that pruning of moringa encouraged the lateral development of branches and increases the canopy size resulting in a larger photosynthetic capacity. In 2014, Eiland received more rainfall of 619.74 mm/annum and its distribution also increased after the first harvest in early 2015 which encouraged the shoot development of moringa crop. A major drought was experienced after the physiological maturity stage in late 2015 when moringa had already produced the seeds, hence drought had less effect on seed yield production.

Ayerza (2011) reported that total rainfall has an influence on seed yield and might also lead to the shorter growing season. This was experienced from the current study where moringa had to grow very fast to avoid drought and hence was harvested in less than 12 months. From a study that was conducted using a spacing of 1 x 1 m in an area receiving a rainfall of over 1000 mm per annum, the seed average yield was 3.44, 3.51 and 3.64 tons ha^{-1} during 2007, 2008 and 2009 harvest. The ambient temperatures were also conducive to moringa growth with mean annual ranging between 22 and 27 °C (Ndubuaku *et al*., 2014). Compared to this study, the results of that study shows higher seed yields with higher plant densities and higher rainfall.

7.4.5 Effect of planting density on seed oil percentage

Other studies concur with findings from this study whereby the concentration of oil in the seed was not significantly affected by planting density. Ayerza (2012) reported no significant oil% from 1 and 2 year old trees planted at a population density of 1666 plants ha^{-1}. The oil results were 37.46% in year 1 and 36.28% in year 2 at Arid Chaco which received a precipitation of 327.0 and 199 mm/annum during years 1 and 2 respectively with an average temperature of 15°C in both years.

Oil percentage of moringa in the current study was relatively low as compared to other studies. Ayerza (2012) reported that oil percentage can be affected by diverse environmental and climatic factors such as temperature, light, soil type and available soil nutrients. This can explain the low oil% from the results of the current study since no fertilizer nor irrigation was applied and this might have led to low oil percentage of moringa in both harvests. The study that was conducted by Anwar *et al*. (2006), revealed moringa seed oil percentage of 30.36 and 38.37% under drought and irrigated conditions, respectively. High oil content of 38.3% was also reported by Lalas and Tsaknis (2002). The main factor that might be considered as a most visible factor to affect some parameters of *Moringa oleifera* oil content mainly the oil percentage is moisture content (Anwar *et al.,* 2006).

7.4.6 Effect of planting density on yield components of moringa

Little information is available on yield components of moringa. The number of seed per pod ranging between 12 and 16 in this study were also similar to findings by Ayerza (2011) with 15-16 seeds per pod. Rainfall had an impact on 100 seed weight of moringa which is the major determinant of seed yield. Similar findings were reported by Ayerza (2011), whereby rainfall influenced 200 seed weight. The findings showed that 200 seed weight of moringa was 59.0 and 50.4 g in 2003 and 2004 respectively. The study indicated that drought decreased seed weight. The drought that was experienced in late 2015 might have influenced individual seed weight.

7.4.7 Pearson’s correlations between moringa seed yield and other yield components

It was observed that dry leaf biomass correlated weakly with seed yield and oil yield (0.363 and 0.364, respectively) during year 2. This might be due to low leaf biomass that was harvested during harvest 2 as a result of drought effect. During harvest 2, more yield parameters were significantly correlated and this might have been influenced by pruning at harvest 1 which induced shoot development and lead to more canopy as compared to harvest 1. However, the majority of the correlations had weak to moderate relationships due to the negative climatic effect on the crop. Yücel (2004) reported that unsuitable weather conditions led to a decrease in some *Vicia narbonensis* parameters such as plant height, number of seeds per plant and harvest index. No correlation studies are available on moringa for other yield parameters.

7.4.8 Nutritional composition of moringa leaves under different planting population

Findings from this study showing the effect of planting density on the nutritional composition of *Moringa oleifera* leaves due to plant densities are in agreement with findings by Sánchez *et al*. (2006) and Mendieta-Araica *et al*. (2013). The authors reported that the CP contents did not differ among planting densities. Zheng *et al*. (2016), on the other hand, reported that the crude protein of moringa consistently increased as the planting density increased during the rainy season. However, the effect was not significant during the dry season. The significant crude protein was 26.8, 24.7 and 23.5 at a density of 20 x 20, 40 x 40 and 80 x 80 cm, respectively during the rainy season.

Basra *et al*. (2015) reported contradictory results on leaf phosphorus and calcium concentration during year one, where the nutrients were significantly influenced by plant density. However, in year 2, phosphorus, potassium and calcium were not significantly affected by planting density. In year 1, higher planting density with a spacing of 15 x 30 cm, led to higher leaf phosphorus (3.28%) and potassium (7.59%) contents, as compared to lower density at a spacing of 15 x 60 cm with phosphorus and potassium contents of 1.57% and 6.66%, respectively. The non-significant effect on chemical composition of foliage was expected especially when the differences in planting density are not high enough to create competition demand for plant nutrient ions (Mendieta-Araica *et al*., 2013). Under circumstances where leaf nutrients are affected, factors such as agro-climatic conditions, soil type, fertilization, the age of the tree, could contribute to some of the differences (Sánchez *et al*., 2006).

The average nutritional compositions recorded in this study were relatively higher compared to other studies. The mean nutritional composition of *Moringa oleifera* leaves recorded the following: calcium (2.52%), magnesium (0.93%), potassium (1.24%), phosphorus (0.3%), zinc (27.69 mg/kg), manganese (83.72 mg/kg), iron (147.47 mg/kg) and protein (34.46%). Moringa had a slightly higher nutritional composition as compared with other studies. Basra *et al*. (2015) reported an average calcium content of 2.09%. Zheng *et al.* (2016), Sánchez *et al*. (2006), Mendieta-Araica *et al*. (2013) and Moyo *et al*. (2011), reported mean protein content of moringa leaf powder at 23.00, 21.34, 27.50 and 30.29%, respectively.

A study conducted by Asante *et al*. (2014), in the semi-deciduous forest and guinea savanna regions of Ghana reported the following levels of nutrients from moringa leaf powder; potassium (0.12 and 0.10%), calcium (0.19 and 0.15%) and iron (26.83 and 25.04 mg/kg). Anjorin *et al*. (2010) reported low magnesium content of 0.80%, while calcium was 3.46%. Higher mineral contents as compared to the current study were reported by Moyo *et al*. (2011), who found that the calcium, potassium, zinc, manganese, and iron had a value of 3.65 %, 1.50 %, 31.03 mg/kg, 86.8 mg/kg and 490.0 mg/kg, respectively. Moyo *et al*. (2011) conducted the study at Sedikong sa Lerato in Tooseng Village, Ga-Mphahlele in the Limpopo Province of South Africa and concluded that dried moringa leaves can assist in concentrating the nutrients through the powder for consumption since the powder can be transported to other areas where environmental conditions do not favour the cultivation of the tree.

7.5 Conclusion

This study indicates that moringa can be produced successfully in the Limpopo Province of South Africa. Furthermore, the study showed that management practices should be taken into consideration if the higher yield is targeted. A population of 5000 plants ha^{-1} produced the highest biomass and seed yield of moringa whereas

the lowest was obtained at a density of 1250 plants ha^{-1}. The results from the study further suggested that environmental and climatic conditions such as soil fertility, soil moisture, extremely high or low temperatures could have a negative impact on growth and yield of moringa crop. It is recommended that further studies should be conducted under irrigation and fertilizer application in order to improve yield. Drought also played a significant role in assessing the correlation of moringa parameters in season 2 as evidenced by observed weak and moderate relationships.
This study proved that ratooning is important in moringa since it stimulated new shoot development leading to the bigger canopy and increased yield under both favourable and unfavourable environmental conditions.

Due to its high nutritional content, moringa can serve as a potential tree in combating malnutrition and food insecurity (through leaf powder or juice consumption and sale) in developing countries. With low inputs demand, moringa can easily be cultivated in marginal rainfall areas and by small holder farmers who are interested in leaf production. This study revealed that moringa contains a high level of leaf nutrients even under marginal production areas irrespective of the planting density. This gives moringa an added advantage to be a valuable crop to be produced by smallholder farmers and also by any community in their backyard to sustain food security and serve as a good source of food supplement for the human body. These low population densities are important as they also facilitate intercropping with food crops. Higher populations of moringa can only be considered where the tree is grown in pure stands, and where rainfall is relatively high.

If management practices can be improved, moringa can give even more nutrients as compared to the current results which were satisfactory though the trees were produced without inputs such as fertilizer and irrigation. Further studies on *Moringa oleifera* are recommended for multiple locations and improved management practices for leaf and seed biomass production as well as seed oil concentration enhancement.

CHAPTER 8

MORINGA OLEIFERA LEAF NUTRITIONAL COMPOSITION AS INFLUENCED BY SOIL PHYSICAL AND CHEMICAL PROPERTIES AND TREE AGE UNDER DIVERSE AGRO-ECOLOGICAL CONDITIONS

ABSTRACT

Moringa oleifera is a multipurpose tree cultivated all over the world mainly for medicinal use, water purification, climate change mitigation and to some extent, improving soil fertility as well as life sustenance against food insecurity threats due to its enormous nutrients content. A study was carried out in the five districts of the Limpopo Province to determine the influence of soil physical and chemical properties on the nutritional composition of moringa leaves. Soil samples under moringa canopy and 5 m away from the base of the trees as well as fresh leaf samples were collected from 31 moringa farming locations in Limpopo Province during the summer season (November 2015 to January 2016). Soils at a depth of 0 to 30 and 30 to 60 cm were grouped according to textural classes and analyzed for physical and chemical properties. The harvested leaves were dried at room temperature and their nutritional compositions were determined using standard methods. The study revealed improved soil nutritional composition under moringa trees, mainly in areas where the trees were more than three years old as compared to control. The higher nutritional composition was also recorded in soils with higher clay content relative to low clay soils. The results of leaf nutritional composition revealed no significant differences between the soil textural classes. Moreover, there was no significant correlation between soil and leaf nutritional compositions. The study concluded that moringa can be produced in many locations and diverse soils of the Limpopo Province without negatively affecting leaf nutritional composition.

Keywords: Locations, moringa, nutrients, soil textural classes, weather

8.1 Introduction

Moringa is gaining global consideration due to its beneficial aspects such as food supplement, medication, use for industrial purposes as well as for water purification (Fahey, 2005; Moyo *et al*., 2011; Oshunsanya *et al*., 2015; Lamidi *et al*., 2017).

Almost all parts of the moringa tree are consumed for various purposes, for both human food and livestock feed as well as for its medicinal values (Lamidi *et al*., 2017). Moringa trees have been planted in many developing countries with the aim to combat malnutrition amongst poor families and contribute significantly to reducing food insecurity (Fahey, 2005; Jongrungruanchok *et al*., 2010; Gandji *et al*., 2018). The dried nutritional leaf powder can be used to fortify meals during dry seasons when there is a lack of other green leafy vegetables (Kumssa *et al*., 2017). There is considerable variation in moringa nutritional composition of the dried leaf powder depending on factors such as the genetic background of the plant and prevailing environmental conditions (Moyo *et al*., 2011).

Besides its nutritional composition, moringa is reported to increase soil fertility liter fall and its leaves can also be used as a nutrient-agent for biofertilizer production (Adiaha, 2017). A study conducted by Undie *et al*. (2013) showed that moringa leaves can serve as an alternative source of soil organic matter and can be a replacement for inorganic fertilizers for optimum crop production. The moringa tree is also strongly recommended for inclusion in agroforestry systems since its relatively deep root system minimizes moringa's competitiveness with companion crops for nutrient uptake in the system. This ultimately it helps to improve soil organic matter and fertility where moringa is grown (Ashfaq *et al*., 2012).

Moringa tree thrives under harsh conditions, where the majority of agricultural crops cannot survive, especially in tropical and subtropical areas (Leone *et al*., 2016). The tree grows best at a temperature ranging between 25 to 35ºC, but can still survive extreme temperatures of up to 48ºC and tolerate a soil pH of 5.0 to 9.0 (Amaglo, 2006; Saini *et al*., 2016). Besides being tolerant from various environmental conditions, it is a fast growing tree that is known for its drought-tolerance abilities and can reach a height of 6 to 7 m within 12 months of establishment in areas receiving a rainfall of less than 400 and up to 1500 mm/annum (Morton, 1991; Odee, 1998; Amaglo, 2006; Yamato *et al*., 2009). Its survival to drought conditions is attributed to the presence of water storing organs in the root system and its symbiosis with mycorrhizal fungi (Yamato *et al*., 2009). Studies by Yamato *et al*. (2009), Muthukumar *et al*. (2006) and Cosme *et al*. (2014) reported on the colonization of arbuscular mycorrhizal (AM) fungi in moringa species and showed that the AM association contributes towards soil nutrients uptake, drought tolerance and disease resistance of the host plant.

Moringa is found in all countries, particularly those which experience malnutrition (Ashfaq *et al*., 2012). However, in South Africa, moringa is a fairly new crop that is grown by few farmers (Pakade *et al*., 2013) in provinces such as Kwa-Zulu Natal, Mpumalanga, and Limpopo (Lekgau, 2011). In Limpopo Province, the majority of farmers grow the tree on a small area of fewer than two hectares (Mabapa *et al*., 2017a). Majority of such farmers grow the tree for household purposes. Mabapa *et al*. (2017a), reported that moringa is produced in all districts of the Limpopo province. There is, however, limited information on the influence of soil characteristics on the mineral composition of moringa leaves. This study was established to investigate and compare the nutritional composition of *Moringa oleifera* leaves produced under diverse soil textural classes and types in the Limpopo Province.

8.2 Materials and Methods

8.2.1 Study area

The study was conducted during the summer season from November 2015 to January 2016 in all the five districts of the Limpopo Province (23.4013° S, 29.4179° E), namely Capricorn, Sekhukhune, Waterberg, Mopani, and Vhembe. Limpopo province falls within the summer rainfall region of South Africa, with the western part being semi-arid and the eastern part largely sub-tropical. Typical rainfall for the province ranges from 200 mm in the hot dry areas to more than 1500 mm in the high rainfall areas, with most of it falling between October and April (Limpopo, D.F.E.D, 2004). The province experiences the highest temperatures during the months of October to March. Temperatures peak in December and January at about an average of 25^{o}C. The lowest temperatures occur in July with an average of 15^{o}C (Tshiala *et al*., 2011).

