A CROSS SECTIONAL COMPARISON OF CHEMICAL TREATMENT ON PLANT BIODIVERSITY AT NEUDAMM FARM, KHOMAS REGION

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ABSTRACT

This study determined the impacts of chemical application on plant biodiversity in comparison to the control ecosystems over a three-year period at Neudamm farm in Khomas Region, Namibia. In this study, for herbaceous plant sampling, a total of 40 ($1m^2$) quadrats were randomly laid in each of the three chemically treated sites (treated in 2015, 2016 and 2017) and in the control site to record the herbaceous plant density, plant species composition, dry matter production and ground cover. For woody plant sampling, a total of three 250 m^2 belt transects were randomly laid in each of the three chemically treated sites and also in the control. All woody plants in the belt transects were identified, measured and recorded for plant height and canopy diameters. For soil sampling, a total of ten soil samples were collected from the three the belt transects in each of the three chemically treated sites and also in the control at a depth of 15 cm using a soil auger. The soil was analysed for pH, soil minerals, organic carbon and organic matter. A total of 20 grass species were identified in all the four sites, of which 55% were perennials and 45% were annuals.

The mean total grass tuft density was significantly higher ($P < 0.05$) in control and the chemically treated sites of 2015 and 2017, but lower in the chemically treated site of 2016. Herbaceous biomass production was significantly higher ($P < 0.05$) in chemically treated site of 2015 (975 Kg DM ha^{-1}), followed by 2016 (925 Kg DM ha^{-1}) and least in the other two sites. The chemically treated site of 2016 had greater ($P < 0.05$) ground cover percentage than the other three treatment sites. The total woody plant density was significantly higher ($P < 0.05$) in the control (14 160 TE ha^{-1}) than in all three similar chemically treated sites. The canopy cover percentage and woody plant densities in all woody height categories were higher ($P < 0.05$) in the control and the chemically treated site of 2017, than in the other two sites.

The chemically treated site of 2015 had the highest amount of soil pH (6.06), followed by the control (5.61) and the chemical treatment site of 2017 (5.5), and they were statistically significant ($P < 0.05$). The organic carbon and organic matter percentages were significantly ($P < 0.05$) higher in the chemically treated site of 2015 than in all the other sites. The soil in the chemically treated site of 2016 had the highest Ca (551 ppm), K (197.3 ppm), Mg (76 ppm), P (23.3) contents, followed by the site of 2015 than in the control.

This study concluded that chemical treatments have impacted on the plant biodiversity of the treated rangelands by improving the herbaceous plant species, biomass yields, reduced bush density and enhanced the soil chemical properties.

Keywords: Bush encroachment, arboricides, plant density, biomass production, canopy

LIST OF CONFERENCE PROCEEDINGS

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TABLE OF CONTENTS

Content **Page**

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS AND ACRONYMS

ANOVA	Analysis of Variance
C	Carbon
Ca	Calcium
CCA	Canonical Correspondence Analysis
CEC	Cation Exchange Capacity
DAPEES	Directorate of Agric. Production, Extension and Engineering Services
DCA	Detrended Correspondence Analysis
EC	Electrical Conductivity
HCA	Hierarchical Cluster Analysis
MAWF	Ministry of Agriculture, Water and Forestry
IUPAC	International Union of Pure and Applied Chemistry
OC	Organic Carbon
SOC	Soil Organic Carbon
SOM	Soil Organic Matter
TE	Tree Equivalent

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For all that has been achieved in this research study, I give the glory to the Almighty.
I can do all things through Christ who strengthens me (Phil. 4:13 KJV).

DEDICATION

I dedicate this thesis to my children; Mugowe, Ndeya and Kuku.

DECLARATIONS

I, Diina Nalimanguluke Shigwedha, 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.

I, Diina Nalimanguluke Shigwedha, grant The University of Namibia the right to reproduce this thesis in whole or in part, in any manner, which The University of Namibia may deem fit.

Diina N. Shigwedha	………………………	……………………
Name of Student	Signature	Date

CHAPTER 1

INTRODUCTION

1.1 Background of the study

Land degradation is a complex phenomenon in Africa (Klintenberg and Gustad, 2002). About 60% of the arid and semi-arid savanna rangelands are degraded (Du Preez *et al*., 2003) and degradation poses a risk to the ecosystem integrity of these fragile dryland environments (UNDP *et al*., 2005). One of the most visible forms of savanna rangelands degradation is bush encroachment, which is defined as the invasion and/or thickening of aggressive indigenous woody species resulting in an imbalance of grass to bush ratio, a decrease in biodiversity and carrying capacity (Wiegand *et al.*, 2005; Von Oertzen, 2009; Rohde and Hoffman, 2011). Bush encroachment also reduces the growth and reproduction of individual plants (Rohde and Hoffman, 2011; Kgosikoma, 2013). The vegetation competitive abilities have for decades been considered as an environmental and economic problem of rangelands in Southern African countries (Skarpe, 1991; Ward, 2005). In Namibia, bush encroachment is a serious environmental and economic threat (Meik *et al*., 2002), which results in loss of natural resource productivity, loss of agricultural productivity and land degradation. About 67% of Namibia land surface is affected by bush encroachment, which disturbs multiple ecosystems and land uses with up to N$1.7 billion farming economic losses coming from commercial rangelands (De Klerk, 2004) on which over 65% of the National Agriculture Output is produced.

