THE EFFECT OF BUSH CLEARING ON SOIL RESPIRATION IN NORTH-CENTRAL NAMIBIA: CHEETAH CONSERVATION FUND AND ERICHSFELDE

A RESEARCH THESIS SUBMITTED IN PARTIAL FUFILLMENT

OF THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF ARTS (GEOGRAPHY AND ENVIRONMENTAL STUDIES)

OF

THE UNIVERSITY OF NAMIBIA

BY

WILHELMINA KL NUULE

201176149

April, 2018

MAIN SUPERVISOR: Dr S T Angombe

CO-SUPERVISOR: Dr H Wanke

ABSTRACT

Changes in vegetation or land use that affects soil respiration are a major concern for global climate change. Bush clearing in north-central Namibia has been used as a solution to problems of bush encroachment. However, the effect of bush clearing on soil processes, such as the carbon cycle and soil CO_2 efflux has not yet been quantified in Namibia. The main aim of this study was to determine and compare the amount of soil respiration between the cleared and uncleared sites at different seasons and also to determine the effect of soil temperature and moisture on soil respiration in two farms; Erichsfelde and CCF located in Otjozondjupa region. Soil respiration was measured using a soil respiration chamber connected to the Infrared Gas Analyzer LI-COR 6400 XT. The results showed no significant difference in soil respiration between the cleared and uncleared sites at CCF in both seasons ($P>0.05$). This could be due to an equal amount of soil respiration between root respiration (as a result of high root biomass of woody vegetation) in the uncleared site and microbial respiration from increased litter decomposition together with root respiration of grass and herbaceous plants in the cleared site. On the other hand, both seasons at Erichsfelde showed that soil respiration was significantly higher in the uncleared site than in the cleared site ($P<0.05$). This could be attributed to the higher root biomass and litter content in the uncleared site than in the cleared site. Both study areas showed significantly higher soil respiration in the wet season than in the dry season ($P<0.05$) due to high root activities, high decomposition rate of litter and substrate availability because the soil is wet and vegetation productivity is high and active. Apart from the dry season of Erichsfelde that showed a very weak negative correlation, the rest showed no significant correlation between soil respiration and soil temperature. At the same time, soil respiration exhibited a positive correlation with soil moisture. Despite the negative effect of bush clearing on atmospheric CO_2 absorption, this study concluded that bush clearing itself does not lead to increased soil CO_2 efflux. However, there is a need for ongoing and extended studies on soil CO_2 efflux in different parts of the country and long term soil respiration monitoring, with special emphasis on the times directly after the land.

Key words: Soil respiration, bush clearing, Carbon dioxide, Seasons, Soil moisture, Soil Temperature, North-central Namibia

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACRONYMS

CCF	Cheetah Conservation Fund
CO_2	Carbon dioxide
PPM	Parts Per Million
SPP	Species
SPSS	Statistical Package for Social Sciences
SASSCAL	Southern Africa Science Service Centre for Climate Change and Adaptive Land Management
IPCC	Intergovernmental Panel on Climate Change

ACKNOWLEDGEMENTS

Firstly, I would like to thank the Almighty God for his protection and for giving me the energy and strength to complete the whole project. Secondly, I would like to express my deepest appreciation to my supervisors, Dr Simon Angombe and Dr Heike Wanke for all the support, patient guidance and advice throughout the course of this study. Your constructive comments and criticisms really helped me a lot. I really appreciate your valuable time and the effort you have put in my study.

I would like to give my sincere gratitude to the Southern Africa Science Service Centre for Climate Change and Adaptive Land Management (SASSCAL) for the financial support. I would like to thank the University of Namibia's Geology Department for allowing me to use their laboratory facilities and the Biological Sciences Department, in particular Mr Asser Katunahange for providing me with some research equipment needed during the field work.

I would also like to thank the farm managers of Erichsfelde and Cheetah Conservation Fund for allowing me to do my research in their farms and for allowing me to use their services during field work.

Special thanks go to Prof Heather Throop from Arizona State University and Dr Dave Joubert from the Namibia University of Science and Technology for the training on how to take measurements using the Gas analyser.

This thesis would not have been completed without the help of Vijanda Kaukuetu, Nahas Enkono, Cecilia Ndunge, Nabot Mbeeli, Vistorina Amputu, Allan Kandjai and Nyasha Musekiwa. Thank you so much for assisting me with my field work, I really appreciate your support. Great thanks to Ms Rufina Shifa for guiding me on statistical analysis and thesis write up and Ms Fransiska Kangombe for going through my research proposal when I was stuck and for your encouraging words.

Finally, I must express my profound gratitude to my mom (Meme Selma Nuule) for your love, support and for encouraging me to never give up, my entire family and friends as well as my lovely colleagues (the M-block crew - Nahas, Annalisa, mee Martha, David and Mr Goodman) for your support and continuous encouragement throughout the process of researching and writing this thesis. Thank you very much.

DEDICATION

This thesis is dedicated to the loving memory of my father, Tate Johannes Tuhanganeni Nuule and to my mother (Meme Selma Kauna Amwaalwa-Nuule), who had the tough task of raising six children by herself after the death of my father. Thanks meme, for being strong and for believing in me.

DECLARATIONS

I Wilhelmina Kakwali Lyuuvika Nuule, hereby declare that this study is my own work and is a true reflection of my research, and that this work, or any part thereof has not been submitted for a degree at any other institution. No part of this thesis may be reproduced, stored in any retrieval system, or transmitted in any form, or by means (e.g. electronic, mechanical, photocopying, recording or otherwise) without the prior permission of the author, or The University of Namibia in that behalf.

I Wilhelmina KL Nuule, grant the University of Namibia the right to reproduce this thesis in whole or part, in any manner or format, which The University of Namibia may deem fit.

……………………………… ………………………… ……………………..

Name of Student Signature Date

CHAPTER 1: INTRODUCTION

1.1 Background of the study

Since the introduction of the industrial revolution, greenhouse gases emissions such as methane, chlorofluorocarbons, nitrous oxide and carbon dioxide (CO_2) have exponentially increased (Intergovernmental Panel on Climate Change (IPCC), 2007). The amount of CO_2 concentration in the atmosphere has gone beyond its natural range in the last 65,000 years as determined from ice cores. The increase is being heavily attributed to human activities such as burning of fossil fuels, forest fires, deforestation and land use changes (IPCC, 2007). Carbon dioxide traps the heat within the atmosphere which leads to warming of the earth's atmosphere and change in climate.

The anthropogenic disturbance of forest ecosystems such as deforestation can stimulate a large amount of CO_2 emissions from the soil both by directly releasing biomass carbon and by indirect CO_2 emissions from the accelerated decomposition of tree debris and soil organic matter (Ma et al., 2013). The amount of CO_2 released to the atmosphere as a result of human activities may seem very small in comparison with the rates of CO_2 released through natural processes. However, it only takes a little change to set off the balance of the global carbon cycle (Luo & Zhou, 2006). Changes in soil CO_2 efflux caused by human activities, including soil disturbances play a role in the increase of atmospheric CO_2 and they are a potential cause of global warming (Schlesinger & Andrews, 2000).

The exchange of CO_2 between the land and atmosphere is mostly mediated by soil respiration and its slight alteration would lead to a considerable change in the atmospheric CO_2 concentration (Kaur, Jalota, Midmore, & Walsh, 2006; Fan et al., 2015). Soil respiration is defined as an ecosystem process that releases CO_2 from soil through living plant roots and their symbiotic mycorrhizal fungal partners and the decomposition of detritus and soil organic matter (Butler et al., 2012). Soil respiration is mainly influenced by soil temperature and moisture, thus any changes in these two environmental factors may alter soil CO_2 efflux. Soils store vast quantities of organic carbon, and the emissions of soil CO_2 to the atmosphere through soil respiration is one of the most important fluxes in the global carbon cycle (Zhang, Chen, Li, & Zhao, 2007). Soil respiration is the second largest component of total respiration between the atmosphere and terrestrial ecosystems and it contributes around 20-40% to the total annual input of CO_2 into the atmosphere (Luo & Zhou, 2006).

Terrestrial ecosystems can act as a sink (removing CO_2 from the atmosphere) or a source (adding CO_2 to the atmosphere) of atmospheric CO_2 on the basis of the net difference between the two fluxes of photosynthesis and respiration (Cacciotti, Saunders, Tobin, & Osborne, 2010). With soil being the largest carbon pool, it is therefore the reaction of this large pool to changes in climate that determines whether terrestrial ecosystems continue to absorb CO_2 from the atmosphere or whether the increase in the decomposition of soil organic matter will turn the present carbon sinks into carbon sources (Subke, Reinchstein, & Tenhunen, 2003). An increase in the concentrations of CO_2 in the atmosphere as well as global climate change has led to a strong need for data and information on the global carbon cycle in terrestrial ecosystems (Unver, Kucuk, Tefekcioglu, & Dogan, 2010).

Land use change is one of the human activities that has a significant effect on the variability in terrestrial ecosystems and soil CO_2 emission, therefore, it has a great contribution to the rise of atmospheric CO_2 (Fan et al., 2015). Land-use change such as bush clearing may alter total soil respiration. Different models have predicted that, the total amount of CO_2 released to the atmosphere annually increases with the global deforestation rate/bush clearing (IPCC, 2007). Furthermore, Ma et al. (2013) have declared that bush clearing may have an influence on the soil respiration rate by causing a decrease in root respiration which often contributes approximately half of the total soil respiration. Changes in temporal and spatial variability in soil temperature and soil moisture due to bush clearing may also influence soil microbial activities and therefore affect soil respiration (Ma et al., 2013).

There has been a rise in concerns that changes in climatic conditions and bush clearing may increase the rate of soil respiration and soil organic carbon loss and further elevate the concentration of CO_2 in the atmosphere (Thomas, Hoon, & Doughill, 2011). Despite several studies on soil respiration being done in dry and semi-arid areas, the ability to predict the effects that land use changes play on soil respiration is still not assured. Fenn, Malhi and Morecroft (2010) argue that it is important to understand the environmental controls of soil respiration in order to evaluate potential responses of ecosystems to climate change. The overall aim of this research study therefore was to determine how bush clearing affects soil respiration.

Currently, there's an overwhelming global concern about greenhouse gasses emissions as a result of human activities and its effects on climate change. There appears to be a lot of research publications from the developed countries on this subject, however, only limited publications appear from the developing countries, including Namibia. Hence, this study is very significant to the advancement of knowledge on the influence of bush clearing on soil respiration.

1.2 Statement of the problem

Soil respiration is important in balancing carbon at different temporal and spatial scales as well as at many other ecosystems (Ma et al., 2013; Zheng, Chen, Noormets, Euskirchen, & Moine, 2005). Bush clearing has been used as a solution to problems of bush encroachment in north-central Namibia, but so far, no study has been done on investigating how bush clearing affects soil respiration in Namibia. An investigation whether bush clearing results in no change, low or high soil respiration needs to be done in Namibia because if bush clearing leads to a high release of CO_2 into the atmosphere, this may accelerate global warming, and thus, bush clearing may be one of the contributing factors to the changing climatic conditions that Namibia is facing at the moment. Currently, there is lack of data specifically for Namibian conditions on this topic. Other related studies carried out on the effects of land use on soil respiration done in similar allied environments to Namibia show variations in their results. Therefore, there is still lack of understanding on how changes in land use (including bush clearing) can affect soil respiration. As highlighted by Misson, Tang and Xu (2005), predicting changes in soil respiration in the aftermath of bush clearing is complicated and no consistent general trend has been found so far. These contradicting results require further studies to provide clear evidence to deepen the understanding of the effects of land-use changes on soil CO_2 efflux.

1.3 Research objectives

1.3.1 General objective

The main aim of this study was to investigate the effect of bush clearing on soil respiration in two farms located in north-central Namibia.

1.3.2 Specific objectives

i. To compare the rate of soil respiration between the cleared and uncleared sites at different seasons (wet and dry)
ii. To compare the rate of soil respiration under different micro-sites (bush, bare soil and grass) within the cleared site and uncleared site in the dry and wet season
iii. To investigate the effects of soil temperature and soil moisture on soil respiration

1.4 Research hypotheses

i. There is a significant difference in soil respiration between the cleared and the uncleared site at different seasons

i. There is a significant difference in soil respiration under different micro-sites (bush, bare soil and grass) within the cleared site and uncleared site
ii. Soil temperature and soil moisture have a positive effect on the rate of soil respiration.

1.5 Significance of the study

Soil respiration and its rate across ecosystems is extremely important to understand. This is because soil respiration plays an important role in global carbon cycling (as it is one of the largest components of CO_2 emission into the atmosphere) as well as other nutrient cycles. Changes in land use shift the rate of global soil respiration. Soil respiration is associated with positive feedbacks in relation to global climate change; therefore, soil respiration rates can be affected by land use change and they may then enhance climate change. This research contributes to the understanding on how soil respiration takes place under different land use conditions. This will inform policy makers about this critical phenomenon and this study may lead to a better formulation of policy documents and envisage good land management practices that are adaptive to climate change.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

Soil respiration releases CO_2 into the atmosphere eleven times of current fossil fuel burning (Dorji, 2010), and it is one of the most important components of ecosystem carbon budgets (Carlisle, Steenwerth, & Smart, 2006). There are two major components that contribute to total soil respiration; heterotrophic and autotrophic respiration (Butler et al., 2012). Heterotrophic respiration involves CO_2 that is released through the decomposition of animal and microbial residues while autotrophic respiration involves CO_2 that is released through the decomposition of the plant residues (Butler et al., 2012). These residues (plant, animal and microbial) are referred to as soil organic matter. The two components of soil respiration (heterotrophic and autotrophic) contribute to total soil respiration in different proportions depending on the number of biotic and abiotic variables such as soil temperature, moisture, litter quality and quantity, the composition of the soil organic matter and aboveground vegetation structure and composition (Butler et al., 2012; Luo & Zhou, 2006; Subke et al., 2003).

Soil temperature and moisture content are the two key environmental factors that influence CO_2 efflux from soils (Luo & Zhou, 2006). Davidson, Verchot, Cattanio, Ackerman, and Carvalho (2000) posit that soil organic matter depends on these two environmental factors (temperature and moisture) for their production and consumption. Soil carbon efflux is predicted to respond to climatic changes because organic matter decomposition rates are linked to soil temperature and moisture regimes (Trumbore, 2000). If any change occurs in the chemical composition of the soil organic matter or in the environmental conditions, it may change the rate at which the soil organic matter is decomposed which changes the rate of soil respiration too (Luo & Zhou, 2006). However, the degree of the influence of soil temperature and moisture as well as their contributions to soil respiration differ significantly depending on the variations of the seasonal climate and soil conditions, particularly in areas characterized by wet-dry cycles (Liu et al, 2014). Liu et al. (2014) further present that there is a wide variation in soil respiration due to changing environmental conditions, and this results in poor understanding and inaccurate estimations of soil carbon efflux in many ecosystems.

Land management practice is one of the major human activities that have an influence on the release of CO_2 into the atmosphere. Any change in vegetation or in land use that affects soil respiration is a major concern to global warming (Kaur et al., 2006). A change in land use type directly affects CO_2 fluxes from the soil surface (Kato, Nkoya, Place, & Mwanjalolo, 2010). For instance, in terms of bush clearing, if the bushes are cleared off the land, the soil will be more exposed to direct sun rays which lead to high soil temperature and high evaporation (Luo & Zhou, 2006). High evaporation rates reduce the amount of soil moisture and in return change the optimum conditions of the microbial activities and ultimately, affect soil respiration (Ma et al., 2013).

The difference in vegetation, management and soil property under different land use / land cover types leads to the difference in diurnal variation of soil moisture, temperature and soil respiration (Lihua, Yaning, Weihong, & Ruifeng, 2007). Zhang et al. (2007)'s research on the study of seasonal variations of soil respiration under different land use /

land cover conditions in arid environments revealed that soil respiration significantly varies among different land use types, but the variations depend on the hydrology and temperature regime of the given ecosystem. Soil respiration reflects vegetation type and productivity as well as the seasonal changes in soil temperature and soil moisture (Carbone, Winston, & Trumbore, 2008). The vegetation of markedly different structure, biomass and productivity that is subjected to the same climate will have distinct seasonal patterns of soil respiration (Butler et al., 2012). However, this varies from ecosystem to ecosystem and it is difficult to model them without prior knowledge of the specific ecosystem plant allocation patterns (Carbone et al., 2008).

The current trends in ecosystem research shows that reliable estimations about the behaviours of the ecosystems with respect to their abilities of storing carbon can only be achieved if there is a better understanding of belowground processes as well as factors and processes that lead to high carbon emissions from the soil in a particular ecosystem (Subke et al., 2003). Therefore, identifying the environmental factors that control soil CO_2 emissions and their effects on emission rates is a necessary step in assessing the potential impacts of environmental change on soil respiration (Raich & Tufekcioglou, 2000).

Several methods such as the open-flow infra-red gas analyser method, the closed chamber method, the dynamic closed chamber method and the alkali absorption method are commonly used in measuring soil respiration.

2.2 The carbon cycle

The soil is the largest reservoir of terrestrial carbon and it contains a large and dynamic of carbon pool, which is a critical regulator of the global carbon budget (Johnston et al., 2004). Therefore, soils are particularly critical to our understanding of the changing global carbon cycle (Chapin III et al., 2009). Vast quantities of carbon in the form of roots and decomposed organic matter are stored in soils and emitted into the atmosphere in the form of CO_2 (Johnston et al., 2004). Several models treat net CO_2 emissions from ecosystems as the balance between Net Primary Production (NPP) and decomposition (Chapin III et al., 2009). There is a strong bond between NPP and decomposition, such that carbon inputs to soils control decomposition, and ⁄ or decomposer activities control carbon inputs to vegetation (Chapin III et al., 2009). The balance between these two processes determines whether an ecosystem is a sink or a source of atmospheric carbon dioxide (Valentini et al., 2000).

Naturally, the earth’s carbon reservoirs act as both sinks and sources (University of New Hampshire, n.d.). A single carbon pool can often have several fluxes both adding and removing carbon simultaneously. For example, the atmosphere has inflows from soil respiration, forest fires and fossil fuel combustion and outflows from plant growth and uptake by the oceans (University of New Hampshire, n.d.). If all sources are equal to all sinks, the carbon cycle is said to be in an equilibrium state and there is no change in the size of carbon pools overtime (University of New Hampshire, n.d.). However, if the adding of carbon (for example due to soil respiration) exceeds the removal of carbon (for example NPP), the system becomes a source of atmospheric CO_2 (Chapin III et al., 2009). This occurs due to the physical, chemical, and biological processes in the environment that affect the balance between the uptake of carbon from the atmosphere and the storage of organic carbon compounds and their release to the atmosphere as CO_2 (Johnston et al., 2004). Hence, slight changes in the processes governing soil carbon cycling have the potential to release large amounts of CO_2 into the atmosphere (Johnston et al., 2004) and turn an ecosystem into a source.

As the largest carbon reservoir of the terrestrial biosphere, soil organic carbon pool strongly impacts and is impacted by climate change (Lal, 2014). According to Chapin III et al. (2009), soil resources and climate exert primary control on the production of carbon in soils. In particular, the rate of decomposition is temperature dependent, and approximately doubles with every 10°C increase in soil temperature-Hoff's Rule. Since the decomposition rate is temperature sensitive, global warming will most likely create a positive feedback, causing soils to release more CO_2 into the atmosphere (Johnston et al., 2004). An increase in temperature speeds up decomposition, depletes the soil organic carbon pool and its dynamics, and worsens climate change (Lal, 2014).

According to Keitt, Addis, Mitchell, Salas, and Hawkes (2015), the response of soil microbes (that are responsible for decomposition) to climate change partly controls the balance of carbon storage and loss. As a result, the effects of climate change on the activities and physiology of the soil microbes will partly determine what proportion of annual soil carbon input is respired versus stored in the long term reservoir of soil organic carbon (Keitt et al., 2015). Biologically mediated CO_2 flux is the only large carbon flux in the ecosystem, and carbon balance is the most important ecosystem feedback to the climate system (Lal, 2014). Hence, in order to quantify soil respiration and their dynamics at scales relevant for the ecosystem, regional and global carbon budgets, we first need to understand the mechanisms that control soil organic matter chemistry, formation, and accumulation (Chapin III et al., 2009).