8.2.2 Data collection

Soil samples and fresh leaf samples were collected from the fields of 31 farmers who produce moringa on an area of 0.5 ha and above. The farmers were identified through a survey conducted by Mabapa *et al*. (2017a). Profile of sampled moringa trees with the sampled areas is presented in Table 8.1. Fully expanded leaf samples were harvested from the lower, mid and upper parts of the tree canopy from each location. Soil samples and gravimetric soil moisture were also determined from each location. Preliminary assessment of sampled soils revealed that the five districts had a variable textural class; therefore the textural classes were grouped and used as treatments for the overall analysis of soil and leaf nutrition across locations.

8.2.3 Soil sampling and analysis

Soil samples were taken under moringa canopy and 5 m away from the trees to determine the impact of the change in soil property beneath the moringa canopy area. Soils were sampled at a depth of 0 to 30 and 30 to 60 cm using an auger, to determine physical and chemical characteristics (Tables 8.1 and 8.2) from each location. Gravimetric soil moisture percentage was also determined from the same depths. Zip-lock plastic bags were used to keep soil for moisture retention before measurement. Fresh soil moisture weight was determined immediately after sampling using a battery-operated top loading weighing balance (RADWAG, W/C6/12/C1/R model). Soils were placed in aluminum drying pans and dried in an oven (Scientific oven Economy, 240 litres, Model 223) for 24 hours at a temperature of 105ºC. Gravimetric soil moisture percentage was determined when the soil samples had reached a constant weight, using a method described by Black (1965). Soils textural classes were determined based on particle size distribution and soil samples were analysed for P, K, Ca, Mg, Zn, Mn, Cu (mg/L), pH (KCl), organic carbon, total N (%), using analytical methods used by the soil fertility and analytical services section in Kwa-Zulu Natal (Manson and Roberts, 2000).

8.2.4 Nutrients determination in moringa leaves

Samples of moringa leaves collected from different locations were shade-dried at room temperature (24ºC) for 72 hours, to ease the defoliation from the rachis. Dried leaf samples were ground to pass through a 2 mm sieve and samples from the aforementioned locations within each soil textural class were bulked and mixed thoroughly. A 10 g sample of a fine fraction was used to determine their chemical composition. The analyses were carried out in triplicate. Crude protein was determined using the Kjeldahl method (AOAC, 1990). Other minerals such as N, P, Ca, and Fe were determined using atomic absorption procedure (Gaines and Mitchell, 1979).

8.2.5 Statistical analysis

The data collected were subjected to analysis of variance using Statistix 10.0 to determine the effect soil texture on measured variables. Where significant F-values from the treatment effect were found, means were separated by the least significant difference (LSD) at a probability level of 0.05. Linear correlation and regression analyses were performed using Statistix 10.0 and Microsoft Excel to determine the relationship between soil and leaf nutrient properties of moringa trees.

8.3 Results

8.3.1 Sampled locations and weather data

Profile of sampled locations which included districts, location, tree age and soil textural classes are presented in Table 8.1. The results showed that moringa is grown in all the districts of the Limpopo Province. It was observed that 55% of the farmers had three years and lesser experience in moringa farming. Majority of the sampled locations were dominated by sandy loam soil.

The mean annual temperature, annual rainfall, locations where moringa is growing in the Limpopo Province and soil textural classes are shown in Figures 8.1 and 8.2. Many areas of the Limpopo Province experience high temperature to an extent such that the average could be more than 23^{o}C (Figure 8.1). The province also receives erratic annual rainfall ranging between 300 to 500 mm (Figure 8.2).

Figures 8.1 and 8.2 showed that moringa can grow on various soils textural classes depending on the location where a farmer is growing the trees in the Limpopo Province.

Table 8.1: Locations and profile of moringa trees examined from the 5 districts in the Limpopo Province.

Number	District	Location/Area	Tree Age (Years)	Soil Textural Class	Clay Percentage
1	Capricorn	Polokwane	7	Loamy Sand	18
2	Capricorn	Matlala	2	Sandy Loam	19.5
3	Capricorn	Polokwane	2	Sandy Loam	25
4	Capricorn	Lebowakgomo	3	Sandy Clay Loam	26.5
5	Capricorn	Ga-phasha	3	Sandy Clay Loam	30
6	Capricorn	Makotse	5	Sandy Clay Loam	31.5
7	Capricorn	Tooseng	4	Loamy Sand	26
8	Mopani	Nkowankowa	1	Loamy Sand	18.5
9	Mopani	Milliekloof	1	Loamy Sand	17
10	Mopani	Woster	3	Sandy Loam	21.5
11	Mopani	Ofcolaco	2	Sandy Clay Loam	30
12	Mopani	Sekororo	5	Sandy Loam	28
13	Mopani	Woster	3	Sandy Clay Loam	31
14	Mopani	Lorraine	4	Sandy Clay	42
15	Mopani	Baloon	6	Sandy Clay	44
16	Mopani	Eiland	4	Sandy Loam	17.5
17	Sekhukhune	Driekop	10	Sandy Loam	16
18	Sekhukhune	Denilton	4	Loamy Sand	20
19	Sekhukhune	Dithabaneng	5	Loamy Sand	28
20	Vhembe	Makwarela	3	Sandy Clay Loam	31.5
21	Vhembe	Thohoyandou	3	Sandy Loam	27.5
22	Vhembe	Ha-Budeli	3	Sandy Clay	38.5
23	Vhembe	Tshakhuma	5	Clay Loam	49
24	Vhembe	Tshiande	5	Clay Loam	52
25	Vhembe	Ha-Mutsha	2	Clay Loam	56
26	Vhembe	Thohoyandou	2	Sandy Loam	28
27	Vhembe	Lufule	2	Sandy Loam	20.5
28	Vhembe	Ha-Dumase	2	Sandy Clay Loam	30.5
29	Vhembe	Tshipise	4	Sandy Loam	22
30	Waterberg	Mmapela	3	Clay	60
31	Waterberg	Mokopane	4	Sandy Clay Loam	32.5

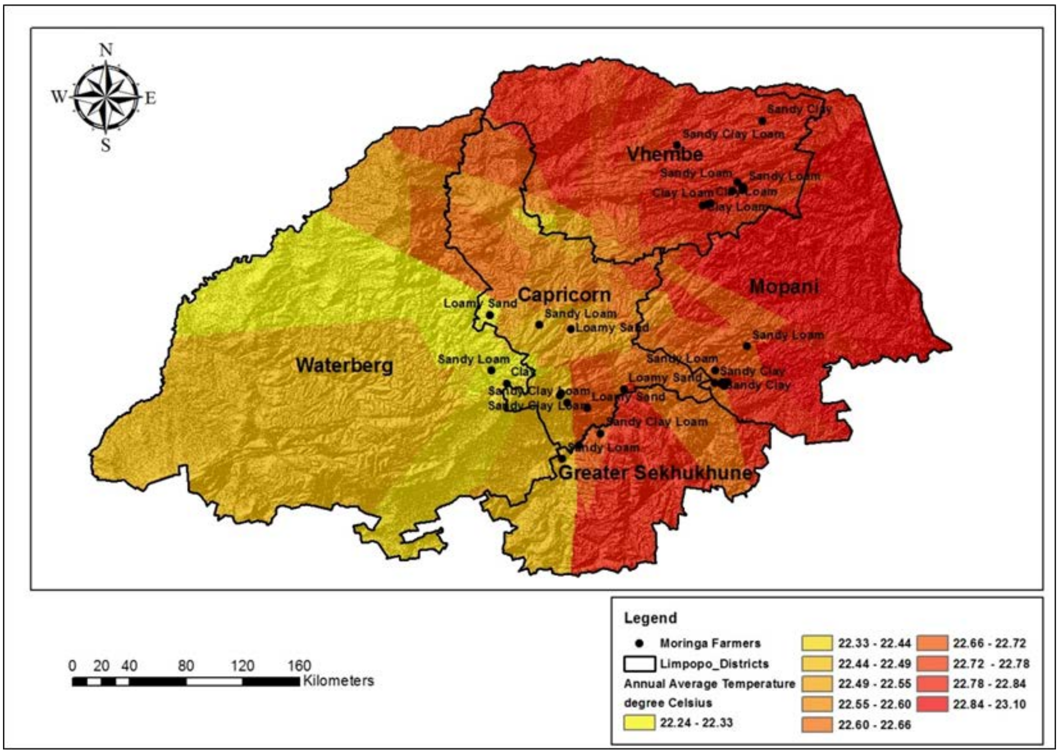


Figure 8.1: Average annual temperature and soil textural classes from various locations where moringa is growing in Limpopo Province.

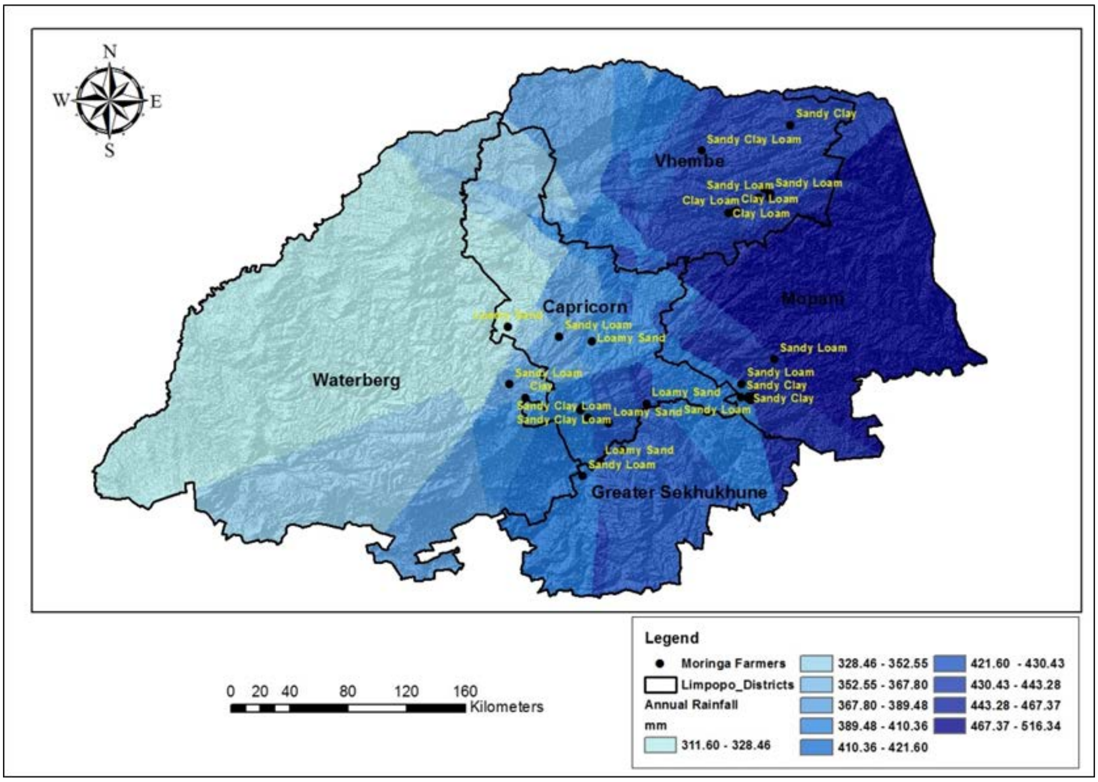


Figure 8.2: Total annual rainfall and soil textural classes from various locations where moringa is growing in Limpopo Province.

Weather data collected from the nearest weather station of each location during the study period is shown in Figure 8.3. It was observed that the average maximum temperature ranged between 30 to 35ºC with minimum temperature raging between 15 to 22ºC and a total rainfall of between 75 to 200 mm during the study period (Figure 8.3).

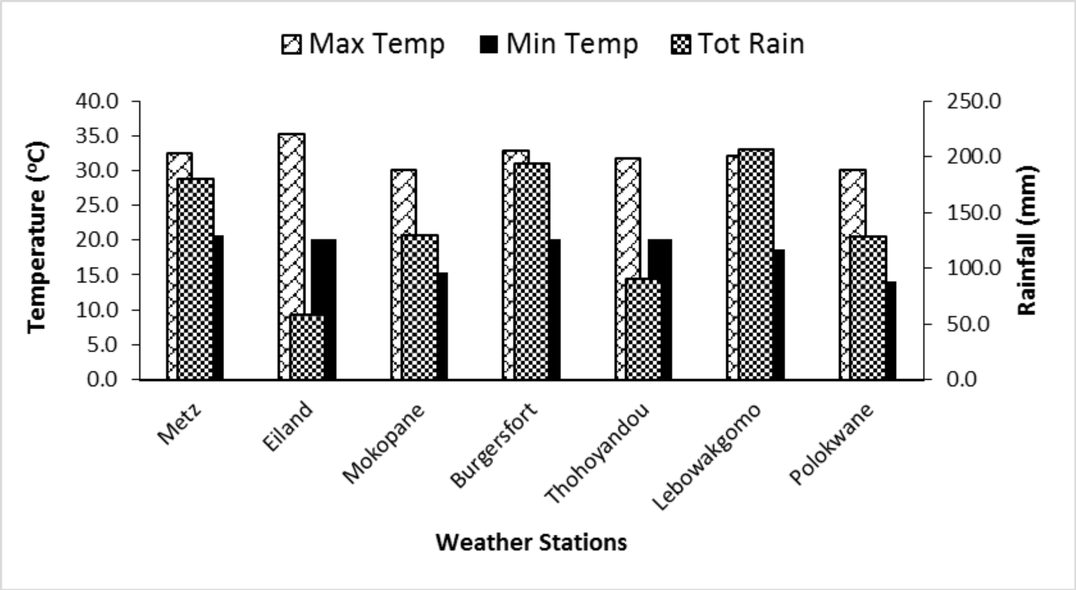


Figure 8.3: Weather data collected during the study from selected locations in Limpopo Province

8.3.2 Changes in soil physical and chemical properties under and away from moringa trees

Chemical properties of the soil samples collected from the selected 31 locations are shown in Table 8.2. In many cases, the chemical composition in the soil at 0 to 30 cm depth was relatively higher compared to the lower depth of 60 cm in both the control and moringa canopy samples (Table 8.2).