Bush encroachment has adverse effects on the livestock production, as a result of the loss of grass production on grazing lands (Woiters, 1994). An estimated 45 million hectares of Namibia are bush encroached and the main encroaching species are *Senegalia mellifera* (Black thorn) in the central parts of Namibia, *Dichrostachys cinerea* (Sickle bush), *Terminalia sericea* (Silver terminalia),

Terminalia prunioides (Purple-pod terminalia), *Acacia erubescens* (Blue thorn), *Acacia reficiens* (False umbrella thorn) and *Colophospermum mopane* (Mopane) in the northern part of Namibia (SAIEA, 2015).

Reactive interventions such as chemical treatment, mechanical and biological control methods are common in combating bush encroachment in Namibia (De Klerk, 2004; Joubert, 2014). However, despite the interventions, bush thickening still remains a problem, partly caused by the fast re-growth of woody plants (Joubert, 2014). According to Van Eck and Van der Merwe (2004), good veld management serves as the basis for bush control measures and when it is combined with a follow-up or after-care programme.

1.2 Statement of the problem

About 45 million hectares of the livestock rangelands in Namibia are severely bush encroached, significantly decreasing the country's ability to sustain livestock production (De Klerk, 2004). The worst affected areas are the most productive livestock grazing areas of Namibia, such as the Highland Savanna and Savannas of the north (Adams and Werner, 1990). It has also severely negatively impacted Namibia's beef production, which has decreased by about 50% of what it was in 1950s (NAU, 2010). A large part of Highland savanna in Namibia is encroached by a single invasive woody species, *Senegalia mellifera* (Wiegand *et al*., 2005). Neudamm farm management has been combating bush encroachment for the past several years using chemical treatment. However, no regular rangeland assessment has been conducted to determine if the rangeland has improved in terms of increased grass cover and reduced bush biomass following the chemical treatment. Hence, this study aimed at assessing chemically treated sites over a period of three years in comparison to the untreated (control) site.

1.3 Objectives of the study

1.3.1. General objective

The general objective of this study was to assess the impact of chemical bush control on plant biodiversity in comparison to the reference ecosystems over a three-year period at Neudamm farm.

1.3.2. Specific objectives

1) To determine the grass cover composition, density and biomass yield in chemically treated sites in comparison with the untreated (control) sites.

2) To determine the woody plant composition, canopy cover percentage and woody plant densities in chemically treated sites in comparison with the untreated (control) site.

3) To determine the soil chemical property (P. K. Ca. Mg. Na., organic matter and organic carbon) in chemically treated sites in comparison with the untreated (control) site.

1.4 Hypotheses of the study

H_0: There is no significant difference in the grass cover composition, density and biomass yield of the chemically treated sites and the untreated (control) sites.

H_0: There is no significant difference in the woody plant composition, canopy cover percentage and woody plant densities in chemically treated sites and the untreated (control) sites.

H_0: There is no significant difference in the soil chemical property (P. K. Ca. Mg. Na. organic matter and organic carbon) in chemically treated sites and the untreated (control) sites.

1.5 Significance of the study

The main purpose of chemical bush control is to improve the productivity of the rangelands. Hence, farmers have to realize the need of bush control and understand that bush thinning is not a once off operation. When farmers are applying arboricides, they may not consider or realize the impact that the chemicals have on the ecosystem (woody plants, grass layer as well as on the soil chemical properties). It is envisaged that the findings of this study would be helpful in advising farmers on proper management, to control and reverse the trend of environmental degradation, which is a direct threat to the future livelihood of the farmers. Moreover, the results of this study would provide a better understanding of the impacts of chemical application on the ecosystem with respect to their advantages and disadvantages. The research results would also contribute to literature on the effects of chemical application on woody species, grass and herbaceous plants as well as its effects on the soil chemical properties.

1.6 Limitation of the study

Lack of clear records on targeted treated study site (when and how chemicals were applied) would make it difficult to have a better understanding of the study sites.

1.7 Delimitation of the study

Alternative options for the limitation when the records were not clear were to carry out research only on the sites which had clear records.

CHAPTER 2

LITERATURE REVIEW

2.1 Bush encroachment

Bush encroachment is a term that describes the transition of grassland into a dominance of several indigenous woody species, which instantaneously reduces the productivity of rangelands, resulting in reduction of livestock productivity (Eldridge *et al.*, 2011; Throop *et al.*, 2012). According to Ward (2005) some of the key drivers of bush encroachment include the suppression of fire regimes, replacement of mega browsers with severe grazers, and changes associated with rainfall patterns as well as increase in atmospheric carbon dioxide (CO_2). Bush encroachment is a serious phenomenon in savanna ecosystems particularly in southern Africa, where there is overgrazing (Kambatuku, 2013). The impact of bush encroachment includes loss in biological diversity, reduction in rangeland productivity, change of the ecosystem structure, disturbance in the functioning of the soil microbes and limitation of the proper functioning of the ecosystem (Francina and Smit, 2006).

The replacement of grass cover with woody species results in reduction of the carrying capacity of the rangeland and animal diversity of the areas infested with bushes (De Klerk, 1999). According to Joubert *et al.* (2008), the ecological mechanisms driving the thickening of bush species are poorly understood though several models have been proposed to explain the conversion from the grassland state to the bush encroached state. In arid savanna ecosystems, bush encroachment is a form of land degradation which remains a major agricultural concern mostly to the livestock production (De Klerk, 2004). In addition, *Senegalia mellifera* (formerly known as *Acacia mellifera*) is one of the major bush encroacher species particularly in the African savanna. At present, *Acacia* and *Prosopis* species are regarded as the main bush species that causes the problem of bush encroachment in

Africa. The invasion by *Prosopis* species threatens the productivity of rangelands, reduces water resources and also displaces native flora and fauna species, leading to extinction of some species (Witt, 2010).