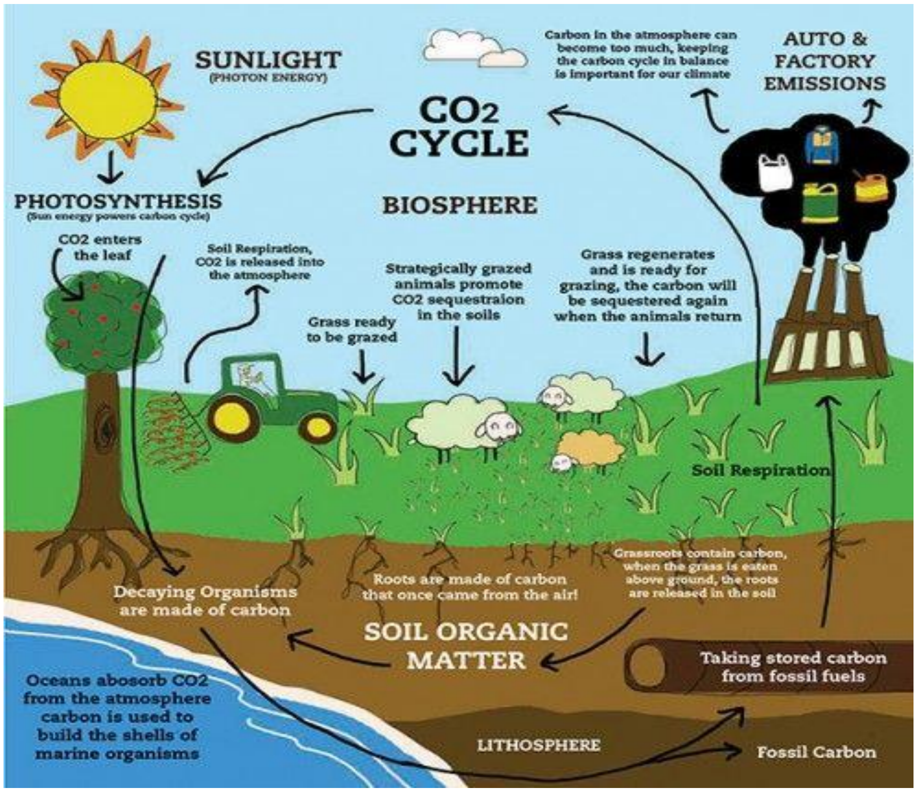

Figure 1. The Carbon cycle

2.3 The effects of bush clearing on soil respiration

Land use change, in particular its conversion into agricultural lands through bush clearing is one of the activities that alter the global carbon cycle (Bolstand & Vose, 2005). Among the changes in land use types, bush clearing is one of the major causes of increasing CO_2 in the atmosphere (Zheng et al., 2005). Carbon from standing vegetation is lost through direct removal of the vegetation (vegetation clearing) (Bolstand & Vose, 2005). In North-central Namibia, farmers clear the land to combat bush encroachment in such a way that allow grass to grow for their livestock. Bush clearing stimulates, suppresses or has no effect on soil respiration depending on the types of methods used for clearing, the speed of vegetation regeneration and climate conditions (Luo & Zhou, 2006).

Kaur et al. (2006) compared the rate of soil respiration between the cleared (recent, medium and old) and uncleared sites in the semi-arid zone of central Queensland. Queensland has similar environmental conditions to the proposed study area. The similarities of the two areas are characterized by a latitudinal line. These areas fall under semi-arid zones denoted with warm wet summers and cold dry winters. The results disclosed no significant difference (according to the statistical analysis) in the rate of soil respiration between the cleared and the uncleared sites. However, in some months the recently cleared site had a greater mean soil respiration than the uncleared, medium and old cleared sites. However, these measurements were only done during morning time (6-9am). Therefore there is need to conduct a study to observe variations of soil respiration during the day. Raich andTufekcioglou, (2000) also found no significant differences in the soil respiration rate between the crop fields and adjacent fields without plants. However, the crop fields had around 20% higher mean rates of soil respiration than adjacent fields without plants.

Some studies have reported an increase in soil respiration in the first few years after clearing and a decline over time as the vegetation regenerated. For instance, a study by Ma et al. (2013) demonstrated that, in general, cumulated annual soil CO_2 emissions were not significantly affected by bush clearing, but this could not be illustrated as no influence because soil respiration was affected by bush clearing during the first 4 months. In the short term, bush clearing led to a marginally significant increase in soil respiration, whereas in the long term, bush clearing had no influence on soil respiration (Ma et al., 2013). Soil respiration continued to be high for some time after clearing, mostly due to logging debris, erosion as well as the content and rates of decomposition of the soil organic matter, but overtime after clearing, soil respiration decreased (Bolstand & Vose, 2005). Moreover, a study conducted by Ohashi, Gyokusen, and Saito. (1999) revealed that soil respiration rates increased in the first two years after clearing, but this increase disappeared in the third year. Luo and Zhou (2006) also reported that the cleared plots released more CO_2 than the uncleared plots in the first year following the treatment, mainly due to the increase in soil temperature and decomposition of logging debris and fine roots. A reduction in soil cover after clearing exposes the soil to high temperatures which often results in warmer soils and speeds up respiration (Bolstand & Vose, 2005). In addition, soil respiration also increases after clearing due to better ventilation, an improved interaction between soil microbes as well as easily decomposable soil organic matter, and exposure of physically protected soil organic matter (Ohashi et al., 1999).

However, in other studies, soil respiration has been found to decrease after clearing. A comparative study by Striegl and Wickland (1998) in Saskatchewan, showed that tree harvesting reduced soil CO_2 efflux from 22.5 to 9.1 mol CO_2 m^{-2} and this could be due to the disruption of carbon supply from the canopy to the rhizosphere. Kurth, Bradford, Slesak, and D'Amato (2014) also reported that, throughout the study period, soil respiration in the sites where trees were cleared off was significantly lower than in the uncleared sites. Soil respiration remains lower in the cleared site, until vegetation restores (Moroni, Carter & Ryan, 2009). The dynamics of soil respiration during vegetation succession after clear cutting can be attributed to changes in vegetation and its associated carbon supply (Luo & Zhou, 2006). Bush clearing compacts soil, causing a decrease in soil aeration and restricting root growth and microbial activities, causing a decrease in soil respiration (Luo & Zhou 2006). A reduction in root abundance and microbial communities after clearing leads to a reduction in soil respiration (Xu, Chen & Brosofske, 2013; Li, Wang, Zhang, Zhang, & Tian, 2011).

The effects of bush clearing on the emissions of soil CO_2 is closely related to the dynamics of climate change as well as the biotic and abiotic factors that control the production of CO_2 from the soil (Luo & Zhou, 2006). Under changes of climate and precipitation patterns, the effects of land management on soil respiration may interact with precipitation which fluctuates across the year in semi-arid areas (Thomey et al., 2011). The interactions of land use type and environmental factors can directly or indirectly affect the soil conditions, and this significantly alters the soil CO_2 emissions (Liu et al., 2014). Farming, debushing, conversions from forest to open grassland, and other types of land uses have a great contribution to the changes of soil respiration.

Conversion leads to changes in temporal and spatial variability in soil temperature and moisture, and it affects soil microbial communities and carbon allocation patterns (Mauritz, Hale, & Lipson, 2010). Changes in vegetation structure from woodland to open grassland can lead to changes in soil microbial activity and biomass, root density and activity, as well as litter quality and quantity which alter soil respiration (Kaur et al., 2006). This is because grasses and shrubs differ in their below and aboveground biomass allocation, root architecture, phenology as well as litter quality and quantity (Mauritz et al., 2010).

Vegetation structure primarily controls soil respiration through the input of dead plant material into the soil, the composition of the soil organic matter content, plant growth microenvironment as well as root respiration (Davidson, Richardson, Savage, & Hollinger, 2006). Carbon pool sizes and distribution vary from one land use type to the other (Bolstand & Vose, 2005). If the original vegetation of the site changes, this may impair carbon cycling, alter the amount of soil organic matter content and the emission of soil CO_2 and change the net carbon balance of the ecosystem as well (Bini et al., 2013). This is because a change in land use patterns do not only change the surface vegetation, but also changes the permeability of soil, hence influencing the soil organic matter composition and decomposition, microbial activity, and root biomass and consequently affecting the carbon emission rate and the terrestrial ecosystem carbon storage (Casals et al., 2000). Changes in the net carbon balance of ecosystems may have significant implications for regional and global carbon balance (Wang, Ji, Hou, & Schllenberg, 2016). However, the contribution of specific land use types to the local and regional carbon cycle is still not clearly understood (Wang et al., 2016).

2.4 The effects of microsite conditions on soil respiration

Spatial variations in soil respiration occur in a variety of scales, from a few square centimetres to various hectares up to the whole globe (Luo & Zhou, 2006). The spatial variability in soil respiration on the landscape scale occurs due to large variations in the soil's physical properties (soil water content, thermal conditions, porosity, texture, and chemistry), biological conditions (fine root biomass, tunnelling soil animals, fungi, and bacteria), nutrient availability (deposit litter and nitrogen mineralisation), and other factors such as topography, disturbance history, weathering and vegetation types (Luo & Zhou, 2006).

Vegetation type is an important determinant of soil respiration rate, and therefore, changes in vegetation have the potential to modify the responses of soils to environmental change (Raich & Tufekcioglou, 2000). In ecosystems where vegetation distribution is patchy and shows mosaic patterns, the vegetation patches may modify the microenvironment by altering the dynamics of biomass, organic matter and nutrients, which may influence soil respiration processes at different scales (Han et al., 2014). The patches have different microsite conditions created by shrub/tree, grass and open space/bare soil and the impact of these microsites on soil respiration plays a major role (Mauritz et al., 2010). A microsite is defined as a small, distinct area within an ecosystem. In this research thesis, the three microsites referred to are; bare soil, under grass and under shrub microsites. The microsites are associated with different factors (soil temperature and soil moisture, microbial communities, root density and litter quality and quantity) that control soil respiration and this leads to diverse spatial patterns between the microsites (Mauritz et al, 2010; Liu et al., 2014). However, there is lack of understanding on how spatial heterogeneity in semi-arid areas affects soil respiration (Cable et al., 2012).

Soil respiration rates vary between different microsites (Siele, Mubyana-John, & Monyongo, 2008). The difference in soil respiration among the microsites could be due to root abundance, root density, aboveground biomass and productivity that have a great influence on soil respiration (Lihua et al., 2007). In general, the covered (covered with litter, under grass or tree canopy) microsites appear to have higher soil respiration than the uncovered/open space/bare soil microsites; higher rates were recorded in microsites with cover than the uncovered microsites (Siele et al., 2008). Han et al. (2014) also reported significantly higher mean soil respiration from covered microsites (grass and shrub) than at the bare soil. High aboveground biomass and productivity, the decomposition of litter as well as root respiration in the covered microsites also result in high soil respiration (Zhang et al., 2007). Furthermore, covered microsites have a large amount of quality nutrients (Cable et al., 2013).

With soil respiration being significantly higher in the covered microsite than the bare soil/uncovered microsite (Han et al., 2014; Siele et al., 2008), it is still not yet really clear as to which of the covered microsites (between grass and shrub) have higher or lower soil respiration than the other. Therefore, there exist an inconsistency in literature on which covered microsite between shrub and grass has high soil respiration. In general, grasses and shrubs differ in their above and below ground biomass allocation, soil microbial communities, root architecture, litter quality and quantity, soil moisture and temperature, and carbon allocation patterns (Mauritz et al., 2010). Also, different plant species attract different microbial communities (Kaur et al., 2006) that contribute differently to soil CO_2 efflux. Therefore, the effects of grasses and shrubs on soil carbon storage are regionally variable and there is no consistent pattern (Mauritz et al, 2010).

A study by Cable et al. (2012) and Perez-Quezada, Bown, Feuntus, Alfaro, and Franck (2012) found higher soil respiration at the shrub microsite than that at the grass microsite. This could be due to the fact that Shrub microsites usually have high soil respiration rates than the grass microsites due to a larger density of roots and litter distribution under the canopy, whereas the grass microsites are characterized by less litter accumulation and shallow to low root density (Cable et al., 2012). On the contrast, Carbone et al. (2008), Raich and Schlesinger (1992), and Mauritz et al. (2010) reported high soil respiration under the grass than at the shrub microsites; the grass-covered soil released more CO_2 than the shrub-covered soils did. Higher respiration levels in grasses than in shrubs could partially be due to the difference in soil temperature and moisture between grasses and shrubs (Mauritz et al., 2010). The soil characteristics such as its sensitivity to temperature may vary from shrub to grass to bare/open space, likely due to relative autotrophs and heterotrophs activities (Cable et al., 2012).

2.5 Seasonal effects of soil moisture and temperature on soil respiration

Soil temperature and moisture are the important environmental factors affecting the variation in soil CO_2 efflux under different land use types (Wang et al., 2014). However, there is still no clear understanding on how the overall water-temperature interactions influence soil respiration. Cacciotti et al. (2010) reported that there are existing gaps in scientific research on the impacts of climatic conditions on soil respiration. Particularly, how the modifications of temperature and water availability through changing seasonal drying and wetting cycles due to changes in climate and disturbances associated with ecosystem operations influence the emission of CO_2 from the soil (Cacciotti et al., 2010).

The effect of soil moisture on soil respiration is described by a number of equations such as linear, logarithmic, quadratic and parabolic functions and it can be unrelated, positively related, or negatively related to soil respiration, but such relationships are specific to particular sites; no universal model has been found yet (Davidson et al., 2000). Soil water is expressed as matric potential, volumetric water content, fractions of water holding capacity, precipitation indices, and depth to water table (Davidson et al., 2000). On the other hand, the effect of temperature on soil respiration is nearly described as an exponential function, although there is debate as to which exponential formulation will be the most suitable (Davidson et al., 2000).

There is a debate as to which one between the two environmental factors has more influence on soil respiration. Siele et al. (2008) and Luo and Zhou (2006) reported that soil moisture has more significant influence on soil respiration, compared to the soil temperature that has no observable influence in the seasonal variations of soil respiration. Among the climatic factors, precipitation/soil moisture is the most important factor to predict the regional variability in soil respiration (Luo & Zhou, 2006). On the contrary, Bolstad and Vose (2005) reported soil respiration to be strongly and exponentially depended on soil temperature since no relationship between soil moisture and soil respiration at any of their sites of study was found. Davidson et al. (2000) argue that soil temperature is known to have more effect on soil CO_2 efflux than soil moisture. Moreover, the study conducted by Aanderud, Schoolmaster, & Lennon (2011) revealed that soil temperature and soil respiration exhibited a positive correlation. Soil respiration displayed a variation in seasonal patterns due to soil temperature (Sheng, Yang, Chen & Xie, 2009).

In addition, Unver et al. (2010) pointed out that one of these two environmental factors (soil temperature and soil moisture content) can have more influence on soil respiration than the other, depending on the type of vegetation biome. For instance, in arid and semi-arid environments, soil respiration is largely controlled by the soil moisture but this depends on the size of the soil carbon pool (Wang et al., 2014). Low water content can inhibit soil carbon efflux and soil respiration falls as soil water content decreases (Wang et al., 2014). While in other vegetation biomes such as the tropics, temperature is the best single predictor of soil respiration rate (Raich & Schlesinger, 1992).

Some researchers (Butler et al., 2012; Conant, Klopatek, & Klopatek, 2000; Mauritz et al., 2010) have declared that the effect of soil moisture or soil temperature on soil respiration depends on the season; soil moisture can be a control factor in one season while soil temperature can be a control factor in the other. Conant et al. (2000) held that it is only during some periods of the year (especially in winter) that soil respiration is strongly related to soil temperature (Conant et al., 2000). Changes in soil respiration were explained by changes in soil moisture across all months of measurements, however, during the wet seasons, soil respiration increased with soil temperature (Conant et al., 2000). During the wet season, soil CO_2 efflux was predominantly controlled by the soil moisture content and no fluctuations of soil respiration in response to soil temperature were observed, but during the dry season, variations in soil respiration were strongly correlated with soil temperature (Butler et al., 2012).

While some authors (Davidson et al., 2000; Liu et al, 2016; Raich & Tufekcioglou, 2000) argued that soil respiration is not affected by a single factor, but the interactions of both soil moisture and temperature can be linked to the influence of soil respiration. For instance, Conant et al. (2000) reported that warmer temperature can be linked to high soil respiration only during the wet seasons when soil moisture is high. During the day, soil respiration across different land use types shows a significant exponential correlation with soil temperature and soil water content and their interactions. Therefore soil respiration fluctuates with both soil temperature and soil water content (Liu et al., 2016). Raich and Tufekcioglou (2000) stated that the effects of temperature on soil respiration manifest only when there is sufficient soil moisture to allow the production of CO_2 from the roots and microbial activities

Soil respiration varies across the seasons, mostly due to fluctuations in soil temperature and moisture. Studies conducted have reported that soil respiration is higher during summer, when temperatures and water availability are high. A study by Davidson et al. (2000) in the eastern Amazonia found higher rates of soil respiration during the rainy season and that they decline as the dry season approaches. This goes accordingly with the findings of Kaur et al. (2006) who reported that soil respiration displayed seasonal variations and it was greater during the warmer wet seasons compared to the cooler dry seasons. The study further revealed that, a raise in soil moisture increases soil respiration. Mantlana et al. (2009), Zhang et al. (2015), Liu et al. (2016) and Siele et al. (2008), also reported that an increase in soil moisture content during the wet season coincided with an increase in soil respiration, as the wet season showed significantly higher soil respiration than the drier season.

The rates of soil respiration may increase between winter and summer not only because the soils become warm, but also because water contents decline from saturated conditions in the winter to near optimal water contents in the early summer due to rainfall (Davidson et al., 2000). The availability of optimal water content during the wet season favours plant growth as well as the metabolic activities of soil microbes, thereby stimulating soil respiration (Luo & Zhou, 2006). The soil respiration rate reaches the maximum in summer during plant growth when root respiration and decomposition of litter is high and active (Raich, Potter, & Bhagawati, 2002). In general, warmer and wetter conditions exhibit greater rates of soil respiration and decomposition of organic matter than colder and drier conditions (Luo & Zhou, 2006). This indicates a strong bond between variation of soil respiration and soil moisture content among the seasons (Siele et al., 2008).

According to Chang et al. (2016) and Chang et al. (2014), low soil moisture conditions reduce the contact between the substrates, enzymes and microbes, and also slow down the supply of substrate. This makes the diffusion of labile substrates slow and then reduces the activity of exo-enzymes needed for the decomposition of organic matter (Gritsch, Zimmermann, & Zechmeister-Boltenstern, 2015). Moreover, during the dry season when soil moisture is limited, most soil micro-organisms become inactive (Yan, Chen, Xia & Luo, 2014). In terms of rainfall events, soil respiration increases following rainfall, due to the stimulation of soil microbes in the shallow soil (Huxman et al., 2004). Rain water stimulates microbial respiration by speeding up the mineralisation of osmolyte products which have accumulated during the dry period (Fierer & Schimel, 2003; Carlisle et al., 2006).

Table 1. Factors that affect soil respiration

Soil respiration

Microbial respiration	**Root respiration**
Vegetation (type, diversity and biomass)	Vegetation (type, diversity and biomass)
Litter quality & quantity	
Microbial biomass	
Soil temperature	Soil temperature
Soil moisture	Soil moisture

CHAPTER 3: MATERIALS AND METHODS

3.1 Description of the study area

3.1.1 Location

The study was conducted in two farms; Elandsvredge and Erichsfelde located in North-central Namibia. Elandsvregde is a farm owned by the Cheetah Conservation Fund (CCF). CCF is a Namibian non-governmental organisation, situated at 16˚39.0'E, 20˚28.12'S, 44km North-east of Otjiwarongo, in Otjozondjupa region, central-north Namibia. Elandsvregde farm is about 7300 hectares in total, with several cleared and uncleared plots. The aim of CCF is to ensure the long-term survival of the cheetah and its ecosystem through a multi-disciplinary and integrated conservation programme of research and education. The major farm activities involve livestock and large ungulate herbivory.

Erichsfelde is a privately owned traditional cattle farm of 13,000 hectares, situated at 21˚35'48.7"S and 16˚56'41.2''E, 37 km north of Okahandja in Otjozondjupa region. Erichsfelde is a member of the Ombotozu conservancy. Careful husbandry and conservation efforts in Erichsfelde make it possible for domestic and wild animals to coexist (Jürgens, Schmiedel & Hoffman, 2010). Some parts of the farm are encroached with *Senegalia mellifera* which has led to bush clearing (of the encroaching species). The size of the cleared site where the study was done is about 50 hectares and the size of the uncleared site is about 380 hectares. Erichsfelde is home to a wide variety of birds and wildlife; it also hosts a biological research observatory. The major farm activities involve livestock keeping and hunting.