Nitrogen and phosphorus were found to be very low at all locations. The nitrogen content increased slightly by 33 percent mainly in soils with a higher clay content of more than 30 percent, while a reduction of 35 percent was also noticed in sandy soils and the constant results between control and nitrogen content were 32 percent (Table 8.2). The range for phosphorus concentration was between 3 and 100 mg/l under moringa canopy and 2 and 98mg/l under control. There was also a decrease in P content with an increase in sampling depth.

Out of 31 locations, 17 (55 percent) locations recorded higher potassium content under moringa canopy compared to the control. A total of 22 (71 percent) locations also showed an increase in calcium content where there was moringa trees (Table 8.2). The soil pH ranged from 4.95 to 8.02, under moringa trees, while the control ranged from 3.5 to 7.86. The results thus reveal that moringa may have the potential to ameliorate acidic soils. The soil organic carbon ranged between 0.4 to 2.7% under moringa canopy and 0.06 to 3.6% under the control (Table 8.2). It was observed that where soils had high clay content (>30 percent) the amount of organic carbon under moringa canopy had slightly increased.

A significant positive relationship was observed between soil nitrogen with soil calcium (0.40**) and organic carbon (0.73***). Soil calcium also had a positive relationship with organic carbon (0.30**) and soil potassium (0.45**). As the tree matures the amount of phosphorus increased in many occasions which led to a positive relationship of 0.27* (Figure 8.4). Soil pH had a positive relationship with soil phosphorus (0.23*), potassium (0.21*) and calcium (0.13*) (Figure 8.5).

Table 8.2: Chemical and physical characteristics samples from the different locations in the Limpopo Province (*Continued*)

		Locations														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Tree age		7	5	2	3	3	5	4	1	1	3	2	5	3	4	6
Soil Properties	Depth (cm)															
Moringa N (%)	0 – 30	0.04	0.04	0.14	0.08	0.08	0.08	0.06	0.04	0.04	0.04	0.40	0.04	0.11	0.04	0.04
Moringa N (%)	30 – 60	-	0.04	0.10	0.07	0.04	0.04	0.04	0.04	0.04	0.04	0.40	0.05	0.04	0.04	0.04
Control N (%)	0 – 30	0.04	0.04	0.09	0.04	0.08	0.04	0.10	0.06	0.06	0.04	0.40	0.09	0.09	0.04	0.04
Control N (%)	30 – 60	-	0.04	0.05	0.04	0.05	0.04	0.04	0.04	0.04	0.04	0.40	0.04	0.04	0.04	0.04
Moringa P (mg/L)	0 – 30	54	4	3	5	8	5	80	8	7	5	7	7	15	10	3
Moringa P (mg/L)	30 – 60	-	2	5	4	2	3	48	3	4	1	3	7	6	10	2
Control P (mg/L)	0 – 30	03	1	2	5	6	3	98	17	7	1	8	4	4	22	4
Control P (mg/L)	30 – 60	-	1	3	3	3	3	11	13	3	1	3	4	4	13	1
Moringa K (mg/L)	0 – 30	248	191	117	581	226	209	398	83	35	139	136	83	238	47	215
Moringa K (mg/L)	30 – 60	-	223	108	439	139	141	133	34	30	102	120	71	259	55	208
Control K (mg/L)	0 – 30	566	211	107	514	277	278	273	77	77	353	212	89	89	101	135
Control K (mg/L)	30 – 60	-	151	52	228	190	296	157	35	35	384	105	41	41	108	120
Moringa Ca (mg/L)	0 – 30	968	593	1050	2964	2482	2353	737	354	472	582	743	1820	2400	414	550
Moringa Ca (mg/L)	30 – 60	-	716	1003	2810	3040	2732	624	384	389	682	717	1970	1718	397	506
Control Ca (mg/L)	0 – 30	660	321	897	2810	1326	1005	712	422	422	472	646	1004	1004	627	823
Control Ca (mg/L)	30 – 60	-	243	715	3166	1903	1089	565	337	337	442	756	1164	1164	782	702
Moringa pH (KCl)	0 – 30	6.37	4.99	5.56	6.52	7.53	6.61	7.84	5.57	5.73	7.44	5.97	6.54	6.73	7.06	4.95
Moringa pH (KCl)	30 – 60	-	5.20	5.58	6.94	7.16	6.91	8.02	5.18	5.30	7.38	5.57	6.26	7.52	7.04	4.95
Control pH (KCl)	0 – 30	5.49	4.78	4.41	6.88	5.86	6.92	7.82	5.51	5.51	5.53	5.13	6.64	6.64	7.46	6.1
Control pH (KCl)	30 – 60	-	3.95	4.28	7.17	5.60	7.22	7.86	5.29	5.20	5.50	5.22	6.63	6.63	6.85	5.58
Moringa Org C (%)	0 – 30	0.6	0.4	1.15	1.60	1.30	1.50	1	0.80	0.50	0.40	1.10	0.7	1.50	0.40	1.40
Moringa Org C (%)	30 – 60	-	0.4	1	1.40	0.80	0.60	0.70	0.40	0.40	0.40	1.10	0.7	1.00	0.50	1.60
Control Org C (%)	0 – 30	0.7	0.4	1.12	0.9	1.20	0.50	1.40	0.90	0.90	0.40	1.40	1.7	1.70	0.50	1.30
Control Org C (%)	30 – 60	-	0.4	1	0.7	0.80	0.40	0.50	0.40	0.40	0.50	1.10	0.4	0.40	0.40	1.40

Table 8.2: (*Continued*)

		Locations															
		16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
Tree age		4	10	4	5	3	3	3	5	5	2	2	2	2	4	3	4
Soil Properties	Depth (cm)																
Moringa N (%)	0 – 30	0.04	0.06	0.04	0.04	0.06	0.07	0.11	0.08	0.19	0.12	0.09	0.04	0.12	0.05	0.15	0.08
Moringa N (%)	30 – 60	0.04	0.09	0.04	0.04	0.04	0.09	0.04	0.08	0.07	0.20	0.21	0.07	0.04	0.04	0.05	0.05
Control N (%)	0 – 30	0.12	0.08	0.08	0.04	0.11	0.11	0.06	0.09	0.16	0.33	0.04	0.04	0.04	0.04	0.04	0.11
Control N (%)	30 – 60	0.04	0.06	0.06	0.05	0.07	0.07	0.09	0.10	0.07	0.27	0.18	0.04	0.04	0.04	0.1	0.1
Moringa P (mg/L)	0 – 30	46	100	36	20	51	44	7	83	15	34	22	28	8	11	26	53
Moringa P (mg/L)	30 – 60	39	54	8	3	10	13	22	59	20	26	13	26	2	7	3	2
Control P (mg/L)	0 – 30	32	16	16	9	2	2	12	17	15	11	15	67	14	14	2	4
Control P (mg/L)	30 – 60	20	9	9	3	1	1	46	9	6	6	12	3	8	8	5	2
Moringa K (mg/L)	0 – 30	238	389	331	131	512	603	185	407	282	331	183	202	158	79	566	164
Moringa K (mg/L)	30 – 60	228	372	333	104	253	302	238	336	168	294	267	210	50	69	148	49
Control K (mg/L)	0 – 30	155	292	219	294	187	187	999	200	133	254	270	357	91	91	116	149
Control K (mg/L)	30 – 60	126	265	226	96	213	213	482	195	77	194	134	126	80	80	169	111
Moringa Ca (mg/L)	0 – 30	965	1572	827	1156	1641	2602	2453	1653	1842	1738	1120	1050	1875	970	3442	902
Moringa Ca (mg/L)	30 – 60	992	1530	574	1780	856	1882	1670	1610	2686	1719	1833	1044	869	899	3174	916
Control Ca (mg/L)	0 – 30	1314	1119	119	1467	741	2741	1849	979	1668	1192	1942	1213	629	629	2587	1491
Control Ca (mg/L)	30 – 60	1364	1301	310	1641	926	2917	2326	812	2730	1040	1751	515	625	625	2813	1694
Moringa pH (KCl)	0 – 30	6.86	7.61	6.51	7.72	7.5	7.46	6.63	7.01	5.64	7.6	5.78	6.5	5.85	6.36	7.44	6.5
Moringa pH (KCl)	30 – 60	6.74	7.48	5.67	7.64	7.39	7.15	7.2	6.88	7.42	7.31	5.66	6.39	5.46	6.24	7.21	6.36
Control pH (KCl)	0 – 30	5.60	4.57	4.50	7.70	7.02	7.02	7.37	5.76	5.93	5.12	6.94	6.46	5.86	5.86	7.18	6.72
Control pH (KCl)	30 – 60	5.52	5	5.00	7.60	7	7	7.09	5.56	6.96	4.82	5.9	5.06	5.98	5.98	7.21	6.83
Moringa Org C (%)	0 – 30	0.70	0.7	0.4	0.4	0.6	0.9	1.40	1.7	2.7	1.80	1.4	0.4	1.3	1.1	1.7	1.1
Moringa Org C (%)	30 – 60	0.40	0.7	0.4	0.4	0.4	0.6	0.80	1.7	1.4	2.40	2.8	1.0	0.7	0.7	0.6	0.7
Control Org C (%)	0 – 30	1.50	0.8	0.5	0.4	1.4	1.4	1.30	1.6	2.2	3.60	0.7	0.7	0.4	0.4	0.4	1.1
Control Org C (%)	30 – 60	0.06	0.5	0.3	0.4	10	6	1.20	1.6	1.5	3.10	2.2	0.4	0.4	0.4	0.9	0.4

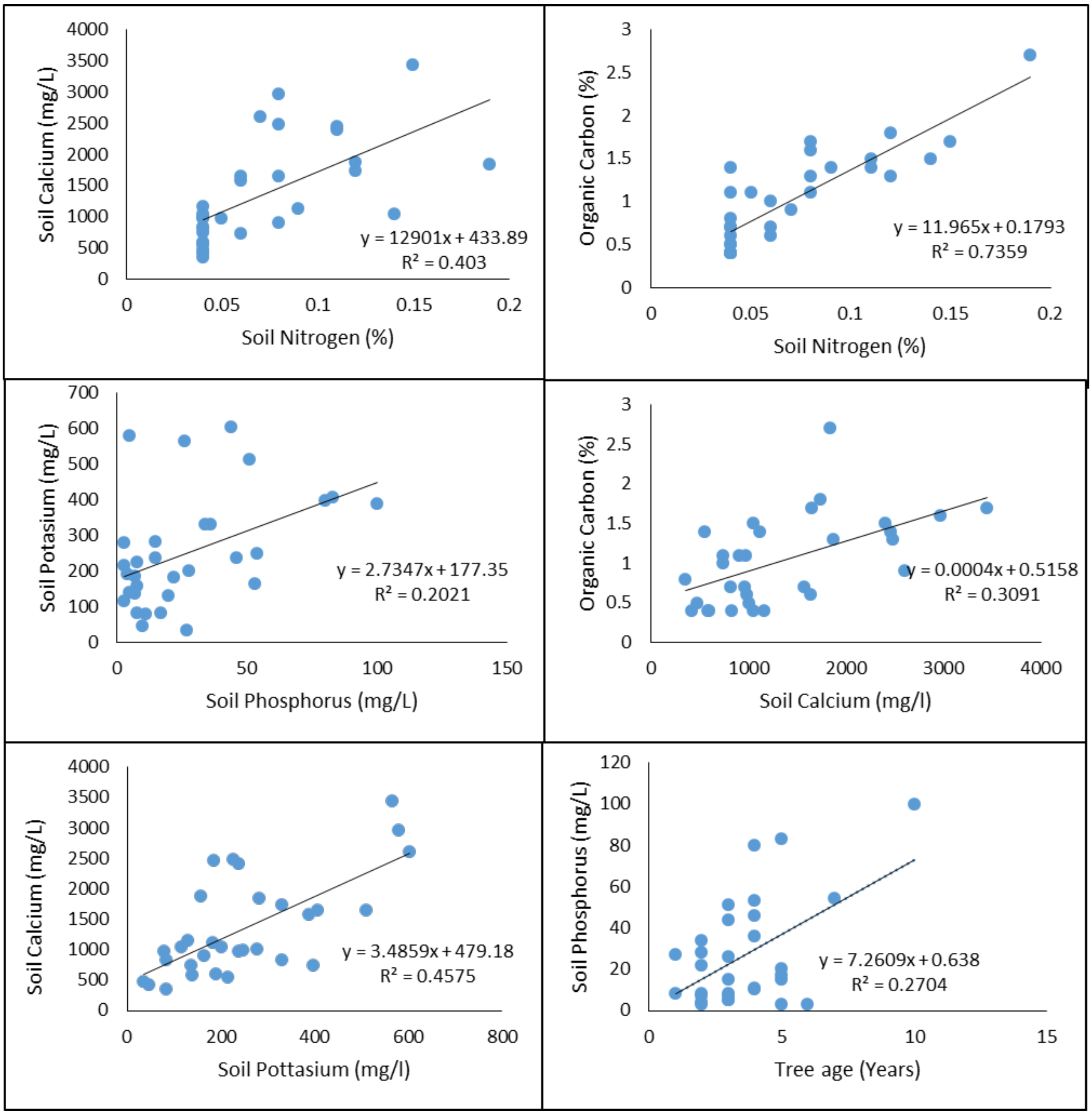


Figure 8.4: Correlation and linear relationship effects of tree age and soil properties under the moringa tree canopy.