Bush encroachment affects various aspects in natural ecosystems which include the general decrease in the normal functioning and processes of the ecosystem. The impacts associated with the ecosystem functioning occur when there is a high density of bushes in grass-dominated systems, as it can lessen the provision of ecosystem services since it has a direct correlation to the situation of ecosystems (Lukomska *et al.*, 2014). The ecosystem services can have a dynamic shift caused by land use and land cover as a result of bush thickening (Ward and Esler, 2011). The thickening of bush encroacher species can have an increase on some of the provisional services while having a decline in other aspects such as the ability of the biological systems to support human needs, which is an indication of degradation within the ecological system (Kraaij and Ward, 2006). Henry *et al.* (2011) emphasized that some of the positive effect of bush encroachment on the ecosystem is to capture carbon in the biomass of plants through the activities of photosynthetic, which has been identified as an important aspect in increasing ecosystem services and can help in mitigating effect of climate change.

In arid and semi-arid regions, where rainfall distribution is reported to be optimal or lower than the sufficient amount has a negative effect on the income for farmers which tend to increase the disbursement (Lukomska *et al.*, 2014). Extremely uncertainty in rainfall distribution causes a negative aspect in the management of rangeland to the optimal level by both commercial and communal farmers. The challenge of rangeland management is to optimally adapt to the highly variable and highly uncertain rainfall, taking into account ecosystem dynamics. Hence, different strategies on the grazing management had been developed for the sake of optimizing the production in cases where rainfall is lower (Rothauge, 2007; Hein and Weikard, 2011). Resting of the rangelands in rainy years is one of the effective grazing management strategies that are practiced by most of the farmers in Southern Africa (Rothauge, 2006). This management practice leaves a fixed part of the rangeland ungrazed by animals in years where rainfall is abundant (Rothauge, 2007; Hein and Weikard, 2011). Resting strategies require a farmer to have a stocking rate that is lower than the grazing capacity of the given rangeland for that year with rainfall above average, while in low rainfall seasons, the rangeland can be used as a grazing area for animals (Lohmann *et al*., 2012). Moreover, Quaas *et al.*, (2007) indicated that the significance of resting strategies is a way of reducing income risks for farmers and it remains one of the efficient strategies as far as conservation grazing management is concerned.

In Namibia, 70% of the country's agricultural output is mainly produced from commercial rangeland of which two third of the country's population directly and indirectly depend on agricultural products for economic well-being especially through income generation (MAWF, 2009). The generation of profit through cattle farming is under restriction of the escalation of bush encroacher species causing a reduction in income generation with the rangeland utilization (Espach, 2006). Bush encroachment is not a permanent phenomenon, therefore a savannah ecosystem could be changed to its grass-dominated state by favourable management (Doughil *et al.*, 1999).

There are a number of bush species responsible for bush thickening that are generally accepted in Namibia under certain conditions, namely *Senegalia mellifera*, *Acacia fleckii*, *Acacia reficiens*, *Colophospermum mopane*, *Dichrostachys cinerea*, *Rhigozum trichotomum*, *Terminalia sericea*, and *Terminalia prunoides* (De Klerk, 2004). Additionally, De Klerk (2004) and SAIEA (2015) found that *Senegalia mellifera* and *Dichrostachys cinerea* are the most widely distributed encroacher species in Namibia.

2.2 Methods of bush control

Various methods exist to control bush encroachment in savanna rangelands, but it should be realized that under all circumstances, prevention is better than cure. Methods of controlling bush encroachment are mechanical, chemical, biological or fire control (Kahumba, 2010; SAIEA, 2015). These methods of bush control may be adopted and they can also be used as aftercare methods (SAIEA, 2015). The application of individual techniques would always depend on individual circumstances such as bush density, bush species composition, soil profile, rainfall, landscape morphology and the capital available (De Klerk, 2004). Moreover, De Klerk (2004) stated that each farmer applies the method(s) that suits his/her particular environment and economy best.

2.2.1. Mechanical control

Rangeland reclamation purposes by using heavy machines such as bulldozers as a way of bush clearing is not necessarily recommended to farmers because this method destroys the biodiversity of different species of the environment (Eldridge *et al.,* 2011). The most effective way of bush clearing is using equipment such as machetes, axes, handsaws and mattocks which remove bushes that are above the ground level and below the ground (De Klerk, 2004). The most crucial aspect when clearing an area that is affected with encroacher species is to consider the height at which the bush and shrub should be cut. According to Dahl and Nepembe (2001), cutting the bush above the ground level allows for a regrowth in most species, especially *Senegalia mellifera*.

The cheapest and effective way of combating bush encroachment by using machinery is to use tractor-mounted saws or alternatively using a blend of machine and hand labour (De Klerk, 2004).

2.2.2. Chemical control

The use of chemical treatment as a way of combating bush encroachment seems to be the most effective and promising, since it is easy to use and the reaction is quick although it has some drawbacks (Francina and Smit, 2006). In cases where mechanical or manual control of bushes is slow and labour intensive, farmers have been using arboricide treatments. However, there are ecological concerns with arboricide treatments, especially in view of biological diversity. The ecological concerns are generally associated with the environmental persistence of the chemicals and that they may have some effects on non-targeted plant species (Du Toit and Sekwadi, 2012).

