THE EFFECT OF BUSH CLEARING ON SOIL PROPERTIES, AT CHEETAH CONSERVATION FUND FARM IN OTJOZONDJUPA REGION, NAMIBIA

A THESIS SUBMITTED IN PARTIAL FULFILMENT FOR THE DEGREE OF MASTER OF ARTS IN GEOGRAPHY AND ENVIRONMENTAL STUDIES

OF

THE UNIVERSITY OF NAMIBIA

BY

ANGULA NAHAS ENKONO

201066114

July, 2016

Main Supervisor: Dr S. T. Angombe

Co-supervisor: Dr E. G. Kwembeya

Abstract

The thesis discusses the problem of bush clearing as they affect soil quality, its productivity and environment in the semi-arid areas. In this case, land clearing came as a result of bush encroachment control mechanism. Bush encroachment is a form of land degradation present prominently in semi-arid areas. Namibia is affected by bush encroachment on a massive scale. The phenomenon is currently understood to affect large part of the country, causing severe economic losses for Namibia, in both the commercial and communal farming areas. The primary aim of the study was to investigate the effect of bush clearing on soil quality, particularly the soil macro-nutrients, N, P and K.

The study was conducted on one farm, Cheetah Conservation Fund (CCF) on two experimental fields. Samples were taken from two differentiated (cleared and non-cleared area) ecosystems. Fifty (50) soil samples were collected at depths of up to 30 cm. In each field 25 samples was collected, the samples were collected at 200 metres interval. The soil was tested for selected macro-nutrients and micro-nutrients. Soil texture and composition was also tested as well as electrical conductivity, pH, and soil organic matter.

The bush encroached site differed significantly from the cleared site with regards to nitrogen content, where high nitrogen content was recorded in the encroached site. The high occurrence of N content in the bush encroached site explain the nitrogen fixation by leguminous trees.

Contrary to the study's initial hypothesis, which hypothesized that there is no significant difference in SOM between bush-cleared and bush encroached sites, the study found that there is however a significant difference in the median SOM between the two sites.

Key words: Bush encroachment, NPK, SOC, SOM, soil nutrients

TABLE OF CONTENTS

Table of figures

LIST OF TABLES

DEDICATION

This thesis is dedicated to my late mother, Selma Ileni Shipanga ,my late Father, my grandmother Selma Namupala my mom Pauline Niita Enkono, my sisters Selma, Pauline, Aina, my brothers Christopher, Tobias, Boyboy, my cousins Bony Tangeni, Selly Megameno, my late brother shilumbu and my daughter Francina Joyce Enkono, for they made me who I am today. Was it not for their unconditional love, tireless effort and commitment in giving me proper guidance during my childhood, perhaps I would not be writing this thesis.

ACKNOWLEDGEMENTS

I would like to thank, first and foremost, the Almighty God for giving me the strength and wisdom to carry out this study. Secondly, the author wishes to convey special thanks and appreciation to the main supervisor Dr. Simon T. Angombe and Co-supervisor Dr Ezekiel Kwembeya for their assistance as the author's supervisors. You are thanked for your suggestions, constructive criticisms, advice, instruction and above all your academic guidance and patience towards me from the beginning till the end of writing this thesis. May the Almighty Father bless you always!

I will always be thankful to Dr Angombe for introducing me to soil science you really made my research worthwhile.

I am most grateful to my mom Pauline Niita Enkono, my siblings Christopher, Selly, Tangeni, Bony, Boyboy as well as my entire family for the moral support.

It is my pleasure to thank Wilhelmina Nuule, thank you for assisting me during fieldwork, I have learned a lot from you, and may God bless you.

I would like to thank Tukaleni Mbeeli, Allen Kandjai, Visto Amputu and Nyasha Musekiwa your assistance during the course of this study cannot be over emphasised thank you so much. May the almighty God bless you.

A special thanks to the Ministry of Agriculture Water and forestry, especially Alberta Sipapo who assisted me with soil sample analysis thank you so much. A very special thanks to John Mendelsohn and Stephie Mendelsohn, your hospitality and assistance was very much valuable, thank you so much and God bless you. The author would also like to thank, Margareth Angula ,Dr Martha Akawa-Shifufa, Martha Mosha and Goodman Gwasira, your support and encouragement cannot be overemphasised thank you and God Bless you all.

My deepest appreciation goes to Southern African Science Service Centre for Climate Change and Adaptive Land Management (**SASSCAL**) for funding my study, the University of Namibia, and indeed the Department of Geography and Environmental Studies (UNAM) for granting me an opportunity to study and complete this Master's degree. To all those individuals who made this thesis possible, but whose names do not appear here, I say thank you and God bless you all.

DECLARATION

This is a thesis prepared in partial fulfilment of the requirements for a of Masters of Arts degree in Geography and Environmental Studies at the University of Namibia in Windhoek, Namibia.

I Enkono Angula Nahas declare hereby that this thesis is the original work of the author and this work, or part thereof has not been submitted for a master's degree in any other institution of higher education. The views and opinions stated therein are those of the author and not necessarily those of the institution.

I, Enkono Angula Nahas, grant The University of Namibia the right to reproduce this thesis in whole or in part, in any manner or format, which The University of Namibia may deem fit, for any person or institution requiring it for study and research; providing that The University of Namibia shall waive this right if the whole thesis has been or is being published in a manner satisfactory to the University.

ANE Date: 13/04/2018

Angula Nahas Enkono

Acronyms

CCF	Cheetah Conservation Fund
EC	Electrical Conductivity
GPS	Global Positioning System
IPCC	Intergovernmental panel on Climate Change
NAU	Namibia Agricultural Union
NRCS	Natural resource conservation services
NPK	Nitrogen, Phosphorus and Potassium
OM	Organic matter
RIRDC	Rural Industries and Development Co-operation
SASSCAL	Southern African Science Service Centre for Climate Change and Adaptive Land Management
SOC	Soil Organic Carbon
SPSS	Statistical Package for Social Scientist

CHAPTER 1: INTRODUCTION

1.1. **Background introduction**

Namibia is a sparsely populated, semi-arid to arid country in south-western Africa (Espach, Lubbe & Ganzin, 2009). The country covers an area of 823,680 km^2. It spans some approximately 1320 km at its longest and 1440 km at its widest point (Mendelsohn, Jarvis, Roberts & Robertson, 2002).

With a mean annual rainfall of approximately 270 mm, Namibia is rated to have the driest climate in sub-Saharan Africa. Unconsolidated sand and shallow, weakly developed soils on Bedrock characterise the main groups of soils in this semi-arid to arid country (Jim & Burke 2008). This aridity is believed to result in the absence of deep soils over much of the country and the low level of nutrients in most soils (Mendelsohn et al., 2002).

The country's rainfall declines in a rather smooth gradient from the wettest and most tropical areas in the north-east (±700 mm) to the extremely arid Namib Desert in the west (<50 mm). Low and variable rainfall is normal and droughts are frequent and expected (Espach et al., 2009; Mendelsohn et al., 2002).

Agriculture is the predominant land use in Namibia. However it is severely limited by extremely variable and low rainfall. It is assumed that about 70% of the population is directly or indirectly involved in livestock farming (Espach et al., 2009). More land is used for agriculture than for any other purpose.

It is understood that grazing capacity has changed over time and consequently rangeland condition has deteriorated considerably due to widespread bush-encroachment. Bester (1996) estimated that about 12–14% of Namibia's surface area suffers from bush encroachment.

Bush encroachment can be defined as the process whereby the woody layer of a savanna increases in density and cover to such an extent that grass production is negatively affected through the resultant increase in competition (de Klerk, 2004; Joubert, 2014). In short, bush encroachment is a form of land degradation present prominently in semi-arid areas.

Namibia is affected by bush encroachment on a massive scale. The phenomenon is currently understood to affects about 26 to 30 million hectares of farmland in eight of the country's 14 regions. That amounts to roughly 30% of Namibia's land area (German Corporation for International Cooperation [GIZ, 2015]. Other studies on bush encroachment, reported that about 260 000 km^2 or 30% of the surface area of Namibia is encroached by invader bushes (de Klerk, 2004). This phenomenon is thought to cause severe economic losses for Namibia, in both the commercial and communal farming areas (GIZ, 2015; de Klerk, 2004).

The proliferation of these bush species is thought to reduce the availability of pastures for grazing animals in two ways; first, the loss of grass cover because grass cannot grow under thick bush. Secondly, animals cannot penetrate dense bush to get to the grass that remain in small patches between the woody plants (GIZ, 2015; Mendelsohn et al., 2002).

Senegalia mellifera (Vahl) Seigler & Ebinger (Black thorn) is a major species responsible for bush thickening in Namibia. It covers the Highland Shrub land, Thorn-bush Shrub land and Southern Kalahari savannas of Namibia (de Klerk, 2004). However, due to its invasive nature (and several other species of indigenous bush) it has been identified as encroacher species that require thinning. Many farmers in Namibia view bush encroachment as an expensive nuisance factor that needs to be eradicated (von Oertzen, 2009). However, in Camel-thorn Kalahari of Namibia, *Senegalia mellifera* is believed to fix nitrogen. More so, with regards to carbon sequestration, bushes are seen as a carbon sink (de Klerk, 2004).

1.2 Problem statement

During the past century, many savannas and grass-dominated ecosystems around the world have been affected by the spread of woody plants (Van Auken, 2000, 2009). These encroaching woody species are believed to be involved in symbiotic nitrogen fixation, thus have the potential to bring additional nitrogen into the ecosystem (Boutton, 2010). Similarly, trends of significantly high content of soil N, OM, P, K, Mg, pH, Na were recorded by Rothauge et al. (2003), in semi-arid Camel thorn savannas, alluding to soil enrichment by leguminous trees. Additionally, Abdallah et al (2008), studied *Vachellia tortilis (Forssk.)* and confirmed high amounts of total N, P, K, Ca, Na, and Mg under trees than in the open.

Consequently, clearing bush may have a negative impact on soil quality, particularly soil nutrients such as P, N and K. While great efforts have gone into understanding the consequences of woody encroachment in Northern- Central Namibia grassland ecosystems, less is known about bush clearing and its effect on soil quality.

1.3 General and specific objectives

The primary objective of the study was to investigate the effect of bush clearing on soil quality, particularly, the soil nutrients, nitrogen, phosphorus and potassium.

The specific objectives for the study are as follows:

- To determine whether selected essential nutrients differ between cleared and un-cleared sites.
- To investigate and compare the selected soil physical (soil texture and composition and selected soil chemical properties) (pH and EC) between cleared and un-cleared sites.
- To quantify and compare Soil Organic Carbon (SOC) between cleared and un-cleared sites.

1.4 **Hypotheses of the study**

1. There is no difference in the levels of selected essential soil nutrients between cleared and un-cleared sites.
2. There is no difference in selected soil physical and chemical properties between cleared and un-cleared sites
3. There is no significant difference in SOC between cleared and un-cleared sites.

1.5 **Significance of the study**

In this study, soil quality at the Cheetah Conservation Foundation (CCF) has been estimated, to determine whether tree clearance results in the loss of soil nutrients which may leads to land degradation and reduced agricultural production.

Estimates of the amounts of soil nutrients is required to balance inflows and outflows of nutrients and thus prevent possible loss of nutrient from the soil due to bush clearing.

Even though, bush clearing is seen as an attempt to reduce the proliferation of bush species and improve grazing capacity, little is known and documented regarding the impact of bush clearing on soil nutrients in Namibia, especially the Northern-Central Namibia where bush encroachment is prominent.

For that reason, this study will be necessary to fill some of these gaps and afford an understanding of the impact of bush clearing on soil quality. The findings of the study will help farmers to attract approaches that aid them adjust to more sustainable ways of dealing with bush encroachment. Nutrients are of great significance to the soil and if lost, the soil may become less fertile and the impact may lead to loss in agricultural production and increased land degradation.

The study is envisioned to apprise people of the consequences of bush clearing, especially; those in the North-Central Namibia, where bush encroachment is prominent and clearing activities are taking place. The result will provide information on the importance of soil quality and how this relates to the presence of invader bush species for without fertile soil, farmers and communities in bush encroached areas may not be able to sustain themselves.

1.6 **Limitation of the study**

The study is envisaged to have the following limitation: The study period is only two years. Therefore, it will not be possible allow for seasonal comparisons and will limit parameters that are dependent on seasonal changes to be measure and compared. In addition the limited time will not allow the study to be conducted in two different areas that are subject to different climatic conditions for comparisons.

1.7 **Delimitation of the study**

The primary focus of the paper is to measure selected soil quality parameters, such as potassium, nitrogen, phosphorus, soil organic carbon, selected trace elements and soil texture and composition of the soil. Further, the study is only limited to Northern-Central Namibia, and will focus only on one farm, the CCF.

CHAPTER 2: LITERATURE REVIEW

2.1. **Introduction**

Many savannas and grass-dominated ecosystems around the world have been affected by the spread of woody plants (Van Auken, 2009). InNamibia Larger part of savanna ecosystems have been affected by bush thickening (de Klerk, 2004; Mendelsohn et al., 2002; Bester, 1996). Better termed “bush encroachment’’ (Joubert, 2014), the process is understood to have severe effects on agriculture, by reducing grazing capacity (Bester, 1996) and resulting in severe economic losses for Namibia, a country where 70% of the population is involved in livestock farming (Espach et al., 2009) and land use is predominantly for agriculture.