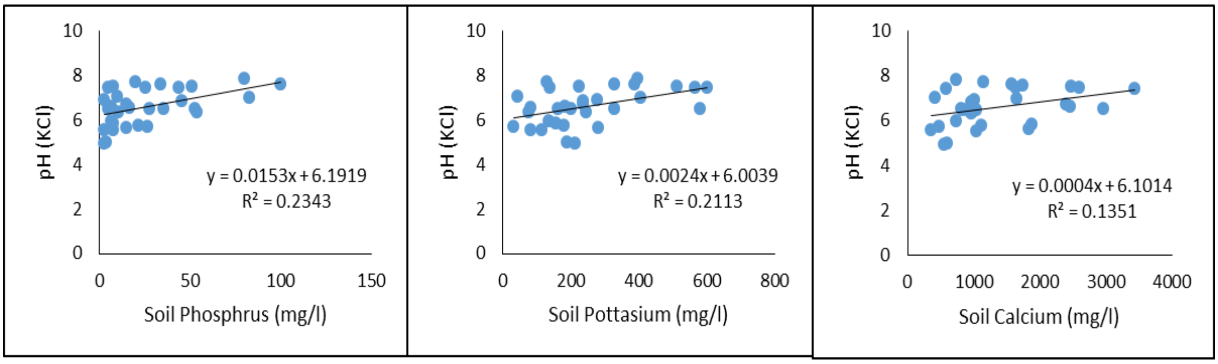


Figure 8.5: Correlation and linear relationship analysis of soil pH and other physical properties under moringa tree canopy.

8.3.3 Effect of soil textural classes on physical and chemical properties under moringa trees

Findings from this study showed that the concentration of soil nitrogen, phosphorus, potassium, calcium and organic carbon was significantly dependent on soil textural class whereas pH was not affected (Table 8.3). It was observed that an increase in clay content (>45 percent) in the soil, improved the soil chemical composition. Soil potassium and calcium content were more than 550 and 3000 mg/L under the clay textured soil (Table 8.3).

Table 8.3: Effect of soil textural class on physical and chemical properties of soil sampled under moringa trees at different locations in Limpopo Province.

	Soil Chemical properties					
Treatment	**Soil N (%)**	**Soil P (mg/L)**	**Soil K (mg/L)**	**Soil Ca (mg/L)**	**pH (KCl)**	**Soil Org C (%)**
Clay	0.15^{a}	26.00^{b}	566.00^{a}	3442.0^{a}	7.44^{a}	1.70$^{a\ b}$
Clay Loam	0.13^{a}	44.00^{a}	340.00^{ab}	1751.5^{b}	6.75^{a}	2.06^{a}
Sandy Clay Loam	0.08^{b}	18.75^{c}	286.63^{ab}	1744.3^{b}	6.69^{a}	1.12^{bc}
Sandy Clay	0.06^{b}	6.66^{d}	222.40^{b}	1139.3^{bc}	6.21^{a}	1.06^{bcd}
Sandy Loam	0.06^{b}	28.00^{ab}	149.00^{b}	1132.4^{bc}	6.51^{a}	0.82^{cd}
Loamy Sand	0.04^{b}	37.50^{a}	204.33^{b}	755.33^{c}	6.62^{a}	0.61^{d}
LSD$_{0.05}$	0.07	25.34	146	646.27	--	0.39
Significance	***	**	**	***	ns	***

*Significance levels: *P < 0.05, **P < 0.01, ***P < 0.001, ns means not significant*

Findings from the study further revealed that soil textural classes containing higher clay content under the moringa tree had a more positive influence on other soil chemical properties as compared to the control (Figure 8.6). High clay content had a significant influence on soil phosphorus, potassium, calcium, potassium and organic carbon (Figure 8.6). Gravimetric soil moisture was relatively low (<10%) across all soil textural classes. However, the soil moisture was significantly higher under the moringa tree as compared to the control. Gravimetric soil moisture ranged between 4 – 8.3% under moringa canopies and from 2.5-7.8 under the control (Figure 8.7).

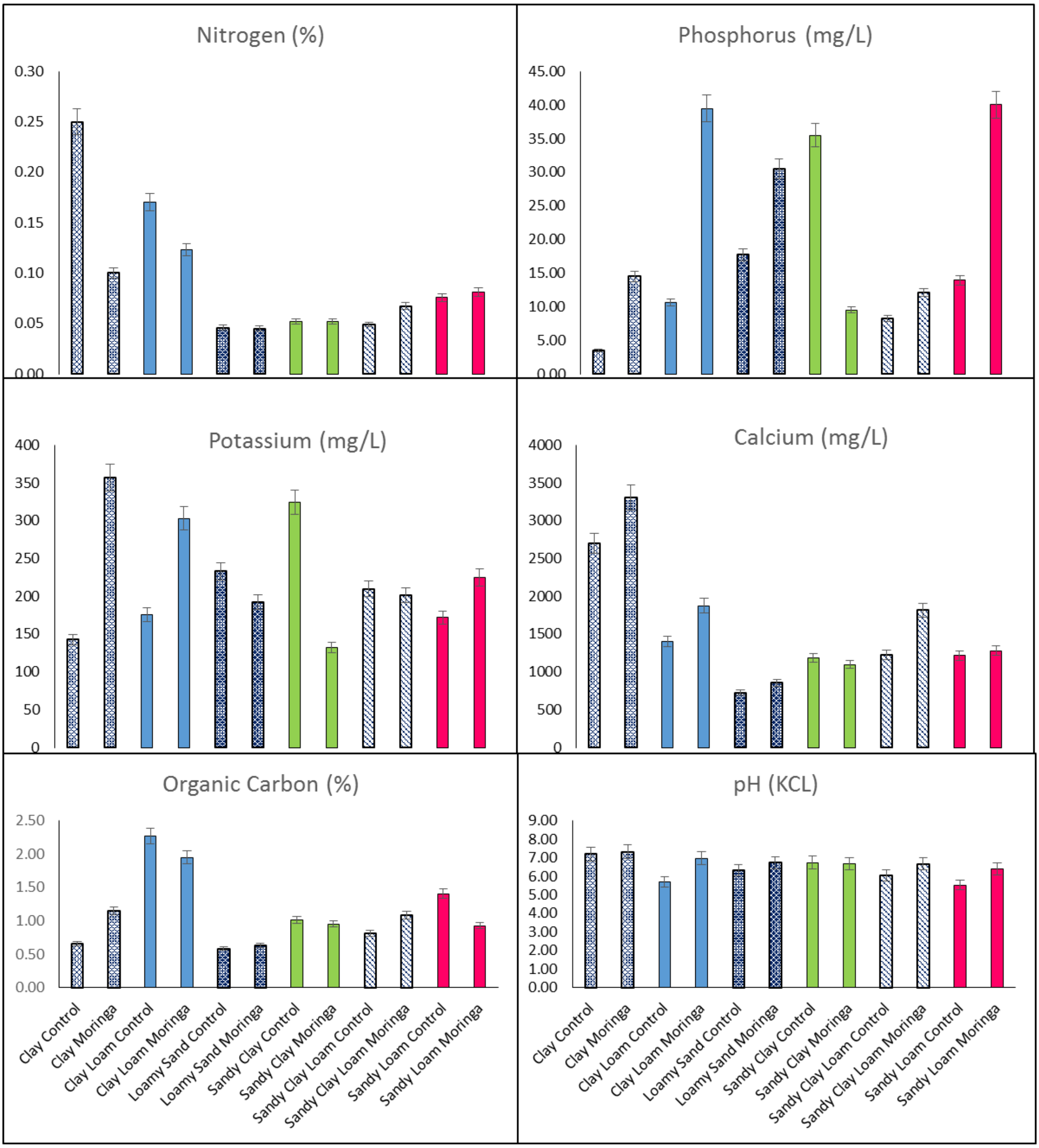


Figure 8.6: Textural classes and chemical properties of soils sampled under moringa trees and control (5 m away) at different locations in Limpopo Province.

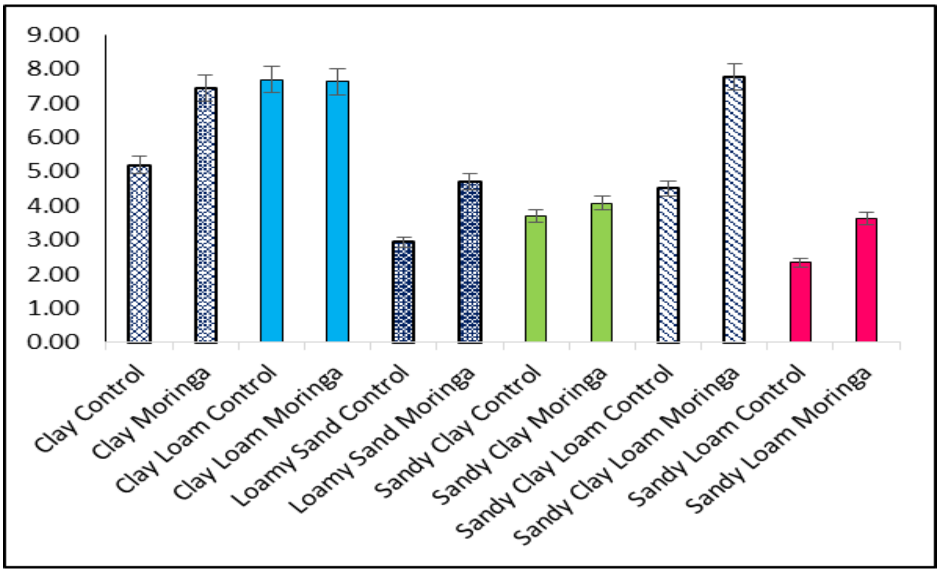


Figure 8.7: Textural classes and gravimetric moisture (%) of soils sampled under moringa trees and control (5 m away) at different locations in Limpopo Province.

8.3.4 Effect of soil textural classes on nutrient composition of moringa leaves

Findings from this study showed that soil textural classes did not significantly affect the nutritional composition of moringa leaves. Across the various textural classes, leaf nutritional composition was however within levels required to meet dietary requirements for both humans and livestock (Table 8.4). An assessment of association test among the nutritional parameters studied showed a positive linear regression between leaf phosphorus content and leaf nitrogen (0.39**) and that of leaf protein (0.32**) content (Figure 8.8).

Table 8.4: Effect of soil textural class on the nutritional composition of moringa leaf powder obtained from different locations in Limpopo Province.

Treatment	**Leaf N (%)**	**Crude Protein (%)**	**Leaf Ca (%)**	**Leaf P (%)**	**Leaf Fe (mg/kg)**
Clay	5.31^a	33.20^a	2.68^a	0.27^a	144.00^a
Clay Loam	3.99^a	26.38^a	1.64^a	0.21^a	174.00^a
Sandy Clay Loam	4.70^a	29.42^a	2.21^a	0.23^a	164.63^a
Sandy Clay	4.60^a	28.76^a	2.60^a	0.21^a	163.67^a
Sandy Loam	4.68a	29.28^a	2.26^a	0.23^a	151.90^a
Loamy Sand	5.21^a	31.55^a	1.99^a	0.28^a	167.00^a
LSD$_{0.05}$	--	--	--	--	--
Significance	ns	ns	ns	ns	ns

Significance levels: ns means none significance

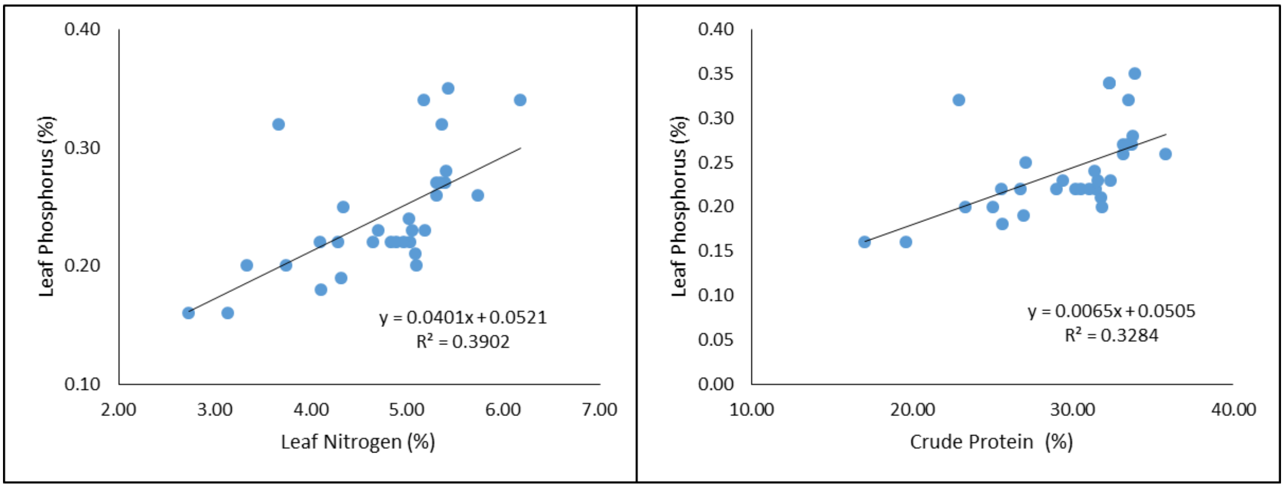


Figure 8.8: Regression and linear relationships analysis of moringa leaf phosphorus, nitrogen, and crude protein.

8.3.5 Correlation and regression analysis of tree age, soil properties, and leaf nutrients

Analysis among soil nutrient ions revealed several significant positive correlations extending to the following: nitrogen and calcium (0.63***); nitrogen and organic carbon (0.86***), potassium and pH (0.46**); potassium and calcium (0.68***); calcium and pH (0.37*) and lastly calcium and organic carbon (0.56***) (Table 8.5). Gravimetric soil moisture did not correlate with any of the parameters measured whereas tree age only revealed a moderate positive correlation with phosphorous (0.52***) (Table 8.5).

Table 8.5: Pearson’s correlation between soil properties and moringa leaf nutritional composition obtained from different locations of the Limpopo Province.