Arboricides such as Tebuthiuron and Bromacil are readily available in Namibia and this chemical is an active ingredient that is mostly effective when applied on the surface of the soil to be absorbed later by plant roots. After application, herbicides remain inactive until such time as rain carries the active ingredient (Tebuthiuron, Ethidimuron or Bromacil) into the soil where it is taken up by the tree roots. The dosage depends on the height of the bush, as it is recommended that larger dosages be applied in two to four portions around the stem (Smit *et al.*, 1999). Most of the arboricides that are available on the market are in pellet or granule form, but some of the chemicals can be purchased in a moisture powder or in liquid form (Smit *et al.*, 1999). Manual application of the arboricide is the most effective and promising way since the chemical is applied under the canopy of the bush or shrub stems and therefore selective application can be done immediately. The ideal arboricide should be toxic only to the target organisms, biodegradable and should not leach into groundwater (De Klerk, 1999). This is to avoid damage to the rangelands and the environment at large.

During the application of arboricides, it is crucial to ensure that all the protected plants are avoided, even big plants should be excluded to comply with policies amended by the Directorate of Forestry and Ministry of Environment and Tourism (MAWF, 2009). In this case, it is important to consider that the chemicals reach the lateral parts of the roots for the desired bush species. In the past, Ethidimuron which is also part of the active ingredient in the arboricide, Ustilan was used but in Namibia but has since been discontinued (Kraaij and Ward, 2006) due to its unforeseen environmental effects. The use of chemicals is not cost effective since most of these chemicals are expensive and high amounts of chemicals are required to cover a large piece of land (De Klerk, 2004). For selective application, employing a lot labourers is recommended (labour-intensive) during the application of chemicals since the application should be done to specific bush species.

In Namibian rangelands particularly in commercial farming systems, Tebuthiuron based arboricides are commonly used in controlling the invasion of bush encroacher species such as *Senegalia mellifera* (De Klerk, 2004). The chemical formula for Tebuthiuron is $C_9H_{16}N_4OS$. According to Hatzios *et al.* (1980), the use of Tebuthiuron in bush control is effective since it is a non-selective inhibitor of photosynthesis. In low rainfall rangelands of Namibia, Tebuthiuron is reported to have a long half-life and some of the chemicals used have been detected in the soil for more than decades after application (Du Toit and Sekwadi, 2012). Furthermore, the chemical can be lethal to germinating seedlings up to eight years of post-treatment, but this may depend on the factors associated with the edaphic and seed banks that are locally available in areas treated with Tebuthiuron.

2.2.3. Biological control

Biological control of encroacher species is through the use of browsers, predominantly goats. For this method of biological control to efficient, the stocking rate of goats or any browsers species that is used should be higher than the carrying capacity of the given area (Witt, 2010). The use of biological control is more effective and suitable as part of aftercare methods to control the re-growth of new shoots.

2.2.4 Fire

Fire is another effective method of controlling bush encroachment, and is used as a preventative rather than a curative measure, even though it can be destructive in areas where monitoring is reduced (Bond and Keeley, 2005). Moreover, for burning to be effective, it is necessary to have a minimum of 1 500 to 2 000 kg of grass per hectare (De Klerk, 2004). In areas where the density of bush is high, grass biomass might not be high enough to ensure the required intensity of fire over a large area (Hein and Weikard, 2011). When using fire to control bush thickening aftercare programmes (like use goats on regrowth) should be applied to ensure successful control. In cases where the re-infestation and re-growth of bushes is experienced, the use of high fire intensity and browsers in tandem is recommended (Smit, 2004). Another effective way of controlling bush thickening is the process known as fire-girdling or stem burning, but the process is labour-intensive and is slow in bringing about the desired outcomes.

2.3 Methods of application of arboricides

Arboricides can be applied through aerial spraying (equivalent to leaf treatment), individual stem treatment and manual application as pellets or grains, spraying and/or painting on (Dube *et al.*, (2009). Application of arboricides in Namibia is carried out through soil or ground dispersal, executed on foot with backpack sprayers or aerial application. The best effects of Bromacil are achieved just before, or during a period of active plant growth (Joubert *et al*., 2013).An example is Brushfree™ which is a granular formulation of Bromacil used to control bushes and shrubs.

At Neudamm farm arboricides (e.g. Bromacil) are normally manually applied at the stem bases of the encroacher woody species using the recommended dosage. Bromacil is sold in Namibia as MBN-BR-800WP. The 800 in MBN-BR-800-WP denotes that the active ingredient should be at least 800g/l. It is available in granular form, water soluble liquid and wettable powder formulations and is taken up rapidly by the roots and slightly absorbed through the leaves (Dube *et al.,* 2009). Bromacil is described as a broad spectrum, systematic herbicide for use on annual and perennial weeds and woody plant species. It is an odourless, white crystalline solid and melts at 158-159°C. Bromacil solubility in water is 815mg/l. Furthermore, United States Environmental Protection Agency (1996) explained that Bromacil is also soluble in solvents like xylene, acetone, acetonitrile, ethyl alcohol and sodium hydroxide. Bromacil disrupts photosynthesis by blocking electron transport and the transfer of light energy in plants.

2.4 The advantages and disadvantages of arboricides

2.4.1 Advantages of using arboricides

According to De Klerk (2004), using herbicides (containing Tebuthiuron, Ethidimuron and Bromacil as active ingredients) is that;

- treatment of individual trees is relatively fast (Smit *et al.*, 1999) and application can be selective, particularly when applied by hand,
- there is little danger of untreated trees being exposed to the herbicide,
- the residual effect can suppress seedling regeneration for up to five years (Smit *et al.*, 1999).