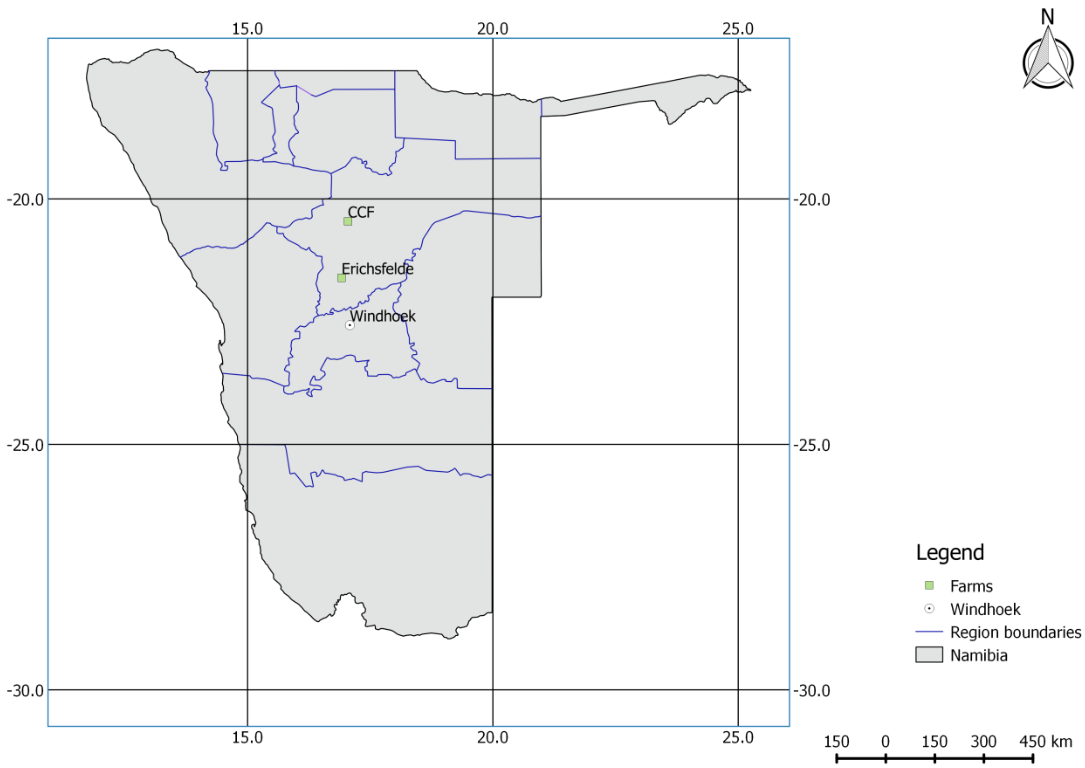

Figure 2. Map showing the location of the two study sites CCF and Erichsfelde in Otjozondjupa region, Namibia

3.1.2 Topography

CCF has distinctive savannah grassland topography and it is normally flat with small rolling hills (Kinyua, Mwakaje, Takawira, Kambewa, 2002). The landscape encloses small isolated granitic outcrops called kopjies which rise above a surrounding matrix of flatland, which has all rocks nearly covered (Kinyua et al., 2002). The Elandsvregde farm is located on a flat surface with minor 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 margin of the study area (Kinyua et al., 2002). A number of shallow ephemeral rivers can be found flowing from the east to the west (Kinyua et al., 2002).

The topography of Erichsfelde is flat with a mean altitude of 1495 meters above mean sea level and a slight inclination towards the north (Jürgens et al., 2010). The western part is divided by a small river (Omuramba) in the south-north direction that meets another river in the north of the farm and drains to the north (Jürgens et al., 2010).

3.1.3 Geology and soils

Otjiwarongo district is situated in the rocky central plateau of Namibia, at the centre between the landforms plateau with ridges in the south, and Karst and Hard Damara limestone to the north (Kinyua et al., 2002). The area is made out of 4 types of rocks associated with the Damaran Sequence: predominantly schist, marble and quartzite (Kinyua et al., 2002). CCF lies next to the plateau at heighten elevation of approximately 1600 m above sea level. The Waterberg Plateau, a 4100 km^2 sandstone inselberg is the main geomorphological feature of the area (Kinyua et al., 2002). The lithology at farm Elandsvreugde are sedimentary and volcanic units of the Damara sequence (ND: Damara undifferentiated). Schists, marble and quartzite cover the major parts of the farm. The south-western part of the farm contains granitic rocks of the Damara Squence (Cgd, undifferentiated); Marbels of the Swakop Group (Nsc) and Nossib Group (Nn), and dolomites of both groups (not differentiated). Sandstone described by Mukaru (2009) as brown to light grey in colour and medium-sized grains belong to the lower part of the Kalahari Sequence. Windblown thick sands from the uncondolidated topmost part of the Kalahari Sequence and cover the sandstone (Mukaru, 2009). Soil types in CCF fall into two main categories: Eutric Regosols and Chromic Cambisols (CCF, n.d.). The soil is very poor in nutrients given that it was derived from red quartzite sand, which is mostly leached out (Mukaru, 2009). Soil pH ranges between 3.6 and 6, with an average value of 4.4, while Phosphorus (P) is $\leq$ 15 ppm, and Calcium (Ca) 200 ppm (Mukaru, 2009).

Geologically, the area around Erichsfelde lies in a transition zone between the western Kalahari margins and the escarpment in the west. The geological units are typical of Damara Granite intrusions with EVI absolute range of 0.115 (2004)-0.373 (2006) (Jürgens et al., 2010). The drainage system heads towards the north, the margins of the Omatako catchment. The soil of the farm can be divided into three areas; (Jürgens et al., 2010). (1) Reddish clayey Luvisols associated with slight acidity and very low nutrient content is found in the eastern part of the farm. (2) Dark brown loamier Calsisols and Cambisols with high Alkaline and high contents of organic carbon are found on the western part of the farm. While (3) the dry river bed consists of shallow Calcisols with a neutral to alkaline pH.

The Calsisols in the western part of the farm have high electrical conductivity and high organic carbon. In most soils of the farm, there is a thin layer of coarse sand that occurs as the residual of rain-splash induced erosive processes (Jürgens, et al., 2010). The pH, clay and silt percentages vary within the soil, but the values are practically constant with depth (Jürgens et al., 2010). Soil organic carbon varies within the profiles and decreases with depth while clay and silt content show a distinctive increase with depth (Jürgens et al., 2010). The soil type is mostly dominated by sandy and clayey-sand but a few samples have also showed a presence of silt content (Jürgens et al., 2010).

3.1.4 Climate

The climate of the area around CCF is considered as semi-arid, with the rainfall season extending from October to April (Kinyua et al., 2002). On average, there are 45 rain days per year and about 400 to 450 mm of precipitation. Hipondoka (2005) distinguished three climatic periods based on precipitation and temperature stratification: A wet and hot season starts in January and lasts until April. A dry and cold season follows from May to August, before the dry and hot season commences in September and lasts until December. Most of the precipitation here falls in February averaging 113 mm. The wet season is characterised by extensive thundershowers and flooding, with significant variation in the amount of precipitation between years (Kinyua et al., 2002). During the year of study (2016), the mean soil moisture recorded at CCF during the wet season was 2.60% while 0.91% was recorded for the dry season. The average annual temperature is 20.3˚C. Maximum temperatures range from 29˚C to 34˚C during summer while in winter, temperatures can be as low as 5˚C (Kinyua et al., 2002). December is the warmest month of the year with an average temperature of 23.8˚C. June is the driest and coldest month, with 0mm of rain and temperatures averaging at 14.4˚C. The dominant wind directions throughout the year are from the north, north-east and east. However, strong westerly winds occur during three pre-summer months; August, September and October (Kinyua et al., 2002).

For Erichsfelde, the climate of the area is characterised as semi-arid. Rainfall occurs during summer from September to April, peaking in February (Jürgens et al., 2010). Erichsfelde receives an annual average rainfall of 372 mm/a (Jürgens et al., 2010). The annual mean temperature is 20.6˚C, with January being the warmest month and July being the coldest. The observed mean lowest temperature is above the freezing point, but frost occurs sometimes during the months of May to August (Jürgens et al., 2010). The dry season starts in May and lasts until September. In 2016, the average soil moisture content recorded in Erichsfelde during the dry season was 2.67% and 4.40% for the wet season. The wind mainly blows south-westerly in spring and summer, but a weak north-easterly component is also observed (Jürgens et al., 2010). While in autumn and winter, there is a major north-easterly component (Jürgens et al., 2010). Early afternoons have the highest wind speed, which can go up to 10 km/h (Jürgens et al., 2010).

3.1.5 Flora

CCF is situated in the Thornbush Savannah vegetation zone. The vegetation is typical of xeromorphic thornbush savanna with dominant woody plant genera consisting of *Senegalia and Vachellia spp*, *Dichrostachys cinerea*, *Grewia spp*, *Terminalia spp*, and *Boscia spp*. Understory vegetation is sparsely distributed, but ephemeral forbs grow after rainfalls (Kinyua et al., 2002). This area has changed drastically over the last century due to human-caused disturbances in combination with natural climatic fluctuations (Kinyua et al., 2002). Several native species such as *Senegalia mellifera*, *Vachellia tortilis*, and *Dichrostachys cinerea* have resulted into bush thickening, which is referred to as bush encroachment. The perennial grasses have been reduced throughout this area to the extent that only remnant patches of historic open Savannah habitat exist (Kinyua et al., 2002). Due to the grass depletion from overgrazing, many areas of the natural savannah ecosystem have become overgrown with a variety of thornbush species. The excessive growth of bushes creates a serious threat to cheetahs and other native species, because the bushes cover up the whole landscape, making it hard for animal movements and the thorns can potentially puncture the animals (Feller, Mahony, Sazanowiz, & Wise, 2006).

In 2001 CCF management established a project to reduce the encroachment of native shrubs in the savanna while manufacturing Bushblok (Feller et al., 2006). CCF Bush (PTY) Ltd. aims to restore the natural savanna ecosystem while stimulating the Nambian economy (Feller *et al*., 2006). The operation targets the encroaching *Senegalia mellifera*, *Vachellia reficiens* and *Dichrostachys cinerea* species (Feller *et al*., 2006). Harvesting commenced in 2003 till to this day.

The vegetation of Erichsfelde is also categorized as open Thorn Bush Savannah, with *Senegalia* and *Vachellia* species as main woody components and the most dominant grasses are *Stipagrostis*, *Aristida* and *Eragrostis* species in the herb layer (Jürgens et al., 2010). Erichsfelde has around 266 grass species (Jürgens et al., 2010). Annual grasses dominate over perennial grasses in the herb layer depending on the habitat type and the intensity of disturbance caused by grazing and trampling animals (Jürgens et al., 2010). The area around the small river is covered by different grass species, dwarf shrubs and dense woody vegetation. The plains and the river have very distinct vegetation structure and a very rich species composition. The farm has three distinct vegetation units (Jürgens et al., 2010); the first one is the *Bothriochloa radicans-Ziziphus mucronata* community that is found along the river. The sandy nature of the riverbed and deep soil layers store enough water to boost the growth of tree species such as *Ziziphus mucronata*, *Vachellia reficiens* and *Senegalia mellifera*. The understory vegetation is associated with high species composition of annual grasses and herbaceous plants (Jürgens et al., 2010). The second vegetation unit is the *Seddera suffruticosa-Melhania virescens.* This vegetation community is found in some parts of the plain habitats that have calcrete layers. Grass species such as *Enneapogon desvauxii* and *Monelytrum luederitzianum* and shrub species such as *Cataphractes alexandri* also form part of this vegetation unit (Jürgens et al., 2010). The third vegetation community is *Eragrostis ridigor-Gisekia Africana* which covers most of the farm area. This unit is also made up of annual herbs such as *Gisekia africana, Crotalaria heidmannii* and *Tephrosia burchellii*. These herbs grow in abundance after good rainfalls, other than in bad ones (Jürgens et al., 2010). This unit has a high diversity of woody species such as *Vachellia fleckii, Vachellia tortilis, Vachellia hebeclada* and *Boscia albitrunca*. Some parts of this unit are abundantly dominated by grassy vegetation of the *Aristida* species while some are associated with high densities of *Senegalia mellifera* referred to as bush encroachment (Jürgens et al., 2010). The thickening of *Senegalia mellifera* has resulted in reduced space of the grass species to grow. This has led to low food availability for the livestock to feed on. As a solution, Erichsfelde farm managers have begun to clear off the encroaching bush species to make space for the growth of grass.

3.1.6 Fauna

A study conducted by SRK Consulting (1999) in Otjiwarongo region indicated that birds and reptiles represent more than 300 species despite the relatively homogenous nature of the arid thornbush woodland habitats. Larger animals include *Acinonyx jubatus Panthera pardus*, *Hyaena brunnea*, *Canis mesomelas, Tragelaphus strepsiceros, Oryx gazella*, *Taurotragus oryx*, *Alcelaphus buselaphus caama*, *Phacochoerus africanus, Raphicerus campestris*, and *Sylvicapra grimmia* (Kinyua et al., 2002). Surveys conducted under the support of CCF in the surrounding commercial farms (Boskop, Cheetah View, Elandsvreugde, Gross Hamakari, Hebron, Nogverder, Okosongomingo, Ombujomatemba, Oros, Osonanga, Padberg, Uitsig and Vaalwater) suggested that the region has about 3500 *Phacochoerus africanus*, 3200 *Tragelaphus strepsiceros*, 300 to 1500 *Oryx gazella*,, 500 *Taurotragus oryx*, 700 *Raphicerus campestris*, and over 600 *Sylvicapra grimmia*. Research conducted in CCF by Ngarue (2000) and Richardson (1998) has shown that the grazer's biomass is the highest in open savannah type of habitat, and bush encroachment can have an adverse impact on their density. According to Kinyua et al. (2002), bush encroachment reduces the quality of the habitat for grazers such as *Alcelaphus buselaphus caama* due to the disappearance of palatable grasses and an increase in woody species, while on the other hand benefiting the browsers such as *Tragelaphus strepsiceros* and *Sylvicapra grimmia*.

Erichsfelde is mainly used for cattle farming, but there is also hunting involved which generates a small proportion of income (Jürgens et al., 2010). Erichsfelde is home to a number of different animal species ranging from herbivores such as *Antidorcas* *marsupialis*, *Madoqua kirkii*, *Taurotragus oryx*, *Tragelaphus strepsiceros*, *Sylvicapra grimmia*, *Alcelaphus buselaphus caama*, *Raphicerus campestris*, *Phacochoerus africanus*; predators that include *Acinonyx jubatus Panthera pardus*, *Canis mesomelas, Felis silvestris lybica* and also small mammals such as *Orycteropus afer*, *Manis temminckii*, *Procavia capensis*, *Erethizon dorsatum*, *Lepus saxatilis*, *Xerus inauris*, *Papio ursinus* occur are found on the farm. The presence of *Macrotermes michalseni* and *Odontotermes okahandjae* can also be observed as they have built mounds in the farm.

3.2 Experimental design and layout

The study followed a quantitative research design, using standardized experimental methods to measure the amount of CO_2 efflux from the soil as well as soil temperature and soil moisture. The field work measurements were made in March, June, September and December 2016. Nine (9) sampling points were selected in each of the two sites; the uncleared site and the cleared site in both study areas (CCF and Erichfelde). The size of the plots were as follow; Elandsvredge uncleared site was about 300 hectors and the cleared site was about 10 hectors, Erichsfelde uncleared site was about 280 hectors and the cleared site was about 50 hectors. The sampling points were selected using systematic sampling; after every Kth point. $K = \frac{N}{n}$; where by N = Number of hectors per site (site size) and n = number of points of measurements per site, as described in the University of Idaho soil sampling manual (1997).

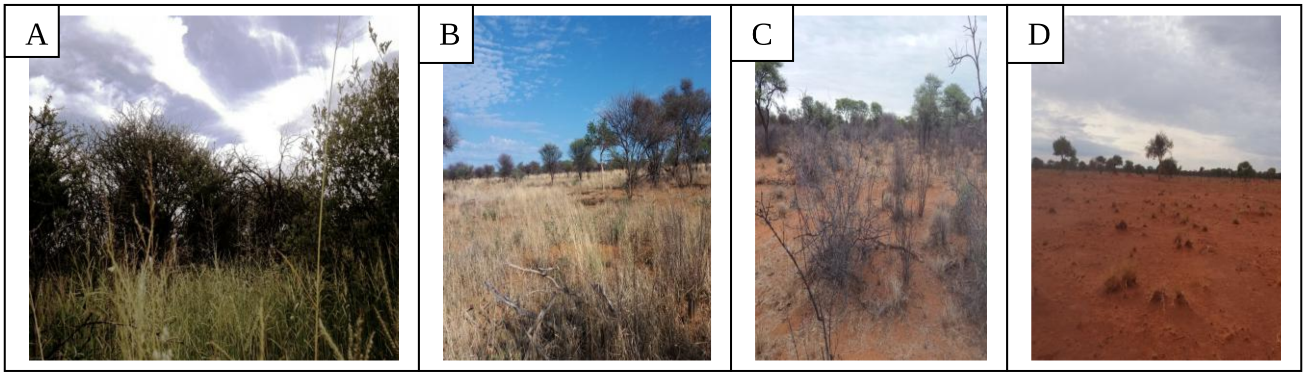

Figure 3. The four sites; uncleared site of CCF (A), cleared site of CCF (B), uncleared site of Erichsfelde (C), cleared site of Erichsfelde (D)

3.3. Field measurements

3.3.1 Calibration, installation and soil respiration measurements

Soil respiration was measured using a soil respiration chamber connected to the Infrared Gas Analyser LI-COR 6400 XT. The soil chamber rested on a collar (PVC pipe) while it was taking measurements. The collars were inserted to a depth of 1 cm into the soil. Three collars were installed at each point in the uncleared site; under the shrub (the most dominant shrub in the site) under the grass (any type of grass regardless of the species) and on bare ground. In the cleared site, two collars were installed at each point; under the grass and on bare ground. This is because the site is cleared and therefore, no shrubs or trees were present.

Within each collar, all above ground parts of vegetation, new growth or any litter had been removed before measurements were done. The collars remained installed at the sampling points throughout the duration of the study. The Gas analyser was set at 3 cycles which were averaged with an in-depth of 3cm and a target of 390. The instrument was calibrated at the beginning of each set of measurements. Measurements were done throughout the day (from 8h00 to 16h00).

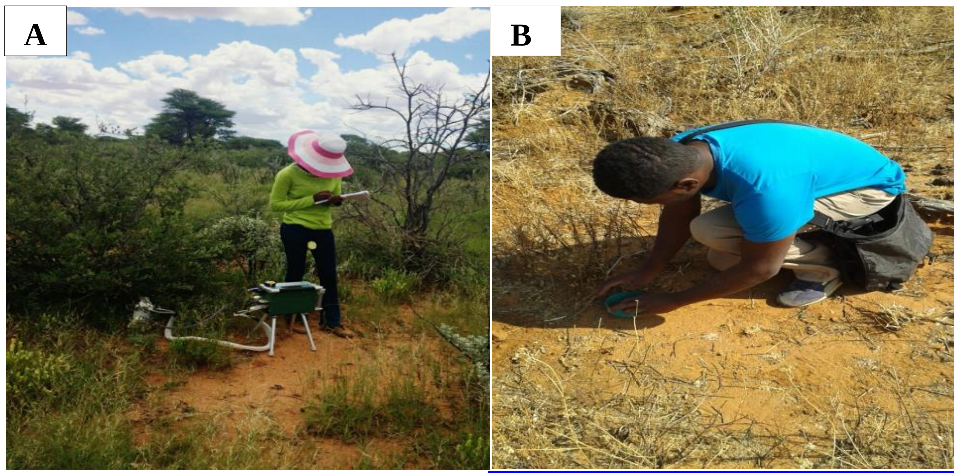

Figure 4. A) Measuring soil respiration with a Gas Analyser Licor 6400 XT and B) Student assistant inserting the collars for soil respiration measurements

3.3.2 Soil temperature measurements

The soil temperature was measured at 10 cm depth at each sampling point, using a temperature probe connected to the Infrared Gas Analyser LI-COR 6400 XT.