	Gravimetric soil moisture (%)	**Tree age (Yrs)**	**Soil N (%)**	**Soil P (mg/L)**	**Soil K (mg/L)**	**Soil Ca (mg/L)**	**pH (KCl)**	**Soil Org C (%)**	**Leaf N (%)**	**Crude Protein (%)**	**Leaf Ca (%)**	**Leaf P (%)**
Gravimetric soil Moisture (%)	1											
Tree Age (Yrs)	-0.14±0.43 ^{ns}	1										
Soil N (%)	0.16±0.39^{ns}	-0.14±0.45 ^{ns}	1									
Soil P (Mg/L)	-0.20±0.27 ^{ns}	0.52±0.00***	-0.09±0.65 ^{ns}	1								
Soil K (Mg/L)	-0.04±0.82 ^{ns}	0.19±0.31 ^{ns}	0.27±0.14 ^{ns}	0.45±0.01**	1							
Soil Ca (Mg/L)	0.29±0.11 ^{ns}	-0.03±0.89 ^{ns}	0.63±0.00***	0.03±0.88 ^{ns}	0.68±0.00 ***	1						
pH (KCL)	0.11±0.57 ^{ns}	0.27±0.15 ^{ns}	-0.04±0.85 ^{ns}	0.48±0.01**	0.46±0.01**	0.37±0.04 *	1					
Soil Org C (%)	0.28±0.13 ^{ns}	-0.06±0.74 ^{ns}	0.86±0.00***	-0.08±0.67 ^{ns}	0.27±0.14 ^{ns}	0.56±0.00***	-0.150.41 ^{ns}	1				
Leaf N (%)	-0.05±0.79 ^{ns}	0.09±0.64 ^{ns}	-0.12±0.51 ^{ns}	0.25±0.17 ^{ns}	0.33±0.07 ^{ns}	0.01±0.94 ^{ns}	0.160.39 ^{ns}	-0.22±0.23 ^{ns}	1			
Crude Protein (%)	-0.01±0.94 ^{ns}	0.11±0.56 ^{ns}	-0.03±0.89 ^{ns}	0.16±0.37 ^{ns}	0.33±0.07 ^{ns}	0.07±0.70 ^{ns}	0.070.72 ^{ns}	-0.14±0.44 ^{ns}	0.96±0.00***	1		
Leaf Ca (%)	0.23±0.21 ^{ns}	0.03±0.85 ^{ns}	-0.16±0.38	-0.05±0.79 ^{ns}	0.23±0.22 ^{ns}	0.24±0.19 ^{ns}	0.290.11 ^{ns}	-0.19±0.30 ^{ns}	0.11±0.56 ^{ns}	0.09±0.63 ^{ns}	1	
Leaf P (%)	-0.19±0.28 ^{ns}	0.09±0.61 ^{ns}	-0.03±0.86 ^{ns}	0.37±0.06 ^{ns}	0.24±0.19 ^{ns}	-0.04±0.84 ^{ns}	-0.02±0.93 ^{ns}	-0.14±0.47 ^{ns}	0.63±0.00***	0.57±0.00 ***	-0.04±0.84 ^{ns}	1
Leaf Fe (mg/kg)	-0.03±0.86 ^{ns}	0.07±0.69 ^{ns}	-0.02±0.92 ^{ns}	0.17±0.36 ^{ns}	0.16±0.39 ^{ns}	0.04±0.81 ^{ns}	0.21±0.26 ^{ns}	-0.09±0.60 ^{ns}	-0.25±0.17 ^{ns}	-0.25±0.17 ^{ns}	0.13±0.48 ^{ns}	-0.18±0.33 ^{ns}

*Significance levels: *P < 0.05, **P < 0.01, ***P < 0.001, ns- not significant*

8.4 Discussion

8.4.1 Sampled locations and weather data

During the study period, Limpopo Province experienced high temperatures accompanied by erratic rainfall. The highest total rainfall received was approximately 200 mm throughout the season. This was probably due to El Niño effect which was associated with the dry summer season. El Niño is the below normal rainfall phenomenon with above normal temperatures which lead to devastating effect in the farming sector. A 92% chance of extreme El Niño conditions was predicted to occur in January 2016 (Mpheshea and Landman, 2017). This situation was experienced in many regions of Limpopo Province, including the areas where this study was conducted.

8.4.2 Changes in soil physical and chemical properties under and away from moringa trees

In most of the study areas, soil nitrogen content was generally observed to be low under both moringa trees and the control. The standard or critical soil test values in mg/kg reported in the literature are 20-30 (N), >15 (P), 80-200 (K), >2000 (Ca), >80 (Mg), >5 (Fe), 3-150 (Zn) and 50-1000 (Mn) (Havlin *et al.,* 2013). Although nitrogen was relatively low, the presence of moringa trees and mainly those over 5 years showed a slightly improved in the nitrogen content in the soil. This improvement might be due to litterfall from moringa leaves. Nitrogen is required by plants for assimilation into protein, and these mainly occur in non-leguminous plant species. Many pasture plants and mature trees derive a large portion of nitrogen from litter and leaf fall (Peverill *et al*., 1999; Lamb *et al.,* 2014). There are also climatic factors which affect the quantity of soil nitrogen and impact soil organic carbon, which influences soil total nitrogen content. Largely, rainfall and temperature control mineralization, immobilization, denitrification, and leaching of soil nitrogen (Peverill *et al*., 1999).

Large quantities of plant residues are retained in the soil by many crops, and recycling of nitrogen from these residues may add a large portion of nitrogen to the soil for the benefit of the subsequent crop. This was evident in moringa, whereby younger trees utilized more nitrogen but within the older plants, the nitrogen concentration was relatively higher especially in the clay-dominated soils. Soils in this study were generally low in nitrogen content, however, on relative terms; the N content of the soils under moringa canopy was slightly higher. The slight increase could be due to low rainfall that affected the decomposition of organic matter in some moringa production areas. Similarly, soil phosphorus concentration was generally low but an increase of 65% was observed under moringa tree species as compared to the control. From the current study, phosphorus was below the recommended rate of more than 10-20 mg/kg (Peverill *et al*., 1999 and Havlin *et al.,* 2013), in some locations.

Results from the current study showed that potassium and calcium were not limiting nutrients for plant growth in all the study locations. The recommended soil potassium and calcium are reported to be 120-200 mg/kg and 600 – 4000 mg/kg (Peverill *et al*., 1999). Calcium concentration increases when the soil pH becomes neutral or alkaline. Furthermore, an increase in potassium by 71% was observed under moringa canopy as compared to the control across all locations. These results are in agreement with findings by Singh *et al*. (2012) who reported highest available phosphorus, potassium and calcium under plantations of Ber (*Ziziphus mauritiana* Lamk), moringa (*Moringa olerifera* Lam), Karonda (*Carissa congesta* Wt.) and Khejri (*Prosopis cineraria* L. Druce) tree species as compared to control soil. The presence of root hairs increases the absorption of P in many plant species and also deeper root system which could absorb the nutrients at some depth and deposited at the surface.

Furthermore, it is reported that most terrestrial plants have a symbiosis with arbuscular mycorrhizal (AM) fungi and such colonization has been reported in moringa, where it increases the surface area for P absorption (Peverill *et al*., 1999; Yamato *et al.,* 2009; Cosme *et al.,* 2014). On the other hand, the fungus has the ability to absorb P from soil solutions with very low P concentration, thus effectively supplementing the amount of accessible phosphorus to the plant root system (Peverill *et al*., 1999). The presence of AM fungi mainly in areas with low soil moisture assists in alleviating the problems of reduced mineralization, poor uptake of nutrients and failure of the crop (Muthukumar *et al*., 2006; Yamato *et al*., 2009).

Soil pH under moringa canopy was variable, ranging from moderate to slightly acidic as well as slightly to moderately alkaline, all of which favour the growth of moringa plant. Generally, the pH was also slightly improved under moringa trees as compared to the control. A soil pH range of 5.0-6.5 is reported to be optimal for growth of most crop species as it increases the availability of calcium element until a pH concentration of 8 (Peverill *et al*., 1999). From the current study soils under moringa had a good pH level which does not affect nutrient uptake by the tree. Litterfall in moringa assists in pH balancing for ease of nutrient uptake (Singh *et al*., 2012; Dunsin and Odeghe, 2015).

Over 52 percent of the locations under moringa canopy had a satisfactorily organic carbon content which was above 1 percent at the upper 0-30 cm depth as compared to the control. A commendable increase was observed from the trees that were more than 5 years old and with high soil clay content (Table 8.2). According to Peverill *et al*. (1999), under relatively low rainfall condition and for soils intended for crop production**,** soil organic carbon is classified to be low, normal and high when the value is <0.9%, 0.9 to 1.45% and >1.45%, respectively. When the field is intended for pasture production, the values are considered to be low, normal and high when they are <1.74%; 1.74 to 2.62% and >2.62%. Typically the amount of organic carbon is reduced with increasing soil depth. Similar results were reported by Peverill *et al*. (1999), who indicated that soil organic carbon is higher at the soil surface and decreases exponentially with depth.

8.4.3 Effect of soil textural classes on physical and chemical properties under moringa trees

At all locations where data was collected, farmers rely on rainfall for crop water needs. During the study period, many locations of the Limpopo Province experienced drought which affected the production of agricultural crops. During the study, it was found that the rainfall was less than 210 mm with a maximum temperature of above 30°C at all locations (Figure 8.1). This might have affected nutrient uptake mainly in soils with a high percentage of sand due to high infiltration rate. The soils which are low in potassium are likely to be light textured in the areas receiving high rainfall of more than 600 mm annually (Singh *et al*., 2012).

The low rainfall received during the study period might have also affected microbial activities and led to slow release of nutrients by the plants. The change in organic carbon% was mainly observed from locations where the soil had some clay in their textural classes, displayed reasonable water holding capacity and the trees were more than 5 years of age. Singh *et al*. (2012) reported that favourable soil and moisture condition improved the organic carbon of moringa by up to 0.13% compared to control soil with an organic carbon content of 0.04%. Under conditions where warm temperatures prevail, there is a decrease in soil organic carbon due to increased decomposition rate by soil microorganisms (USDA-NRCS, 2009).

Peverill *et al*. (1999) further reported that factors such as topography, climatic conditions, soil texture and moisture content affect the amount of organic carbon present in the soil. Usually, a steep slope has higher soil organic matter content because of the deposition of organic debris that dominates in clay soils, wetter environments, and finely textured soils. Soil organic carbon serves as the energy source for soil micro-organisms and therefore improves the stability of the soil aggregates. In general soil organic carbon is considered to be low, moderate and high for various soil textural classes. For example, values for different soil types are as follows: sand (<0.5, 0.5-1 and >1%), sandy loam (<0.7, 0.7-1.4 and >1.4%), clay loam or clay (<1.2, 1.2-2 and >2%); these findings were reported by Peverill *et al*. (1999). The higher gravimetric soil moisture under moringa canopies relative to the control in some of the study locations might be due to litterfall, which covered the soil and possibly reduced the rate of evaporation. However, gravimetric soil moisture was relatively low; this might be due to drought and scanty rainfall received during the season. These findings are in par with Yamato *et al*. (2009), who reported a soil water content of less than 5%, although the study was conducted during the rainy season. This was attributed to high temperature which accelerated drought.

8.4.4 Effect of soil textural classes on nutrient composition of moringa leaves

No significant differences were found when correlating moringa leaf powder nutritional content and soil properties. The non-significant results on leaf nutritional composition found in this study agrees with the general findings that moringa can be produced under adverse environmental conditions without compromising the leaf nutritional quality. Studies by Anwar *et al*. (2007) and Kumssa *et al*. (2017) reported similar findings showing that moringa grows well under different conditions such as the humid tropics or hot dry environments as well as low fertility environments. The tree also survives in less fertile soils and is rarely affected by drought (Morton, 1991; Anwar *et al*., 2007). A study by Lamidi *et al*. (2017), reported that crude protein was not significantly influenced by harvesting locations ranging from 23.9 to 27.6%. Another study revealed that agro-ecological conditions have no significant effect on the level of moringa leaf nutrients (Asante *et al*., 2014).

The study that was conducted evaluating eleven leaf samples of moringa from various locations in Thailand reported protein content ranging between 19.15 - 28.80 (Jongrungruangchok *et al*., 2010) which was relatively low as compared to protein content found in leaves used in the current study which ranged between 26.38 – 33.20%. Higher concentration of Ca and Mg (3.65 and 0.75 mg/mL) were reported by Anjorin *et al*. (2010), however, in contrary, their study showed that mineral content in moringa leaves differed significantly with locations.

The concentrated amount of nitrogen, calcium, and phosphorus in the leaves are sufficient, rendering the leaf as a suitable material to be considered in biofertilizer production for soil fertility management and improved crop production (Adiaha, 2017; Mokgophi, 2017). The green leaves are nutritionally rich and can be used as green manure for soil fertility improvement (Mridha, 2015). Moringa leaves can serve as an alternative source of organic matter and calcium or replacement of expensive inorganic fertilizers which majority of smallholder farmers are unable to afford, including facilitating of soil pH and nutrients release for subsequent plant growth (Undie *et al*., 2013). The leaves improve soil concentration of N, K, Ca and organic carbon (Undie *et al*., 2013; Adiaha, 2017). A study conducted under two agroecological conditions of South Africa also revealed that dried moringa leaves assist to concentrate the high nutrient content of moringa leaves (Moyo *et al*., 2011), as such it can be used during the time of drought when there is scarcity of food (Thurber and Fahey, 2009; Lamidi *et al*., 2017). Pakade *et al*. (2013) recommended that the high levels of trace elements found in moringa are safe for human consumption and the leaves contain a substantial amount of flavonols which make the tree to be a natural antioxidant.

8.5 Conclusion

This study revealed that moringa can grow under soils with diverse textural classes. The tree showed a capability to recycle soil nutrients and improve soil fertility. Soil phosphorus was found to increase under older trees, indicating the potential of moringa to enhance phosphorus nutrition on marginal soils. In general, under many instances, improvement in soil pH and other soil nutrient elements such as calcium and potassium was observed across the study locations. Also, soil organic carbon showed slight increase mainly under older trees. Under the situation where a large portion of the leaves are not harvested for processing, the leaves are allowed to drop on the soil surface and decompose to improve soil structure and mineral elements. This was predominant in soils with high clay content and with older trees that are more than three years of age. Moringa has the potential to contribute towards human and livestock dietary needs and foster rural development, due to its considerable benefits.

CHAPTER 9

GENERAL CONCLUSIONS AND RECOMMENDATIONS

This section addresses all the objectives of the study and also summarise findings generated from the study as well as recommendations for possible future research relating to the study area.