2.4.2 Disadvantages of using arboricides

Agriculture has repeatedly been identified as one of the largest contributors to the loss of biodiversity, this is because large areas are devoted to agricultural activity which is characterized by a high degree of physical manipulation and usage of chemicals. Agricultural chemicals can reduce the abundance of weed and insects which are important food sources for many species (Boatman *et al.*, 2004). Arboricides can change habitats by altering vegetation structure, ultimately leading to vegetation population decline. Chemicals can affect livestock and wildlife directly or indirectly through food sources and habitats. The broad-spectrum arboricides can reduce food sources for birds and mammals. According to Isenring (2010), through changes to vegetation structure, arboricides can render habitats unsuitable for certain species, threaten insects, farmland birds and mammals. However, according to Swart and Lubbe (2012), not all arboricides are equally effective with the various types of identified bush encroachment species.

According to McLaughlin *et al.* (1994), the use of arboricides may lead to loss of habitat, although there are some known instances of non-targeted species population decline due to chemical usage. Arboricides may contain a wide variety of substances in addition to the active ingredient in order to improve stability, mixing, dilution and application (Tominack, 2000). Some examples include solvents, surfactants, emulsifiers, dispersants, binders, wetting agents, fillers, preservatives or other compounds with specific functions (Tominack, 2000). These may be harmful to the environment.

Furthermore, De Klerk (2004) outlined the disadvantages that;

- Even with selective application, trees that have not been treated may die because their roots extend to the vicinity of application (Smit *et al.*, 1999).

- The active ingredient may be slow to take effect, because it only becomes active once rainwater has carried it into the soil profile.
- Trees that die remain standing and show a resistance to decay and decomposition when certain of these arboricides are applied. Nutrients contained in their wood remain unavailable for use by other plants for long periods of time (Smit *et al.*, 1999).
- Trees differ in respect of their sensitivity to arboricides. Some trees require a higher rate of application. Therefore, a person applying the arboricides without the necessary knowledge of trees and correct application rates may cause failures and substantial subsequent financial losses.
- Furthermore, research (Crouzet *et al.*, 2010 and Sebiomo *et al.*, 2011) has indicated that arboricides applied to soils potentially affect the activity of non-target soil microbes.
- Liquid formulations of Bromacil are moderately toxic, while dry formulations are practically non-toxic to terrestrial animals. Generally, arboricides are irritating to the skin, eyes and respiratory tract, therefore, extra precautions must be taken when using such chemicals.

2.5 Rangelands assessments

2.5.1 Plant density and frequency

Density is the number of individual plants per area. It is necessary to use plant units such as an individual shoot. Density can be determined by counting the number of plants in a transect (Annika, 2000). The frequency sampling is fast and easy to perform in the field. If one determines the plant density of the farm, frequency can be calculated from the same data since frequency represents the percentage of the camp or farm in which the species occur. A study done by Hasen-Yusuf *et al.* (2012) in Ethiopia stipulated that biomass can be estimated using direct or indirect methods. Direct measurement of tree aboveground biomass (AGB) involves felling an appropriate number of trees and estimating their field and oven-dry weights, a method that can be costly and impractical, especially when dealing with numerous species and large sample areas. An indirect method is to use allometric regression equations based on easily accessible and measurable woody plant dimensions, rather than performing this so-called destructive sampling in the field (Bredenkamp *et al.*, 1996). These equations can help predict the biomass component based on some easily measurable predictor variables such as stem diameter/circumference, shoot height or crown diameter, which can be measured non-destructively (Hasen-Yusuf *et al.*, 2012).

2.5.2 Woody plant composition

Plant cover is effective in preventing erosion when rainfall is most aggressive, slows down runoff and keeps the soil surface porous. However, it is difficult to assess the protective action of plant cover without a close look at the farming techniques involved (Brandt *et al.*, 2015). Also woody plants generally develop leaves markedly ahead of the first rainfall events, in contrast to herbaceous vegetation dependent on an increase in soil moisture for massive germination.

2.5.3 Woody species canopy cover

Canopy refers to the upper layer or habitat zone, formed by a mature tree. Tree canopy cover is the proportion of an area covered by the vertical projection of tree crowns. Sometimes the term canopy is used to refer to the extent of the outer layer of leaves of an individual tree or group of trees. Shade trees normally have a dense canopy that blocks light from lower growing plants (Jennings *et al*., 1999). The canopy layer provides protection from strong winds and storms, while also intercepting sunlight and precipitation, leading to a relatively sparsely vegetated understory layer. Canopy cover plays a critical role in defining current and future forest characteristics via impacts on understory species composition and structure (Canham *et al.,* 1990). Canopy cover is often a primary indicator of wildfire risk and behavior of both modeled and actual wildfires (Agee and Skinner, 2005). Additionally, amounts and types of canopy cover and structure influence habitat suitability for many forest-dwelling vertebrate species (Massé and Côté, 2009).

A method called circular plots census was applied for canopy cover estimation both in Senegal and Mali (Brandt *et al.,* 2015). The crown cover was surveyed using a systematic and replicable sampling method. Each monitoring site was a 1 × 1 km plot selected within a homogeneous area of 3 × 3 km and was inventoried through four circular plots of up to one hectare by woody plant category (generally trees/shrubs/bushes), separated by a distance of 200 m along a transect line of 1 km. The size of the circular plots depends on the density of the woody population, but includes a minimum of 10 individuals per plot. In each plot the species of all individuals of trees and shrubs were recorded and height and basal diameter of crowns were measured. These measures were averaged per plot and per site providing means and standard deviations of tree and shrub canopy cover, and the contribution of each species to the overall cover (Brandt *et al.*, 2015).