While great efforts have gone into understanding the consequences of woody encroachment in greater part of Namibia’s savanna ecosystems and bush clearing has been proposed to eliminate these encroaching species.

However, the effect of tree clearing on soil quality has not been assessed and quantified, especially at the CCF area. The study area is a habitat to a wide range of wild game, including Kudu, Oryx, Red hartebeest, Eland, Warthog, Steenbok, and Duiker, these animals make use of the vegetation either to browse or graze (Jeffrey, Buyer, Schmidt-Küntzel, Nghikembua, Maul, & Marker, 2016). Indicating that trees create fertility islands that continue to benefit domestic livestock and game by grazing and browsing (Nzehengwa, 2013). The CCF is part of the greater Waterberg Conservancy.

Notably, this study will seek an understanding on the effect of bush clearing on soil quality. Looking at selected soil nutrients properties. The study will be guided by literatures that have looked at similar studies, critically assessing their assertion and suggestions towards the subject matter, while fitting them in with findings from this study.

2.2. **Bush encroachment in Namibia**

Information on the extent of bush encroachment is largely based on estimates which seem unreliable and are often conflicting. For example, studies by Van Niekerk & Bester (1979) originally estimated the area affected by bush encroachment at 8 million hectares, of which 5.3 million hectares were seriously encroached.

Other estimates on the degree of bush encroachment in Namibia, reported that the invasive species covered about 15 million hectares of land, representing almost 50 percent of the commercial farming area of 34.89 million hectares (Bester,1998). While, de Klerk (2004) in his study of bush encroachment in Namibia, reported that about 260 000 km^2 or 30% of the surface area of Namibia is encroached by invader bushes.

This process, also referred to as bush thickening, is highly significant, both ecologically and economically. It is understood to be responsible for the decline in grazing capacity of large areas of the southern African savanna, often to such an extent that many previously economic livestock properties are now no longer economically viable (Smit, 2004). Other estimates reported that about 50% of the commercial ranching areas of Namibia are affected by bush thickening, mainly by *Senegalia Mellifera* (Rothauge & Smit, 2003; Joubert, 2008).

There seem to be no agreement among researchers regarding the area of Namibia affected by bush thickening. However, the literature that exist is based on estimates that are unreliable and conflicting. The causes of bush encroachment and thickening are varied and they are not clearly understood.

There are no clear cut simple generalities regarding causes of bush encroachment however, more complex generalities will have to take into account a diversity of implicated species, climates and soil types (Joubert, 2014).

Although the mechanisms of encroachment and thickening are varied and not clearly understood (Ward, 2005). Bush encroachment is understood to have been caused by two main factor:

First, is the primary determinants which is defined by climate (rainfall, to a lesser extent temperature and humidity ranges), soils, nutrients and topography. These determinants affect species composition, species occurrence in the area as well as the abundance of the species. Secondly, are the secondary determinants which are those factors influencing ecosystem dynamic within a given habitat and other sequences of happening that results in bush encroachment (de Klerk, 2004).

However, there are different views on the cause of bush encroachment. Many possible drivers have been proposed for this phenomenon, including changes in climate, atmospheric CO_2, herbivory, and fire regime, although the relative importance of different factors probably varies among eco-regions (Blaser, Shanungu, Edwards & Olde Venterink, 2014).

While, Wiegand, Ward and Saltz (2005) noted that bush encroachment in many semi-arid and arid environments is a natural phenomenon occurring in ecological systems governed by patch-dynamic processes. Therefore suggesting that bush encroachment is widespread in areas where there is a single soil layer and where grazing is infrequent and light (Ward, 2005).

Eventhough, the replacement of indigenous browsing animals by cattle and heavy livestock grazing are generally considered to be the primary cause of bush encroachment (Hoffman and Ashwell, 2001).

The plethora of evidence has accumulated suggesting that savannas throughout the world are being altered by a phenomenon known as bush encroachment. In Namibia, bush thickening is believed to have severely affected agricultural production (Smit, 2004; Namibia Agricultural Union [NAU], 2010). Through their extensive root systems, encroacher bushes compete with grasses for available soil moisture (Joubert, 2014; Smit, 2004). Once densely established, bush inhibits grass growth and prevents animals getting in to graze what little grass is available, (NAU**,** 2010).

Senegalia mellifera. subsp. *detinens* and *Dichrostachys cinerea* are the most dominant bush thickening species and has long been considered an ecological and economic problem in the rangelands of Namibia (Joubert, 2014). The phenomenon has resulted in reduced beef production, which is now only between 30% and 50% of what it was in the 1950's. The loss to the economy is estimated at N$1.6 billion / year (NAU, 2010).

Otherwise, the proliferation of these bush species is believed to alter nitrogen cycling in semi-arid to arid ecosystems, as nutrients become rapidly concentrated under the developing canopy and amplify a number of biogeochemical feedbacks within the system that can act to accumulate or reduce Soil Organic Matter (SOM) stocks (Creamer et al., 2012).

The process is also understood to impact adversely on biodiversity, water-use efficiency and underground water tables, thereby contributing to the process of desertification (de Klerk, 2004). For instance, southern Africa semi-arid and arid savannahs ecosystems are water-limited. Therefore, the encroacher species has been considered as contributing factor to the low occurrence or absence of herbaceous species, because trees out-compete the grass due to grass extensive root system that cannot reach for underground water compared to bushes which have longer root tap that can draw water from the water table (Smith, 2004).

More over , trees and bushes with bigger roots are understood to use up more water as compared to grasses (NAU, 2010).

2.3. **Effect of bush encroachment on soils nutrients**

Although bush encroachment may be viewed as a problem by many people, leguminous trees and shrubs have some positive impact on soil nutrients. For example, Rural Industries Research and Development Corporation (RIRDC) (1998) reported that bushes play an important role on soil chemistry, which involves nutrient release through litter fall and organic matter (OM) decomposition, acidification through the secretion of acids by roots to compensate cation uptake, organic acid additions from decomposing litter, and addition of nitrogen through fixation.

There seem to be evidence which suggests that, the presence of bushes and trees also contributes to the abundance of SOM. The RIRDC (1998), states that SOM tends to accumulate under natural forest ecosystems, because plant roots make a continuous contribution to SOM through decay and their annual contribution to the organic pool can be as high as that from above-ground litter. The *Acacia* trees had a strong effect on soil nutrient concentration, with highest soil nutrient concentration found near older trees and also high concentrations found in soils close to dead trees (Ludwig, De Kroon, Berendse & Prins, 2004).

All plants species are believed to have an influence on soil properties, but trees are likely to have greater effects than other plant life forms because of their size and longevity. It is reported that trees tend to have many direct and indirect effects on the physical, chemical and biological properties of soils (Miles, 1986).

In drylands woody desert trees, such as *acacias*, evade drought by shedding their leaves as the dry season sets in (Heshmati & Squires, 2013). Many dryland species have deep taproots that explore deep underground water layers and many are leguminous species which improve soil fertility.

Therefore, leguminous savanna tree such as Acacia *albida* (*syn. Faidherbia albida*), have been proposed to combat desertification in the Sahel. They provide valuable livestock fodder, hardwood, and enhances soil fertility (Heshmati & Squires, 2013).

Although, invader bushes in the savannah ecosystem are known to compete with grasses, these tree species are also found to maintain soil fertility which benefit grasses (Hoffman, Schmiedel, & Jürgen, 2010). They are believed to create fertility islands beneath their canopies thus increasing the organic matter and enriching the top soil with nutrients (Smit, 2004). Suggesting that soils under tree crowns have high concentrations of OM, high concentrations of available N and other nutrients, better physical structure and faster water infiltration rates, compared to neighbouring grasslands (Belsky et al., 1989). Therefore competition with grass is minimal because the grass form part of the fertility island created by the trees and shrubs.

The SOM is of vital importance in agriculture because of its reverse effects on denudated soils (de Klerk, 2004). Therefore, a decrease in soil organic matter can also negatively affect soil structure, stability, compactness, nutrient storage and supply, and soil biological life such as mycorrhizae and nitrogen-fixing bacteria (Henry, Valentini & Bernoux, 2009).

Notably, SOM is a key component of any terrestrial ecosystem, therefore any variation in its abundance and composition has important effects on many of the processes that occur within this system (Henry et al., 2009). Essentially, trees act as biological agents by creating islands that differ from the bare soils (Smit, 2004; Joubert et al., 2008), and provide a habitat for grass species to grow.

Invader bushes are also essential for maintaining OM, which is a major source of nutrients such as N, available P, and K in unfertilised soils such as desert soils (Smit, 2004). Blaser, Sitters, Hart, Edward and Venterink (2013) found that N-fixing woody plants increase soil N more than other woody plants. The increase in soil N under encroached area is due to shrubs producing more biomass than competing grasses and to their capacity to fix N (Blaser et al., 2014).

More so, woody encroachment in grasslands increases soil C and N stocks in drier regions, but decreased them in regions with Mean Annual Precipitation (MAP) greater than 500 mm/year (Jackson, Banner, Jobbagy, Pockman & Wall, 2002).

Additionally, one potentially beneficial effect is that the tree-dominated ecosystems may continue to sequester C and act as a buffer for increased atmospheric CO_2 levels (Blaser et al., 2013). Indeed, as grasslands and savanna ecosystems are believed to account for 30–35% of the global terrestrial net primary production an increase in C input through shrub encroachment and subsequent changes in C storage could have global implications for the earth–atmosphere system (Knapp et al., 2008; Field, Behrenfeld, Randerson & Falkowski, 1998).

It has been proposed that trees act as a nutrient pump taking up nutrients from deeper soil layers or from soil outside the canopy and depositing them under their canopy through litter fall or leaching (Ludwig et al., 2004). This seem to suggest that trees facilitate understorey plant growth through increased nutrient availability. However, (Shifa, 2017) stated that, lower concentration of major nutrients in bush encroached site can be observed due to nutrient deficiency in bush encroached areas therefore, offering no positive contribution regarding soil nutrients.

2.4. **Soil quality**

Soil quality as defined by the Natural Resources Conservation Service (2001) is the capacity of a specific kind of soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal, maintain water and air quality, and support habitat able ecosystem. Variations in the capacity of soil to function are reflected in soil properties that change in response to management or climate (Herrick, 2000).

In short, soil is a dynamic resource that supports plant life. It is made up of different sized mineral particles (sand, silt, and clay), OM, and numerous species of living organisms. Accordingly, soil has biological, chemical, and physical properties, some of which are dynamic and can change in response to how the soil is managed (Herrick, 2000).

Selected soil quality attributes which contribute to the fertility of a soil are measured at depths from 0-30 cm, Inter-governmental Panel on Climate Change (IPCC) (2006). The measurement of soil fertility include N, P, K, Ca, Mg and Na. While,soil test analysis are used to indicate nutrient availability in a soil (Winder, 2003).

Soil quality indicators, such as chemical and physical parameters are also important attributes, where indicators such as pH, Electrical conductivity (EC) and SOC are the chemical properties while bulk density, particle size and moisture as indicators of physical soil parameters that can be measured. The measurement of these soil quality indicators is necessary to understand soil function and the effects of use and management on the soil resource (Winder, 2003).

Therefore, evaluating soil quality can improve the response to many resource concerns, including loss of OM, nutrient loss or imbalance, degradation of soil aggregates or soil structure and loss of soil by erosion (NRCS, 2001). The concept of soil quality has recognised SOM as an important attribute that has a great deal of control on many of the key soil functions (Franzluebbers, 2002). SOM is a surrogate for soil carbon and is measured as a reflection of overall soil health. When monitored for several years, it gives an indication whether soil quality is improving or degrading (Horneck, Sullivan, Owen & Hart, 2011).

Studies by Islam and Weil (2000), that looked at the use of soil deterioration index found that soil quality deteriorated significantly (44%) under cultivation, while in sites revegetated with fast-growing Acacia or grasses, it improved by 6–16%. Further stating that degradation of soil quality may have resulted from increased disruption of macro-aggregates, reductions in microbial biomass, and loss of labile OM due to fire, deforestation, tillage and accelerated erosion (Islam & Weil 2000).

Soil quality assessments can be made using a framework that prioritises management goals, identifies critical soil functions necessary for achieving those goals, and selecting indicators that provide useful information regarding how a specific soil is functioning (Karlen, Ditzler & Andrews, 2003). A minimum dataset of indicators was proposed by Doran and Parkin (1994) (see Table 1). These indicators represent the minimum variables that should be measured in order to assess soil quality.

Table 1. Proposed minimum data set of physical, chemical and biological indicators for soil quality determination

	Indicators	
Physical	**Chemical**	**Biological**
Texture	Soil organic matter	Microbial biomass C and N
Topsoil and rooting depth	pH	Potentially mineralisable N
Infiltration	Electrical conductivity	Soil Respiration
Bulk density	Extractable N P and K,	
Water holding capacity		

(Source: Doran and Parkin, 1994).

Soils qualities indicators are important, in that we simply accept that the ground beneath us supports grasses, trees, crops and soak up rainwater. The extent to which the soil gives this support depends on its depth, structure and composition (Mendelsohn et al., 2002).