Objective 1: To generate baseline information through a survey on moringa production, management practices and utilization of the tree by farmers in Limpopo Province.

Hypothesis: Farmers in Limpopo Province grow and manage moringa in a similar manner.

Conclusion: The study concludes that moringa is produced in all the five districts of Limpopo Province of South Africa for various uses, although production for nutritional and medicinal purposes seems to dominate. Moringa is mainly grown by male farmers and the majority of them grow it under a relatively small area, ranging from 0.25 ha to 1 ha. Production is carried out under different management practices and mainly for processing the leaves into powder. The hypothesis of equal management in the study is therefore rejected. Moringa also has strong potential to generate income in Limpopo Province as the powder and moringa juice are now beginning to be produced at industrial level.

Recommendation: There is a need to promote moringa production with the aim of sustaining its commercialization. There is also a need to increase the level of cultivation of the species among rural communities and farmers at large. Further research is recommended on i) moringa as a potential crop in agroforestry system, ii) market stabilisation and pricing strategies to reduce the inconsistency.

Objective 2: To determine the effect of planting density and cutting frequency on the nutritional quality of moringa under diverse agro-ecological conditions.

Hypothesis: Planting density and cutting frequency do not have an effect on the quantity and nutritional quality of moringa under diverse agro-ecological conditions.

Conclusion: The study revealed that planting moringa at a density of 435 000 plants/ha resulted in enhanced biomass accumulation at all cutting intervals. The hypothesis of the study is rejected because planting density significantly influenced biomass production at different cutting frequency and nutritional composition of moringa, mainly iron content at Syferkuil and majority of the nutrients at Ofcolaco experimental sites.

Recommendation: Further studies are recommended to evaluate the nutritional requirements of moringa through the application of organic and inorganic fertilizers under diverse weather conditions and soil types for farmers who are willing to commercialize the product.

Objective 3: To assess the effect of planting density on the gaseous exchange of moringa in comparison with other indigenous drought-tolerant tree species.

Hypothesis: i) Planting density has no effect on the gaseous exchange of moringa and ii) moringa is less drought resilient than mopane and marula tree species.

Conclusion: The study revealed that planting density had no influence on various gaseous exchange parameters of the moringa tree. The hypothesis of the study is accepted for the lack of effect on planting density and rejected for the comparison of the species. Furthermore, findings of the study showed that moringa can survive harsh conditions such as high temperatures and moisture deficit which occur under the semi-arid climates, relative to mopane and marula trees. It was found out that, under soil water deficit and high temperature, moringa reduces stomatal conductance and transpiration as an adaptation strategy which enhances its water use efficiency. Moringa has a number of stomata which is advantageous for maintaining high photosynthetic rate, stomatal conductance, transpiration rate and sub-stomatal CO_2. These results showed no doubt that moringa can be a good crop for the semi-arid conditions of Limpopo Province, where frequent drought periods prevail.

Recommendation: Moringa showed with no doubt that it can be a good crop in the semi-arid conditions of Limpopo Province, where the frequency of drought periods prevail. Further studies are recommended under variable agro-ecological conditions where weather parameters are considerably different, to come up with a clearer picture of the species potential for use to mitigate climate change effects.

Objective 4: To evaluate the effect of plant densities and weather conditions on biomass, seed and oil yield production of moringa tree.

Hypothesis: Plant densities and weather conditions have no effect on biomass, seed and oil yield production of moringa tree.

Conclusion: The study concluded that a density of 5000 plants ha^{-1} produced the highest biomass and seed yield of moringa. The study further showed that environmental and climatic conditions such as soil fertility, soil moisture, extremely high or low temperatures could have an impact on the growth and yield of moringa crop. The hypothesis of the study is therefore rejected. The study also revealed that moringa contains a high level of leaf nutrients even under marginal production areas and irrespective of the planting density.

Recommendation: Further studies are therefore recommended on use of multiple locations and improved management practices for biomass and seed yield as well as seed oil production enhancement.

Objective 5: To determine the effect of soil physical and chemical properties on moringa nutritional composition under diverse agro-ecological conditions of the Limpopo Province.

Hypothesis: Soil physical and chemical properties have no effect on moringa nutritional composition under diverse agro-ecological conditions of the Limpopo Province.

Conclusion: This study revealed that moringa can be produced under different soil textural classes as well as recycle soil nutrients and improve soil fertility. The hypothesis of the study is accepted because moringa had high nutritional content from different agro-ecological conditions of the Limpopo Province. The high nutritional content of moringa renders it as a potential tree in combating malnutrition and food insecurity in developing countries as it was not affected by soil physical and chemical properties. This makes moringa a valuable crop to be produced by smallholder farmers and also by any community in the backyard to sustain food security and serve as a good source of food supplement for the human body.

Recommendation: There is a need to study the root system and mycorrhiza colonization of moringa under different locations of the Limpopo Province, to explore their potential contribution to the plants high nutrient accumulation properties. An awareness campaign is needed to increase the level of cultivation of the species among rural communities and farmers at large due to its enormous benefits.

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APPENDICES

Appendix 4.1: Analysis of variance (ANOVA) for biomass to moringa planting density during the first harvest at Syferkuil.

Source	DF	SS	MS	F	P
Rep	3	457918	152639		
Treatment	3	1097043	365681	8.82	0.0048
Error	9	373070	41452		
Total	15	1928031			

Appendix 4.2: Analysis of variance (ANOVA) for biomass to moringa planting density during the second harvest at Syferkuil.

Source	DF	SS	MS	F	P
Rep	3	88441	29480		
Treatment	3	479671	159890	35.73	0.0000
Error	9	40275	4475		
Total	15	608387			

Appendix 4.3: Analysis of variance (ANOVA) for biomass to moringa planting density during the third harvest at Syferkuil.

Source	DF	SS	MS	F	P
Rep	3	152940	50980		
Treatment	3	314400	104800	9.25	0.0041
Error	9	102012	11335		
Total	15	569351			

Appendix 4.4: Analysis of variance (ANOVA) for biomass to moringa planting density during the fourth harvest at Syferkuil.

Source	DF	SS	MS	F	P
Rep	3	3152767	1050922		
Treatment	3	2389484	796495	6.40	0.0130
Error	9	1120220	124469		
Total	15	6662471			

Appendix 4.5: Analysis of variance (ANOVA) for biomass to moringa planting density during the first harvest at Ofcolaco.

Source	DF	SS	MS	F	P
Rep	3	318494	106165		
Treatment	3	7369511	2456504	53.98	0.0000
Error	9	409592	45510		
Total	15	8097597			

Appendix 4.6: Analysis of variance (ANOVA) for biomass to moringa planting density during the second harvest at Ofcolaco.

Source	DF	SS	MS	F	P
Rep	3	252493	84164		
Treatment	3	1573562	524521	13.27	0.0012
Error	9	355759	39529		
Total	15	2181814			

Appendix 4.7: Analysis of variance (ANOVA) for biomass to moringa planting density during the third harvest at Ofcolaco.

Source	DF	SS	MS	F	P
REP	3	166184	55395		
Treatment	3	554585	184862	18.50	0.0003
Error	9	89923	9991		
Total	15	810692			

Appendix 4.8: Analysis of variance (ANOVA) for biomass to moringa planting density during the fourth harvest at Ofcolaco.

Source	DF	SS	MS	F	P
Rep	3	752847	250949		
Treatment	3	4711276	1570425	23.80	0.0001
Error	9	593948	65994		
Total	15	6058071			

Appendix 5.1: Analysis of variance (ANOVA) for water use efficiency to density and monthly effect of moringa tree.

Source	DF	SS	MS	F	P
Rep	7	53.31	7.6150		
Density	3	15.18	5.0599	1.83	0.1409
Month	11	375.15	34.1046	12.36	0.0000
Density*Month	33	91.21	2.7640	1.00	0.4699
Error	329	908.17	2.7604		
Total	383	1443.01			

Appendix 5.2: Analysis of variance (ANOVA) for photosynthesis to density and monthly effect of moringa tree.

Source	DF	SS	MS	F	P
Rep	7	232.74	33.248		
Treatment	3	16.66	5.554	0.43	0.7327
Month	11	2464.90	224.082	17.29	0.0000
Treatment*Month	33	356.05	10.790	0.83	0.7323
Error	329	4263.62	12.959		
Total	383	7333.97			

Appendix 5.3: Analysis of variance (ANOVA) for transpiration to density and monthly effect of moringa tree.

Source	DF	SS	MS	F	P
Rep	7	25.855	3.6936		
Treatment	3	3.655	1.2183	1.12	0.3398
Month	11	211.449	19.2226	17.72	0.0000
Treatment*Month	33	26.699	0.8091	0.75	0.8457
Error	329	356.897	1.0848		
Total	383	624.555			

Appendix 5.4: Analysis of variance (ANOVA) for sub-stomatal CO_2 to density and monthly effect of moringa tree.

Source	DF	SS	MS	F	P
Rep	7	69680	9954.3		
Treatment	3	7042	2347.3	0.38	0.7670
Month	11	839141	76285.5	12.37	0.0000
Treatment*Month	33	196871	5965.8	0.97	0.5224
Error	329	2028437	6165.5		
Total	383	3141171			

Appendix 5.5: Analysis of variance (ANOVA) for stomatal conductance to density and monthly effect of moringa tree.

Source	DF	SS	MS	F	P
Rep	7	0.03220	0.00460		
Density	3	0.00907	0.00302	1.57	0.1956
Month	11	0.86209	0.07837	40.80	0.0000
Density*Month	33	0.07743	0.00235	1.22	0.1938
Error	329	0.63204	0.00192		
Total	383	1.61283			

Appendix 5.6: Analysis of variance (ANOVA) for photosynthesis to density and seasonal effect of the moringa tree.

Source	DF	SS	MS	F	P
Rep	7	232.74	33.248		
Density	3	16.66	5.554	0.35	0.7892
Season	3	1277.93	425.976	26.84	0.0000
Density*Season	9	77.19	8.576	0.54	0.8449
Error	361	5729.46	15.871		
Total	383	7333.97			

Appendix 5.7: Analysis of variance (ANOVA) for transpiration to density and seasonal effect of the moringa tree.

Source	DF	SS	MS	F	P
Rep	7	25.855	3.6936		
Density	3	3.655	1.2183	0.84	0.4723
Season	3	62.434	20.8114	14.36	0.0000
Density*Season	9	9.425	1.0472	0.72	0.6883
Error	361	523.186	1.4493		
Total	383	624.555			

Appendix 5.8: Analysis of variance (ANOVA) for sub-stomatal CO_2 to density and seasonal effect of the moringa tree.

Source	DF	SS	MS	F	P
Rep	7	69680	9954		
Density	3	7042	2347	0.31	0.8155
Season	3	333309	111103	14.84	0.0000
Density*Season	9	29138	3238	0.43	0.9173
Error	361	2702002	7485		
Total	383	3141171			

Appendix 5.9: Analysis of variance (ANOVA) for stomatal conductance to density and seasonal effect of the moringa tree.

Source	DF	SS	MS	F	P
Rep	7	0.03124	0.00446		
Density	3	0.00870	0.00290	0.80	0.4944
Season	3	0.22666	0.07555	20.85	0.0000
Density*Season	9	0.02748	0.00305	0.84	0.5772
Error	361	1.30791	0.00362		
Total	383	1.60197			

Appendix 6.1: Analysis of variance (ANOVA) for leaf stomatal density of drought-tolerant tree species.

Source	DF	SS	MS	F	P
Rep	4	38988	9747		
Treatment	2	1262357	631178	80.87	0.0000
Error	8	62442	7805		
Total	14	1363788			

Appendix 6.2: Analysis of variance (ANOVA) for monthly photosynthesis of moringa tree.

Source	DF	SS	MS	F	P
Rep	7	135.35	19.3358		
Month	11	1074.60	97.6907	4.66	0.0000
Error	77	1613.00	20.9481		
Total	95	2822.95			

Appendix 6.3: Analysis of variance (ANOVA) for monthly photosynthesis of mopane tree.

Source	DF	SS	MS	F	P
Rep	7	9.563	1.36617		
Month	11	75.984	6.90760	4.66	0.0000
Error	77	114.097	1.48178		
Total	95	199.644			

Appendix 6.4: Analysis of variance (ANOVA) for monthly photosynthesis of marula tree.

Source	DF	SS	MS	F	P
Rep	7	0.5332	0.07618		
Month	11	4.2277	0.38434	4.66	0.0000
Error	77	6.3561	0.08255		
Total	95	11.1170			

Appendix 6.5: Analysis of variance (ANOVA) for monthly transpiration of moringa tree.

Source	DF	SS	MS	F	P
Rep	7	5.689	0.81267		
Month	11	76.327	6.93882	8.26	0.0000
Error	77	64.673	0.83992		
Total	95	146.689			

Appendix 6.6: Analysis of variance (ANOVA) for monthly transpiration of mopane tree.

Source	DF	SS	MS	F	P
Rep	7	3.5679	0.50970		
Month	11	47.7646	4.34223	8.25	0.0000
Error	77	40.5245	0.52629		
Total	95	91.8570			

Appendix 6.7: Analysis of variance (ANOVA) for monthly transpiration of marula tree.

Source	DF	SS	MS	F	P
Rep	7	0.7598	0.10855		
Month	11	10.2839	0.93490	8.28	0.0000
Error	77	8.6910	0.11287		
Total	95	19.7347			

Appendix 6.8: Analysis of variance (ANOVA) for monthly sub-stomatal CO_2 of moringa tree.

Source	DF	SS	MS	F	P
Rep	7	64034	9147.7		
Month	11	160952	14632.0	2.30	0.0170
Error	77	489429	6356.2		
Total	95	714414			

Appendix 6.9: Analysis of variance (ANOVA) for monthly sub-stomatal CO_2 of mopane tree.

Source	DF	SS	MS	F	P
Rep	7	36349	5192.66		
Month	11	91370	8306.33	2.30	0.0170
Error	77	277838	3608.29		
Total	95	405557			

Appendix 6.10: Analysis of variance (ANOVA) for monthly sub-stomatal CO_2 of marula tree.