2.6 The impact of bush encroachment on soil nutrients

Rangelands are generally characterized by low precipitation, poor drainage, rough topography and often low soil fertility. Fire, rainfall, soil type, and grazing animals are the driving forces determining plant species composition, distribution and productivity. The amount of rangeland in the world is expected to decline substantially in the future due soil infertility. Large amounts of rangelands in Africa are presently being extensively overgrazed and degraded, which could lead to desertification (Hoale and Frost, 2004).

According to Du Preez *et al*. (2011), most South African soils have low organic matter levels because of low rainfall that leads to poor plant growth. Similar to South Africa, Namibia´s climate has been generally dry for many millions of years and as a result, there is a lack of deep soils around the country and evidence of low levels of soil nutrients and organic matter in most of the soils (Mendelsohn *et al*., 2002). A study conducted by Heathcote (1983) found that the low available moisture in arid environments slows down both the chemical processes, and the breakdown of plant materials into organic matter and humus. Consequently, the depth and quantity of both soil organic matter and humus in arid soils is low and declines rapidly down the rainfall gradient. Organic matter is the major source of nutrients such as nitrogen, available phosphorus and potassium in unfertilized soils such as desert soils (Smit, 2004). Thus, given that desert soils are low in organic matter due to their low litter supply and rapid mineralization, amounts of these nutrients are expected to be low too (Smit, 2004). However, if soils in bush encroached areas are found to be rich in Calcium, Nitrogen and Phosphorus which occur due to contributions by nitrogen-fixing invader bushes, they could potentially enhance microbial activity and nutrient availability in the soils, provided that temperatures are favourable (Smit, 2004).

Soil is one of the most important abiotic components of ecosystems that support biodiversity. Studies indicate that the structure and process of terrestrial ecosystems, especially those of vegetation are largely influenced by soil chemical and physical properties (Whitford, 2002; Hoffman *et al*., 2010). While encroacher species and shrubs in savanna ecosystems compete with grasses for moisture, they also maintain soil fertility, which also benefits grasses. Trees and shrubs create fertility beneath their canopies, thus increasing the organic matter and enriching the top soil with nutrients (Smit, 2004; Hoffman *et al*., 2010). This demonstrates the reason why it is of great importance to strike an optimum balance between woody species and grasses in order to help maintain soil fertility, prevent soil erosion and optimize grazing resources.

Soil organic matter is described as any biological material that decomposes and becomes part of the soil (Bot and Benites, 2005). This organic matter is created by the cycling of organic compounds in plants, animals and microorganisms into the soil. Soils in arid environments worldwide are generally Nitrogen and Phosphorous- deficient, (Morlon, 1990; Smith *et al.,* 2002). Most Nitrogen available to plants is held in the top 10 cm of soil as a result of breakdown of organic matter and Nitrogen-fixing algae in cryptogrammic crusts (Smith and Morlon, 1990).

CHAPTER 3

METHODOLOGY

3.1 Study area

The study was carried out at Neudamm farm in Khomas Region (Figure 3.1 and Figure 3.2). Neudamm farm is located 22º27'02″ S and 17º21'38″ E and at an altitude of 1856 m (Mendelsohn *et al.,* 2002). Neudamm farm is about 37 km east of Windhoek and was established in 1904. It covers an area of 10 187 hectares, which are demarcated into nine blocks (A, B, C, D, E, F, G, H and I) and sub divided into 197 camps.

The vegetation type in this area is classified as Highland savanna, which occupies approximately 45 000 km^2 of Namibia's land area (Coetzee, 1998). The average annual rainfall at Neudamm ranges from 300 - 350 mm and monthly mean temperature ranges from 26°C in summer to 16°C in winter (Mendelsohn *et al.,* 2002). During the cooler period, the night temperature drops to -1°C while day temperatures rise to 27°C or higher. The hottest period is from September to December, when maximum day temperature may reach 38.7°C.

The Highland savanna is dominated by homogenous Lithic Leptosols and Eutric Regosols soil types. This vegetation type is dominated by *Senegallia mellifera* and also characterized with shrubs and low trees, mainly *Acacia* species. The undisturbed rangelands consist of climax grasses such as *Anthephora pubescens, Schmidtia pappophoroides, Brachiaria nigropedata, Heteropogon contortus, Cymbopogon species* and *Digitaria eriantha* but *Eragrostis nidensis* (considered a sub-climax grass) is usually the most abundant (Joubert, 1997). A general-purpose arboricide (chemical) called BushWhacker GG (Bromacil 200g/kg) is annually applied manually at the base of encroacher plant species in some of the camps (sites) at Neudamm in order to control bush encroachment, hence this farm offered pre-existing ideal conditions to carry out the research and meet the objectives of this study.