3.4 Laboratory analysis

3.4.1 Soil moisture determination

Soil samples were collected at a depth of approximately 10 cm at each sampling point using a soil auger. The soil samples were analysed at the laboratory of the Geology Department at the University of Namibia. Soil moisture was determined using the Gravimetric method. The analytical procedures were as follow; soil samples were weighed and this weight was recorded as wet weight (g). The samples were then put in the oven and dried at 105^{o}C for 24 hours. After 24 hours, the samples were taken out of the oven and allowed to cool down to room temperature and then weighed again and this weight was recorded as dry weight (g). The soil moisture content (%) was calculated as:

$$\frac{\textbf{Wet weight of soil (g)} - \textbf{Dry weight of soil (g)}}{\textbf{Dry weight of soil (g)}} \times \mathbf{100}$$

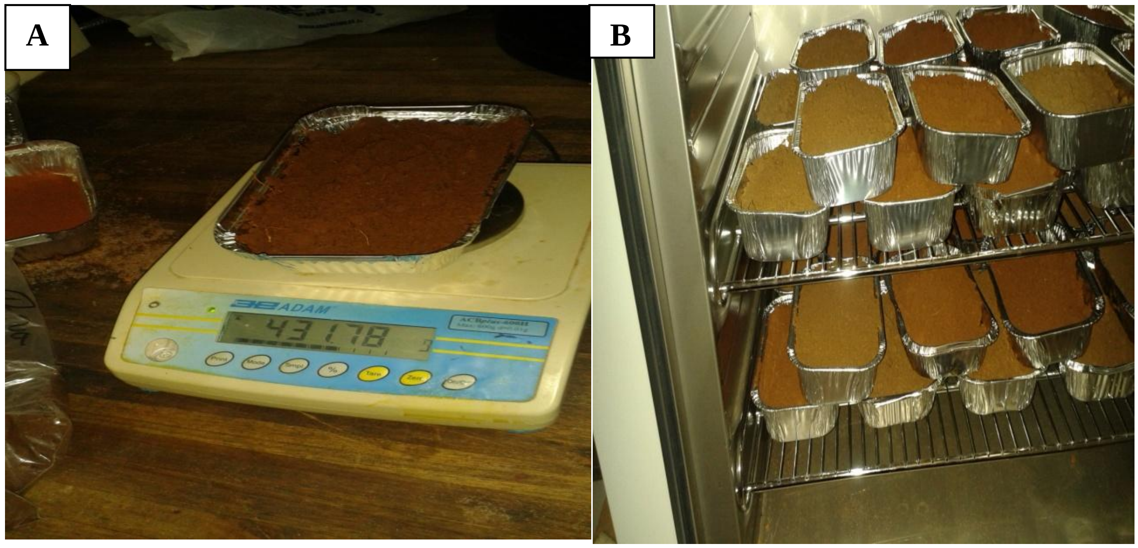

Figure 5. Weighting soil samples (A) and drying soil samples in the oven for soil moisture estimations (B)

3.4.2 Soil particle size analysis

After drying, the soil samples were analysed for grain size distribution through sieving them in a set of 8 sieves (<63µm, 63µm, 100µm, 200µm, 400µm, 600µm, 1mm and 2mm) in which only the grains that are smaller than the sieve could pass through. The 8 sieves were placed on a tray in a descending order, with the largest mesh size sieve being on top. The soil samples were passed through the 2 mm sieve into the tray and the sieve was covered. The electrical shaker was switched on at 3 minutes and amplitude of 0.25 mm/g. The soil retained in each sieve was weighted and the mass was recorded. The soil textural classes for each site were determined using the soil textural triangle.

3.5 Statistical analysis

Soil respiration measurements were made in March, June, September and December 2016. March and December data were combined to represent the wet season while the June and September data were combined to represent the dry season data. All data were tested for normality using a Shapiro Wilk test because the sample size was less than 2000 (Dytham, 1999). Where the data were normally distributed, the T-test was used to test for the significant difference in soil respiration between the uncleared and cleared sites as well as between the bare and grass microsites, and where the data were not normally distributed the Mann-Whitney test was used. The Kruskal-Wallis test was used to test for the significant difference in soil respiration between the microsites within the uncleared sites, and where any difference occurred, the Mann-Whitney was used to reveal where the differences were.

T-test is an analysis of two population means through the use of a statistical examination; testing the difference between the samples when the variances of two normal distributions are not known (Runyon, Haber, Pitternger, & Coleman, 1996).

Mann-Whitney U test is a non-parametric test, alternative to the independent sample T-test, that is used to compare whether two sample medians that come from the same population are equal or not. It is used when the data is ordinal and the assumptions of the t-test are not met (Runyon et al., 1996).

The Kruskal-Wallis H test is a non-parametric test that is alternatively used when the assumptions of the one-way ANOVA are not met. It can be used to determine whether there are statistically significant differences between three or more groups of an independent variable on a continuous or ordinal dependent variable (Struwig & Stead, 2001).

Linear regression (least squares regression) was used to evaluate the correlation between soil temperature and soil respiration as well as the correlation between soil moisture and soil respiration. All data for each season irrespective of the site were combined to determine the significant relationship between soil respiration and soil temperature and also between soil respiration and soil moisture in each season; such that $y = mx+c$, whereby y is soil respiration, x is soil temperature or soil moisture, m and c are constant variables.

All statistical analyses were performed using SSPSS 24 (SPSS for Windows, Version 24, Chigago, IL, USA).

CHAPTER 4: RESULTS

NB: For the graphs, the same scale for the y-axis has been chosen to allow better comparison.

4.1 Seasonal variations in soil respiration between the uncleared and cleared sites

At CCF during the dry season, soil respiration ranged from 0.134 µmol m^{-2} s^{-1}-0.773 µmol $m^{-2}s^{-1}$ in the uncleared site and 0.203 µmol $m^{-2}s^{-1}$-1.084 µmol $m^{-2}s^{-1}$ in the cleared site. While in the wet season, mean soil respiration ranged from 1.798 µmol $m^{-2}s^{-1}$-4.295 µmol $m^{-2}s^{-1}$ in the uncleared site and 1.161 µmol $m^{-2}s^{-1}$-4.59 µmol $m^{-2}s^{-1}$ in the cleared site. The T-test for both seasons showed no significant difference in mean soil respiration between uncleared and cleared site (t= 1.667, df=34, P=0.105>0.05) for dry and (t= -2.031, df=34, P=0.051> 0.05) for wet season.

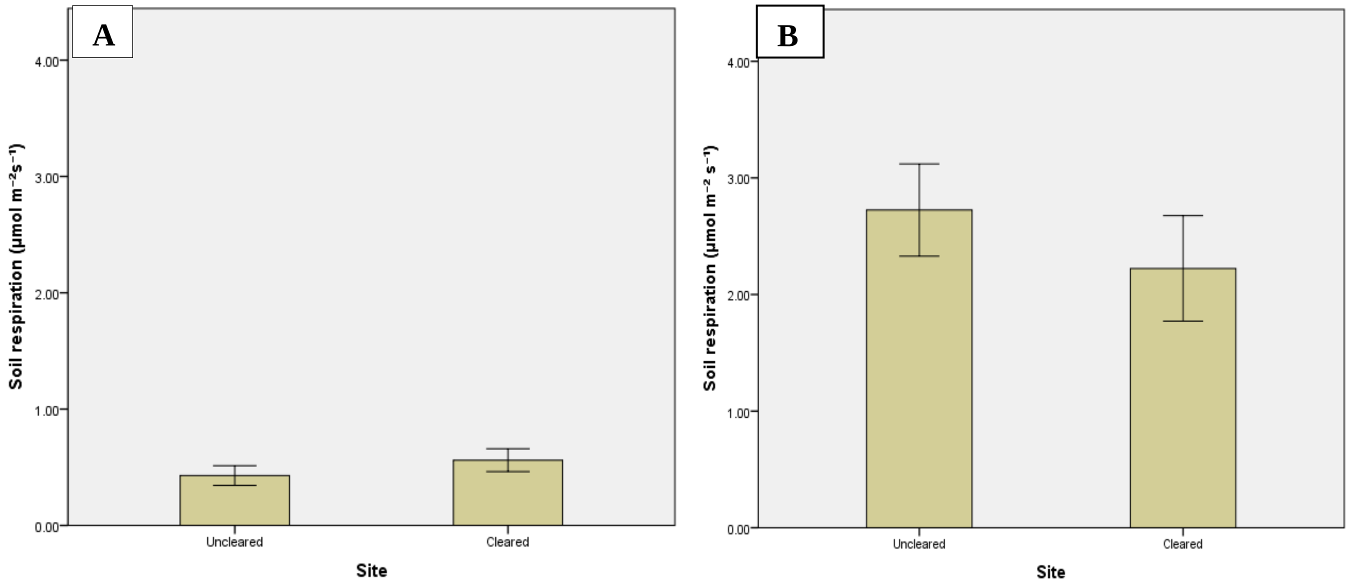

Figure 6. Comparison of soil respiration between the uncleared and cleared site of CCF during the dry (A) and wet season (B)

In Erichsfelde, soil respiration in the dry season ranged from 0.362 μmol $m^{-2}s^{-1}$-1.53 μmol $m^{-2}s^{-1}$ in the uncleared site and 0.244 μmol m^{-2} s^{-1}-0.53 μmol $m^{-2}s^{-1}$ in the cleared site. In the wet season soil respiration ranged from 0.479 μmol $m^{-2}s^{-1}$-3.71 μmol $m^{-2}s^{-1}$ and 0.334 μmol $m^{-2}s^{-1}$-3.13 μmol $m^{-2}s^{-1}$ for the uncleared and cleared sites respectively. The median soil respiration in the uncleared site was significantly higher than the median soil respiration in the cleared site as shown in figure 6. Mann-Whitney test depicted that there was a significant difference in median soil respiration between the two sites ($u=19.00$, $Z=-3.344$, $P=0.001<0.05$) for dry and ($u=80.00$, $Z=-2.594$, $P=0.009<0.05$) for wet season.

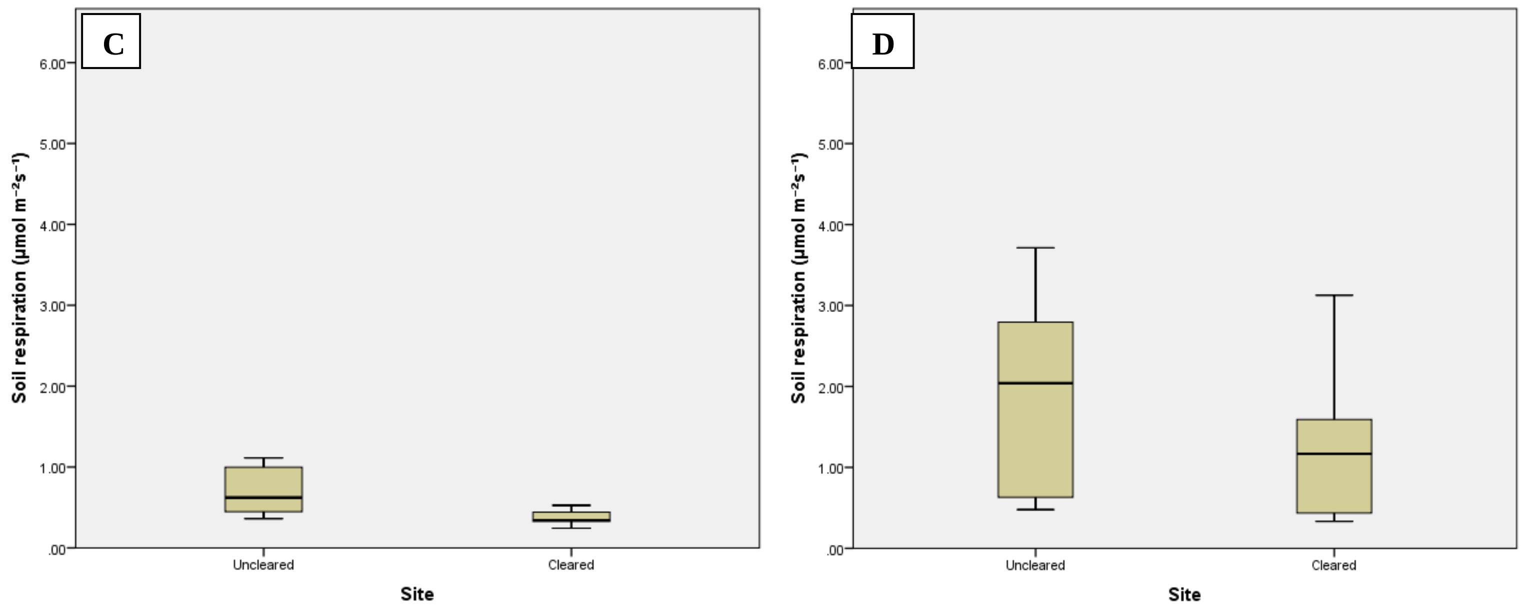

Figure 7. Comparison of soil respiration between the uncleared and cleared site of Erichsfelde during the dry season (C) and wet season (D)

4.2 Seasonal variations of soil respiration in the microsites

For the uncleared site in CCF during the dry season, soil respiration ranged from 0.13 μmol $m^{-2}s^{-1}$ -0.79 μmol $m^{-2}s^{-1}$ in the bare, 0.14 μmol $m^{-2}s^{-1}$ -0.76 μmol $m^{-2}s^{-1}$ in the grass and 0.09 μmol $m^{-2}s^{-1}$ -1.57 μmol $m^{-2}s^{-1}$ in the shrub microsite. The Kruskall-Wallis test indicated no significant difference in median soil respiration between the three microsites during the dry season (H=3.007, df=2, P=0.222>0.05). In the wet season, soil respiration ranged from 1.17 μmol $m^{-2}s^{-1}$-4.08 μmol $m^{-2}s^{-1}$ in the bare, 1.45 μmol $m^{-2}s^{-1}$ -3.83 μmol $m^{-2}s^{-1}$ in the grass and 1.82 μmol $m^{-2}s^{-1}$ -6.13 μmol $m^{-2}s^{-1}$ in the shrub microsite. Unlike in the dry season, the kruskall-Wallis test showed a significant difference in soil respiration in the wet season (H=6.305, df=2, P=0.043<0.05). The difference was revealed to be between the bare and the shrub microsite, whereby the shrub microsite had significantly higher median soil respiration than the bare microsite (P=0.016<0.05), shown in figure 8.

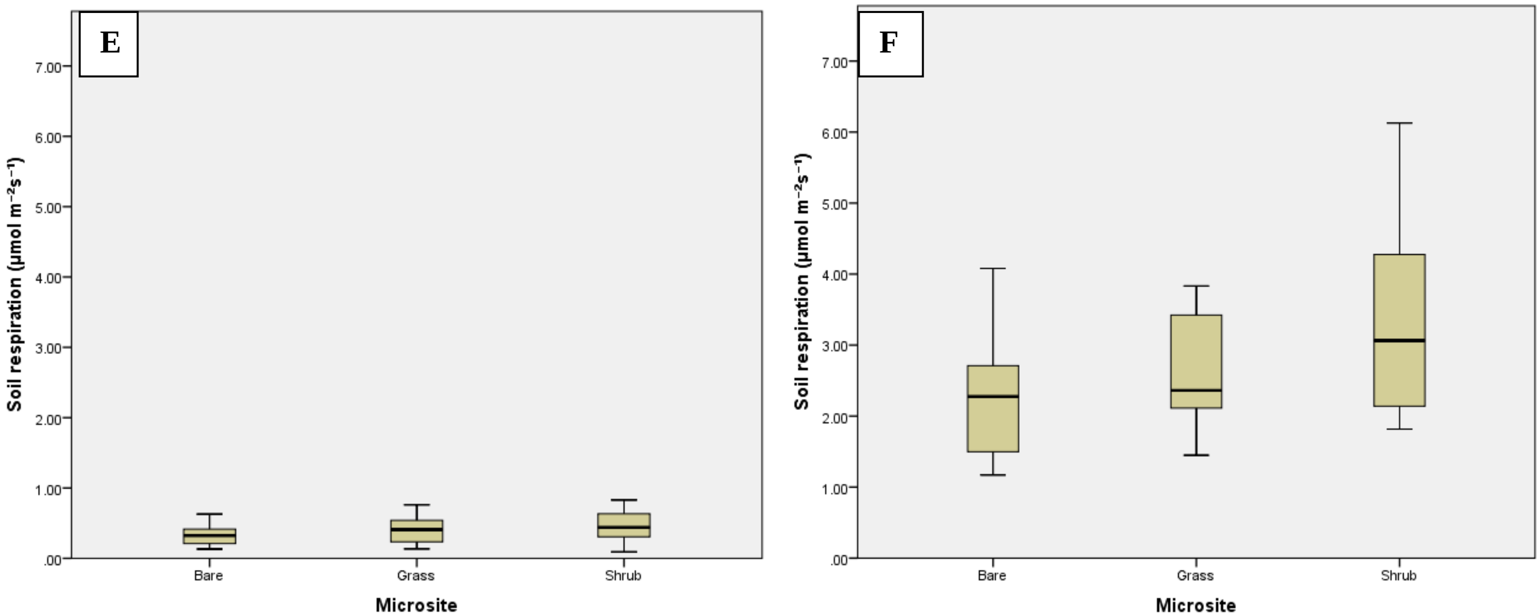

Figure 8. Comparison of soil respiration between the microsites of the uncleared site at CCF in the dry (E) and wet season (F)

In Erichsfelde during the dry season, soil respiration ranged between 0.14 µmol $m^{-2}s^{-1}$ -3.34 µmol $m^{-2}s^{-1}$ in the bare, 0.21 µmol $m^{-2}s^{-1}$ -3.55 µmol $m^{-2}s^{-1}$ in the grass and 0.29 µmol $m^{-2}s^{-1}$ -2.35 µmol $m^{-2}s^{-1}$ in the shrub microsite. Similarly to CCF, the Kruskal-Wallis test also showed that median soil respiration under the bare, grass and shrub microsite was not significantly different during the dry season ($H= 2.745$, $df=2$, $P=0.253>0.05$). In the wet season, soil respiration ranged between 0.25 µmol $m^{-2}s^{-1}$ -3.44 µmol $m^{-2}s^{-1}$ in the bare microsite, 0.433 µmol $m^{-2}s^{-1}$ -4.34 µmol $m^{-2}s^{-1}$ in the grass microsite and 0.47 µmol $m^{-2}s^{-1}$ -5.40 µmol $m^{-2}s^{-1}$ in the shrub microsite, shown in figure 9.Contrarly to the dry season, the wet season revealed a statistically significant difference in median soil respiration ($H=8.427$, $df=2$, $P=0.015<0.05$). The statistical difference existed between the bare and the shrub microsite, whereby the shrub had significantly higher median soil respiration than the bare microsite ($P=0.001<0.05$).

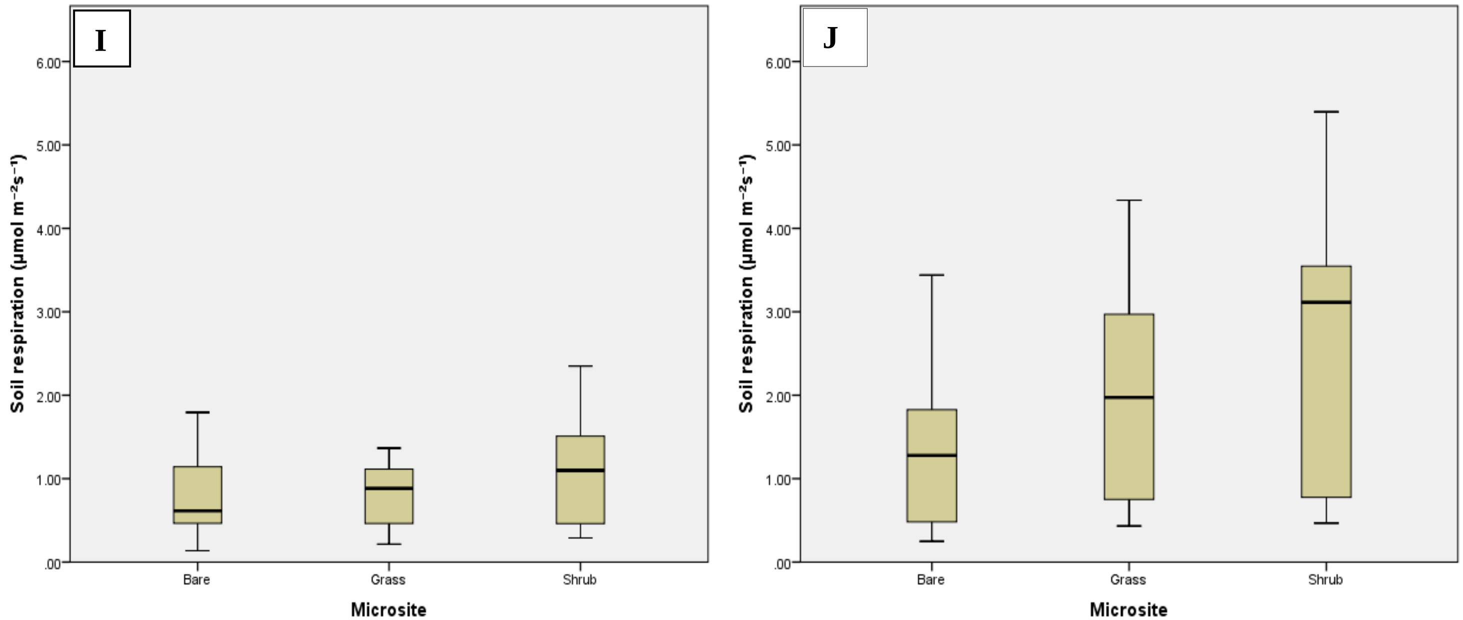

Figure 9. Comparison of soil respiration between the microsites of the uncleared site in Erichsfelde during the dry (I) and wet season (J)

For the cleared sites at CCF during the dry season, soil respiration ranged between 0.26 µmol $m^{-2}s^{-1}$ -1.63 µmol $m^{-2}s^{-1}$ in the bare and 0.11 µmol $m^{-2}s^{-1}$ -0.98 µmol $m^{-2}s^{-1}$ in the grass microsite. The T-test showed mean soil respiration between the bare and grass microsites during the dry season to be similar (t=-0.969, df= 28, P=0.0.341>0.05), as shown in figure 10. While in the wet season soil respiration ranged between 0.44 µmol $m^{-2}s^{-1}$ -3.98 µmol $m^{-2}s^{-1}$ in the bare and 1.33 µmol $m^{-2}s^{-1}$ -7.38 µmol $m^{-2}s^{-1}$ in the grass microsite. The T-test revealed a significantly higher mean soil respiration in the grass microsite than in the bare microsite (t=-2742, df=33, P=0.010<0.05), shown in figure 10.