The use of indicators are essential to measure how well a soil is performing its functions, this will also help with soil monitoring which is essential to assess the sustainability of the soil resource in response to human induced pressures such as land use and soil contamination (Winder, 2003). Moreover, these soil qualities determine, for example how much water the soil retain, the depth to which plants roots may extend and what nutrients the soil contain for the plant to grow (Mendelsohn et al., 2002).

Although these parameters are influenced primarily by texture and clay type, SOM and fungal mycelia can bind soil particles into aggregates resulting in structural stability and desirable pore size distribution which in turn provides adequate water holding capacity, favourable permeability and aeration and resistance to surface erosion (RIRDC, 1998). Soils situated in the same semi-arid savanna environment may show similarity in soil parameter (Vourlitis et al., 2015).

2.5. **Effects of clearing woody savanna on soil nutrients**

Land clearing is a usual pre-planting process. Under the traditional farming system, clearing is a manual procedure. However faced with increasing population and declining food supply, many individuals and farming agencies have employed mechanical land clearing as a means to bringing land into food Production. Nonetheless, land clearing has been found to have adverse effect on soil quality (Eneji & Ayade, 2000).

Nyaudoh (2007), found that the depletion in SOM and soil macronutrients with time was more pronounced in the bush clearing method due to the complete removal of the vegetation cover and the subsequent exposure of topsoil to the erosive effects of torrential rainfall typical of the study area.

Complete removal of the vegetation cover in the bush clearing method caused significant adverse changes in soil chemical properties, such as SOC (Nyaudoh, 2007). This means, the unconscious disruption and removal of the topsoil and SOM during the windrowing operation may also significantly contribute to the above observations.

Likewise, when clearing land, particularly for agricultural purposes, the density of native cover and soil type must be considered to help conserve the topsoil (Adewole & Anyahara, 2010). Findings by Henao and Baanante (1999), point to population pressure and poor crop management practices coupled with the topography as some of contributing factors to soil erosion, and soil nutrient loss.

In addition, it is understood that clearing natural vegetation for agriculture results in large reductions in soil quality such as SOC levels and further declines may occur due to management practices (Chan, 2008). Although physical clearing is preferable to chemical clearing from an eco-toxicological perspective, there are also ecological consequences associated with physical clearing, especially when the topsoil is disturbed (Adams, 1967; de Klerk, 2004).

Largely, findings from various sources can be simplified to a rule of thumb on the magnitude of SOC stock change following land use change, findings by Richards, Dalal and Schmidt (2007) indicate that loss of SOC is inevitable during the initial land clearing. Further arguing that, a detailed met- analysis of the effect of land use change on tropical mineral soils showed that largest SOC stock losses (0-30 cm depth) of 21 and 32 t C ha-1 (i.e. 25 and 30%) occurred when primary forests were converted into cropland and perennial crops, respectively (Richards et al., 2007).

Soil beneath a canopy has a generally higher nutrients status than soil in open areas (de Klerk, 2004). These, reports are echoed by Hagos & Smith, (2004), who recorded high OM content in the soil from the stem base area. That said, trees effectively, recycle plant nutrients and thus maintain a high soil fertility. The increase in soil nutrients under tree canopy may be due to tree roots gathering nutrients from soil below the grass (de Klerk, 2004).

Similarly, the presences of bush encroachment is thought to be a good enhancer of soil nutrients and carbon stock. The encroachment of woody plants into grasslands, pastures and croplands is generally thought to increase the carbon stored in these ecosystems (Alberti et al., 2011).

These literatures seem to provide suggestion that, generally soil enrichment occurs under trees. Some of the key points highlighted are that, soil nutrients such as N, P and biomass, where significantly higher from the canopies than those from the roots and grass. Therefore, complete clearing of trees may lower long term productivity of the soil (Alberti et al., 2011; de Klerk, 2004).

A widely held opinion in Namibia is that the major increase in woody cover resulted in reduced grazing capacity and loss in biodiversity. Hence, various attempts to clear the bushes. Even though there have been many studies on bush encroachment and soil nutrients. Not all studies have confirmed that there is substantial influence of woody species on soil quality.

Amongst other studies, findings by Hagos and Smit (2004) have reported significantly high total N, OM, Ca, limited P under canopy of *Senegalia mellifera,* and limited N in the open on deep Kalahari sand soils in South Africa. Although N fixation by leguminous trees is believed to improve soil fertility under trees (Hagos & Smit, 2004), other nutrients inputs into the soil especially through tree litter cannot be overlooked, because they have the potential to transport nutrients from surrounding surface and subsurface soils to their canopy and drop the nutrients in leaf and stem litter. While bird droppings are also thought to be major inputs of nutrients since they densely covered the ground under the trees (de Klerk, 2004). These nutrients include N, P, and other selected essential nutrients.

More of the same, high content of soil N, OM, P, K, Mg, pH, Na on *vachellia erioloba,* were recorded in semi-arid Camel thorn savannas, alluding to soil enrichment by leguminous trees (Rothauge et al., 2003). While Na is not a plant nutrient and therefore is not necessary for plant growth. High levels of Na are detrimental to soil structure, soil permeability, and plant growth (Horneck et al., 2011).

The origins of P is generally from the weathering of parent rock. It is rapidly taken up by biomass and released when plants decompose (Knecht, 1998). Otherwise, the addition of OM is understood to increase the nutrient status of the soil, and subsequently improve structural stability and aggregation of soil particles and stimulate biological activity (RIRDC, 1998). Soil pH indicate the presence or absence of calcium carbonate ($CaCO_3$) and levels of OC in the soil (Britz & Ward, 2007). OM in the soil is a direct source of nutrients (Whitehead, 2000) and it also positively affects the capacity of the soil to hold cations.

Notably, soil enrichment can differ between tree species that grow in the same environment, for instances, soil under both leguminous trees (mainly *Senegalia erubescens*) and *non-leguminous* trees (mainly *C. apiculatum*) was rich in total N, SOC, Ca and Mg, but nutrients like K and Mg were found in high concentrations under *senegalia erubescens* compared to *C. apiculatum* (Hagos & Smit, 2004).

In sub-Sahara Africa, where there is an increasing demand for food, farmers may be encouraged to reduce the length of fallow periods and cultivate continuously, overgraze fields and remove much of the above-ground biomass through fuel collection and as building materials (Lal, 2004). However, these practices may result in the reductions of SOC (Lal, 2004). Notwithstanding that Nutrients, such as nitratesand essential utrients are essential to the nutrition of plants.

While the base richness of the parent material is initially important in determining soil fertility, biological activities are important in the creation and maintenance of localised areas of enhanced soil fertility. Therefore, trees may act as a biological agent, creating islands that differ from those in the open (Hagos, 2005).

Moreover, encroacher species such as, *Senegalia mellifera* have been found to improve the soil, plant nutrients and influenced the herbaceous layer under tree crown zone and beyond (Nzehengwa, 2013). OM has been shown to provide much of the exchange capacity of surface soils. Therefore, levels of SOM influence the levels of most nutrients.

Studies by Campbell, Frost, King, Mawanza and Mhlanga (1994) have shown that soil texture is an important factor controlling SOM dynamics. The OC levels are higher on the sites with fine-textured soils even though the sandy soils have species with generally more unmanageable litter. Nutrient like P is potentially the most limiting for grass growth in semi-arid savannas, especially within the sandy soils of the semi-arid savannas.

While, levels of N in the soil is particularly relevant to the dynamics of N-fixing trees *versus* grasses within savannas (Britz & Ward, 2007). Otherwise high OM in the fine-textured soils probably occurs because of OM incorporation into soil aggregates on the fine textured soils and the consequent protection from decomposition and/or eluviation (Campbell et al., 1994).

SOM losses can be as a result of reduced carbon input to the soil, while soil erosion is also another factor that is believed to contribute towards losses in SOM (Ram & Sanjutha, 2015). SOC is an integral component of SOM and 58% of SOM is made up of SOC (IPCC, 2006).

More so, soil OM is important to a wide variety of soil chemical, physical, and biological properties. As soil OM increases, so does cation exchange capacity (CEC), soil total N content, and other soil properties such as water-holding capacity and microbiological activity (Horneck et al., 2011). This, suggest the essentials of SOC to soil stability and provision of long term storage of C in the earth system. It is therefore safe to state that SOC depends on the relative rate at which OM is added or loss from the soil (Ram & Sanjutha, 2015). Seemingly,tree clearing may potentially result in loss of essential soil nutrients. The influence of trees on cations (N, K, Ca, Mg, Cu, Zn and Mn) levels is greater on sandy soils than fine-textured soils because the exchange capacity of fine-textured soils is determined largely by soil texture whereas OM is the prime determinant of exchange capacity in sandy soils (Campbell et al., 1994).

In summary, evidence in the literature seem to suggest that, encroacher species are important to the savanna ecosystem, because of the role they play by creating Fertility Island and further contributing to soil fertility. While further stating that, soil erosion and land degradation may be accelerated if the trees are cleared, because these tree also create a buffer which protect the soil from erosion by wind or surface runoff.

CHAPTER 3: MATERIALS AND METHODS

3.1 **Study sites description**

The study was conducted in Elandsvreugde farm, at the CCF. The CCF is a Namibian non-governmental organisation, situated at 20º31′10.1″ S and 16˚55'27.2"E farm 267-Rte D2440, 44km North-east of Otjiwarongo, Otjozondjupa region in Northern-central Namibia.

The Elandsvreugde farm located at (20 ˚ 25 S, 17 ˚ 40 E) is 7300 ha in size. Due to bush encroachment on the farm, a project on Cheetah Habitat Restoration through partial de-bushing of *Senegalia mellifera*, *Vachellia tortilis* and *Dichrostachys cinerea* has been proposed.

Several research works have been conducted on the farm over the past years. These mostly, focused on conservation and land use practices management (Jeffrey et al., 2016; Assessment, 2002). The farm has been selected to be part of the project funded by Southern African Science Service Centre for Climate Change and Adaptive Land Management (SASSCAL).

For this study, only selected soil physical properties which were tested (soil textural class). While the selected soil chemical properties that were tested are pH and salinity (EC). Furthermore, other selected soil quality parameters that were measured, are OM and selected essential nutrients P, N, K, Ca, Zn, Cu, Mg, Mn, Fe and Na.

3.1.1 Location

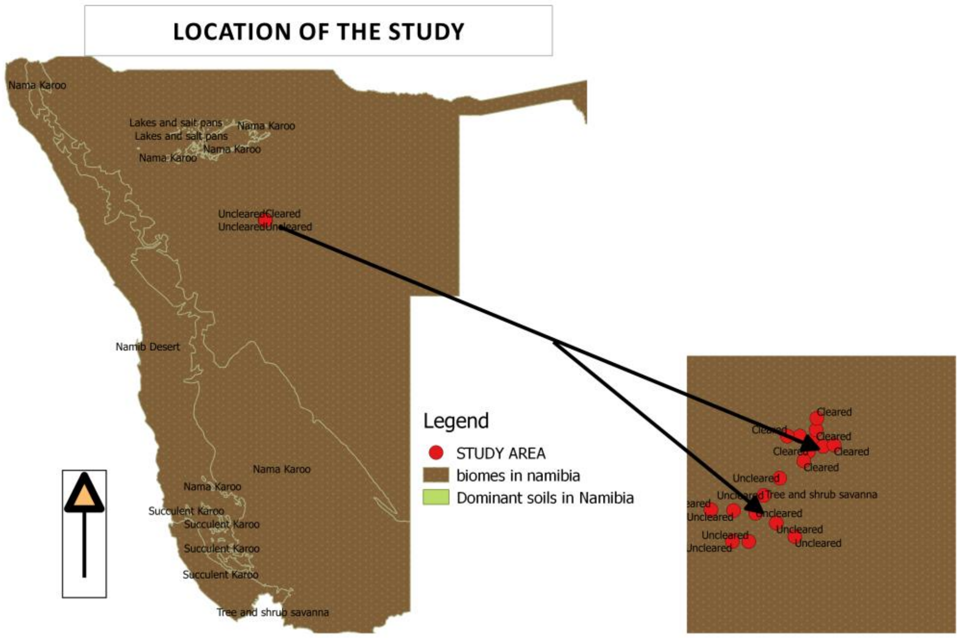


*Figure 1***.** Location of the study area (also see Appendix 4)

3.1.2 Vegetation

The vegetation in this area is typical of xeromorphic thorn bush savanna with dominant woody plant. The vegetation is characterized as thorn bush savanna, with woody species such as *Senegalia mellifera* predominating.

Understory vegetation is sparse except for forbs, which are briefly present following rainfall. The major grass species is hairy flower lovegrass (*Eragrostis trichophora*) (Jeffrey et al., 2016).

Senegalia mellifera, *Dichrostachys cinerea* have proliferated the area resulting in thickened bushes. *Senegalia mellifera* and *Dichrostachys cinerea* are the dominating encroaching bush species in the area (de Klerk, 2004).

The vegetation is used by wild game, including Kudu (*Tragelaphus strepsiceros*), Oryx (*Oryx gazella*), Red hartebeest (*Alcelaphus buselaphus subsp.caama*), Eland

(*Tragelaphus oryx*), Warthog (*Phacochoerus africanus*), steenbok (*Raphicerus campestris*), and Duiker (*Sylvicapra grimmia*) (Jeffrey et al., 2016).