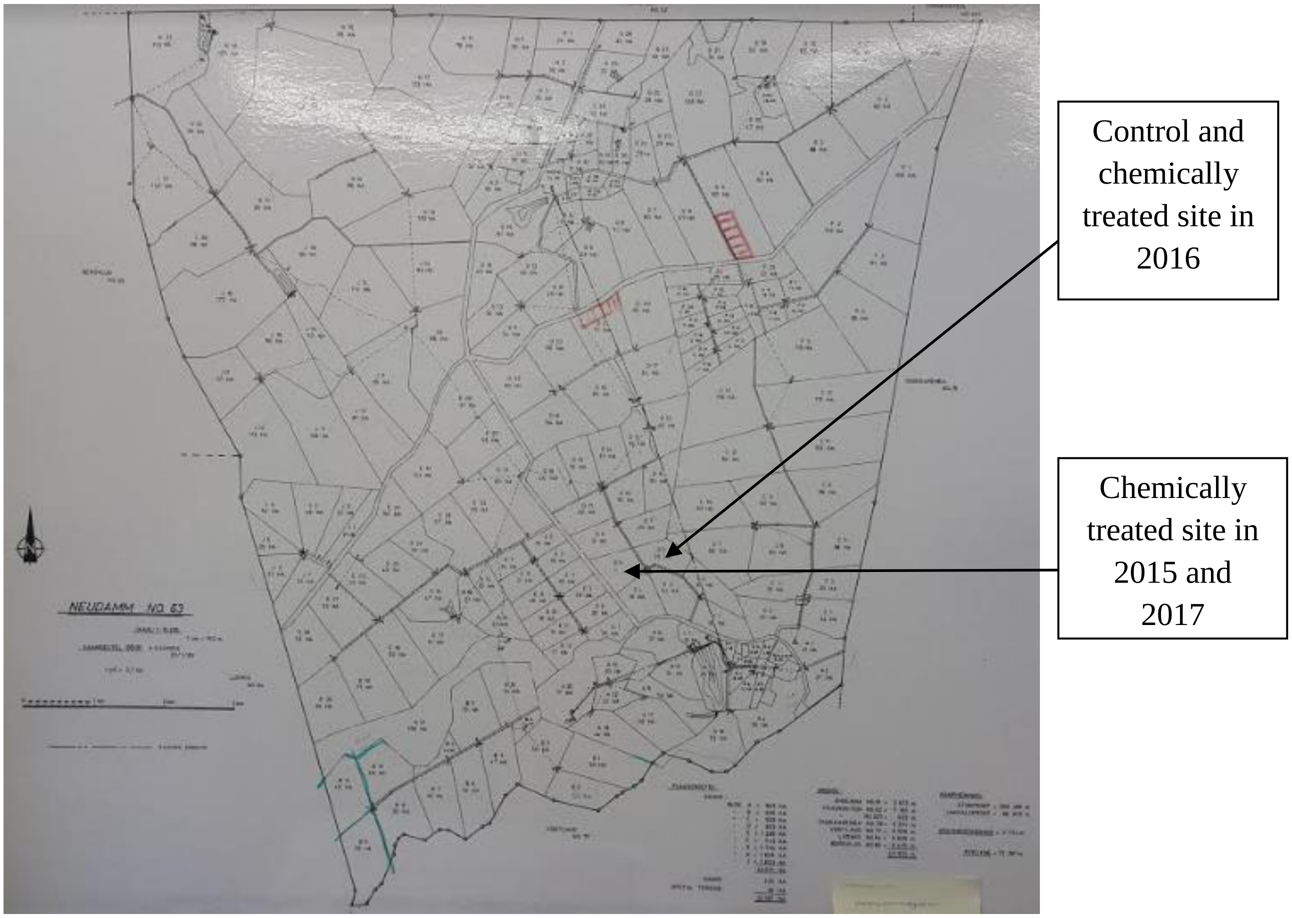


Figure 3.1 Neudamm farm map where the study was conducted (Beukes, 2018).

Figure 3.2 The study sites where the data were collected (Google Earth, 2018).

3.2. Research Design

A Completely Randomized Design (CRD) was used for this study, when three belt transects (50 m x 5 m) were randomly laid in the sampled sites (chemical treatment sites of 2015, 2016 and 2017) and one untreated site, whereby forty quadrats (nested plots) of 1 m x 1 m were established in twelve erected belt transects (250 m^2) at a distance of about 3 m intervals. Transects were at a distance of 50 m intervals as outlined by Barbour *et al.*, (1987). The study was conducted in three chemically treated sites (treated in 2015, 2016 and 2017) and one untreated site.

3.3 Population

The population of the study was the whole area of Neudamm farm which covers an area of 10 187 hectares and divided into nine blocks (A, B, C, D, E, F, G, H and I).

3.4 Samples

A total of 12 belt transects (9 belt transects in treated sites and 3 belt transects in untreated sites) were randomly laid in chemical treated sites of 2015, 2016 and 2017, and one untreated site. A total of 240 quadrats were also randomly laid in treated sites (manually treated with granules of BushWhacker GG (Bromacil 200g/kg)) of 2015, 2016 and 2017, and one untreated site. These were the sites that had been heavily encroached by *Senegalia mellifera* and chemically treated in different consecutive years on this farm, particularly in block D. A total of 6 composite soil samples were randomly collected from all belt transects in each of the chemically treated sites of 2015, 2016 and 2017, and the one untreated site.

3.5 Research instruments

The main research instruments that were used in the study were; rope (50 m x 5 m), 4 x metal rods, 1 m x 1 m quadrat, paper bags, grass clipper, calibrated dumpy level staff, camera, stationeries, soil auger, sampling bags, field guide books (Grasses of Namibia, Grasses of Southern Africa and Tree Atlas of Namibia).