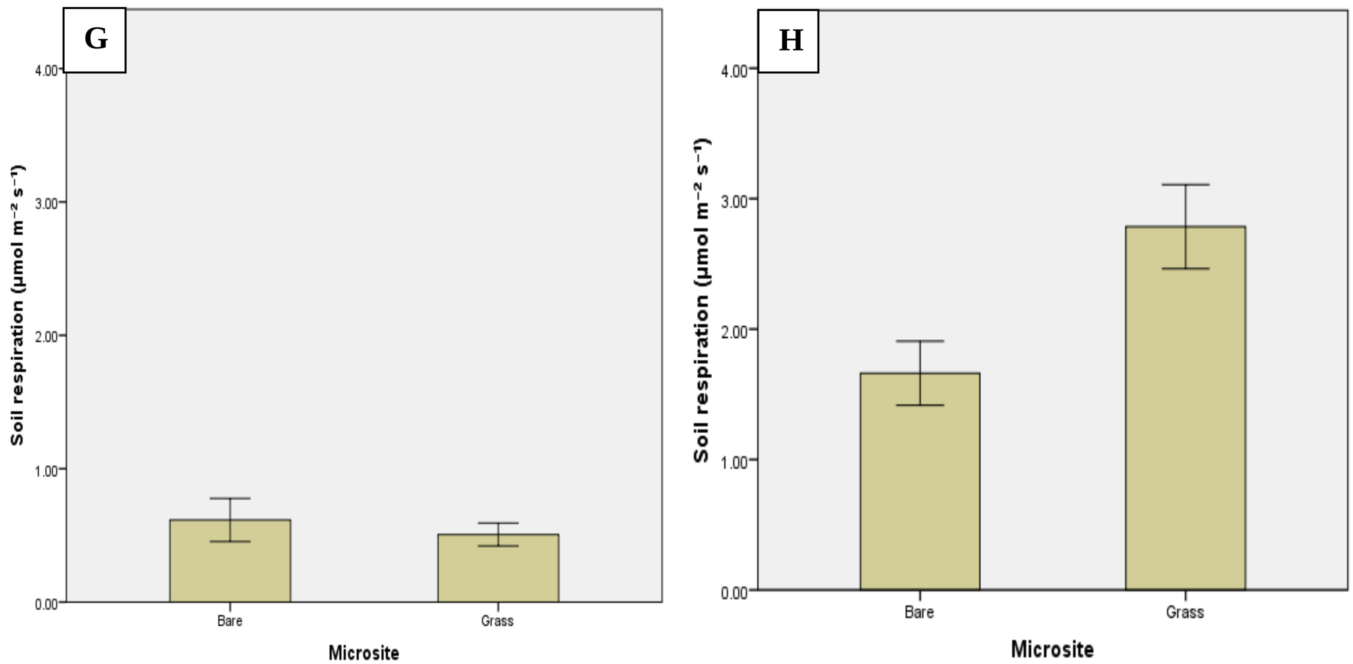

Figure 10. Comparison of soil respiration between the microsites of the cleared site at CCF during the dry (G) and wet season (H)

In the microsites of the cleared site at Erichsfelde, soil respiration ranged between 0.15 $m^{-2}s^{-1}$ -0.45 μmol $m^{-2}s^{-1}$ in the bare microsite and 0.28 $m^{-2}s^{-1}$ -0.84 μmol $m^{-2}s^{-1}$ in the grass microsite during the dry season. Mann-Whitney test indicated significantly higher mean soil respiration under the grass microsite than the bare microsite (u=32.00, Z=-3.29, P=0.001>0.05) in the dry season. In the wet season, soil respiration ranged between 0.230 $m^{-2}s^{-1}$ -2.46 μmol $m^{-2}s^{-1}$ in the bare microsite and 0.293 $m^{-2}s^{-1}$ -2.157 μmol $m^{-2}s^{-1}$ in the grass microsite. Unlike in the dry season, the Mann-Whitney test revealed a similarity in median soil respiration between the two microsites during the wet season (u=111.00 Z=-1.386, P=0.166>0.05), shown in figure 11.

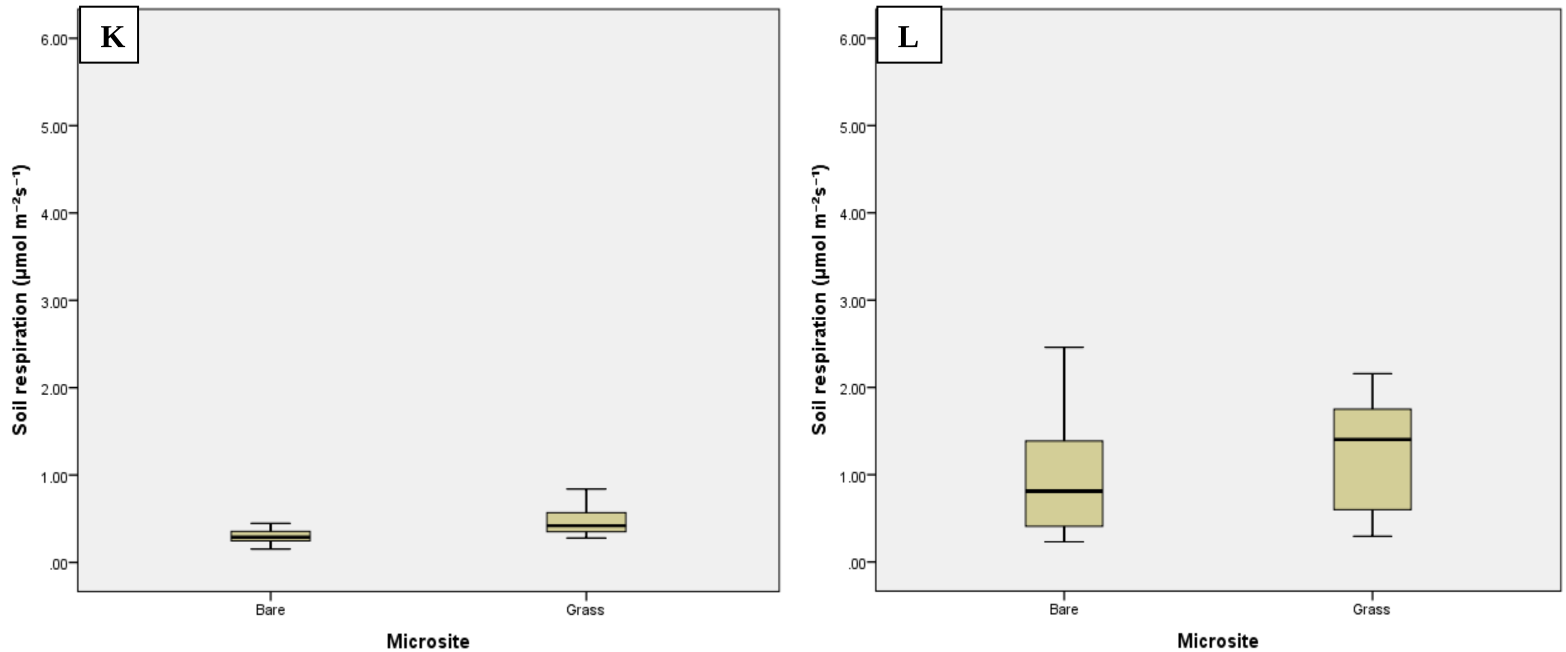

Figure 11. Comparison of soil respiration between the microsites of the cleared site at Erichsfelde during the dry (K) and wet season (L)

4.3 Variation of soil respiration between the seasons

Overall the season regardless the sites, soil respiration in CCF ranged between 1.16 μmol $m^{-2}s^{-1}$ -4.59 μmol $m^{-2}s^{-1}$ in the wet season and 0.134 μmol $m^{-2}s^{-1}$ -1.084 μmol $m^{-2}s^{-1}$ in the dry season. While in Erichsfelde soil respiration ranged between 0.334 μmol $m^{-2}s^{-1}$ -3.71 μmol $m^{-2}s^{-1}$ in the wet season and 0.244 μmol $m^{-2}s^{-1}$ -2.57 μmol $m^{-2}s^{-1}$ in the dry season. In both study areas, the T-test showed that soil respiration was significantly higher in the wet season than in the dry season, ($t= 12.55$, $df=70$, $P<0.05$) for CCF and ($t=3.92$, $df=70$, $P<0.05$) for Erichsfelde (figure 12). Across the study areas, the wet season of CCF had significantly higher soil respiration than the wet season of Erichsfelde ($t=4.019$, $df=70$, $P<0.05$) while the dry season of Erichsfelde had significantly higher soil respiration than the dry season of CCF ($t=2.965$, $df=70$, $P<0.05$), shown in figure 12. In spite of that, the overall results showed no significant difference in soil respiration between CCF and Erichsfelde ($P=0.083>0.05$).

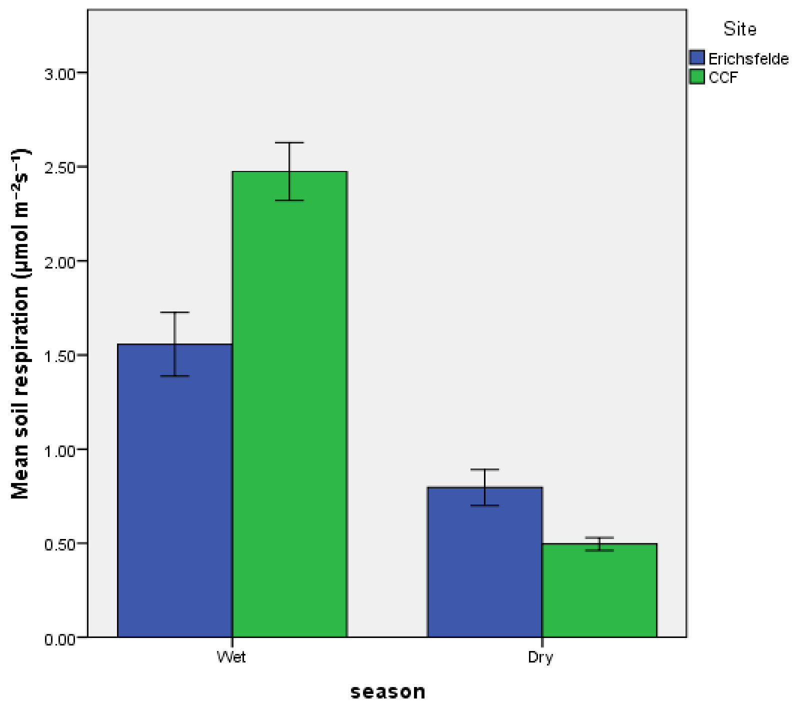

Figure 12. Comparison of mean soil respiration between wet and dry seasons for CCF and Erichsfelde

4.4 The response of soil respiration to soil temperature

In CCF, during the dry season, the minimum soil temperature recorded was 14.6 ˚C and the maximum temperature recorded was 44.7 ˚C while during the wet season the minimum and maximum temperatures recorded were 20.6˚C and 43.5 ˚C respectively. Erichsfelde recorded a minimum of 10.9˚C and a maximum 41.6 ˚C during the dry season and, 25.0 ˚C minimum and 49.6 ˚C maximum soil temperatures during the wet season. No significant correlation between soil respiration and soil temperature was found in both seasons of CCF and the wet season of Erichsfelde ($P>0.05$). However, the dry season of Erichsfelde showed a very weak negative significant correlation between soil respiration and temperature ($P<0.05$). An increase in soil temperature especially beyond 30˚C resulted in a decrease in soil respiration and about 15% of the variation in soil respiration could be explained by soil temperature. Soil respiration was mostly active and peaked at temperatures between 20 ˚C to 35 ˚C and started declining at temperatures beyond that.

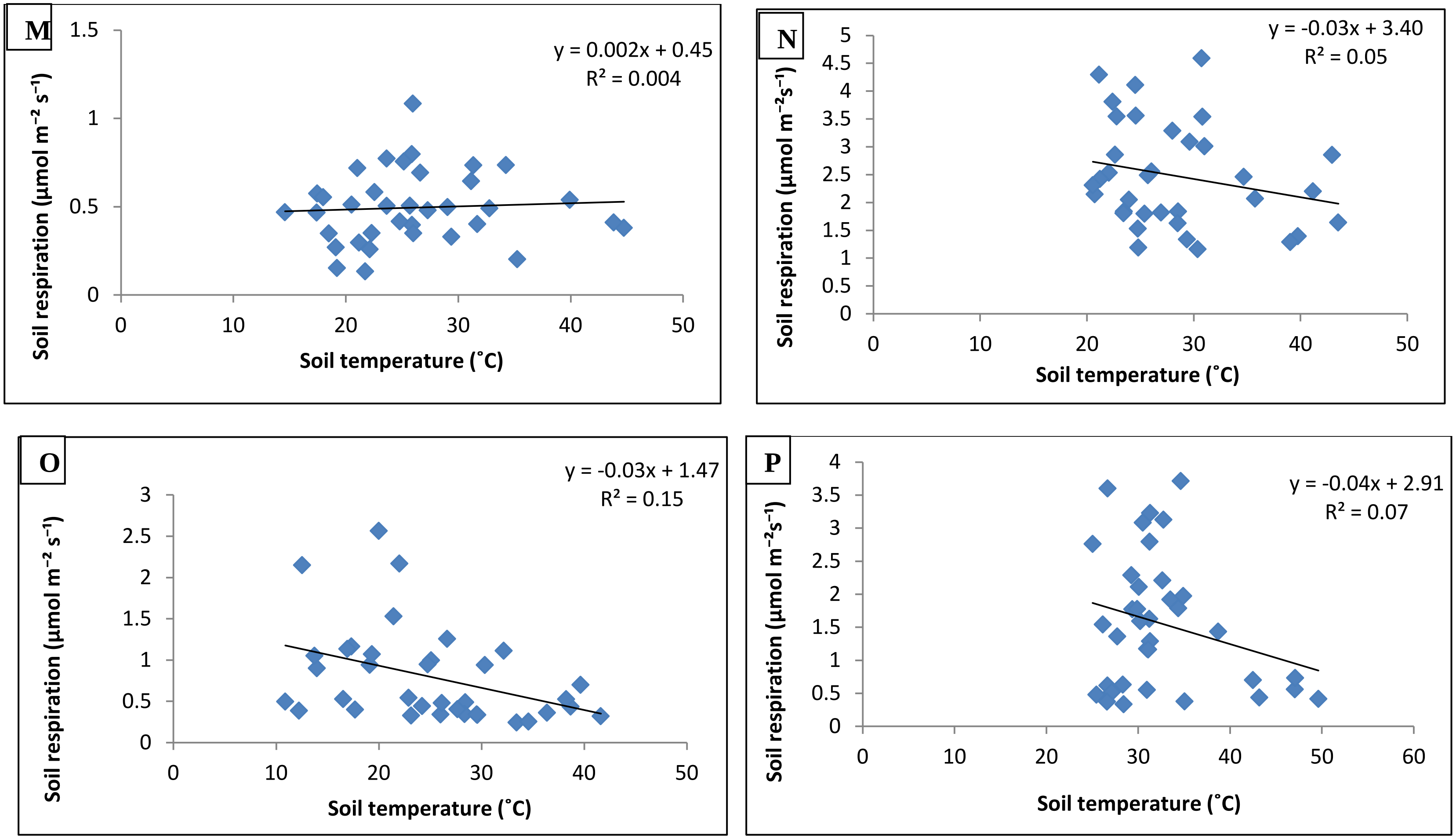

Figure 13. The response of soil respiration to soil temperature in the dry and wet season for CCF (M & N) and Erichsfelde (O & P) respectively

4.6 Seasonal variation of soil temperature between the sites

The results of both CCF and Erichsfelde showed significantly higher mean soil temperature in the cleared sites than the uncleared sites (t=-2.262, df=34, P<0.05 and t=-2.104, df=34, P<0.05 for dry and wet seasons respectively) in CCF and (t=-4.143, df=34 P<0.05 and t=-2.935, df=34, P<0.05 for dry and wet seasons respectively) in Erichsfelde as shown in figure 14. Furthermore, the T-test indicated no significant difference in overall soil temperature between the wet and dry season in CCF (t=1.417, df=70, P>0.05). Whereas, the dry season of Erichsfelde had significantly lower average soil temperature compared to the wet season (t=4.304, df=7=, P<0.05).

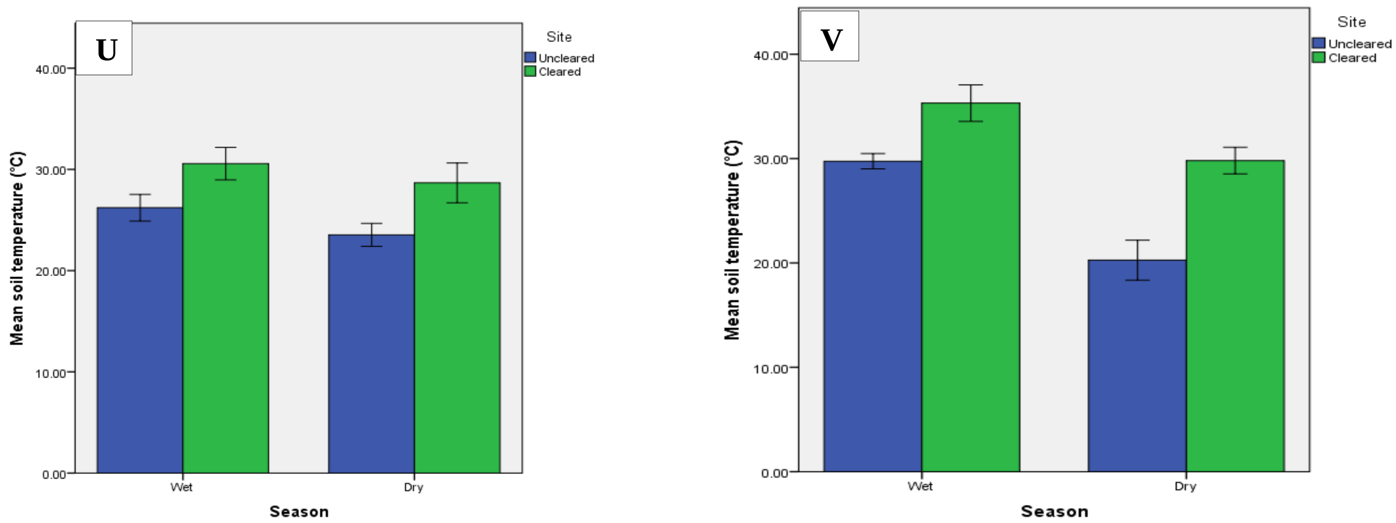

Figure 14. Comparison of average soil temperature between the cleared and uncleared sites in the wet and dry season at CCF (U) and Erichsfelde (V)

4.5 The response of soil respiration to soil moisture

In CCF, during the dry season, the minimum soil moisture recorded was 0.34% and the maximum soil moisture recorded was 3.06% while during the wet season the minimum and maximum soil moistures recorded were 0.79% and 5.41% respectively. Erichsfelde recorded minimum and maximum soil moistures of 0.46% and 9.77% respectively during the dry season and 1.06% minimum and 15.71% maximum soil moistures during the wet season. Soil respiration and soil moisture had very weak (graph Q) to weak (graph R, S and T) positive correlation, $P<0.05$. As shown in figure 15, about 11% (graph Q), 36% (graph R) 48% (graph S) and 36% (graph T) of the variation in soil respiration could possibly be due to soil moisture. The graphs in figure 15 also show that soil respiration was low at low soil moisture and increased at some point where soil respiration was high; an increase in soil moisture resulted in an increase in soil respiration (figure 15). However, there were some points where soil moisture was high, but still soil respiration was low.