Figure 2. Two research sites, a) bush encroached site and b) bush cleared site

3.1.3 Geology and soils

CCF is part of the Waterberg Conservancy. The Waterberg Plateau, a 4100 Km^2 sandstone uplift is the dominant geological feature of the region. The CCF research centre lies adjacent to the plateau at around 1600 metres above sea level.

Soils in the area are classified as Chromic Cambisols based on a soil atlas. The name of each soil for example 'Chromic Cambisols' comprises two parts, where the first part of the name provides information on the properties of the soil. While the second name is the soil group which reflects the condition s or processes that led to the soil's formation (Mendelsohn et al., 2002).

Chromic Cambisols are soils with bright colours. The Cambisols soils are formed quite recently in geological time, mainly from medium- to fine- textured parent materials deposited during sporadic flooding. Since the parent material is only slightly weathered, the Cambisols are characterised by appreciable quantities of accumulated clay, organic material, aluminium and iron. However, their fertility is usually moderate or high in part because of their good water- holding capacity and internal drainage (Mendelsohn et al., 2002).

3.1.4 Climate

The region has a semi-arid climate and lies between the 400 mm and 450 mm annual rainfall isohyets. Namibia has three seasons, namely a hot dry season from September to December, a hot wet season from January to April and a cold dry season from May to August. Annual rainfall is highly variable, with the majority of rain received between November and April (Assessment, 2002).

The CCF receives an average annual rainfall of 400–500 mm, thus classifying it as a semi-arid zone. The wet–hot season is January to April, followed by a dry–cold season from May to August, with September to December intermediate (Jeffrey et al, 2016).

3.1.5 Topography

The local topography is typical savannah grassland and is generally flat with small rolling hills. The landscape is interspersed by small isolated granitic outcrops called *kopjies*. These outcrops rise above a surrounding matrix of flatland, which has virtually no exposed rock. The farm proposed for this project is situated on a flat surface with slight undulations occurring at some parts of the farms at the foot of the Waterberg Plateau, a 4100 km^2 sandstone uplift, lying on the southern periphery of the study area and the dominant geological feature of the region. Several shallow ephemeral rivers exist within these farms flowing from the east to the west (Assessment, 2002).

3.2. **Experimental design and layout**

The study was quantitative and followed a systematic sampling along transects. The study was conducted on one farm, CCF on two fields. One experimental field was cleared of bush encroacher species and the other control field was not cleared of bush encroacher species. Each field measures 10 hectares.

3.3. **Sample type, sampling techniques and sample preparation**

All soil samples were taken from the Elandsvreugde farm at the CCF in Otjozondjupa Region, Namibia. The soil samples were collected from the two sites; bush-clear site and bush-encroached site. A stratified sampling method was used to stratify site areas according to medium low and low (well managed site and un-cleared site).

On each site of the farm, five fields (100 m² each) were selected using a linear transect. Within each plots, five square sub-field of (1m x1m quadrant) were selected. In each 100m² plot, there were 1000 1m x1m quadrats in each 100m² field, and only five 1m x1m quadrats were required for sampling soil in each field. A simple random sampling was used to select the starting point and the numbers that were used were from 1 to ….. 200. A systematic sampling was used to collect soil samples at Kth (200m) intervals along a linear transect. 25 soil samples were collected on each site. A total of 50 soil samples were collected at a depth of 0-30cm as recommended by the Inter-governmental Panel on Climate Change (IPCC).

Soil samples are dried at a temperature not greater than 35 degrees C. The part of the sample retained on a 2 mm sieve, called the fine earth fraction, is used for analysis. The fraction >2mm is referred to as stones and gravel.

The soil analytic methods used in the study are indicated in the appendices .These analytic methods are in a soil analysis manual available at the Ministry of Agriculture, Water and Forestry, Directorate of Agricultural Research. (see appendix for soil analytic methods).

Figure 3. Collecting soil samples a) and soil auger used to collect soil samples b)

3.4. **Laboratory analysis**

Firstly, a permanent plot or microsite was located by means of a tape transect. On each site of the farm, the points were selected randomly at regular spaced intervals.

A field centre or starting point was identified and marked with a collar, the collar was convenient, because it did not interfere or pose a hazard to livestock, vehicles, agricultural equipment, etc. The filed centre was located using a GPS receiver. Soil samples were taken per site at 0-30 cm depth and analysed for Total Nitrogen (N) and other elements such as pH; organic matter; available phosphorus (P); particle size distribution and exchangeable cations Ca, K, Na, Mg, Fe, Mn, Zn and Cu.

A soil auger was used to collect soil samples. A garden shovel was also used as an alternative to a soil auger in instances where the soil was dry and very sandy making it difficult to collect by a soil auger. A GPS was also used to geo-reference location of each 1m×1m quadrat.

Figure 4. Steps in experimental layouts: (a) Laying of a linear transect and (b) locating plot centre by means of a GPS.

3.5. **Statistical analysis**

All soil samples were analysed at the Ministry of Agriculture, Water and Forestry, Directorate of Agricultural Research.. Soil texture was analysed to identify if soil is similar in all sites and sub-plots. If difference in soil texture exist within sites, then they will be analysed differently because the effect of bush encroachment on soil Carbon (C) and Nitrogen (N) pools differs between soils types.

The soil textural class was the same between the sites. Samples (or fraction) were weighed fresh and then dried at a temperature not greater than 35°C in the oven to correct for water content. Thereafter, the sample will be weighed again.

Data was analysed using SPSS. Normality of the data distribution was confirmed with the Shapiro–Wilks test (Appendix 2). Only magnesium, sand, clay and silt were normally distributed, while other soil properties tested were not normally distributed. An Independent T-test was used to analyse the data that were normally distributed p>0.05, While, a Mann Whitney U-test was used to analyse data that were not normally distributed (p<0.05).

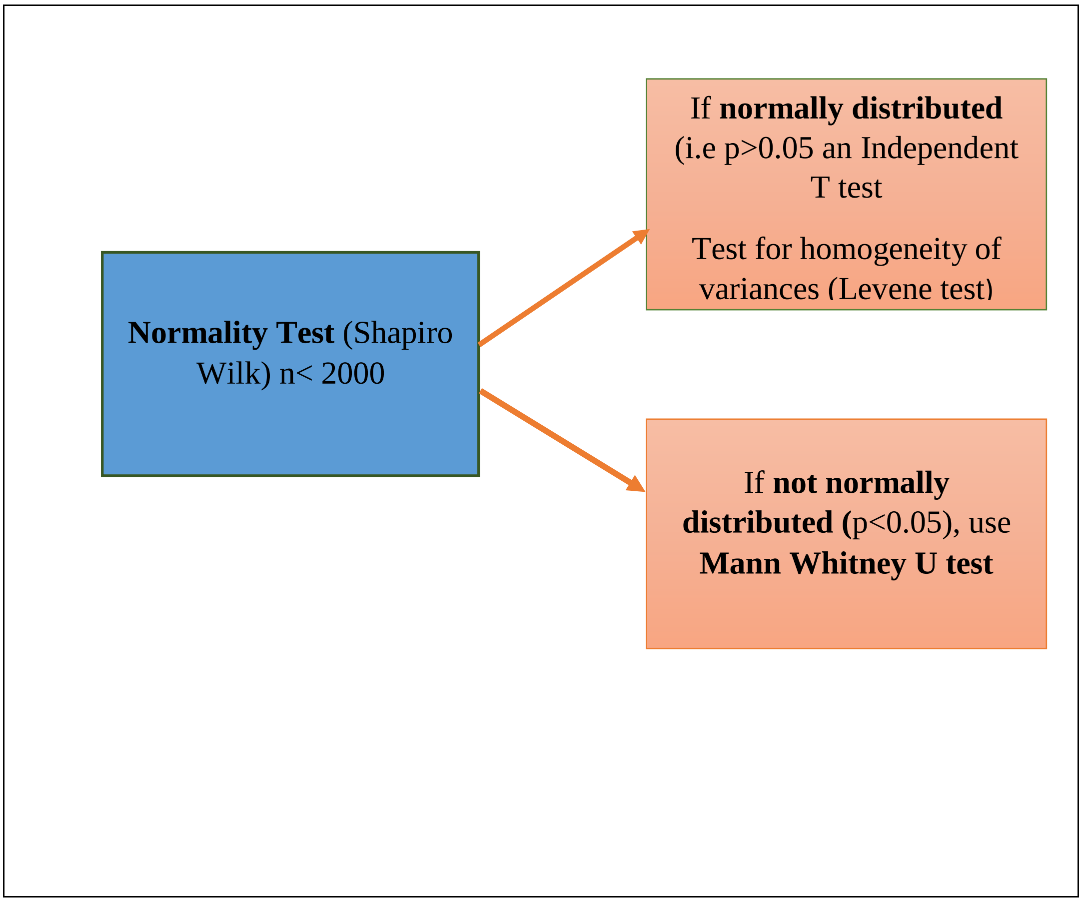


Figure 5. Framework for data analysis

CHAPTER 4: RESULTS

4.1 Introduction

This section consists of the observations and measurements recorded while conducting the procedures described in the methods section. These components addresses the objectives raised in the introduction and the hypotheses formulated there. In this section, the observations of selected essential soil nutrients (Soil macro and micro-nutrients), soil textural class and composition as well as SOC are presented.

4.2 Bush clearing effect on soil macronutrient distribution

4.2.1 Phosphorous (P)

There was no significant difference in the median soil P between the two sites (Mann-Whitney Test: $U = 262.5$, $z = -0.971$, $P = 0.332 > 0.05$) where P content range between 1.8 – 24.9 ppm in the cleared site and 1.7 -12.9 ppm in the un-cleared.

4.2.2 Potassium (K)

There was no significant difference in the median soil K between the two sites (Mann-Whitney Test: $U = 246.5$, $z = -1.281$, $P = 0.200 > 0.05$) where K content range between 74– 338 ppm in the cleared and 67– 224 ppm in the un-cleared

4.2.3 Calcium (Ca)

There was a significant difference in the median soil Ca between the two sites (Mann-Whitney Test: $U = 170.5$, $z = -2.755$, $P = 0.006 < 0.05$) where Ca content range between 116 – 404 ppm in the cleared and 124 - 783 ppm in the un-cleared (see Figure 6).

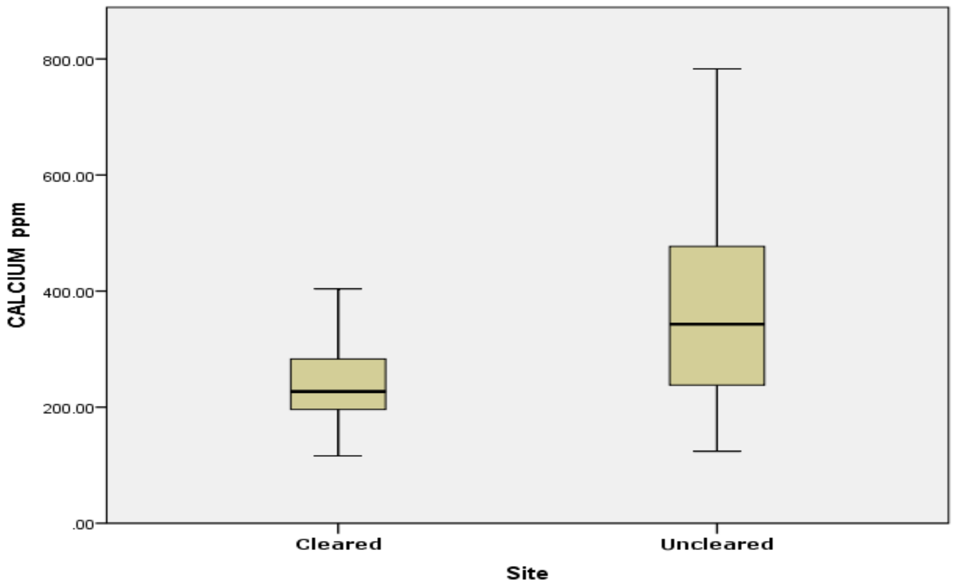


Figure 6. Comparison of soil Ca in the cleared and un-cleared sites at Cheetah Conservation Fund, Otjozondjupa region.

4.2.4 **Nitrogen (N)**

There was a significant difference in the median soil N between the two sites (Mann-Whitney Test: $U = 203.5$, $z = -2.118$, $P = 0.003 < 0.05$) where N content range between 0.031 – 0.073 % in the cleared and 0.036 - 0.095 % in the un-cleared site (see Figure 7).