Source	DF	SS	MS	F	P
Rep	7	34715	4959.35		
Month	11	87262	7932.88	2.30	0.0170
Error	77	265344	3446.03		
Total	95	387321			

Appendix 6.11: Analysis of variance (ANOVA) for monthly stomatal conductance of the moringa tree.

Source	DF	SS	MS	F	P
Rep	7	0.00887	0.00127		
Month	11	0.23227	0.02112	9.87	0.0000
Error	77	0.16466	0.00214		
Total	95	0.40580			

Appendix 6.12: Analysis of variance (ANOVA) for monthly stomatal conductance of the mopane tree.

Source	DF	SS	MS	F	P
Rep	7	0.00100	1.429		
Month	11	0.02153	1.958	9.28	0.0000
Error	77	0.01625	2.110		
Total	95	0.03878			

Appendix 6.13: Analysis of variance (ANOVA) for monthly stomatal conductance of the marula tree.

Source	DF	SS	MS	F	P
Rep	7	0.00027	3.810		
Month	11	0.00588	5.348	9.29	0.0000
Error	77	0.00443	5.758		
Total	95	0.01058			

Appendix 6.14: Analysis of variance (ANOVA) for seasonal photosynthesis of moringa tree.

Source	DF	SS	MS	F	P
Rep	7	135.35	19.336		
Seasons	3	507.58	169.193	6.60	0.0005
Error	85	2180.02	25.647		
Total	95	2822.95			

Appendix 6.15: Analysis of variance (ANOVA) for seasonal photosynthesis of mopane tree.

Source	DF	SS	MS	F	P
Rep	7	9.563	1.3662		
Seasons	3	35.905	11.9684	6.60	0.0005
Error	85	154.176	1.8138		
Total	95	199.644			

Appendix 6.16: Analysis of variance (ANOVA) for seasonal photosynthesis of marula tree.

Source	DF	SS	MS	F	P
Rep	7	0.5332	0.07618		
Seasons	3	1.9889	0.66296	6.56	0.0005
Error	85	8.5949	0.10112		
Total	95	11.1170			

Appendix 6.17: Analysis of variance (ANOVA) for seasonal transpiration of moringa tree.

Source	DF	SS	MS	F	P
Rep	7	5.689	0.81267		
Seasons	3	28.323	9.44098	7.12	0.0003
Error	85	112.678	1.32562		
Total	95	146.689			

Appendix 6.18: Analysis of variance (ANOVA) for seasonal transpiration of mopane tree.

Source	DF	SS	MS	F	P
Rep	7	3.5679	0.50970		
Seasons	3	17.6614	5.88715	7.09	0.0003
Error	85	70.6276	0.83091		
Total	95	91.8570			

Appendix 6.19: Analysis of variance (ANOVA) for seasonal transpiration of marula tree.

Source	DF	SS	MS	F	P
Rep	7	0.7598	0.10855		
Seasons	3	3.8245	1.27484	7.15	0.0002
Error	85	15.1503	0.17824		
Total	95	19.7347			

Appendix 6.20: Analysis of variance (ANOVA) for seasonal sub-stomatal CO_2 of moringa tree.

Source	DF	SS	MS	F	P
Rep	7	64034	9147.7		
Seasons	3	52984	17661.4	2.51	0.0639
Error	85	597396	7028.2		
Total	95	714414			

Appendix 6.21: Analysis of variance (ANOVA) for seasonal sub-stomatal CO_2 of mopane tree.

Source	DF	SS	MS	F	P
Rep	7	36349	5192.7		
Seasons	3	30079	10026.2	2.51	0.0639
Error	85	339129	3989.8		
Total	95	405557			

Appendix 6.22: Analysis of variance (ANOVA) for seasonal sub-stomatal CO_2 of marula tree.

Source	DF	SS	MS	F	P
Rep	7	34715	4959.35		
Seasons	3	28725	9575.04	2.51	0.0639
Error	85	323881	3810.36		
Total	95	387321			

Appendix 7.1: Analysis of variance (ANOVA) for leaf biomass to moringa planting density during the first harvest.

Source	DF	SS	MS	F	P
Rep	7	150709	21529.9		
Treatment	3	263568	87855.8	15.77	0.0000
Error	21	117016	5572.2		
Total	31	531292			

Appendix 7.2: Analysis of variance (ANOVA) for dry total biomass to moringa planting density during the first harvest.

Source	DF	SS	MS	F	P
Rep	7	2453159	350451		
Treatment	3	1633265	544422	7.97	0.0010
Error	21	1434778	68323		
Total	31	5521203			

Appendix 7.3: Analysis of variance (ANOVA) for total grain yield to moringa planting density during the first harvest.

Source	DF	SS	MS	F	P
Rep	7	1257881	179697		
Treatment	3	1207689	402563	21.52	0.0000
Error	21	392756	18703		
Total	31	2858327			

Appendix 7.4: Analysis of variance (ANOVA) for seed yield to moringa planting density during the first harvest.

Source	DF	SS	MS	F	P
Rep	7	80946	11563.8		
Treatment	3	79944	26647.9	49.08	0.0000
Error	21	11402	543.0		
Total	31	172292			

Appendix 7.5: Analysis of variance (ANOVA) for oil % to moringa planting density during the first harvest.

Source	DF	SS	MS	F	P
Rep	7	8.4550	1.20786		
Treatment	3	6.4850	2.16167	1.19	0.3388
Error	21	38.2550	1.82167		
Total	31	53.1950			

Appendix 7.6: Analysis of variance (ANOVA) for oil yield to moringa planting density during the first harvest.

Source	DF	SS	MS	F	P
Rep	7	5.032	7187931		
Treatment	3	5.518	1.839	38.56	0.0000
Error	21	1.002	477025		
Total	31	1.155			

Appendix 7.7: Analysis of variance (ANOVA) for number of seeds per pod to moringa planting density during the first harvest.

Source	DF	SS	MS	F	P
Rep	7	47.219	6.74554		
Treatment	3	17.094	5.69792	1.32	0.2944
Error	21	90.656	4.31696		
Total	31	154.969			

Appendix 7.8: Analysis of variance (ANOVA) for 100 seed weight to moringa planting density during the first harvest.

Source	DF	SS	MS	F	P
Rep	7	69.066	9.8665		
Treatment	3	36.579	12.1928	1.31	0.2975
Error	21	195.449	9.3071		
Total	31	301.093			

Appendix 7.9: Analysis of variance (ANOVA) for leaf biomass to moringa planting density during the second harvest.

Source	DF	SS	MS	F	P
Rep	7	137136	19590.9		
Treatment	3	35747	11915.8	4.63	0.0123
Error	21	54033	2573.0		
Total	31	226916			

Appendix 7.10: Analysis of variance (ANOVA) for dry total biomass to moringa planting density during the second harvest.

Source	DF	SS	MS	F	P
Rep	7	2586072	369439		
Treatment	3	2596673	865558	10.54	0.0002
Error	21	1724905	82138		
Total	31	6907650			

Appendix 7.11: Analysis of variance (ANOVA) for total grain yield to moringa planting density during the second harvest.

Source	DF	SS	MS	F	P
Rep	7	1915173	273596		
Treatment	3	1693969	564656	23.59	0.0000
Error	21	502673	23937		
Total	31	4111815			

Appendix 7.12: Analysis of variance (ANOVA) for seed yield to moringa planting density during the second harvest.

Source	DF	SS	MS	F	P
Rep	7	139762	19966.0		
Treatment	3	195853	65284.3	19.31	0.0000
Error	21	71008	3381.4		
Total	31	406624			

Appendix 7.13: Analysis of variance (ANOVA) for oil % to moringa planting density during the second harvest.

Source	DF	SS	MS	F	P
Rep	7	1.9637	0.28054		
Treatment	3	3.5838	1.19458	0.86	0.4763
Error	21	29.1113	1.38625		
Total	31	34.6588			

Appendix 7.14: Analysis of variance (ANOVA) for oil yield to moringa planting density during the second harvest.

Source	DF	SS	MS	F	P
Rep	7	1.081	1.545		
Treatment	3	1.647	5.491	18.36	0.0000
Error	21	6.280	2.990		
Total	31	3.356			

Appendix 7.15: Analysis of variance (ANOVA) for number of seeds to moringa planting density per pod during the second harvest.

Source	DF	SS	MS	F	P
Rep	7	91.969	13.1384		
Treatment	3	10.594	3.5313	0.38	0.7705
Error	21	196.656	9.3646		
Total	31	299.219			

Appendix 7.16: Analysis of variance (ANOVA) for 100 seed weight to moringa planting density during the second harvest.

Source	DF	SS	MS	F	P
Rep	7	38.219	5.4598		
Treatment	3	81.344	27.1146	2.94	0.0568
Error	21	193.656	9.2217		
Total	31	313.219			

Appendix 7.17: Analysis of variance (ANOVA) for moringa leaf protein to planting density during the second harvest at Eiland.

Source	DF	SS	MS	F	P
Rep	7	32.184	4.59768		
Treatment	3	18.476	6.15875	1.23	0.3244
Error	21	105.339	5.01613		
Total	31	155.999			

Appendix 7.18: Analysis of variance (ANOVA) for moringa leaf calcium to planting density during the second harvest at Eiland.

Source	DF	SS	MS	F	P
Rep	7	0.44702	0.06386		
Treatment	3	1.14601	0.38200	1.68	0.2022
Error	21	4.78047	0.22764		
Total	31	6.37350			

Appendix 7.19: Analysis of variance (ANOVA) for moringa leaf magnesium to planting density during the second harvest at Eiland.

Source	DF	SS	MS	F	P
Rep	7	0.01664	0.00238		
Treatment	3	0.05744	0.01915	2.82	0.0637
Error	21	0.14251	0.00679		
Total	31	0.21659			

Appendix 7.20: Analysis of variance (ANOVA) for moringa leaf potassium to planting density during the second harvest at Eiland.

Source	DF	SS	MS	F	P
Rep	7	0.31465	0.04495		
Treatment	3	0.33345	0.11115	2.08	0.1328
Error	21	1.11965	0.05332		
Total	31	1.76775			

Appendix 7.21: Analysis of variance (ANOVA) for moringa leaf phosphorus to planting density during the second harvest at Eiland.

Source	DF	SS	MS	F	P
Rep	7	0.01835	2.621		
Treatment	3	0.00730	2.433	1.72	0.1934
Error	21	0.02970	1.414		
Total	31	0.05535			

Appendix 7.22: Analysis of variance (ANOVA) for moringa leaf zinc to planting density during the second harvest at Eiland.

Source	DF	SS	MS	F	P
Rep	7	61.670	8.8100		
Treatment	3	50.125	16.7083	4.22	0.0174
Error	21	83.060	3.9552		
Total	31	194.855			

Appendix 7.23: Analysis of variance (ANOVA) for moringa leaf manganese to planting density during the second harvest at Eiland.

Source	DF	SS	MS	F	P
Rep	7	230.22	32.8884		
Treatment	3	187.59	62.5313	1.08	0.3807
Error	21	1220.66	58.1265		
Total	31	1638.47			

Appendix 7.24: Analysis of variance (ANOVA) for moringa leaf iron to planting density of moringa during the second harvest.

Source	DF	SS	MS	F	P
Rep	7	398.72	56.960		
Treatment	3	247.09	82.365	0.63	0.6063
Error	21	2764.16	131.626		
Total	31	3409.97			

Appendix 7.25: Analysis of variance (ANOVA) for soil nitrogen (0-30 cm) to planting density of moringa during the first harvest at Eiland.

Source	DF	SS	MS	F	P
Rep	7	0.00174	2.482		
Treatment	3	0.00134	4.458	0.79	0.5152
Error	21	0.01191	5.673		
Total	31	0.01499			

Appendix 7.26: Analysis of variance (ANOVA) for soil nitrogen (30-60 cm) to planting density of moringa during the first harvest at Eiland.

Source	DF	SS	MS	F	P
Rep	7	0.00174	2.482		
Treatment	3	0.00134	4.458	0.79	0.5152
Error	21	0.01191	5.673		
Total	31	0.01499			

Appendix 7.27: Analysis of variance (ANOVA) for soil phosphorus (0-30 cm) to planting density of moringa during the first harvest at Eiland.

Source	DF	SS	MS	F	P
Rep	7	958.72	136.960		
Treatment	3	381.59	127.198	1.16	0.3472
Error	21	2296.16	109.341		
Total	31	3636.47			

Appendix 7.28: Analysis of variance (ANOVA) for soil phosphorus (30-60 cm) to planting density of moringa during the first harvest at Eiland.

Source	DF	SS	MS	F	P
Rep	7	1346.72	192.388		
Treatment	3	831.09	277.031	1.41	0.2689
Error	21	4138.16	197.055		
Total	31	6315.97			

Appendix 7.29: Analysis of variance (ANOVA) for soil potassium (0-30 cm) to planting density of moringa during the first harvest at Eiland.

Source	DF	SS	MS	F	P
Rep	7	4327.5	618.21		
Treatment	3	9209.0	3069.67	4.16	0.0185
Error	21	15501.5	738.17		
Total	31	29038.0			

Appendix 7.30: Analysis of variance (ANOVA) for soil potassium (30-60 cm) to planting density of moringa during the first harvest at Eiland.

Source	DF	SS	MS	F	P
Rep	7	8744.0	1249.14		
Treatment	3	6624.8	2208.28	2.77	0.0673
Error	21	16768.9	798.52		
Total	31	32137.7			

Appendix 7.31: Analysis of variance (ANOVA) for soil calcium (0-30 cm) to planting density of moringa during the first harvest at Eiland.

Source	DF	SS	MS	F	P
Rep	7	4207481	601069		
Treatment	3	4221476	1407159	4.91	0.0097
Error	21	6015853	286469		
Total	31	1.444			

Appendix 7.32: Analysis of variance (ANOVA) for soil calcium (30-60 cm) to planting density of moringa during the first harvest at Eiland.

Source	DF	SS	MS	F	P
Rep	7	2603037	371862		
Treatment	3	9862537	3287512	9.69	0.0003
Error	21	7127414	339401		
Total	31	1.959			

Appendix 7.33: Analysis of variance (ANOVA) for soil magnesium (0-30 cm) to planting density of moringa during the first harvest at Eiland.