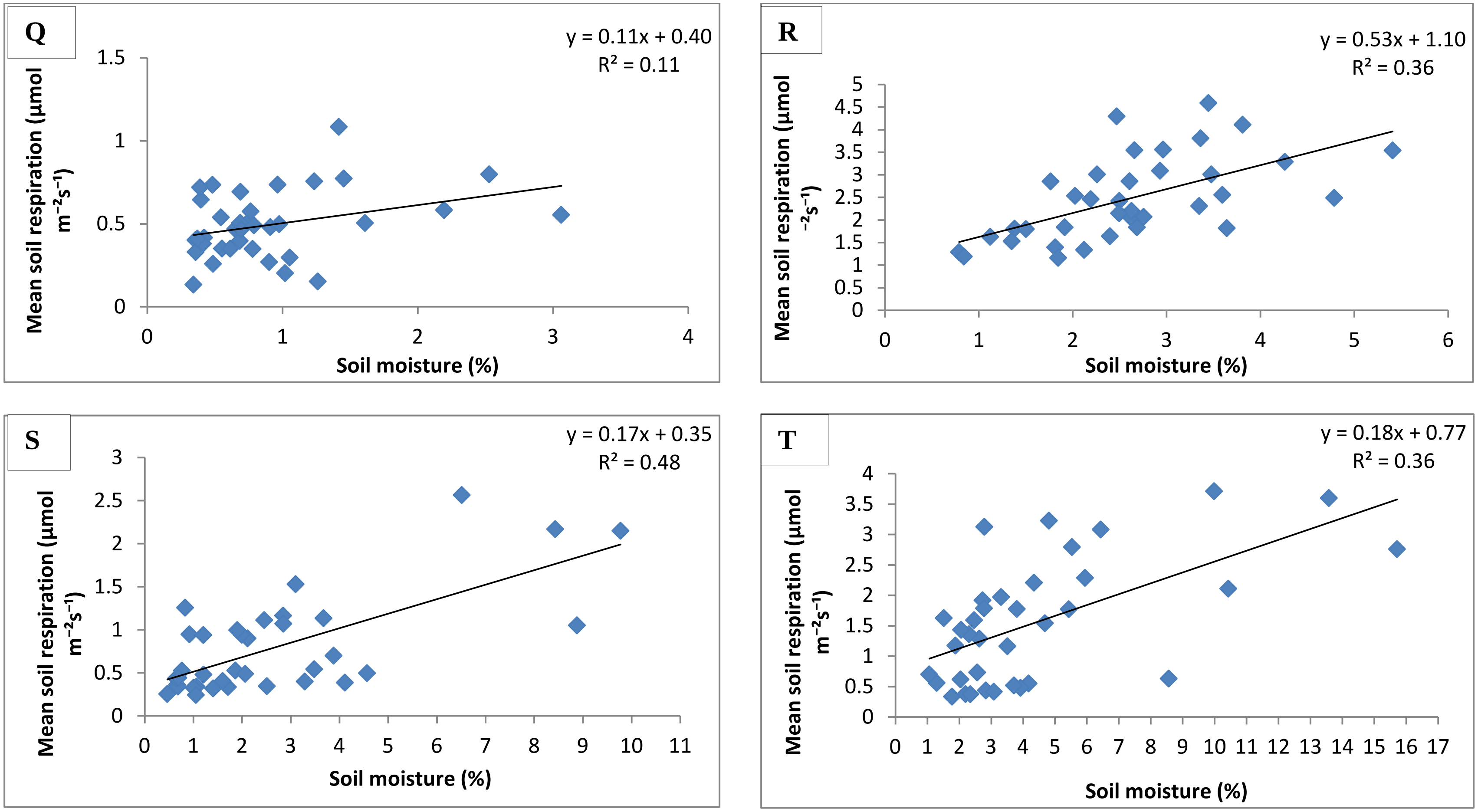

Figure 15. Response of soil respiration to soil moisture during the dry and wet season for CCF (Q & R) and Erichsfelde (S & T) respectively

4.7 Seasonal variations of soil moisture between the sites

On average, soil moisture was significantly higher in the wet season than in the dry season in both study areas ($t=2.51$, $df=70$, $P<0.05$ for Erichsfelde and $t=8.39$, $df=70$, $P<0.001$ for CCF). Both seasons of Erichsfelde depicted that the uncleared site had significantly higher mean soil moisture than the cleared sites ($P<0.05$), (figure 16). But in CCF, there was no significant difference in mean soil moisture between the cleared and uncleared sites in both seasons ($P>0.05$), as shown in figure 16. In addition, Erichsfelde had much higher mean soil moisture compared to CCF.

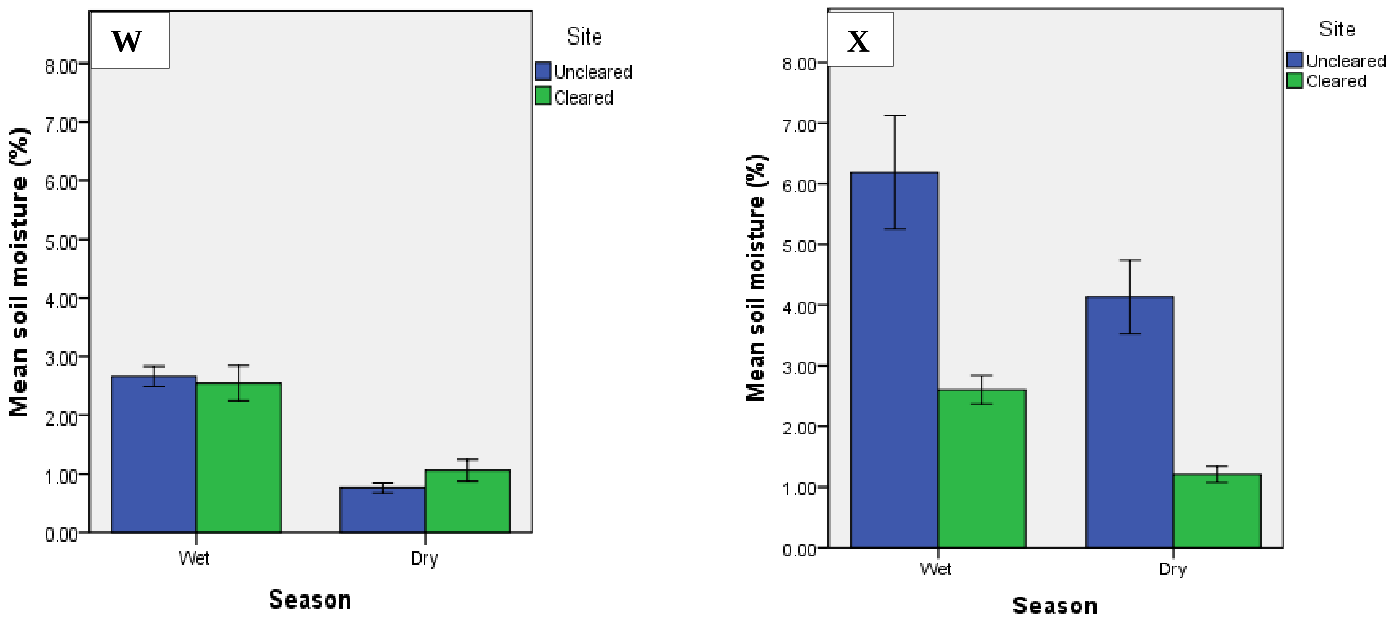

Figure 16. Comparison of average soil moisture between the cleared and uncleared sites during the wet and dry season at CCF (W) and Erichsfelde (X)

Table 2. Summary table

Site (Uncleared & Cleared)	CCF dry season	No significant difference
	CCF wet season	No significant difference
	Erichsfelde dry season	Significant difference
	Erichsfelde wet season	Significant difference
Microsites (within the uncleared site)	CCF dry season	No significant difference
	CCF wet season	Significant difference
	Erichsfelde dry season	No significant difference
	Erichsfelde wet season	Significant difference
Microsites (within the cleared site)	CCF dry season	No significant difference
	CCF wet season	Significant difference
	Erichsfelde dry season	Significant difference
	Erichsfelde wet season	No significant difference
Seasons (between wet & Dry)	CCF	Significant difference
	Erichsfelde	Significant difference
Seasons (between CCF and Erichsfelde)	Wet season	Significant difference
	Dry season	Significant difference
Soil temperature between uncleared and cleared	CCF dry season CCF wet season	Significant difference Significant difference
	Erichsfelde dry season	Significant difference
	Erichsfelde wet season	Significant difference
Soil moisture between uncleared and cleared	CCF dry season	No significant difference
	CCF wet season	No significant difference
	Erichsfelde dry season	Significant difference
	Erichsfelde wet season	Significant difference
Soil respiration and soil temperature	CCF dry season	No significant correlation
	CCF wet season	No significant correlation
	Erichsfelde dry season	Very weak negative correlation
	Erichsfelde wet season	No significant correlation
Soil respiration and soil moisture	CCF dry season	Very weak positive correlation
	CCF wet season	Weak positive correlation
	Erichsfelde dry season	Weak positive correlation
	Erichsfelde wet season	Weak positive correlation

CHAPTER 5: DISCUSSION

5.1 Variations in soil respiration between uncleared and cleared sites

There was no significant difference in soil respiration between the cleared and uncleared sites of CCF for both seasons. Studies done by Raich and Tufekcioglou (2000), Luo and Zhou (2006), and Kaur et al. (2006) reported similar results. In CCF the cleared site only had few trees left after clearing. However, after clearing a lot of grass and herbaceous species grew in the cleared site resulting in high grass and herbaceous plants' biomass, which also turned out to be litter in the dry season. Meaning soil respiration in the cleared site was a result of decomposition of high litter content as well as root respiration of the grass and herbaceous plants. On the other hand, the uncleared site had high vegetation biomass mostly dominated by the woody vegetation (since the farm is affected by bush encroachment), thus this reflects high root biomass of the woody vegetation. Hence soil respiration in the uncleared site mostly resulted from root respiration of the woody vegetation. Therefore, a non-significant difference in soil respiration between the two sites could be due to an equal amount of soil respiration between root respiration as a result of high root biomass of woody vegetation in the uncleared site and microbial respiration from increased litter decomposition together with root respiration of grass and herbaceous plants in the cleared site. The decomposition of increased litter inputs (microbial respiration) after clearing can offset the reduction in root respiration leading to no significant difference in soil respiration (Luo & Zhou, 2006).

The time interval between bush clearing and the start of the study may also have influenced the observed results of soil respiration. The site was cleared in 2013 and the study was conducted in 2016, 3 years after clearing. Soil respiration had probably already attained a steady state, even if changes in soil respiration existed at the beginning of clearing (Ma et al., 2013).

Furthermore, soil moisture could also have influenced soil respiration. CCF recorded no significant difference in soil moisture between the cleared and uncleared site (figure 16). Hence, a non-significant difference in soil moisture between the cleared and the uncleared site recorded at CCF could also be one of the reasons for no significant difference in soil respiration between the two sites. As reported by Kaur et al. (2006) and Thomas et al. (2011) that in semi-arid and arid ecosystems soil respiration is mostly influenced by soil moisture.

In Erichsfelde, the uncleared site had significantly higher soil respiration than cleared site. Kaur et al. (2006) mentioned that this could be due to numerous factors such as root abundance and density, changes in vegetation type and composition, microbial activities, microbial biomass, time since clearing, litter quality and quantity, and changes in soil temperature and moisture.

Firstly, high soil respiration in the uncleared site could be a function of high root respiration. The uncleared site had high vegetation biomass and diversity mostly shrubs and trees. High vegetation biomass is associated with high root biomass which in return results in high root respiration. Whereas the cleared site had very few trees left after clearing. Also, the farm manager of Erichsfelde mentioned that even after clearing, the grass does not grow and he attempted to plant the Buffalo grass (*Cenchrus cilliaris*) that only grew in some parts of the site. Thus, the cleared site had low soil respiration as a result of reduction in root biomass which then decreased root respiration. According to Xu et al. (2013), Li et al. (2011), and Zhou, Wan & Luo (2007), clearing/the removals of aboveground biomass potentially decrease the abundance of roots, rhizospheric micro-organisms as well as the supply of photosynthates to roots and mycorrhizal fungi. Xu et al. (2013) and Li et al. (2011) further stated that clearing of aboveground biomass slows down and reduces root respiration in the cleared site; a reduction in root respiration due to clearing suppresses soil respiration. In their study, Moroni et al. (2009) mentioned that following bush clearing tree roots die and root respiration is significantly reduced. Hence, until vegetation re-establishes soil respiration in cleared sites stays lower than the soil respiration in uncleared sites (Moroni et al., 2009).

Secondly, the difference in soil respiration between the two sites could also be due to differences in microbial respiration. According to Kaur et al. (2006), changes in vegetation structure and diversity lead to changes in soil biological properties because different plant species harbour different microbial communities. As noted already, the uncleared site had high vegetation biomass and diversity. Kaur et al. (2006) also noted that high vegetation diversity accommodates high microbial diversity as well as high microbial biomass, resulting in high soil respiration. Also, the uncleared site of Erichsfelde had high litter content compared to the cleared site (figure 2). Thus high soil respiration in the uncleared site could also be caused by the existence of high microbial biomass and high decomposition of available litter. Unlike the cleared site that had very low biomass after clearing. Kaur et al. (2006) stated that tree clearing reduce vegetation species diversity which reduces soil microbial biomass and hence reduce soil respiration. Erichsfelde was cleared in 2008 and this study was conducted 8 years after clearing. By the time of measurements there was very little litter on the ground resulting from *Cenchrus cilliaris* that was planted in the cleared site. This implies that even if there was any increase in soil respiration in the cleared site probably due to increased litter decomposition of log debris after clearing it would not show because all the litter was already decomposed.

Thirdly, bush clearing leads to changes in temporal and spatial variability in soil temperature and moisture, and it affects soil microbial communities and carbon allocation patterns (Mauritz et al., 2010). Erichsfelde recorded significantly higher soil moisture in the uncleared site than in the cleared site (figure 16). As noted already that soil moisture is the primary factor that influences soil respiration in the semi-arid ecosystems (Kaur et al., 2006; Thomas et al., 2011), therefore, higher soil respiration in the uncleared site could possibly also be due to high soil moisture and moderate soil temperatures as favourable conditions for microbial and root activities as reported by Hagemann, Moroni, Gleißnerc, & Makeschina (2010) and Moroni et al. (2009). Low soil respiration in the cleared site was also due to limited soil moisture.

5.2 Variations in soil respiration between the microsites

During the wet season, soil respiration was significantly higher in the shrub microsite than in the bare microsite within the uncleared site. While in the cleared site grass had significantly higher soil respiration than the bare microsite. Clearly, the bare microsites had the lowest soil respiration compared to the grass and shrub microsites. This could be because shrubs, grass and bare microsites are associated with different chemical and physical soil properties which might affect soil organic matter, root density, litter quality and quantity, biomass allocation, micro organisms' communities, soil moisture and temperature and carbon allocation patterns, thereby ultimately leading to variations in soil respiration between the microsites as stated by Mauritz et al. (2010), Liu et al. (2014) and Kaur et al. (2006).

Higher soil respiration in the shrub and grass microsites than in the bare microsite could be attributed to both microbial and root respiration. Shrubs and grass microsites had large amounts of decomposing litter from their broken-off plant parts which are often absent in the bare microsites. These high amounts of litter on the soil surface underneath shrubs and grasses are generally favourably microclimates for microbes, and boosts decomposition thus enhancing high soil respiration in these microsites. Low soil respiration in the bare soil was due to the absence of surface litter and low microbial biomass. Cable et al. (2013) also confirmed that high soil respiration in the shrub and grass microsites could be due to higher nutrient quality and quantity under shrubs and grasses than in the bare soil.

Furthermore, as already stated, the significant difference between the microsites was observed during the wet/growing season. The wet season is usually allied with a significantly increase in high plant productivity. Plant productivity enhances the growth of plant roots. High root biomass stimulates high root respiration leading to high total soil respiration. So, this could also explain the high soil respiration in the shrub and grass microsite (that contained high root biomass) than the bare microsites. This goes accordingly with Zhang et al. (2007) who avowed that high soil respiration in the shrub and grass microsites is caused by high aboveground and belowground biomass and productivity that increase high litter content and root respiration.

In related studies, Siele et al. (2008), Han et al. (2014) and Cable et al. (2012) also found the shrub and grass microsites to have significantly higher soil respiration than the bare soil. Cable et al. (2012) explained that high soil respiration in shrub and grass microsites is likely due to high microbial biomass, substrate availability and quality, and higher root biomass than in bare soil. Hence, low soil respiration in the bare microsites compared to the other two microsites.

On the contrast, in the dry season, apart from the microsites of the cleared site in Erichsfelde, all the other microsites showed no significant difference in soil respiration. According to Yan et al. (2014) this could be explained as during the dry season, generally, photosynthesis and productivity is strongly reduced, and most of the soil microbial activities are inactive due to low soil moisture since most microbes become dormant during the dry period. Therefore, a no significant difference in soil respiration between the microsites occurred because the grass was dry, root respiration was low (roots are less active) and also there was very low to no decomposition of litter due to the dry state (Cable et al., 2013). As a result, this led to an equal amount of soil respiration between the bare microsites and covered microsites (shrub and grass) which usually have significantly high soil respiration.

5.3 Variations in soil respiration between the seasons

Both areas have shown that soil respiration was significantly higher in the wet season than in the dry season. This difference could be due to differences in soil moisture observed between the two seasons that have influenced both microbial and root respiration. Overall, the wet season had higher soil moisture than the dry season (figure 16). Therefore, high soil respiration in the wet season could be because during the wet season there was optimal water content. The optimal water content favours plant growth, and plants allocate considerable substrate to roots during this particular season. Thus, root respiration peaks because of an increase in root production and biomass as a result of high plant productivity which then results in high soil respiration (Thomas, Cook, Whitehead, & Adams, 2000; Raich et al., 2002).

In addition, optimal soil moisture also activates soil microbial activities (Luo & Zhou, 2006), leading to an increase in microbial populations, activity and substrate availability during the wet season (Borken & Matzner, 2009). Johnson, Phoenix and Grime (2008) stated that as a result of high plant productivity, the litter content increases resulting in high decomposition. Hence, soil respiration in the wet season increases with increasing biomass due to increased carbon input from litter (Johnson et al., 2008).

Plants shed off some tissues in the dry season which therefore increases substrate availability. However, even if there is more substrate available and optimum temperature for microbial activities, a decrease in soil water availability due to dryness strongly restricts microbial activities (Shen, Jenerette, Hui, Phillips, & Ren, 2008). Thus, decomposition of the litter shed in the dry season will only be carried out during the wet season when there is enough soil moisture, resulting in high soil respiration in the wet season. Therefore, as reported by Gritsch et al. (2015), high soil respiration during the wet season could be due to that soil moisture and temperature were more favourable for litter decomposition because the stubborn, strong materials are being favourably decomposed to simply degradable material when the soil conditions are optimal

Low soil respiration in the dry season could be explained by limited soil moisture. Soil moisture restricts plant productivity and microbial activities which then results in low root respiration and low decomposition of litter. As explained by Davidson et al. (2006) Chang et al., (2014) Chen et al. (2010) and Han et al. (2014) that soil moisture restrict microbial metabolism through desiccation and reduce the contact between the substrate, enzyme and microbes, and also slows down the supply of substrate due to the increased drying out of the soil. In their study, Smith et al., (2003) revealed that soil microbial communities experience osmotic stress during the dry season. This is because a thinner film of water coats the soil particles, slowing the diffusion of labile substrates and reducing the activity of exo-enzymes needed for the decomposition of organic matter

(Gritsch et al., 2015). Also, water stress conditions in the dry season cause a reduction in photosynthesis which diminishes translocation of photosynthates to the rhizosphere (Yu et al., 2011). Thus, in the dry season, microbes and plant roots have to invest more energy to produce protective molecules and this reduces their growth and the amount of carbon allocated to respiration (Yu et al., 2011). Therefore, during the dry season when soil moisture is limited most microbes become dormant rather than using the limited water and other resources in the soil to maintain their activities (Yan et al., 2014), resulting in low soil respiration. Plus also root respiration decrease in the dry season due to a decrease in the plant productivity and growth (Chang et al., 2016). All these conditions results in low soil respiration which can then explain lower soil respiration in the dry season than in the wet season.

Similarly, Luo and Zhou (2006), Davidson et al. (2000), Mantlana et al., (2009), Zhang et al. (2015), Liu et al. (2014) and Siele et al. (2008) also reported higher soil respiration in the wet season than in the dry season. Luo & Zhou (2006) noted that warmer and wetter conditions exhibit greater rates of soil respiration than colder and drier conditions. Luo and Zhou (2006) further stated that seasonal variation in soil respiration has been observed in almost all ecosystems and it occurs mostly due to alterations in soil temperature, soil moisture, photosynthetic production and decomposition of litter. According to Chang et al. (2016), low soil respiration in the dry season could be due to low soil moisture. Dry soil forms an environment that slows down the diffusion of solutes and as a consequence suppresses microbial respiration by limiting the supply of substrate. Chang et al. (2016) further affirmed that the decrease in plant substrate and photosynthetic activity caused by low water content during the dry season lead to low soil respiration.

5.4 Variation of soil respiration between CCF and Erichsfelde

The wet season of CCF had higher soil respiration compared to the wet season of Erichsfelde. Higher soil respiration in CCF than in Erichsfelde could mainly be explained by microbial respiration and rainfall events. Firstly, CCF had higher litter content and higher vegetation biomass than Erichsfelde (figure 3). Secondly, CCF wet season measurements were taken after rainfall; it had rained a few hours before taking measurements. Thus, a combination of rainfall and high litter on the ground could explain higher soil respiration in CCF than in Erichsfelde during the wet season. Thomas et al. (2011) stated that soil CO_2 increases after rains due to the stimulation of heterotrophic activity in soil. Also, litter fall-triggered respiration is very sensitive to soil moisture; thus an increase in soil moisture as a result of rainfall largely enhances litter fall respiration as mentioned by Wang et al. (2013) and Y. Wang et al. (2012). According to Huxman et al. (2004), soil respiration increases after rain events because rainfall activates the activities of soil microbes and stimulates microbe respired CO_2 in the shallow soil. Therefore, soil rewetting after rainfall speeds up decomposition by soil microbes (Huxman et al., 2004) resulting in high soil respiration.