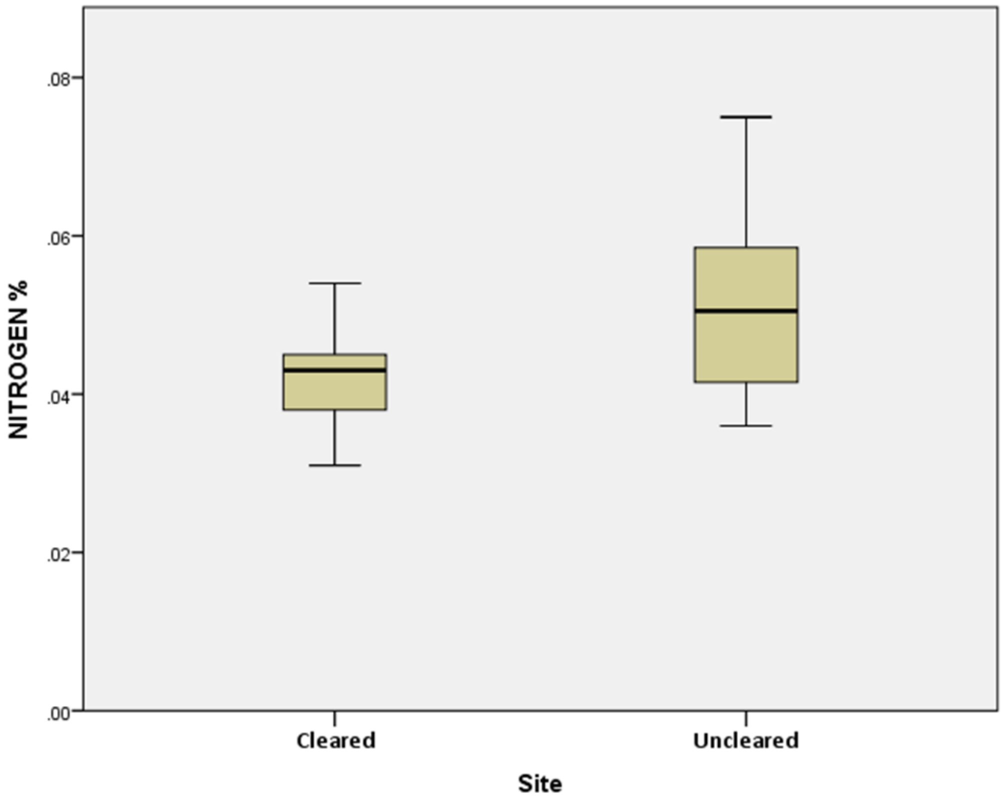


Figure 7. Comparison of soil N content in the cleared and un-cleared sites at Cheetah Conservation Fund in Otjozondjupa region.

4.2.5 **Magnesium (Mg)**

Independent T-test indicated that there was no significant difference in the mean soil Mg between the two sites ($t = -1.444$, $df = 48$, $P = 0.155 > 0.05$) where soil Mg content range 30 – 109 ppm in the cleared site and 33 – 112 ppm in the un-cleared site.

4.3 **Bush clearing effect on soil micronutrient distribution**

4.3.1 **Iron (Fe)**

Mann-Whitney U-Test indicated that there is a significant difference in median soil Fe content between the two sites. (Mann-Whitney: $U = 183$, $z = -2.513$, $P = 0.012 < 0.05$)

where the soil Fe content range between 24.0 – 66.4 ppm in the cleared and 23.3 – 75.8 in the un-cleared site (see Figure 8).

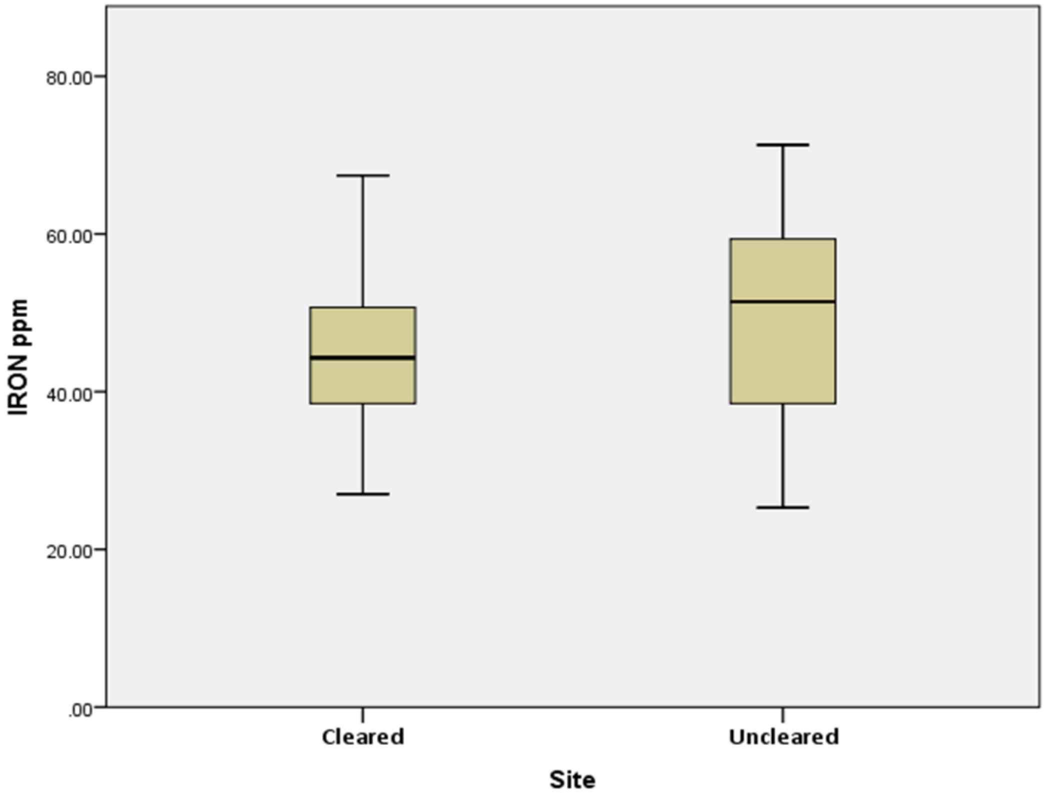


Figure 8. Comparison of soil Fe content in cleared and un-cleared sites at Cheetah Conservation Fund in Otjozondjupa region.

4.3.2 **Copper (Cu)**

There is no significant difference in median soil Cu content between the two sites (Mann-Whitney: U = 245.5, z= -1.327, P = 0.185 > 0.05) where soil Cu content range between 0 – 12.9 ppm in the cleared and 0 – 7.5 ppm in the un-cleared site.

4.3.3 **Zinc (Zn)**

The Mann-Whitney U-Test indicated that there is no significance difference in median soil Zn content between the two sites (Mann-Whitney: U= 244.5, z = -1.326, P = 0.185

> 0.05) where soil Zn content range between 0.0 – 3.0 ppm in the cleared and 0.0 – 6.3 in the un-cleared site.

4.3.4 **Manganese (Mn)**

Mann-Whitney U-Test indicate that there is no significant difference in median soil Mn between the two sites (Mann-Whitney Test: $U = 154$, $z = -1.461$, $P = 0.144 > 0.05$) where soil Mn content range between 34.2 – 121.7 ppm in the cleared and 52.0 – 109.9 ppm in the un-cleared site.

4.4 **Soil textural class**

4.4.1 **Clay content**

Independent T-Test indicate that there is no significant difference in mean clay content between the two sites ($t = -0.696$, $df = 48$, $P = 0.490 > 0.05$) where clay content in the soil range between 8.0 – 15.3 % in the cleared and 8.3 – 15.9 % in un-cleared site

4.4.2 **Silt content**

Independent T-Test indicate that there is no significant difference in mean silt content between the two sites ($t = -0.210$, $df = 48$, $P = 0.835 > 0.05$) where silt content in the soil range between 2.0 – 14.6 % in the cleared and 4.7 – 12.9 % in the un-cleared site

4.4.3 **Sand content**

Independent T-Test indicate that there is no significant difference in mean sand content between the two sites ($t = 0.699$, $df = 48$, $P = 0.488 > 0.05$) where the sand content range between 77 – 83.6 % in the cleared and 72.7 – 85.5 % in the un-cleared site.

4.4.4 **Soil composition**

The soil on the two sites is comprised of Loamy Sand and Sandy Loam soil respectively (seeTable 2). Soil analysis test further indicate that soil texture between the two sites was dominated by sand particles, clay particles and Silt particles respectively.

Table 2. Comparison of soil textural class in the bush cleared and un-cleared sites at Cheetah Conservation Fund.

Site	**Soil Textural Class**						
	Clay Loam	Sand	Loamy Sand	Sandy Loam	Loam	Silt Loam	Sandy Clay Loam
Cleared	Absent	Present	Present	Present	Absent	Absent	Absent
Un-cleared	Absent	Present	Present	Present	Absent	Absent	Absent

4.5 Bush clearing effect on soil chemical properties

4.5.1 Electrical conductivity (EC)

The Mann-Whitney U-Test indicate the there is a significance different in median soil ECw between the two sites (The Mann-Whitney: $U = 59$, $z = -3.683$, $P = 0.000 < 0.05$) where the ECw content range between 97– 193 uS/cm in the cleared and 75 – 129uS/cm in the un-cleared site. (see Figure 9).

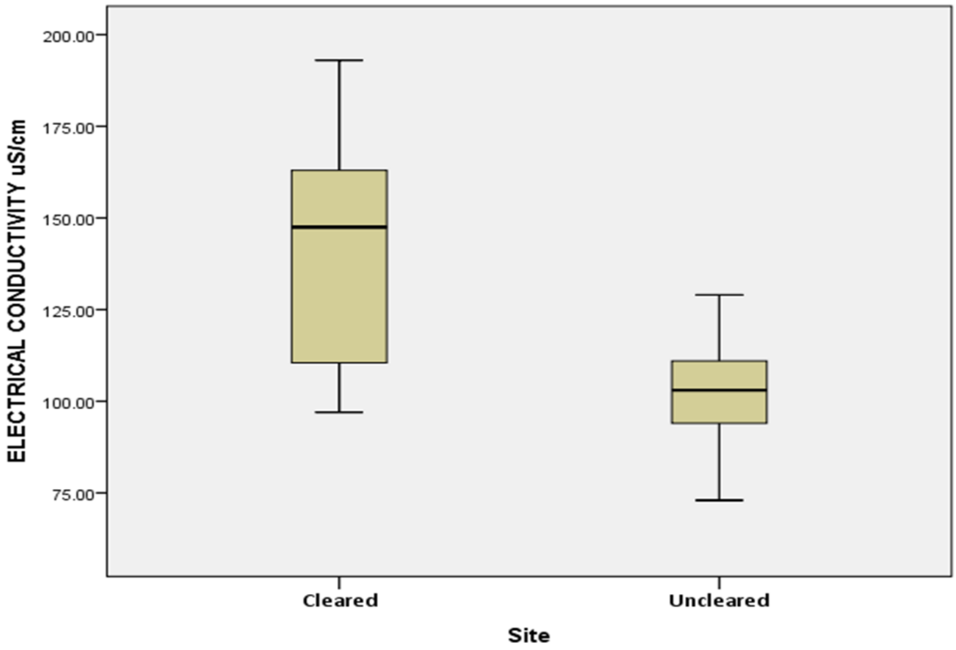


Figure 9. Comparison of soil EC in the cleared and un-cleared sites at Cheetah Conservation Fund in Otjozondjupa Region.

4.5.2 **pH**

The Mann-Whitney U-Test indicate that there is no significant different in soil pH content between the two sites (The Mann-Whitney: U = 256, z = -1.097, P = 0.273 > 0.05) where soil pH content range between 5.62 – 7.32 in the cleared and 5.70 – 6.51 in the un-cleared.

4.5.3 **SOM**

The Mann-Whitney U-Test indicate that there is a significant difference in median SOM between the two sites (The Mann-Whitney; U = 88, z = -2.702, P = 0.006 < 0.05) where SOM content range between 0.44 – 0.83 % in the cleared and 0.51 – 1.36 % in the un-cleared site. (see Figure 10).

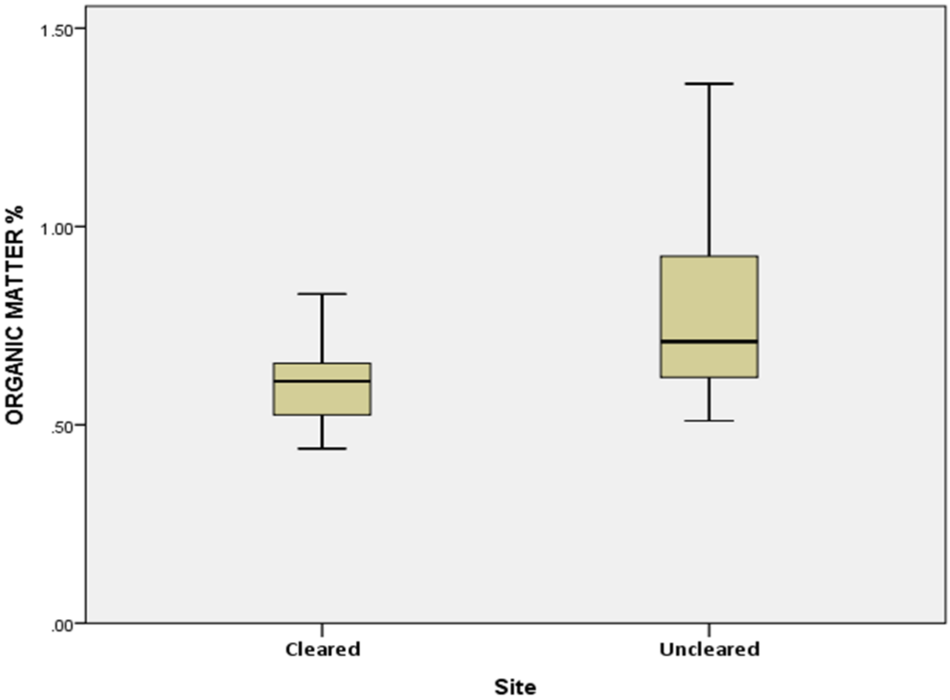


Figure 10. Comparison of SOM content in the cleared and un-cleared sites at Cheetah Conservation Fund in Otjozondjupa Region.