Source	DF	SS	MS	F	P
Rep	7	451460	64494.3		
Treatment	3	64057	21352.5	2.42	0.0950
Error	21	185591	8837.7		
Total	31	701109			

Appendix 7.34: Analysis of variance (ANOVA) for soil magnesium (30-60 cm) to planting density of moringa during the first harvest at Eiland.

Source	DF	SS	MS	F	P
Rep	7	203487	29069.6		
Treatment	3	180662	60220.7	2.76	0.0677
Error	21	458400	21828.6		
Total	31	842549			

Appendix 7.35: Analysis of variance (ANOVA) for soil zinc (0-30 cm) to planting density of moringa during the first harvest at Eiland.

Source	DF	SS	MS	F	P
Rep	7	26.5172	3.78817		
Treatment	3	3.6759	1.22531	1.28	0.3060
Error	21	20.0516	0.95484		
Total	31	50.2447			

Appendix 7.36: Analysis of variance (ANOVA) for soil zinc (30-60 cm) to planting density of moringa during the first harvest at Eiland.

Source	DF	SS	MS	F	P
Rep	7	14.7997	2.11424		
Treatment	3	6.2134	2.07115	1.43	0.2633
Error	21	30.4991	1.45234		
Total	31	51.5122			

Appendix 7.37: Analysis of variance (ANOVA) for soil manganese (0-30 cm) to planting density of moringa during the first harvest at Eiland.

Source	DF	SS	MS	F	P
Rep	7	1260.88	180.125		
Treatment	3	307.37	102.458	1.59	0.2209
Error	21	1350.63	64.315		
Total	31	2918.88			

Appendix 7.38: Analysis of variance (ANOVA) for soil manganese (30-60 cm) to planting density of moringa during the first harvest at Eiland.

Source	DF	SS	MS	F	P
Rep	7	455.88	65.125		
Treatment	3	1143.37	381.125	6.77	0.0023
Error	21	1182.63	56.315		
Total	31	2781.87			

Appendix 7.39: Analysis of variance (ANOVA) for soil copper (0-30 cm) to planting density of moringa during the first harvest at Eiland.

Source	DF	SS	MS	F	P
Rep	7	16.4850	2.35500		
Treatment	3	8.0200	2.67333	1.17	0.3451
Error	21	48.0150	2.28643		
Total	31	72.5200			

Appendix 7.40: Analysis of variance (ANOVA) for soil copper (30-60 cm) to planting density of moringa during the first harvest at Eiland.

Source	DF	SS	MS	F	P
Rep	7	46.0688	6.58125		
Treatment	3	2.3238	0.77458	0.34	0.7977
Error	21	48.0662	2.28887		
Total	31	96.4588			

Appendix 7.41: Analysis of variance (ANOVA) for soil pH (0-30 cm) to planting density of moringa during the first harvest at Eiland.

Source	DF	SS	MS	F	P
Rep	7	22.8893	3.26991		
Treatment	3	1.2234	0.40781	0.21	0.8869
Error	21	40.3760	1.92267		
Total	31	64.4888			

Appendix 7.42: Analysis of variance (ANOVA) for soil pH (30-60 cm) to planting density of moringa during the first harvest at Eiland.

Source	DF	SS	MS	F	P
Rep	7	10.2955	1.47078		
Treatment	3	3.8209	1.27362	0.75	0.5334
Error	21	35.5672	1.69368		
Total	31	49.6835			

Appendix 7.43: Analysis of variance (ANOVA) for soil organic carbon (0-30 cm) to planting density of moringa during the first harvest at Eiland.

Source	DF	SS	MS	F	P
Rep	7	1.48219	0.21174		
Treatment	3	0.84094	0.28031	2.48	0.0894
Error	21	2.37656	0.11317		
Total	31	4.69969			

Appendix 7.44: Analysis of variance (ANOVA) for soil organic carbon (30-60 cm) to planting density of moringa during the first harvest at Eiland.

Source	DF	SS	MS	F	P
Rep	7	0.64875	0.09268		
Treatment	3	0.01125	0.00375	0.12	0.9487
Error	21	0.66875	0.03185		
Total	31	1.32875			

Appendix 7.45: Analysis of variance (ANOVA) for soil nitrogen (0-30 cm) to planting density of moringa during the second harvest at Eiland.

Source	DF	SS	MS	F	P
Rep	7	0.00135	1.929		
Treatment	3	0.00038	1.250	0.25	0.8625
Error	21	0.01062	5.060		
Total	31	0.01235			

Appendix 7.46: Analysis of variance (ANOVA) for soil nitrogen (30-60 cm) to planting density of moringa during the second harvest at Eiland.

Source	DF	SS	MS	F	P
Rep	7	0.00182	2.603		
Treatment	3	0.00023	7.813	0.16	0.9203
Error	21	0.01009	4.805		
Total	31	0.01215			

Appendix 7.47: Analysis of variance (ANOVA) for soil phosphorus (0-30 cm) to planting density of moringa during the second harvest at Eiland.

Source	DF	SS	MS	F	P
Rep	7	2702.9	386.13		
Treatment	3	7542.4	2514.13	6.96	0.0020
Error	21	7588.6	361.36		
Total	31	17833.9			

Appendix 7.48: Analysis of variance (ANOVA) for soil phosphorus (30-60 cm) to planting density of moringa during the second harvest at Eiland.

Source	DF	SS	MS	F	P
Rep	7	867.88	123.98		
Treatment	3	4239.38	1413.13	16.89	0.0000
Error	21	1756.63	83.65		
Total	31	6863.88			

Appendix 7.49: Analysis of variance (ANOVA) for soil potassium (0-30 cm) to planting density of moringa during the second harvest at Eiland.

Source	DF	SS	MS	F	P
Rep	7	6179.7	882.82		
Treatment	3	22777.6	7592.53	12.36	0.0001
Error	21	12902.2	614.39		
Total	31	41859.5			

Appendix 7.50: Analysis of variance (ANOVA) for soil potassium (30-60 cm) to planting density of moringa during the second harvest at Eiland.

Source	DF	SS	MS	F	P
Rep	7	5713.4	816.20		
Treatment	3	27897.4	9299.13	7.33	0.0015
Error	21	26649.1	1269.01		
Total	31	60259.9			

Appendix 7.51: Analysis of variance (ANOVA) for soil calcium (0-30 cm) to planting density of moringa during the second harvest at Eiland.

Source	DF	SS	MS	F	P
Rep	7	2878839	411263		
Treatment	3	1822342	607447	1.62	0.2158
Error	21	7894769	375941		
Total	31	1.260			

Appendix 7.52: Analysis of variance (ANOVA) for soil calcium (30-60 cm) to planting density of moringa during the second harvest at Eiland.

Source	DF	SS	MS	F	P
Rep	7	4484290	640613		
Treatment	3	1256452	418817	0.95	0.4342
Error	21	9253818	440658		
Total	31	1.499			

Appendix 7.53: Analysis of variance (ANOVA) for soil magnesium (0-30 cm) to planting density of moringa during the second harvest at Eiland.

Source	DF	SS	MS	F	P
Rep	7	46549	6649.8		
Treatment	3	81458	27152.8	1.87	0.1657
Error	21	305029	14525.2		
Total	31	433036			

Appendix 7.54: Analysis of variance (ANOVA) for soil magnesium (30-60 cm) to planting density of moringa during the second harvest at Eiland.

Source	DF	SS	MS	F	P
Rep	7	84741	12105.9		
Treatment	3	52078	17359.5	0.93	0.4423
Error	21	390818	18610.4		
Total	31	527638			

Appendix 7.55: Analysis of variance (ANOVA) for soil zinc (0-30 cm) to planting density of moringa during the second harvest at Eiland

Source	DF	SS	MS	F	P
Rep	7	6.9887	0.99839		
Treatment	3	6.2537	2.08458	0.75	0.5367
Error	21	58.6763	2.79411		
Total	31	71.9187			

Appendix 7.56: Analysis of variance (ANOVA) for soil zinc (30-60 cm) to planting density of moringa during the second harvest at Eiland.

Source	DF	SS	MS	F	P
Rep	7	13.4122	1.91603		
Treatment	3	9.1609	3.05365	2.89	0.0595
Error	21	22.1766	1.05603		
Total	31	44.7497			

Appendix 7.57: Analysis of variance (ANOVA) for soil manganese (0-30 cm) to planting density of moringa during the second harvest at Eiland.

Source	DF	SS	MS	F	P
Rep	7	357.38	51.0536		
Treatment	3	34.38	11.4583	0.28	0.8385
Error	21	856.13	40.7679		
Total	31	1247.88			

Appendix 7.58: Analysis of variance (ANOVA) for soil manganese (30-60 cm) to planting density of moringa during the second harvest at Eiland.

Source	DF	SS	MS	F	P
Rep	7	796.72	113.817		
Treatment	3	263.59	87.865	2.11	0.1295
Error	21	874.66	41.650		
Total	31	1934.97			

Appendix 7.59: Analysis of variance (ANOVA) for soil copper (0-30 cm) to planting density of moringa during the second harvest at Eiland.

Source	DF	SS	MS	F	P
Rep	7	10.6450	1.52071		
Treatment	3	2.0700	0.69000	0.56	0.6499
Error	21	26.0650	1.24119		
Total	31	38.7800			

Appendix 7.60: Analysis of variance (ANOVA) for soil copper (30-60 cm) to planting density of moringa during the second harvest at Eiland.

Source	DF	SS	MS	F	P
Rep	7	15.4387	2.20554		
Treatment	3	2.3538	0.78458	0.96	0.4295
Error	21	17.1463	0.81649		
Total 31	34.9387				

Appendix 7.61: Analysis of variance (ANOVA) for soil pH (0-30 cm) to planting density of moringa during the second harvest at Eiland.

Source	DF	SS	MS	F	P
Rep	7	4.5437	0.64910		
Treatment	3	0.8015	0.26715	0.24	0.8662
Error	21	23.2036	1.10493		
Total 31	28.5487				

Appendix 7.62: Analysis of variance (ANOVA) for soil pH (30-60 cm) to planting density of moringa during the second harvest at Eiland.

Source	DF	SS	MS	F	P
Rep	7	11.3289	1.61842		
Treatment	3	2.0330	0.67766	0.56	0.6478
Error	21	25.4488	1.21185		
Total 31	38.8107				

Appendix 7.63: Analysis of variance (ANOVA) for soil organic carbon (0-30 cm) to planting density of moringa during the second harvest at Eiland.

Source	DF	SS	MS	F	P
Rep	7	1.00219	0.14317		
Treatment	3	0.31594	0.10531	0.91	0.4550
Error	21	2.44156	0.11626		
Total	31	3.75969			

Appendix 7.64: Analysis of variance (ANOVA) for soil organic carbon (30-60 cm) to planting density of moringa during the second harvest at Eiland.

Source	DF	SS	MS	F	P
Rep	7	0.64375	0.09196		
Treatment	3	0.31125	0.10375	0.65	0.5896
Error	21	3.33375	0.15875		
Total	31	4.28875			

Appendix 8.1: Analysis of variance (ANOVA) for soil nitrogen to soil textural classes under diverse moringa cultivation areas.

Source	DF	SS	MS	F	P
Soil texture	5	0.02267	4.534	4.48	0.0047
Error	25	0.02528	1.011		
Total	30	0.04795			

Appendix 8.2: Analysis of variance (ANOVA) for soil phosphorus to soil textural classes under diverse moringa cultivation areas

Source	DF	SS	MS	F	P
Soil texture	5	3323.8	664.763	0.99	0.4450
Error	25	16827.7	673.107		
Total	30	20151.5			

Appendix 8.3: Analysis of variance (ANOVA) for soil potassium to soil textural classes under diverse moringa cultivation areas.

Source	DF	SS	MS	F	P
Soil texture	5	185599	37119.7	1.66	0.1818
Error	25	559926	22397.0		
Total	30	745524			

Appendix 8.4: Analysis of variance (ANOVA) for soil calcium to soil textural classes under diverse moringa cultivation areas.

Source	DF	SS	MS	F	P
Soil texture	5	8860590	1772118	4.05	0.0079
Error	25	1.094	437625		
Total	30	1.980			

Appendix 8.5: Analysis of variance (ANOVA) for pH to soil textural classes under diverse moringa cultivation areas.

Source	DF	SS	MS	F	P
Soil texture	5	1.3704	0.27409	0.37	0.8673
Error	25	18.7506	0.75002		
Total	30	20.1210			

Appendix 8.6: Analysis of variance (ANOVA) for organic carbon to soil textural classes under diverse moringa cultivation areas.

Source	DF	SS	MS	F	P
Soil texture	5	5.21508	1.04302	6.34	0.0006
Error	25	4.11267	0.16451		
Total	30	9.32774			

Appendix 8.7: Analysis of variance (ANOVA) for moringa leaf nitrogen to soil textural classes under diverse cultivation areas.

Source	DF	SS	MS	F	P
Soil texture	5	3.4693	0.69386	1.12	0.3733
Error	25	15.4314	0.61726		
Total	30	18.9007			

Appendix 8.8: Analysis of variance (ANOVA) for moringa crude protein to soil textural classes under diverse cultivation areas.

Source	DF	SS	MS	F	P
Soil texture	5	70.233	14.0466	0.65	0.6618
Error	25	537.566	21.5027		
Total	30	607.799			

Appendix 8.9: Analysis of variance (ANOVA) for moringa leaf calcium to soil textural classes under diverse cultivation areas.

Source	DF	SS	MS	F	P
Soil texture	5	1.9662	0.39324	0.74	0.6019
Error	25	13.3150	0.53260		
Total	30	15.2812			

Appendix 8.10: Analysis of variance (ANOVA) for moringa leaf phosphorus to soil textural classes under diverse cultivation areas.

Source	DF	SS	MS	F	P
Soil texture	5	0.01909	3.817	1.63	0.1891
Error	25	0.05860	2.344		
Total	30	0.07768			

Appendix 8.11: Analysis of variance (ANOVA) for moringa leaf iron to soil textural classes under diverse cultivation areas.

Source	DF	SS	MS	F	P
Soil texture	5	41819	8363.79	1.02	0.4295
Error	25	205901	8236.06		
Total	30	247720			