Moreover, the rapid increase in the availability of soil water following rains can induce microbial cell lysis or the rapid mineralisation of the cytoplasmic solutes and release the mineralised product into the surrounding environment (Fierer & Schimel, 2003; Calrisle et al., 2006). Thus, rainfall events induced soil respiration also results from the decomposition of microbial cellular materials (Yan et al., 2014).

Apart from microbial stimulation, soil respiration also increases after rainfall because rain water also promotes the absorption process by roots, which increases root respiration (Yan et al, 2014; Huxman et al., 2004). Therefore, more rainfall means more water infiltrates into the rhizhosphere and activates soil microbes as well as root activities (Yan et al., 2014). The fact that Erichsfelde had higher soil moisture than CCF is acknowledged, however, rainfall has more influence on soil respiration than soil moisture. This is because, rain water infiltrate the soil and becomes readily available to plant roots and stimulates the microbial activities rapidly. Unlike soil moisture that sometimes gets too deep into the soil and becomes inaccessible by most plants and microbes. Finally, the infiltration of rainwater causes physical displacement in the soil environment and consequently release CO_2 accumulated in the soil pores (Carlisle et al., 2006). Therefore, higher soil respiration in CCF wet season than in Erichsfelde wet season was due to rainfall events that stimulated roots and microbial activities.

On the contrast, the dry season of Erichsfelde had significantly higher soil respiration than the dry season of CCF. This could be explained by soil moisture. The dry season of Erichsfelde had higher soil moisture than the dry season of CCF (figure 16). Meaning, while soil moisture was the limiting factor in CCF when it was dry, Erichsfelde had enough moisture to keep the activities of plants and soil microbes going. Therefore, although CCF had high litter and vegetation biomass than Erichsfelde, low soil moisture limited plants and microbial activities during the dry season, resulting in low soil moisture.

5.5 The response of soil temperature and moisture on soil respiration

This study found that it was only the dry season of Erichsfelde that showed a negative correlation between soil respiration and soil temperature; an increase in soil temperature caused a decrease in soil respiration. This could be because as soil temperature increased, this changed the favourable conditions of plants and soil microbial activities, denaturing their enzymes and thus decreasing soil respiration. Frank et al. (2015) mentioned that simultaneous direct effects of high temperatures vary from disruptions in enzyme activity affecting photosynthesis and respiration, to alterations in growth and development.

No significant correlation was found between soil respiration and soil temperature in both seasons of CCF as well as in the wet season of Erichsfelde. On the other hand, soil respiration exhibited a positive correlation with soil moisture. This could be due to that, soil temperature did not show much variations between the seasons compared to soil moisture that had relatively big differences across the seasons (figure 14 & 16). This goes accordingly with the findings of Kaur et al. (2006) and Thomas et al. (2011) who recognised that in arid and semi-arid ecosystems, soil moisture is the main factor limiting soil respiration while soil temperature usually has a little effect on soil respiration. Therefore, seasonal patterns of soil respiration closely follow dynamics of soil moisture suggesting that, microbial activities as well as root respiration are mostly restricted by soil moisture than by soil temperature (Thomas et al., 2011). Soil respiration increased with increasing soil moisture because when soil moisture increases, plants and soil micro-organisms were receiving adequate amounts of water which is a transport medium of nutrients needed by plants and microbes (Oertel, Matschullat, Zurba & Zimmermann, 2016). However at lower levels of soil moisture, water stressed and limited the growth of the plants and microbes hence low soil respiration (Oertel et al., 2016).

The same results were reported by Siele et al. (2008), Carlisle et al. (2006), Lihua et al. (2007) and Luo and Zhou (2006), who pointed out that soil moisture had more significant influence on soil respiration, compared to the soil temperature that had no observable influence in the seasonal variations of soil respiration. In addition, Unver et al. (2010) revealed that in some ecosystems, one of these two environmental factors (soil temperature or soil moisture content) can have more influence on soil respiration than the other, depending on the type of vegetation biome. For instance, in arid and semi-arid environments, soil respiration is largely controlled by the soil moisture but this also depends on the size of the soil carbon pool as stated by Wang et al.(2014).

Although soil moisture content had a positive significant influence on soil respiration, the correlation was quite weak. This could be due to that soil respiration also depends on other factors such as root biomass, litter quality and quantity, light intensity and temperature which thus reduce the proportional dependence of soil respiration on soil moisture (Nghalipo, 2016). The derivation of the influence of a single climate parameter is difficult to measure due to seasonal changes in root biomass, litter inputs, microbial population, nitrogen availability and other seasonally fluctuating processes and conditions (Davidson et al., 2000). Thus these conclusions reflect community responses, which may differ from temperature and moisture responses of the respiratory processes (Gritsch et al., 2015; Davidson et al., 2000).

5.6 Variations of soil temperature and soil moisture between the sites

In Erichsfelde, the cleared sites had significantly higher soil temperature, and significantly lower soil moisture than the uncleared sites (figure 13 and 15). Kaur et al. (2006) explained that cleared sites usually have higher soil temperatures than uncleared sites because uncleared sites are shaded by trees and shrubs, hence retain moisture for longer periods and prevents the development of high soil temperatures compared to the cleared sites that have less vegetation cover which exposes the soil to high temperatures and lets the soil to dry up quickly.My Agriculture Information Bank (2015) also explained that vegetation acts as an insulating agent, which limits the escape of moisture and does not allow the soil to become too hot, whereas bare soil quickly absorbs heat, quickly dries up and becomes very hot

CCF recorded significantly higher soil temperature in the cleared than in the uncleared site and no significant difference in soil moisture between the two sites. This is because the cleared site had reduced vegetation cover but at the same time had high litter accumulation. Organic matter increases the water holding capacity of the soil and it has a dark colour which increases its heat absorbability (My Agriculture Information Bank, 2015), thus this explains why the cleared site had high soil temperatures. High litter accumulation in the cleared site of CCF acted as a mulch/insulating layer that moderated soil moisture and prevented moisture from escaping (by reducing surface evaporation from the soil) even after temperatures increased in the cleared site. Hence, a no significant difference in soil moisture between the two sites of CCF was due to a balance between soil moisture retained by vegetation cover in the uncleared site and soil moisture retained by the litter layer in the cleared site. According to Hagemann et al. (2010), soil temperature and organic matter generally increase after clearing, while soil moisture may decrease or increase after clearing due to several factors such as climate, slope, or litter quality and quantity.

5.7 Summary of the discussion

This study found no significant difference in soil respiration between the uncleared and cleared sites of CCF because the uncleared site had high root biomass as a result of high woody vegetation biomass and the cleared site had high litter content plus root respiration of the grass and herbaceous plants that grew after clearing. Thus, the no significant difference in soil respiration between the two sites was due to an equal amount of soil respiration between mostly root respiration in the uncleared site (that had high root biomass of woody vegetation) and increased decomposition of litter along with root respiration of the grass and herbaceous plants in the cleared site. The decomposition of increased litter inputs (microbial respiration) in the cleared site after clearing can offset the reduction in root respiration leading to no significant difference in soil respiration between the cleared and uncleared site (Luo & Zhou, 2006).

Higher soil respiration in the uncleared site than in the cleared site at Erichsfelde was because the uncleared site had higher vegetation biomass than the cleared site. High vegetation biomass results in high root biomass (leading to high root respiration) and accommodates high microbial biomass, hence high soil respiration. The cleared site had very low litter content, low grass growth after clearing and had reduced woody vegetation, hence low soil respiration. Bush clearing also changes temporal and spatial variability in soil temperature and moisture which affects soil microbial communities and carbon allocation patterns.

In the wet season, the shrub and bare microsites had higher soil respiration than the bare microsites due to high root respiration of the grass and shrubs, and also because the soil beneath the shrubs and grass contain higher litter content and forms favourable conditions for microbes than the bare soils.

In the dry season, there was no significant difference in soil respiration between the shrub, grass and bare microsites. This was because of limited soil moisture that reduced plant productivity and restricted microbial activities. The dry state significantly reduced both root respiration and decomposition of litter by microbes, thus resulting in an equal amount of soil respiration between the three microsites.

In both study areas, soil respiration was significantly higher in the wet season than in the dry season. The wet season had higher soil respiration than the dry season due to the availability of soil moisture that favours high plant productivity and microbial activities. This results in high root biomass leading to high root respiration as well as high decomposition of litter by microbes, which results in high soil respiration. Low soil respiration in the dry season was due to limited moisture that restricted plant production and activities of the soil microbes.

CCF had higher soil respiration than Erichsfelde during the wet season. This was because CCF had higher vegetation biomass and litter content than Erichsfelde, and also, the CCF measurements were taken a few hours after rainfall. Therefore, the interactions between higher vegetation biomass, litter and rainfall stimulated microbial activities and root respiration resulting in high soil respiration. Higher soil respiration in Erichsfelde than in CCF during the dry season was due to high soil moisture in Erichsfelde that kept the activities of roots and soil microbes going. CCF had low soil moisture during the dry season which limited root activities and decomposition of litter, hence low soil respiration.

The results showed that soil respiration was more controlled by soil moisture than by soil temperature. This could be because there was no much variation between temperatures while soil moisture showed large differences both across the sites and seasons, making it a limiting factor.

CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

This study found no significant difference in soil respiration between the uncleared and cleared site at CCF in both seasons. While at Erichsfelde in both seasons the uncleared site had significantly higher soil respiration than the cleared site because of higher root biomass and litter content in the uncleared site than in the cleared site. Overall the seasons, the wet season had significantly higher soil respiration than the dry season due to optimal water content that stimulate plant and microbial activities leading to high root and microbial respiration.

Furthermore, the study found a positive correlation between soil respiration and soil moisture in both seasons of both study areas. However no significant correlation was found between soil respiration and soil temperature in both seasons of CCF as well as in the wet season of Erichsfelde, but only the dry season of Erichsfelde showed a very weak negative correlation between soil respiration and temperature which accounted for 15%. Thus seasonal variations in soil respiration were mainly driven by fluctuations in soil moisture; soil moisture rather than soil temperature was the main regulating factor of soil respiration. Differences in soil moisture resulted in differences in soil respiration.

This study has shown that the soil respiration rate in the cleared site could be the same as the soil respiration rate in the uncleared site for approximately 2-3 years after clearing, but once all the litter in the cleared site is decomposed soil respiration in the cleared site decreased and remained low, until vegetation regenerates.

Similar to other studies that have reported inconsistency in their results, this study also found variations in the results as Erichsfelde reported higher soil respiration in the uncleared site than in the cleared site, while CCF showed no significant difference in soil respiration between the sites. This study therefore concurs with other studies (Ma et al., 2013, Kaur et al., 2006) that suggest that the response of soil respiration to bush clearing is influenced by different factors (such as soil organic matter, vegetation type and diversity root biomass, litter quality and quantity, micro organisms’ communities, soil moisture and temperature and carbon allocation patterns) among different areas.

What still remains unclear after this study is whether changes in soil respiration after clearing follows the same trend in all parts of the country or it differs from one area to another since the study only covered two areas. A general trend of changes in soil respiration after bush clearing is difficult to compute because soil respiration is ecosystem dependent. This study has shown the importance of soil moisture on soil respiration. Soil moisture differs across the country with <50mm along the coast, about 370mm in the central part of the country and up to 600mm in the Zambezi region (Climate Namibia, n.d). With these differences in soil moisture, soil respiration is also expected to differ in other parts of the country. Therefore, further investigations in different parts of the country have to be done, considering time since clearing as soon as clearing commence to monitor soil respiration changes across the years until vegetation in the cleared site regenerates.

This study signify that in Namibia soil respiration changes after bush clearing thus also leading to changes in the global carbon cycle and other nutrient cycles. However, despite changes in the global carbon cycle and the negative effects of bush clearing on the absorption of atmospheric CO_2, in this study no high soil respiration was recorded in the cleared sites in both study areas. It is therefore safe to say that this specific study did not find bush clearing as a cause of high atmospheric CO_2 concentration and hence a contributing factor to global warming is rather limited.

6.2 Recommendations

- There is need for long term, spatial and temporal continuous measurements of soil respiration in order to improve the model of soil respiration and offer a more precise prediction of the total emission CO_2 flux, especially for long-term observation.
- Soil respiration measurements in different vegetation units considering the type of encroaching species since different parts of the country have different encroaching species.
- Future studies should also look at how the changes in climatic patterns affect soil respiration in the terrestrial ecosystem towards global climate change.

- More soil respiration measuring equipment and methods are needed for comparison of soil CO_2 efflux, in order to come up with good and accurate estimates of soil respiration.
- Since this study has concluded that bush clearing does not lead to high soil respiration, it thus recommend that clearing of the encroaching species can continue as supported by the government policies.

REFERENCES

Aanderud, Z. T., Schoolmaster, D. R., & Lennon J. T. (2011). Plants mediate the sensitivity of soil respiration to rainfall variability ecosystems. *Ecosystems, 14*(1), 156–167. Retrieved form https://link.springer.com/article/10.1007/s10021-010-9401-y.

Bai, C., Liang, Y., Zhu, Y., Ge, Y., Lin, X., & Jia, W. (2012). The temporal and spatial variation of soil respiration in pepper (*Capsicum annuum* L.), eggplant (*Solanum melongena* L.) and maize (*Zea mays* L.) agro-ecosystems in Northwest of China. *Australian Journal of Crop Science, 6*(11), 1565-1571.

Bini, D., Santos, C.A., Carmo, K.B., Kishino, N., Andrade, G., Zangaro, W., & Nogueira, M. A. (2013). Effects of land use on soil organic carbon and microbial processes associated with soil health in southern Brazil. *European Journal of Soil Biology, 55*, 117-123.

Bolstad, P. V., & Vose, M. V. (2005). Forest and pasture carbon pools and soil respiration in the southern appalachian mountains. *Forest Science, 51*(4), 372-383.

Borken, W., & Matzner, E. (2009). Reappraisal of drying and wetting effects on carbon and nitrogen mineralization and fluxes in soils. *Global Change Biology, 15,* 808-824.

Butler, A., Meir, P., Saiz, G., Maracahipes, L., Marimon, S. B., & Grace, J. (2012). Annual variation in soil respiration and its component parts in two structurally contrasting woody savannas in Central Brazil. *Plant Soil, 352*, 129–142.

Cable, J.M., Barron-Gafford, G.A., Ogle, K., Pavao-Zuckerman, M., Scott, R.L., Williams, D.G., & Huxman, T.E. (2012). Shrub encroachment alters sensitivity of soil respiration to temperature and moisture. *Journal of Geophysical Research: Biogeosciences, 117*(1), 1-11. Retrieved from onlinelibrary.wiley.com/doi/10.1029/pdf.

Cable, J.M., Ogle, K., Barron-Gafford, G.A., Bentley, L.P., Cable, W.L., Scott, R.L., Williams, D.G., & Huxman, T.E. (2013). Antecedent conditions influence soil respiration differences in shrub and grass patches. *Ecosystems, 16*(7), 1230–1247. Retrieved from https://asu.pure.elsevier.com/publications.

Cacciotti, A., Saunders, M., Tobin, B., & Osborne, B. (2010). *The effect of climate and land use change on soil respiratory fluxes.* 19th World Congress of Soil Science, Soil Solutions for a Changing World, Brisbane, Australia. Published on DVD. Retrieved from iuss.org/Symposium/pdf.

Carbone, M.S., Winston, G.C., & Trumbore, S. E. (2008). Soil respiration in perennial grass and shrub ecosystem: Linking environmemtal controls with plant and microbial sources on seasonal and diel timescales. *Journal of Geophysical Research: Biogeosciences, 113*, 1-14. Retrieved from https://www.researchgate.net/publication/253047958.

Carlisle, E. A., Steenwerth, K., L., & Smart, D.R. (2006). Effects of Land Use on Soil Respiration: Conversion of Oak Woodlands to Vineyards. *Journal of Environmental Quality, 35*, 1396–1404.

Casals, P., Romanyà, J., Cortina, J., Bottner, P., Coûteaux, M., & Vallejo, V. R. (2000). CO_2 efflux from a Mediterranean semi-arid forest soil. I. Seasonality and effects of stoniness. *Biogeochemistry, 48,* 261–281.

Chang, C. T., Sabaté, S., Sperlich, D., Poblador, S., Sabater, F., & Gracia, C. (2014). Does soil moisture overrule temperature dependence of soil respiration in Mediterranean riparian forests? *Biogeosciences*, *11,* 6173–6185.

Chang, C. T., Sperlich, D., Sabaté, S., Sánchez-Costa, E. Cotillas, M., Espelta, J. M., & Gracia, C. (2016). Mitigating the stress of drought on soil respiration by selective thinning: contrasting effects of drought on soil respiration of two oak species in a mediterranean forest. *Forests, 7*(11), 263-278. Retrieved from www.mdpi.com/1999-4907/7/11/263.

Chapin III, F.S., McFarland, J., McGuire, A. D., Euskirchen, E. S. Ruess, R.W., & Kiellan, D. K. (2009). The changing global carbon cycle: linking plant–soil carbon dynamics to global consequences. *Journal of Ecology*, *97*, 840-850.

Cheetah Conservation Fund (n.d.). *Bush blok management plan*. Retrieved from https://cheetah.org/blog/bushbloking-saving-savannah-comperative-soil-analysis/

Chen, X., Post, W. M., Norby, R.J., & Classen, A. T. (2010). Modelling soil respiration and variations in source components using a multi-factor global climate change experiment. *Climate Change, 107*(3-4), 459-480. Retrieved from https://link.springer.com/article/10.1007/s10584-010-9942-2.

Climate Namibia (n.d). *Climate and average weather in Namibia.* Retrieved from https://weather-and-climate.com/average-monthly-Rainfall-Temperature-Sunshine-in-Namibia.

Conant, R.T., Klopatek, J, M., & Klopatek, C.C. (2000). Environmental factors controlling soil respiration in Three Semiarid Ecosystems. Forest & Range Soils. *Journal of Soil Sciences, 64*, 383–390.

Davidson, E. A., Richardson, A. D., Savage, K. E., Hollinger, D.Y. (2006). A distinct seasonal pattern of the ratio of soil respiration to total ecosystem respiration in a spruce-dominated forest. *Global Change Biology, 12,* 230–239.

Davidson, E.A., Verchot, L.V., Cattanio, J.H., Ackerman, I. L., & Carvalho, J.E.M. (2000). Effects of soil water content on soil respiration in forests and cattle pastures of eastern Amazonia. *Biogeochemistry, 48*, 53–69.

Dorji, K. (2010).The effects of soil water content and temperature on tropical soil respiration (Master's thesis, Suranaree University of Technology, Nakhon Ratchasima, Thailand). Retrieved from sutir.sut.ac.th/sutir/bitstream/fulltext.

Dytham, C. (1999). *Choosing and using statistics: A biologist's guide*. New York, NY: Blackwell Science.

Fan, L.C., Yang, M.Z., & Han, W.Y. (2015). Soil respiration under different land uses in Eastern China. *Plos One, 10*(4), 124-139: Retrieved from journals.plos.org/plosone/article?id=10.1371/journal.pone.0124198.

Feller, S., Mahony, J., Sazanowicz, R., & Wise, J. (2006). Development of Bushblock industry in Namibia: An interactive qualifying project report (BSc thesis, Worcester Polytechnic Institute, Worcester, USA). Unpublished.

Fenn, K. M., Malhi, Y., & Morecroft, M. D. (2010). Soil CO2 efflux in a temperate deciduous forest: Environmental drivers and component contributions. *Soil Biology and Biochemistry, 42*, 1685-1693.

Fierer, N., & Schimel, J. P. (2003). A proposed mechanism for the pulse in carbon dioxide production commonly observed following the rapid rewetting of a dry soil. *Soil Science Society of America Journal, 67*, 798–805.

Frank, D., Reichstein, M., Bahn, M., Thonicke., K., Frank, D., Mahecha., M., Smith, P., Velde, M. V. D., Vicca, S., Babst, F., Beer, C., Buchmann, N., Canadell, J. G., Ciais, P., Crammer, W..., & Zscheischler, J. (2015). Effects of climate extremes on the terrestrial carbon cycle: concepts, processes and potential future impacts. *Global Change Biology, 21*(8), 2861-2880. Retrieved from onlinelibrary.wiley.com/doi/10.1111/gcb.12916.

Gritsch, C., Zimmermann, M., & Zechmeister-Boltenstern, S. (2015). Interdependencies between temperature and moisture sensitivities of CO2 emissions in European land ecosystems. *Biogeosciences, 12*, 5981–5993.

Hagemann, U., Moroni, M. T., Gleißnerc, J., & Makeschina, F. (2010). Disturbance history influences downed woody debris and soil respiration. *Forest Ecology and Management*, *260*(10), 1762-1772. Retrieved from https://doi.org/10.1016/j.foreco.2010.08.018.