4.6. **Sodium (Na)**

Mann-Whitney U-Test indicated that there was a significant difference in median soil Na content between the two sites. (Mann-Whitney: U = 189.5, z = -2.552, P = 0.011 < 0.05) where soil Na content range between 0 – 68 ppm in the cleared and 0 – 18 ppm in the un-cleared site. There are some observed outliers in the un-cleared site, however removing these outlier shift the rest of the variables to become extreme variables. And also most of the values are close to zero parts per million, (see Figure 11).

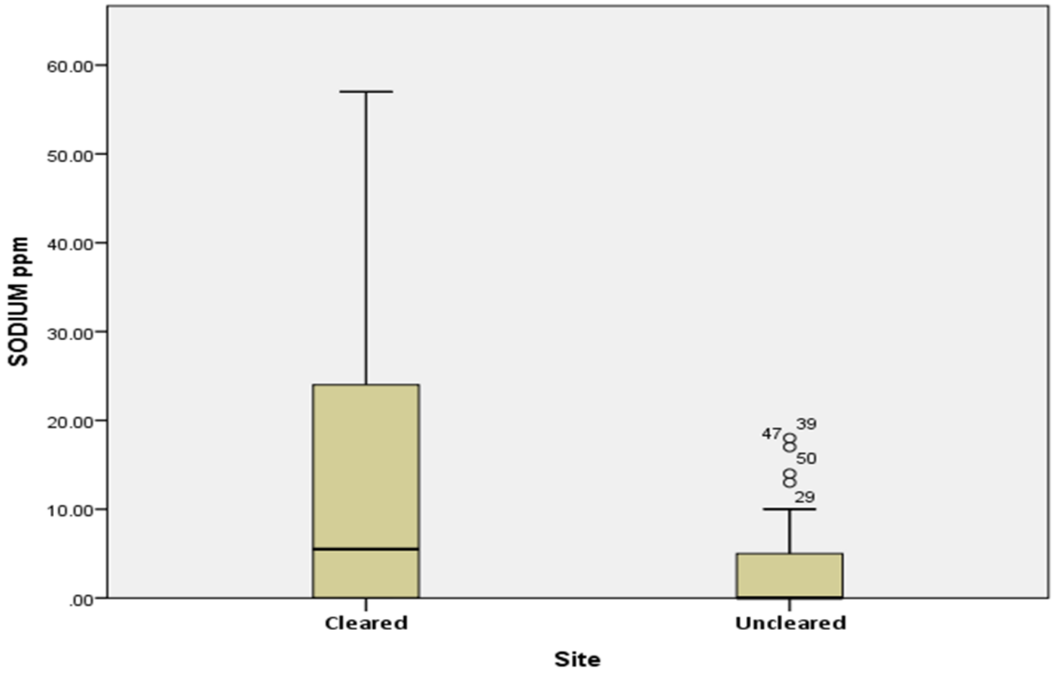


Figure 11. Comparison of soil Na content in the cleared and un-cleared sites at Cheetah Conservation Fund in Otjozondjupa Region.

CHAPTER 5: DISCUSSION

5.1 **Selected essential nutrients**

The bush thickening and encroachment phenomenon has generated considerable interest throughout savanna ecosystems in southern Africa. In Namibia this interest has largely been driven by the national nature of encroachment and its supposed association with widespread landscape degradation (e.g. loss in biodiversity, reduced grazing capacity, agriculture and desertification) in greater part of country's savanna ecosystems. Amidst various attempt to clear the encroaching species, much less is known about the effect of bush clearing with respect to soil quality, especially the soil nutrients N, P and K.

These selected essential nutrients, such as P, N, K, SOM, Mg, and various selected ions, are important soil quality indicators, because they are determinants of the composition, structure and productivity of the soil.

Contrary to reports of high P, K and Mg under tree canopies (Rothauge et al., 2003; Abdallah et al., 2008). This study have shown no significance difference in the soil median P, K and Mg between the two sites. Likewise, these results are in consistence with findings by Hagos and Smit (2004) whose results also show no significant difference ($p>0.05$) in P, Mg and K between the sub-habitats. These results could be attributed to the fact that the study was conducted in a sandy dominated soil, suggesting that sandy soils are known to have low nutrients status (Hagos & Smit, 2004). Similarly, this study was also conducted in sandy dominated soil, with soil textural class that comprises both sandy loam and loamy sand. Otherwise, the primary source of K in soil solution is the weathering of parent rocks, while, P also generally originates from the weathering of parent rock (Knecht, 1998). Nutrients like P are likely to come from deeper soil layers (Ludwig et al., 2004; Knecht, 1998), because trees collect nutrients from deeper soil layers and laterally from areas beyond the canopy, which are then deposited below and beyond canopy through litter fall and leaching.

There are indication that soil enrichment can differ between tree species that grow in the same environment. In comparison to this study it is notable that of the measured macro-nutrients, only N and Ca differed significantly ($p< 0.05$) between the two sites. The bush encroached site differed significantly from the cleared site with regards to N content, where the highest N content was recorded in the encroached site. The high occurrence of N content in the bush encroached site explain the N fixation by leguminous trees.

Although not all leguminous plants fix N, the findings of this study are supported by Boutton (2010); RIRDC (1998), who found that encroaching woody species are known to fix N symbiotically and may contribute to additional N into the ecosystem. Similarly, studies by Abdallah et al., (2008); Hagos and Smit (2004); Rothauge et al., (2003), also confirmed high content of N, Ca under the tree canopy. Further alluding to soil enrichment by leguminous plants. N fixing woody plant increase N in the soil more than other woody plants. This increase in soil N content under leguminous trees is due to shrubs producing more biomass than competing grasses and to their capacity to fix N (Blaser et al., 2014).

Although highly significance difference was found in the median Na content between the two sites. There are some outliers that can be observed, however removing these outliers results in most of the other values to become extreme values, this is because most of the values in the cleared sites are zero parts per million (see Figure 8). Otherwise, high occurrence of Na content was recorded in the bush cleared site. These findings are not in agreement with results by Hagos and Smit (2004), who reported high occurrence of Na, in a bush encroached area.

Even though trees are believed to act as a biological agent, creating islands that differ from those in the open (Hagos & Smit, 2004). Grasslands may also contribute to a net nutrients content in the soil. Nevertheless, Na is not regarded as a plant nutrient and may not be necessary for plant growth (Horneck et al., 2011). Simultaneously, high levels of Na is harmful to soil structure, soil permeability, and plant growth.

Notably, only the selected macro-nutrients, , N, Ca differed significantly between the two sites, with the highest Ca and N content recorded in the encroached site, and highest Na recorded in the cleared site. In addition there was also a significant difference between the two sites, with regards to the beneficial element Na. The high occurrence of Na may be due to micro-climatic conditions as explained by Brady & Weil (1999) who stated that prolonged periods of high evaporation and low precipitation in semi-arid ecosystems may explain the accumulation of salt elements such as Ca and Na. Otherwise, Na is widespread in nature, and is found in all plant material in amounts large enough to be analysed.

There was no significant difference in the P, Mg and K between the two sites. (Shifa, 2017) stated that, high bush encroached site having lower concentration of major nutrients, is an indication that high bush encroached areas are nutrient deficient and offer no positive contribution regarding soil nutrients.

Soil micro-nutrients results revealed similarities in Zn, Mn and Cu between the two sites. However, there was a significant difference in Fe content between the two sites.

The similarity in soil Zn, Mn and Cu between the sites could be attributed to that fact that the soil are from the same parent material. In their study, Vourlitis et al. (2015), affirm that similarity in soil parameter may be attributed to the fact that these soils are situated in the same semi-arid savanna environment.

However,the high occurrence of Fe, can be explained by the ability of trees to facilitate understorey plant growth through increased nutrient availability, because they act as a nutrient pump taking up nutrients from deeper soil layers or from soil outside the canopy and depositing them under their canopy through litter fall or leaching (Ludwig et al., 2004). This is also in agreement with Belsky et al. (1989), who noted that tree effectively, contribute to high concentrations of available N and other nutrients, better physical structure and faster water infiltration rates, compared to neighbouring grasslands.

Although high Fe content is associated with acidic soil, the median pH of the soil was 6.51, meaning pH level might not be responsible for high iron content in the encroached site.

Despite some notable statistical significant differences of some essential nutrients between the two sites, this study contributes to a growing body of evidence that N-fixing woody plants contribute to nutrient availability which greatly regulates savanna ecosystem processes and functions. Likewise, grasses are also known to contribute to a large amount of nutrients to the soil when decomposed.

5.2 **Soil physical and chemical properties**

The results of the particle size confirmed the sandy nature of the soil, with limited clay and silt content. Furthermore, there was no significant difference in the mean clay, silt and sand content between the two sites. In a similar study by Hagos and Smit, (2004) that assessed deep poor sandy soils and *Senegalia mellifera* trees, have recorded no significant differences among sub-habitats.

Result show that, the soil texture was predominantly sand and the soil textural class comprises of loamy sand and sandy loamy respectively. The sandy dominated texture of the soil is expected, because the CCF is part of the Waterberg Plateau which has a geology dominated by sandstones (Mendelsohn et al, 2002). The soil texture and soil types further suggest that the soil is from the same parent material.

Results indicate that, there was a significant difference in EC between the two sites. Where soil EC was higher in the cleared site compared to the un-cleared site. Soil EC is an indication of total salinity content in the soil. Notably, the cleared site was also high in Na content. Suggesting that the soil in cleared sites is high in salts.

Contrary to reports of low pH under tree canopies by Hagos and Smit, (2004), this study did not record any significant difference in pH values between the two sites. The exact reasons for these differences regarding the influence of tree on soil pH are not known.

However, soil pH is important in nutrient availability, and most nutrients require certain pH levels to be made available to plants. Therefore, understanding and management of soil pH in our rangelands and savanna ecosystems at large cannot be overemphasised because it is a measurement and of the acidity or alkalinity of a soil (Nzehengwa, 2013). Although, the cleared site differed with levels of EC, the result show that soil pH between the two sites did not differed.

5.3 **Comparison of soil organic carbon**

Contrary to the study's initial hypothesis, which hypothesized that there is no significant difference in SOC between bush-cleared and bush encroached site, the study found that there is however a significant difference in the median SOC between the two sites. SOC is a product of SOM, and SOC makes up 58% of soil SOM (IPCC, 2006). Otherwise, SOM is a surrogate for soil carbon. That being so, SOC depends on the relative rate at which OM is added or loss from the soil (Ram & Sanjutha, 2015).

The results of this study are in agreement with reports of high content of soil N, OM, K, Mg, Na, recorded in semi-arid Camel thorn savannas (Rothauge et al., 2003). While (Alberti et al., 2011), also suggested that encroachment of woody species increase the carbon stored in these ecosystems, further alluding to soil enrichment by leguminous trees. The high occurrence of SOC in the encroached site suggest that trees are able to fertilise the soil beneath their canopies thereby increasing the OM and enriching the top soil with nutrients (Smit, 2004; de Klerk, 2004). This is also supported by Hagos & Smith (2004), who reported high OM content in the soil beneath a canopy. Giving the idea that soils under tree crowns have high concentrations of OM, high concentrations of available N and other nutrients (Belsky et al., 1989). This is ascribed to biological N fixation, shading, litter, 'nutrient pump' and decomposition of roots and nodules (Nzehengwa, 2013). Therefore, the potential of trees to contribute to soil quality cannot be over emphasised, as Miles (1986) affirmed that trees tend to have many direct and indirect effects on the physical, chemical and biological properties of soils. This can explain why, high OC was recorded in the bush-encroached site than in the cleared site.

Findings of this study can be better explained by RIRDC (1998), who revealed that SOM tends to accumulate under natural forest ecosystems, because trees act as biological agents by creating islands that differ from the bare soils (Smit, 2004; Joubert et al, 2008). The presence of SOM is important, because it is a major source of nutrients such as N, available P, and K in un-fertilised soils (Smit, 2004).

Although this paper did not find a significant difference of major nutrients P and K between the two sites, the potential of encroacher trees species to contribute to soil fertility cannot be overlooked. Therefore, the overall findings of the study lead to general believe that, trees act as a nutrient pump taking up nutrients from deeper soil layers and depositing them under their canopy through litter fall or leaching (Ludwig et al, 2004).

The difference in SOC between the cleared and un-cleared site could further suggest that, land clearing may have an effect on soil quality (Eneji & Ayade, 2000), resulting in loss of SOM and major nutrients. Although this is partly true, textural differences also have significant effect on SOC differences. This is in agreement with Nyaudoh (2007), who stressed that the depletion in SOM and soil macronutrients with time is caused by bush clearing, thereby exposing the topsoil to the erosive effects of torrential rainfall and wind.

However, population pressure and poor crop management practices coupled with the topography may also contribute to soil erosion, and soil nutrient loss (Henao & Baanante, 1999). Indeed, clearing natural vegetation for agriculture may reduce soil quality such as soil organic carbon (Chan, 2008).

Evidence from this study suggest that tree clearing could lead to loss in major soil nutrients, this is demonstrated in the difference in SOC between the cleared and the un-cleared site, suggesting that the cleared site had experienced losses in SOC. The low occurrence of SOC in the cleared site could be due to the absence of trees.

Trees, especially, leguminous ones contribute to other nutrients inputs into the soil through tree litter, and bird droppings are also thought to be major inputs of nutrients since they densely covered the ground under the trees (de Klerk, 2004 Hagos & Smit, 2004).

Therefore lack of OM may limit the soil of other nutrients. This is also supported by Whitehead (2000) who noted that OM in the soil is a direct source of nutrients and provide a positive feedback of the soil capacity to hold cations. Notwithstanding that most SOC stock losses at 0-30 cm depth take place when primary forests is converted into cropland (Richards et al., 2007). Therefore, complete clearing of trees may alter soil quality and lower long term productivity of the soil (Alberti et al, 2011; de Klerk, 2004).

Although Campbell et al., (1994), found SOM to be high on sites with fine-textured soil, this study did not find any significant difference in soil textural class between the two sites, but find OM to be high on the bush encroached sites. These difference can be further explained by the fact that encroacher species such as, *Senegalia mellifera* have the potential to improve the soil and plant nutrients (Nzehengwa, 2013).

Namibia is relatively a dry country, and the CCF only receives an average annual rainfall of 400–500 mm, thus classified as a dry zone (Jeffrey et al, 2016). This is in agreement with Jackson et al (2002)'s report, who assert that bush encroachment in grasslands increases soil C and N stocks in drier regions, but decreased them in regions with mean annual precipitation greater than 500 mm/year. This finding is in consistent with results from other African savanna ecosystems, where sites encroached by trees have been compared with open grassland. Indeed some difference can be established with regards to other studies who differed.

CHAPTER 6: CONCLUSIONS

The study was carried out at The CCF farm in Otjozondjupa region, Namibia. The main aim of the study was to look at the effect of bush clearing on soil quality. The study hypothesized that there is no difference in the levels of selected essential nutrients between the cleared and un-cleared sites;

However, the study could not confirmed this to be true, as there was a significant difference in some selected essential soil nutrients. The study thus concludes that the bush encroached site had a higher N content compared to the cleared site. High level of N is attributed the fact that leguminous trees fix N, and very much so, they were responsible for the net N in the bush encroached site.

The Ca content was also high in the bush encroached site while, Na content was high in the cleared site. However, major nutrients P, Mg and K did not differ between the two sites. In addition, micro-nutrients such as Fe and Mn differed significantly between the two sites. Otherwise there was no significant difference in the level of copper and zinc recorded between the two sites.

This study therefore, reject the null hypothesis and conclude that the high occurance of nitrogen may be due to nitrogen fixation leguminous trees.On the contrary, not all leguminous palnts fix nitrogen However, the potential of these trees to effectively improve soil quality by contributing to total N to the ecosystem cannot be overlooked.

Furthermore, the study also hypothesized that there is no significance difference in selected soil physical and chemical properties between the sites. The results revealed this to be true for soil textural class where clay, silt and sand did not differ between the two sites. The soil textural class was mainly composed of sandy loamy and loamy sand on both cleared and bush encroached sites, indeed the soil class was the same between the two sites. This could be due the fact that, the soils are derived from the same parent material.

More so, soil pH between the two sites did not differ. However, soil EC differed significantly. The high level of EC in the cleared can be explained by soil rich in salts content in the cleared site, this is because high EC is an indication of soil salinity content, and this leads to further conclusion that this study found the soils on the cleared sites to be have high salts. The high salts could be due to evaporation.

Moreover, the study hypothised that, there is no significant difference in SOC between the cleared and un-cleared sites. However, the result conclude that compared to the cleared site, SOC content was generally higher in un-cleared site. Suggesting that trees acts as biological agents and they are essential in maintaining SOM through tree litter fall and bird dropping. Hence creating Fertility Island that differ from the open.

Although there was no significant difference of some soil quality indicators between the two sites, there are some notable difference, especially with the major nutrients N and SOC, where the presence of bush species is important because they seem to contribute to overall fertility of an ecosystem, given that savanna ecosystems are already nutrient limited.

The results of this study confirm the existence of differences in some soil nutrient status of soil between cleared and un-cleared sites. These differences were statistically significant with regards to total N, Ca, Na, Fe and notably SOM. There was no differences established concerning pH, P, K, Mg, Mn, Zn and Cu.

The results confirmed the sandy nature of the soil with limited clay and silt respectively. Compared to the results of similar studies as reported in the literature, it can be concluded that encroaching bushes and many other woody species, act as a biological agent that facilitate the enrichment of the soil in the bush encroached site.

Leading to further conclusion that, indeed bush clearing might have an effect on soil quality. On that note, the bush encroaching species should be treated with due care, because tree clearing my alter soil quality, through soil erosion as the bare soil is exposed to wind and evaporation.

However, some encroachers species may have an adverse effect on soil quality. While, from a nutrienal point of veiw, some encroacher species may not be desirable by the browsers.

Indeed SOC which is a product of SOM, as well as soil N are important soil quality indicators amongst others soil nutrients. Therefore management and restoration of these essential nutirents is imortant, as it could mitigate soil nutrients loss through clearing and soil erosion.

CHAPTER 7: RECOMMENDATIONS

Bush encroachment is a complex phenomenon, hence the challenges in understanding the process, because the exact cause of bush encroachment cannot be clearly established. Soil quality is equally important, and maintaining soil quality is important for the soil function. Therefore, clearing of invader bushes may result in disruption of macro-aggregates, reductions in microbial biomass, and loss of labile OM due to accelerated erosion.

Based on the on the conclusion made from the study. The study thus recommend tree thinning rather than clearance of the entire bush species, and that thinning of smaller trees is better than thinning bigger trees, because major nutrients such as SOM/SOC and N increases with tree age, this will improve soil quality and enhance biological activity of the soil.

Furthermore, thinning of encroaching bush species rather than clearing them, is recommended since the benefits of N-fixation by this species may be lost with tree clearance. Restoration of these bush species is also recommended, because they play an important role in maintaining islands of fertility, which continue benefiting livestock and game through browse.

Further studies would be needed to determine whether this finding applies for other woody species and in other areas.

This study recommends for further studies that focus on seasonal comparison, because the data of this study was only collected in one season which was the rainy season. Therefore further studies must look at comparing between seasons.

REFERENCES

Abdallah, F., Noumi, Z., Touzard, B., Belgacem, A. O., Neffati, M., & Chaieb, M. (2008). The influence of Acacia tortilis (Forssk.) subsp. raddiana (Savi) and livestock grazing on grass species composition, yield and soil nutrients in arid environments of South Tunisia. *Flora-Morphology, Distribution, Functional Ecology of Plants*, *203*(2), 116-125.

Adams, M. E. (1967). A study of the ecology of Acacia mellifera, A. seyal and Balanites aegyptiaca in relation to land-clearing. *Journal of Applied Ecology*, 221-237.

Adewole, M. B., & Anyahara, U. C. (2010). Adoption rate of land clearing techniques and their effects on some soil fertility parameters of an Alfisol in southwestern Nigeria. *African Journal of Agricultural Research*, *5*(23), 3310-3315.

Alberti, G., Leronni, V., Piazzi, M., Petrella, F., Mairota, P., Peressotti, A. & Novara, A. (2011). Impact of woody encroachment on soil organic carbon and nitrogen in abandoned agricultural lands along a rainfall gradient in Italy. *Regional Environmental Change*, *11*(4), 917-924.

ASSESSMENT, E. I. (2002). CHEETAH CONSERVATION FUND: HABITAT RESTORATION FOR THE NAMIBIAN CHEETAH.

Bester, F. V. (1996). Bush encroachment: a thorny problem. Namibia Environment 1: 175–177.

Bester, F. V. (1999). Major problem-bush species and densities in Namibia. Agricola, 10, 1-3.

Boutton, T. W., & Liao, J. D. (2010). Changes in soil nitrogen storage and δ15N with woody plant encroachment in a subtropical savanna parkland landscape. *Journal of Geophysical Research: Bio geosciences*, *115*(G3).

Belsky, A. J., Amundson, R. G., Duxbury, J. M., Riha, S. J, Ali, A. R. & Mwonga, S. M.(1989). The effects of trees on their physical, chemical and biological environments in a semi-arid savanna in Kenya. Journal of Applied Ecology 26:1005-1024.

Blaser, W. J., Sitters, J., Hart, S. P., Edwards, P. J., & Olde Venterink, H. (2013). Facilitative or competitive effects of woody plants on understorey vegetation depend on N-fixation, canopy shape and rainfall. *Journal of Ecology*, *101*(6), 1598-1603.

Blaser, W. J., Shanungu, G. K., Edwards, P. J., & Olde Venterink, H. (2014). Woody encroachment reduces nutrient limitation and promotes soil carbon sequestration. *Ecology and evolution*, *4*(8), 1423-1438.

Britz, M. L., & Ward, D. (2007) The effects of soil conditions and grazing strategy on plant species composition in a semi-arid savanna, African Journal of Range &Forage Science, 24:2, 51-61.

Campbell, B. M., Frost, P., King, J. A., Mawanza, M., & Mhlanga, L. (1994). The influence of trees on soil fertility on two contrasting semi-arid soil types at Matopos, Zimbabwe. *Agroforestry systems*, *28*(2), 159-172.

Creamer, C. A., Filley, T. R., Olk, D. C., Stott, D. E., Dooling, V., & Boutton, T. W. (2013). Changes to soil organic N dynamics with leguminous woody plant encroachment into grasslands. *Biogeochemistry*, *113*(1-3), 307-321

Chan, Y. (2008). Increasing soil organic carbon of agricultural land. *Prime fact*, *735*, 1-5.

de Klerk, J. N. (2004). Bush encroachment in Namibia. *Report on phase*, *1*, 253.

Doran, J. W., & Parkin, T. B. (1994). Defining and assessing soil quality. *Defining soil quality for a sustainable environment*, (definingsoilqua), 1-21.

Eneji, A. E., & Ayade, B. B. (2000). Land clearing effect on the variability of some soil properties of an Alfisol in south-western Nigeria. *Tropicultura*, *18*(3), 107-111.

Espach, C., Lubbe, L. G., & Ganzin, N. (2009). Determining grazing capacity in Namibia with the aid of remote sensing. African Journal of Range & Forage Science, 26(3), 133-138.

Field, C. B., M. J. Behrenfeld, J. T. Randerson, & P.Falkowski. (1998). Primary production of the biosphere: integrating terrestrial and oceanic components. Science281:237–240.

Franzluebbers, A. J. (2002). Soil organic matter stratification ratio as an indicator of soil quality. *Soil and Tillage Research*, *66*(2), 95-106.

GIZ. (2015) Support to De-Bushing

Henao, J., & Baanante, C. A. (1999). *Estimating rates of nutrient depletion in soils of agricultural lands of Africa* (p. 76). Muscle Shoals: International Fertilizer Development Center.

Hagos, M. G., & Smit, G. N. (2004). Soil enrichment by *Acacia mellifera* subsp. detinens on nutrient poor sandy soil in a semi-arid southern African savanna. Journal of Arid Environments, 47–59, 47–59.

Henry, M., Valentini, R., & Bernoux, M. (2009). Soil carbon stocks in ecoregions of Africa. *Bio geosciences Discussions,* ***6,*** 797-823.

Herrick, J. E. (2000). Soil quality: an indicator of sustainable land management? Applied Soil Ecology, 15(1), 75-83.

Heshmati, G. A., & Squires, V. R. (2013). *Combating desertification in Asia, Africa and the Middle East*. Springer.

Horneck, D.A., Sullivan, D.M., Owen, J.S., & Hart, J.M. (2011) Soil Test Interpretation Guide, Oregon state University, USA.

Hoffman, T., & Ashwell, A. (2001). *Nature Divided: Land Degradation in South Africa*. University of Cape Town Press, Cape Town, South Africa.

Hoffman, M. T., Schmiedel, U., & Jürgen, U. (eds) (2010). Implications for land use and management. Biodiversity in Southern Africa, ***3***, 109-150.

IPCC (2006) Guidelines for national greenhouse gas inventories Volume 4 Agriculture, Forestry and Other Land Use, Forest Land.

Islam, K. R., & Weil, R. R. (2000). Land use effects on soil quality in a tropical forest ecosystem of Bangladesh. *Agriculture, Ecosystems & Environment*, *79*(1), 9-16.

Jackson, R. B., Banner, J. L., Jobbágy, E. G., Pockman, W. T., & Wall, D. H. (2002). Ecosystem carbon loss with woody plant invasion of grasslands. Nature, 418(6898), 623-626.

Joubert, D. F. (2014). *The dynamics of bush thickening by Acacia mellifera in the highland savanna of Namibia* (Doctoral dissertation, University of the Free State Bloemfontein South Africa).

Joubert, D. F., Rothauge, A. & Smit, G.N. (2008). A conceptual model of vegetation dynamics in the semi-arid highland savanna of Namibia, with particular reference to bush thickening by *Acacia mellifera*. Journal of Arid Environments, 72, 2201-2210.

Karlen, D. L., Ditzler, C. A., & Andrews, S. S. (2003). Soil quality: why and how? *Geoderma*, *114*(3), 145-156.

Knapp, A. K., J. M. Briggs, S. L. Collins, S. R. Archer, M. S. Bret-Harte, & B. E. Ewers, et al. (2008). Shrub encroachment in North American grasslands: shifts ingrowth form dominance rapidly alters control of ecosystem carbon inputs. Glob. Change Biol. 14:615–623.