Han, G., Xing, Q., Luo Y., Rafique R., Yu, J., & Mikle, N. (2014). Vegetation types alter soil respiration and its temperature sensitivity at the field scale in an Estuary Wetland. *Plos One*, *9*(3), 1-11. Retrieved from journals.plos.org/plosone/article?id=10.1371/journal.pone.0091182.

Hipondoka, M.H.T. (2005). The development and evolution of Etosha pan, Namibia (Doctoral thesis, Julius-Maximilians-Universität, Würzburg, Germany).

Huxman, T.E., Snyder, K. A., Tissue, D., Leffler, A. J., Ogle, K., Pockman, W. T., Sandquist, D. R., Potts, D. L., & Schwinning, S. (2004). Precipitation pulses and carbon fluxes in semiarid and arid ecosystems. *Oecologia, 141*, 254–268.

Intergovernmental Panel on Climate Change-IPCC. (2007). *Climate Change 2007: The physical science basis*, Paris. Retrieved from https:www.ipcc.ch/publications_ipcc_fourth_assessment_report_wg1_report_the_physical_science-basis.htm

Johnson, D., Phoenix, G. K., & Grime, J. P. (2008). Plant community composition, not diversity, regulates soil respiration in grasslands. *Biology letters, 4*, 345-348. Retrieved from rsbl.royalsocietypublishing.org/content/4/4/345.

Johnston, C. A., Groffman, P., Breshears, D.D., Cardon, G. Z., Currie, W., Emanuel, W., Gaudinski, J., Jackson, R.B., Lajtha, K., Nadelhoffer, K., Nelson Jr, D., Post, W.M., Retallack, G., & Wielopolski, L. (2004). Carbon cycling in soil. *Frontiers ecological environment*, *2*(10), 522–528.

Jürgens, N., Haarmeyer, D.H., Luther-Mosebach, J., Dengler, J., Finckh, M., & Schmiedel, U. (Eds.) (2010). *Patterns at Local Scale: The BIOTA Observatories, Biodiversity in Southern Africa.* Klaus Hess Publishers, Göttingen & Windhoek.

Kato, E., Nkoya, E., Place, F., & Mwanjalolo, M. (2010). *An econometric investigation of impacts of sustainable land management practices on soil carbon and yield risk: A potential for climate change mitigation.* International Food Policy Research Institute discussion papers, USA. Retrieved from https://ideas.respec.org/p/fpr/ifprid/1038.html.

Kaur, K., Jalota, R.K., Midmore, D.J., & Walsh, K. (2006). Impact if tree clearing on soil respiration and soil microbial Biomass in pasture systems of Central Queensland, Australia. *Agricultural Journal, 1*(4), 291-302.

Keitt, T. H., Addis, C., Mitchell, D., Salas, A., & Hawkes, C.V. (2015). Climate change, microbes and soil carbon cycling. In J. Marxsen (Eds,), *Climate change and microbial ecology: Current research and future trends* (pp. 97-112). Haverhill, UK: Caister Academic Press.

Kinyua, D., Mwakaje, ., Takawira, R., & Kambewa, E. (2002). *Cheetah Conservation Fund: Habitat restoration for the Namibian cheetah* (Environmental Impact Assessment). Otjiwarongo, Namibia: Unpublished.

Kurth, V.J., Bradford, J.B., Slesak, R.A., & D’Amato, A, W. (2014). Initial soil respiration response to biomass harvesting and green-tree retention in aspen-dominated forests of the Great Lakes region. *Forest Ecology and Management, 328*, 342–352.

Lal, R. (2014). World soils and the carbon cycle in relation to climate change and food security. In J. Weigelt, A. Müller, C. Beckh, K. Topfer (Eds.), *Soils in the Nexus* (pp.31-66). Müchen, Germany: Oekom Verlag.

Li, Z.G., Wang, X.J., Zhang, R.H., Zhang, J., & Tian, C.Y. (2011). Contrasting diurnal variations in soil organic carbon decomposition and root respiration due to a hysteresis effect with soil temperature in a *Gossypium s.* (cotton) plantation. *Plant and Soil, 343,* 347–355.

Lihua, Z., Yaning, C., Weihong, L., & Ruifeng, Z. (2007). Seasonal variation of soil respiration under different land use/land cover in arid region. *Science in China Series, Department of Earth Sciences, 50,* 76-85.

Liu, X., Zhanga, W., Zhang, B,, Yang, Q., Chang, J., & Hou, K. (2016). Diurnal variation in soil respiration under different land uses on Taihang mountain, North China. *Atmospheric Environment, 125*, 283–292.

Liu, Y., Liu, S., Wang, J., Zhu, X., Zhang, Y., & Liu, X. (2014). Variation in soil respiration under the tree canopy in a temperate mixed forest, central China, under different soil water conditions. *Ecological Research, 29*(2), 133–142. Retrieved from https://link.springer.com/article/10.1007/s11284-013-1110-5.

Luo, Y., & Zhou, X. (2006). *Soil respiration and the environment*. London, England: Academic press.

Ma, Y., Geng, Y., Huang, Y., Shi, Y., Niklaus, P.A., Schmid, B., & He, J.S. (2013). Effect of clear-cutting silviculture on soil respiration in a subtropical forest of China. *Journal of Plant Ecology, 6*(5), 335-345.

Mantlana, K. B., Veenendaal, E.M., Arneth, A., Grispen, V., Bonyongo, C. M., Heitkong, I. G., & Lloyd, J. (2009). Biomass and leaf-level gas exchange characteristics of three African savanna C_4 grass species under optimum growth conditions. *African Journal of Ecology, 47*, 482-489.

Mauritz, M., Hale, I., & Lipson, D. (2010). Invasion of a semi-arid shrubland by annual grasses increases autotrophic and heterotrophic soil respiration rates due to altered soil moisture and temperature patterns. *American Geophysical Union, Fall meeting abstracts, 1*, 387. Retrieved from https://www.researchgate.net/profile/M_Mauritz.

Misson, L., Tang J., & Xu, M. (2005) Influences of recovery from clear-cut, climate variability, and thinning on the carbon balance of a young ponderosa pine plantation. *Agriculture for Meteorology, 130*, 207–222.

Moroni M. T., Carter, P. Q., & Ryan, D. A. J. (2009). Harvesting and slash piling affects soil respiration, soil temperature, and soil moisture regimes in Newfoundland boreal forests. *Journal of Soil Science*, *89,* 343-355.

Mukaru, W. C. (2009). Impacts of large herbivores on vegetation and soils around water points in Waterberg Plateau Park, Central Namibia (MSc. Thesis, University of Namibia, Windhoek, Namibia). Unpublished.

My Agriculture Information Bank. (2015). *Soil Science.* Retrieved from http://www.agriinfo.in/default.aspx.

Ngarue, D. M. (2000). Vegetation density variation and ungulates distribution. (BSc. Thesis Polytechnic of Namibia, Windhoek, Namibia). Unpublished. Retrieved from WWW.encapafrica.org/PD.Fellows

Nghalipo, E. N. (2016). The effect of fire history on soil nutrients, soil organic carbon and soil respiration in a semi-arid savanna woodland, central Namibia (MSc. Thesis, Namibia University of Science and Technology, Windhoek, Namibia). Unpublished.

Oertel, C., Matschullat, J., Zurba, K., & Zimmermann, F. (2016). Greenhouse gas emissions from soils-A review. *Chemie der Erde*, *76*, 327-352.

Ohashi, M., Gyokusen, K., & Saito, A. (1999). Measurement of carbon dioxide evolution from a Japanese cedar (*Cryptomeria japonica* D. Don) forest floor using an open-flow chamber method. *Forest Ecology and Management*, *123,* 105–114.

Perez-Quezad, J.F., Bown, H.E., Fuentes, J.P., Alfaro; F.A., & Franck, N. (2012). Effects of afforestation on soil respiration in an arid shrubland in Chile. *Journal of Arid Environments, 83,* 45-53.

Post, W. M., & Kwon, K. C. (2000). Soil carbon sequestration and land-use change: processes and potential. *Global Change Biology, 6,* 317–328.

Raich, J. W., & Schlesinger, W. H. (1992). The global carbon-dioxide flux in soil respiration and its relationship to vegetation and climate. *Tellus B, 44*(2), 81–99. Retrieved from onlinelibrary.wiley.com/doi/pdf.

Raich, J. W., Potter, C. S., & Bhagawati, D. (2002) Interannual variability in global soil respiration, 1980–94. *Global Change Biology, 8*, 800–812.

Raich, J.W., & Tufekcioglu, A. (2000). Vegetation and soil respiration: Correlations and controls. *Biogeochemistry, 48*, 71-90. Retrieved from https://link.springer.com/article/10.1023/A:1006112000616.

Richardson, J. A. (1998). Wildlife utilization and biodiversity conservation in Namibia: Conflicting or complementary objectives? *Biodiversity and Conservation*, *7*, 549-559.

Runyon, R. P., Haber, A., Pitternger, D. J. & Coleman, K. A. (1996). *Fundamentals of behavioral statistics*. New York, USA: The McGraw-Hill Companies, Inc.

Schlesinger, W.H., & Andrews, J.A. (2000). Controls on Soil Respiration: Implications for Climate Change. *Biogeochemistry*, *48*(1), 7-20.

Shen, W., G. D. Jenerette, D. Hui, R. Phillips, P., & Ren, H. (2008). Effects of changing precipitation regimes on dryland soil respiration and carbon pool dynamics at rainfall event, seasonal and interannual scales. *Journal of Geophysical Research, 113*, 1-15.

Sheng, H.,Yang, Y., Yang, Z, Chen, G., Xie , J., Guo, J., & Zou, S. (2009). The dynamic response of soil respiration to land-use changes in subtropical China. *Global Change Biology, 16*(3), 1107-1121. Retrieved from https://www.researchgate.net/publication/227665036

Siele, M. P., Mubyana-John, T., & Monyongo, M. C. (2008). The effects of soil cover on soil respiration and microbial population in the Mopane woodland (*Colophospermum mopane*) of North Western Botswana. *Dynamic soil, Dynamic Plant, 2*, 61-68.

Smith, K. A., Ball, T., Conen, F., Dobbie, K. E., Massheder, J., & Rey, A. (2003). Exchange of greenhouse gases between soil and atmosphere: interactions of soil physical factors and biological processes. *European Journal of Soil Science, 54*, 779-791.

SRK Consulting (1999). African Portland cement (pty) Ltd; Final environmental audit report.

Striegl, R. G., and Wickland, K. P. (1998). Effects of a clear-cut harvest on soil respiration in jack pine-lichen woodland. *Canadian Journal of Forest Research, 28*, 534–539.

Struwig, F. W. & Stead, G. B. (2001). *Planning, designing and reporting research*. Cape Town, South Africa: Maskew Miller Longman.

Subke, J, A., Reichstein, M., Tenhunen, J, D. (2003). Explaining temporal variation in soil CO2 efflux in a mature spruce forest in Southern Germany. *Soil Biology & Biochemistry, 35*, 1467-1483.

Thomas, A. D. (2012). Impacts of grazing intensity on seasonal variations in soil organic carbon and soil CO_2 efflux in two semi-arid grasslands in southern Botswana. *The Royal Society, 367*(1606), 3076-3086.

Thomas, A. D., Hoon, S. R., & Dougill, A. J. (2011). Soil respiration at five sites along the Kalahari Transect: Effects of temperature, precipitation pulses and biological soil crust cover. *Geoderma, 167-168,* 284-294.

Thomas, S. M., Cook, F. J., Whitehead, D., & Adams, J. A. (2000). Seasonal soil-surface carbon fluxes from the root systems of young *Pinus radiata* trees growing at ambient and elevated CO_2 concentration. *Global Change Biology, 6*(4), 393-406.

Thomey, M. L., Collins, S. L., Vargas, R., Johnson, J. E., Brown, R. F., Natvig, D. O., & Friggens, M. T. (2011). Effect of precipitation variability on net primary production and soil respiration in a Chihuahuan desert grassland. *Global Change Biology, 17*, 1505-1515.

Trumbore, S. (2000). Age of soil organic matter and soil respiration: radiocarbon constraints on belowground c dynamics. *Ecological Applications, 10*(2), 399-411.

University of Hampshire (n.d.). *An introduction to the global carbon cycle.* Retrieved from http://globecarboncycle.uhn.edu/CarbonCycleBackground.pdf

University of Idaho (1997). *Soil sampling, bulletin 704*. Retrieved from www.cals.uidaho.edu>ext>ext0704.

Unver, M. C., Kucuk, M., Atufekcioglu, A., & Dogan, Y. (2010). Effect of different land use on soil respiration in winter. *Egyptian Journal of Experimental Biology, 6*(1), 15-19.

Valentini, R., Matteucchi, G., Dolman, H., Schulze, E. D., Rebmann, C., Moors, E. J., Jarvis, P. G., et al. (2000). Respiration as the main determinant of carbon balance in European forests. *Nature, 404*, 861–865.

Wang, B., Zha, T.S., Jia, X., Wu, B., Zhang, Y.Q., & Qin, S.G. (2014). Soil moisture modifies the response of soil respiration to temperature in a desert shrub ecosystem. *Biogeosciences*, *11*, 259-268.

Wang, W., Zeng, W., Chen, W., Zeng, H., & Fang, J. (2013). Soil respiration and organic carbon dynamics with grassland conversions to woodlands in temperate China. *Plos One, 8*(8), 1-17. Retrieved from journals.plos.org/plosone/article?id=10.1371/journal.pone.0071986.

Wang, Y. D., Wang, Z. L., Wang, H., Guo, C., Bao, W. (2012). Rainfall pulse primarily drives litterfall respiration and its contribution to soil respiration in a young exotic pine plantation in subtropical China. *Canada Journal for Research, 42*, 657–666.

Wang, Z., Ji, L., Hou, X., & Schellenberg, M. P. (2016). Soil respiration in semiarid temperate grasslands under various land management. *Plos One, 11*(1), 1-17. Retrieved from journals.plos.org/plosone/article?id=10.1371/journal.pone.0147987.

Xu, J., Chen,J., Brosofske, J., Q, L., Weintraub, M., Henderson, R., Wilske,B., John, R., Jensen, R., Li,R & Shao., C. (2011). Influence of timber harvesting alternatives on forest soil respiration and its biophysical regulatory factors over a 5-year period in the missouri ozarks. *Ecosystems, 14,* 1310–1327.

Yan, L., Chen, S., Xia, J., & Luo, Y. (2014). Precipitation regime shift enhanced the rain pulse effect on soil respiration in a semi-arid steppe. *Plos One,* 9(8), 1-9. journals.plos.org/plosone/article?id=10.1371/journal.pone.0104217.

Yu, X., Zha, T., Pang, Z., Wu., B., Wang, X., Chen, G., et al. (2011). Response of soil respiration to soil temperature and moisture in a 50-year-old oriental Arborvitae plantation in China. *Plos One 6*(12), 1-7. Retrieved from journals.plos.org/plosone/article?id=10.1371/journal.pone.0028397.

Zhang, L., Chen, Y., Li, W., & Zhao, R. (2007). Seasonal variation of soil respiration under different land use/land cover in arid environments. *Science in China Series D: Earth Science, 50*, 76-85.

Zhang, Q., Katul, G.G., Oren, R., Daly, E., Manzoni, S., & Yang, D. (2015). The hysteresis response of soil CO_2 concentration and soil respiration to soil temperature. *Journal of Geophysical Research: Biogeosciences, 120*(8), 1605-1618. Retrieved from online library.wiley.com/doi/10.1002/2015JG003047/full.

Zheng, D., Chen, J, Noormets, A., Euskirchen, E.S., & Moine, J. L. (2005). Effects of climate and land use on landscape soil respiration in northern Wisconsin, USA: 1972 to 2001. *Climate Research, 28,* 163–173.

Zhou, X., Wan, S., & Luo, Y. (2007). Source components and interannual variability of soil CO_2 efflux under experimental warming and clipping in grassland ecosystem. *Global Change Biology, 13,* 761-775.

APPENDICES

Appendix 1: Coordinates of the sampling points

Cheetah Conservation Fund

Point	Coordinates	
	Uncleared	Cleared
1	S 20˚27’18.1” E 17˚02’45.5”	S 20˚27’07.6” E 17˚02’53.7”
2	S 20˚27’15.5” E 17˚02’46.7”	S 20˚27’06.9” E 17˚02’51.9”
3	S 20˚27’13.2” E 17˚02’49.0”	S 20˚27’06.9” E 17˚02’50.1”
4	S 20˚27’22.2” E 17˚02’44.5	S 20˚27’06.0” E 17˚02’54.3”
5	S 20˚27’22.2” E 17˚02’42.1”	S 20˚27’04.3” E 17˚02’54.4”
6	S 20˚27’17.7” E 17˚02’42.3”	S 20˚27’09.1” E 17˚02’53.2”
7	S 20˚27’17.6” E 17˚02’39.0”	S 20˚27’10.5” E 17˚02’52.5”
8	S 20˚27’19.5” E 17˚02’48.5”	S 20˚27’08.4” E 17˚02’55.3”
9	S 20˚27’21.5” E 17˚02’51.2”	S 20˚27’08.2” E 17˚02’56.9”

Erichsfelde

Point	Coordinates	
	Uncleared	Cleared
1	S 21˚ 36’ 26.8” E 16 ˚54’ 59.4”	S 21˚ 36’ 42.2” E 16˚ 54’ 9.4”
2	S 21˚ 36’ 27.6” E 16˚ 54’ 54.2”	S 21˚ 36’ 45.1” E 16˚ 54’ 10.2”
3	S 21˚ 36’ 27.6” E 16˚ 54’ 49.0”	S 21˚ 36’ 48.2” E 16˚ 54’ 10.9”
4	S 21˚ 36’ 31.2” E 16˚ 55’ 1.6”	S 21˚ 36’ 41.7” E 16˚ 54’ 13.1”
5	S 21˚ 36’ 36.0” E 15˚ 55’ 3.6”	S 21˚ 36’ 41.2” E 16˚ 54’ 16.5”
6	S 21˚ 36’ 25.2” E 16˚ 55’ 4.0”	S 21˚ 36’ 42.5” E 16˚ 54’ 6.0”
7	S 21˚ 36’ 23.1” E 16˚ 55’ 8.3”	S 21˚ 36’ 42.5” E 16˚ 54’ 2.4”
8	S 21˚ 36’ 22.1” E 16˚ 54’ 57.8”	S 21˚ 36’ 38.8” E 16˚ 54’ 9.6”
9	S 21˚ 36’ 17.5” E 16˚ 54’ 57.3”	S 21˚ 36’ 35.4” E 16˚ 54’ 9.2”

Appendix 2: Trees/shrub species encountered during measurements

Cheetah Conservation Fund

Uncleared	Cleared
Grewia bicolor Juss. *Grewia flavescens* Juss. *Grewia flava* DC. *Senegalia mellifera* (Vahl) Seigler &Ebinger *Vachellia hebeclada* (DC.) Kyal. & Boatwr *Vachellia tortilis* (Forssk.) Galasso & Banfi *Dicrostachys cinerea* Wight et Arn. *Boscia albitrunca* (Burch.) Gilg & Ben. *Terminalia prunioides* M. A. Lawson *Vachelia luederitzii* (Engl.) Kyal. & Boatwr.	*Vachellia hebeclada* (DC.) Kyal. & Boatwr *Boscia albitrunca* (Burch.) Gilg & Ben.

Erichsfelde

Uncleared	Cleared
Boscia foetida Schinz *Vachellia erubescens* Welw. ex Oliv. *Vachellia hebeclada* (DC.) Kyal. & Boatwr *Vachellia tortilis* (Forssk.) Galasso & Banfi *Vachellia karoo* (Hayne) Banfi & Galasso *Vachellia luederitzii* (Engl.) Kyal. & Boatwr. *Boscia albitrunca* (Burch.) Gilg & Ben. *Senegalia mellifera* (Vahl) Seigler &Ebinger	*Vachellia erioloba* (E.Mey.) P.J.H.Hurter *Boscia albitrunca* (Burch.) Gilg & Ben.

Albizia anthelmintica Brong. *Grewia bicolour* Juss. *Grewia flava* DC. *Dicrostachys cinerea* Wight et Arn. *Cataphractes alexandri* D.Don *Ziziphus mucronata*	

Appendix 3: Soil type recorded in each site

CCF		Erichsfelde	
Cleared	Uncleared	Cleared	Uncleared
Sandy loamy, Loamy sand, Sand	Sandy loamy, Loamy sand, Sand	Sandy loam, Loamy sand, Sand	Sandy loam, Loamy sand, Sand, Gravel

Appendix 4: Ethical Clearance Certificate

UNAM
UNIVERSITY OF NAMIBIA

ETHICAL CLEARANCE CERTIFICATE

Ethical Clearance Reference Number: FHSS /222/2017 **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 Effects Of Bush Clearing On Soil Respiration In Northern-Central Namibia: Cheetah Conservation Fund And Erichsfelde.

Nature/Level of Project: Masters

Researcher: Wilhelmina K.L. Nuule

Student Number: 201176149

Supervisors: Dr ST Angombe (Main) Dr H Wanke (co)

Faculty: Faculty of Humanities and Social Sciences

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