Knecht, C. (1998). Vertical Movement of Metals in the Ap Soil Horizon in a Pitch Pine Forest, North Haven. Yale University.

Lal, R. (2004). Soil carbon sequestration impacts on global climate change and food security. Science, 304, 1623-1627.

Ludwig, F., De Kroon, H., Berendse, F., & Prins, H. H. (2004). The influence of savanna trees on nutrient, water and light availability and the understorey vegetation. Plant Ecology, 170(1), 93-105.

Mendelsohn J., Jarvis A., & Roberts C, Robertson T. (2002). Atlas of Namibia: a portrait of the land and its people. Cape Town: New Africa Books.

Natural Resources Conservation Service (2001) soil quality- introduction

Namibia Agricultural Union, (2010). The effect of bush encroachment on groundwater resources in Namibia: a desk top study

Ndaeyo, N. U. (2007). Effects of bush clearing and tillage methods on some soil chemical properties in Epemakinde, southwestern Nigeria. *International Journal of Agricultureand Biology (Pakistan)*.

Nzehengwa, J. M. (2013). *The influence of Acacia mellifera on soil fertility, herbage quality and composition and sandy soils in camel-thorn savannas of Namibia*

Richards, A. E., Dalal, R. C., & Schmidt, S. (2007). Soil carbon turnover and sequestration in native subtropical tree plantations. *Soil Biology and Biochemistry*, *39*(8), 2078-2090.

Rothauge, A., Smit, G. N., & Abate, A. L. (2003). The effect of the sub-habitat below savanna trees on soil, grass and its utilization by cattle. Proceedings 7th International Rangeland Congress. (pp. 106-109). Durban, South Africa

Rural Industries Research and Development Corporation, (1998)

Sweet, J., & Burke, A. (2000). Country Pasture/Forage Resource Profiles. *Namibia. FAO.*

Shifa, R. I. (2017). *Assessment of carbon stock and selected soil fertility indicators in a bush encroached savanna at Erichsfelde farm, Namibia* (Doctoral dissertation, University of Namibia).

Smit, G. N. (2004). An approach to tree thinning to structure southern African savannas for long-term restoration from bush encroachment. *Journal of Environmental Management*, *71*(2), 179-191.

Van Auken, O. W. (2009). Causes and consequences of woody plant encroachment into western North American grasslands. *Journal of Environmental Management*, *90*(10), 2931-2942.

Von Oertzen, D. (2009). Biochar in Namibia: Opportunities to convert bush encroachment into carbon offsets.

Vourlitis, G. L., de Almeida Lobo, F., Pinto Jr., O. B., Zappia, A., Dalmagro, H. J., de Arruda, P. H. Z., & de Souza Nogueira, J. (2015). Variations in above-ground vegetation structure along a nutrient availability gradient in the Brazilian pantanal. *Plant Soil*, ***389***, 307-321.

Ward, D. (2005). Do we understand the causes of bush encroachment in African savannas? *Journal of Range & Forage Science,* ***22*** (2), 101-105.

Winder, J. (2003). *Soil quality monitoring programs: A literature review*. AESA.

Wiegand, K. Ward, D. & Saltz, D. (2005). Multi-scale patterns and bush encroachment in an arid environment with a single soil layer. *Journal of Vegetation Science* (in press).

Whitehead, D. C. (2000). *Nutrient Elements in Grassland: Soil-plant animal Relationships*. CABI Publishing, Oxon, UK.

APPENDICES

Appendix 1: Steps followed in the analysis of the soil samples at the Ministry of Agriculture, Water and Forestry's analytical laboratory.

SAMPLE PREPARATION

Soil samples are dried at a temperature not greater than 35 degrees C. The part of the sample retained on a 2 mm sieve, called the fine earth fraction, is used for analysis. The fraction >2mm is referred to as stones and gravel.

AVAILABLE PHOSPHORUS

Ohlsen method: Extraction with sodium bicarbonate. Phosphate measured spectrophotometrically using the phosphomolybdate blue method.

EXTRACTABLE CATIONS (AVAILABLE K, Mg, Ca)

Extraction with 1M ammonium acetate at pH 7. Measurement of calcium, magnesium, potassium and sodium by inductively coulped plasma (ICP).

EXCHANGEABLE CATIONS & CATION EXCHANGE CAPACITY (CEC)

Extraction with 1M ammonium acetate at pH 7 if pH (H2O) <6.8 & EC<0.4 mS/cm. Extraction with 50:50 ammonium acetate (1M) and ethanol at pH 7 if pH (H2O)>6.8

& EC>0.4mS/cm. Calcium, magnesium, sodium and potassium measured by atomic absorption spectrophotometry.

TEXTURE and PARTICLE SIZE ANALYSIS (SAND, SILT and CLAY)

Dispersion of soil with sodium hexametaphosphate/sodium carbonate. Determination of silt and clay by pipette method. Sand fraction determined by sieving to retain >53 micron fraction. Textural Class using the USDA classification system.

ORGANIC CARBON (ORGANIC MATTER CONTENT)

Walkley-Black method (sulphuric acid-potassium dichromate oxidation). A factor is included in calculations to take account of incomplete oxidation. Organic matter content calculated as organic-C x 1.74.

ORGANIC MATTER (by loss on ignition)

Organic matter is estimated by measuring the weight loss when dried samples are heated in a muffle furnace at 360 degrees C for 4 hours.

pH (KCl)

Measured in a 1:2.5 soil: IM potassium chloride ratio suspension on a mass to volume basis.

pH (water)

Measured in a 1:2.5 soil: water ratio suspension on a mass to volume basis.

ELECTRICAL CONDUCTIVITY (SOLUBLE SALT CONTENT)

Measurement in the supernatant of the 1:2.5 soil: water suspension prior to measurement of pH. Units of measurement are mS/cm (1 mS=1000 uS). High results indicating possible salinity hazard are repeated on the extract of a saturated soil paste.

TOTAL NITROGEN

The sample is then introduced to the furnace containing only pure oxygen, resulting in a rapid and complete combustion (oxidation). Nitrogen present are oxidized to NOx respectively. The NOx gases are passed through a reduction tube filled with copper to reduce the gases to N and onto a thermal conductivity cell (TC) utilized to detect the N2.

CARBONATE (as Calcium Carbonate)

Reaction of soil with hydrochloric acid and estimation of acid consumed by titration with sodium hydroxide.

CARBONATE (estimation)

Treatment of dry soil with 10% hydrochloric acid and observation of effervescence.

AVAILABLE SULPHUR (as SULPHATE)

1:2 weight: volume extraction of soil with 0.01M calcium chloride. Sulphate-S estimated by measuring turbidity at 600 nm following treatment with acidified barium chloride.

SULPHATE (estimation)

Soil: water extract from pH/EC measurement made 0.01M with respect to calcium by addition of 1M calcium chloride. Filtered extract reacted with acid barium chloride and turbidity visually compared with standard solution of sulphate-S.

SALINITY ANALYSIS

Saturated soil: water paste prepared and the extract recovered by vacuum filtration. Anions and cations are measured in the extract. Sodium adsorption ration (SAR) is a diagnostic criterion for assessing salinity. It is equal to concentration of sodium divided by the square root of one half the combined calcium and magnesium in the extract. All concentrations measured in me/l.

AVAILABLE MICRONUTRIENTS (Zinc, manganese, copper and iron)

Extraction with 0.5M ammonium acetate: 0.5M acetic acid: 0.02M EDTA at pH 4.65 at a 1:5 extraction ratio. Fe, Mn, Cu and Zn measured by inductively coulped plasma (ICP).Available calcium, potassium and magnesium can also be measured in the extract.

Appendix 2: Shapiro-wilk to test for normality

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Ph	.096	50	.200*	.948	50	.028
ECw	.195	50	.000	.725	50	.000
OM	.146	50	.009	.900	50	.000
P	.212	50	.000	.728	50	.000
K	.187	50	.000	.800	50	.000
Ca	.141	50	.015	.883	50	.000
Mg	.092	50	.200*	.971	50	.255
Na	.268	50	.000	.684	50	.000
Fe	.124	50	.051	.870	50	.000
Cu	.229	50	.000	.723	50	.000
Zn	.241	50	.000	.735	50	.000
Mn	.199	50	.000	.792	50	.000
Sand	.087	50	.200*	.968	50	.195
Silt	.072	50	.200*	.984	50	.719
Clay	.115	50	.094	.958	50	.071
N	.123	50	.056	.904	50	.001

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Appendix 3: Ethical clearance certificate

UNAM
UNIVERSITY OF NAMIBIA

ETHICAL CLEARANCE CERTIFICATE

Ethical Clearance Reference Number: FHSS /221/2017 **Date: 6 June, 2017**

This Ethical Clearance Certificate is issued by the University of Namibia Research Ethics Committee (UREC) in accordance with the University of Namibia's Research Ethics Policy and Guidelines. Ethical approval is given in respect of undertakings contained in the Research Project outlined below. This Certificate is issued on the recommendations of the ethical evaluation done by the Faculty/Centre/Campus Research & Publications Committee sitting with the Postgraduate Studies Committee.

Title of Project: The Effect Of Bush Clearing On Soil Quality, In North Central Namibia

Nature/Level of Project: Masters

Researcher: Angula Nahas Enkono

Student Number: 201066114

Faculty: Faculty of Humanities and Social Sciences

Supervisors: Dr S T Angombe (Main) Dr E G Kwembeya (Co)

Take note of the following:

(a) Any significant changes in the conditions or undertakings outlined in the approved Proposal must be communicated to the UREC. An application to make amendments may be necessary.

(b) Any breaches of ethical undertakings or practices that have an impact on ethical conduct of the research must be reported to the UREC.

(c) The Principal Researcher must report issues of ethical compliance to the UREC (through the Chairperson of the Faculty/Centre/Campus Research & Publications Committee) at the end of the Project or as may be requested by UREC.

(d) The UREC retains the right to:

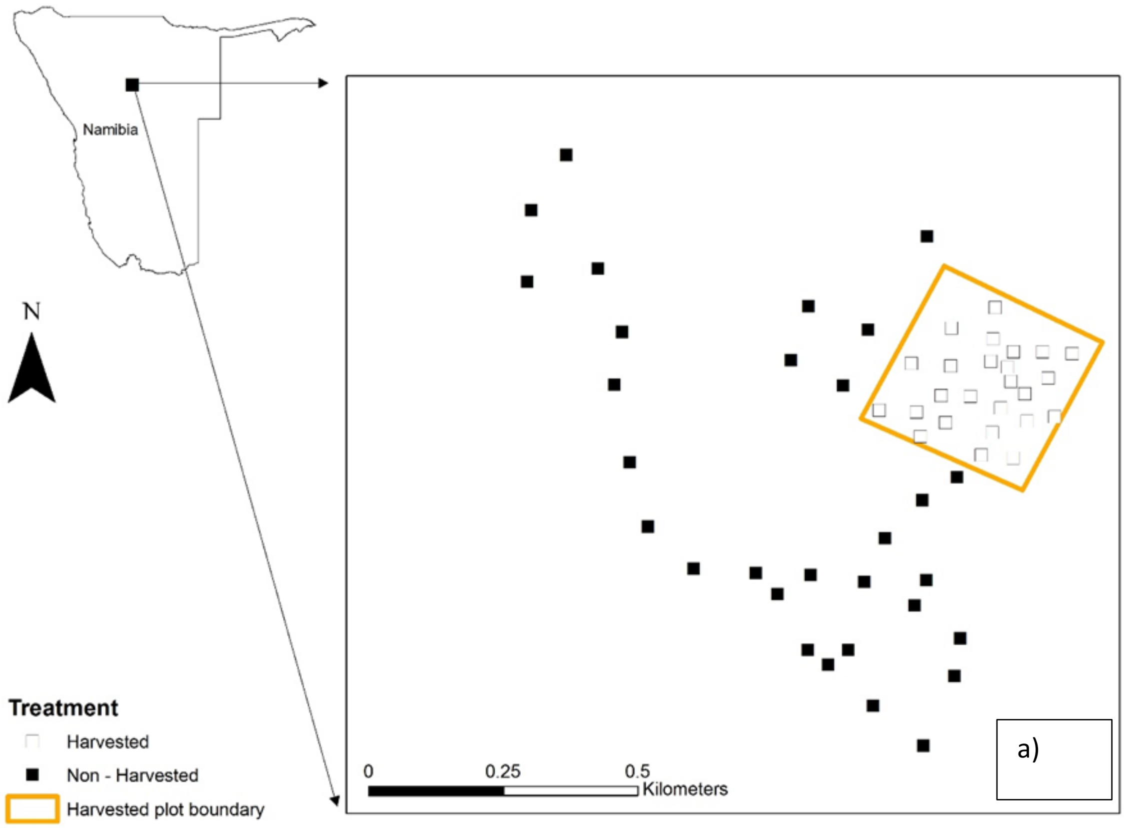
(i) Withdraw or amend this Ethical Clearance if any unethical practices (as outlined in the Research Ethics Policy) have been detected or suspected,

(ii) Request for an ethical compliance report at any point during the course of the research.

UREC wishes you the best in your research.

Prof. P. Odonkor: UREC Chairperson

Ms. P. Claassen: UREC Secretary



Appendix 4: Cleared and uncleared sites a and b.