3.6 Selection of the sampling sites

Neudamm farm was selected for this study. Prior to data collection, a preliminary study of the chemically treated sites in different consecutive years was conducted on the farm. Two camps (camp 5 (26 ha) and camp 6 (31 ha) in block D) that were chemically treated in 2015, 2016, 2017 and an untreated camp (control) were selected for this study. The selected sites were homogeneous, in terms of vegetation structure, soil type as well as topography. The sites were chemically treated with BushWhacker GG (Bromacil 200g/kg) which was manually applied at the stems of the *Senegalia mellifera* woody species. Granules of about 25 grams for small shrubs and 50 grams for big shrubs were applied underneath, at the base of the encroacher species not more than 30 cm from the encroacher species' base. The selected camps were in the small stock section (block D) used for sheep and goats at Neudamm farm. This study was conducted in the summer season (May 2018).

3.7. Data collection

3.7.1 Herbaceous plant vegetation

Grass species composition was estimated from 250 points within each belt transect in the three chemically treated sites (treated in 2015, 2016 and 2017) and also in untreated camp (control) using a step point method (Hardy and Walker, 1991). The nearest plant and basal strikes were recorded from 250 points of observation per belt transect. Based on range monitoring and evaluation principle, this sample size was deemed adequate for reliable detailed scientific studies in semi-arid savannas (Hardy and Walker, 1991). If the tip of the 1 m metal rod struck on a tuft of the herbaceous plant, it was recorded as basal strike. When the distance of the nearest plant was further than 30 cm from the marked step point, it was recorded as 'bare ground'. Point observations were spaced at approximately 1 m intervals and records were made over the length of the belt transect once.

3.7.2 Grass plant density, grass cover and biomass

The 1 m^2 quadrat was used to survey for the grasses and forbs. A total of 40 quadrats (1 m x 1 m) were collected randomly at an interval of 3 m in a 250 m^2 transect on each site. In each quadrat, all grass plant tufts were identified, counted and clipped at about 10 cm stubble height. Grass species specimens that could not be identified in the field were kept in paper bags and identified the same day after data collection using the Grasses of Namibia and Grasses of Southern Africa books (MÜller, 1984; Van Oudtshoorn, 1999). The other assistance and/ or method of identifying some of the species was sought from the National Herbarium. The grass cover in each quadrat was estimated to a percentage level using a visual estimates method (Chmura and Salachna, 2016). Direct estimates of grass cover were done by randomly placing a quadrat (1 m x 1 m) along the transect in a plot. The estimated foliar cover of plants in the plot was recorded (estimated as % of total area). All herbaceous plant materials were air-dried in a warehouse for 10 days until completely dry and the dry matter yield was determined.

3.7.3 Woody botanical vegetation

All live woody plants within each of the belt transects (250 m^2) in all four sites were recorded and counted for the estimation of the woody plant density per area. Plant height and canopy diameters were measured for each individual woody plant. When multiple stems occurred in the belt transect, an arbitrary decision was made to count a stem as a separate individual. The classification of woody species was made on the basis of the description by Curtis and Mannheimer (2005). All woody plants of height >0-1 m were grouped as seedlings; >1–2 m as saplings or young shrubs; >2–3 m as young trees; and >3m as mature trees. Canopy diameter of every woody plant was measured along two axes (length, L, and width, W) perpendicular to each other. Percentage canopy cover was calculated using the formula:

Percentage canopy cover = $(n\pi r^2)/(2.5)$, where n is the number of woody plants and r^2 is equivalent to $LW/4$ (Beyene, 2015).

Woody plant data were standardized to tree equivalent (TE ha^{-1}) (1 TE = 1 tree, 1.5 m high) (Teague *et al*., 1981).

3.7.4 Plant identification

Grass species were identified and classified based on their palatability and ecological status. The classification of grasses was based on the succession theory described by Dyksterhuis (1949) for the ecological information of the arid and semi-arid (Tainton *et al*., 1980; Vorster, 1982). The species were grouped into (i) highly desirable species: those which occur in rangeland in good condition and decrease with over grazing (decreasers); (ii) desirable species: those which occur in rangeland in good condition and increase with moderate over grazing (increaser IIa), and; (iii) less desirable species: those which occur in rangeland in poor condition and increase with severe/extreme overgrazing (increasers IIb and IIc). Grass species were also grouped into their life forms (annuals and perennials). Most plant identification was made in the field. For species that were not identified in the field, a full plant sample with inflorescences and other vegetative parts were collected in khaki paper-bags for further identification at the laboratory/hostel with help of the colleagues.

3.7.5 Soil sampling

During data collection (May 2018), a total of ten soil samples were randomly collected from each belt transect (250 m^2) in each of the three chemically treated sites and also in the control at a depth of 15 cm using a soil auger (Hardy and Walker, 1991). All soil samples from each belt transect were bulked and oven - dried at 105^oC for 48 hours and milled to pass through a 2 mm sieve. Fractions measuring more than 2 mm were referred to as stones and gravel, they were not used in the analysis. The soil pH and chemical analysis were done at the Ministry of Agriculture, Water and Forestry laboratory in Namibia.

3.7.6 Soil chemical analysis

Soil samples underwent chemical analysis at the Ministry of Agriculture, Water and Forestry analytical soil laboratory, following standard procedures (Appendix 5). Soil samples were analyzed for pH, organic carbon (OC), Phosphorus (P), Potassium (K), Calcium (Ca), Magnesium (Mg) and Sodium (Na). Soil pH was determined by using electrodes and based it on $CaCl_2$. Organic carbon was determined by the modified wet oxidation method (Walkley and Black, 1934). Soil Potassium was determined by emission spectroscopy, while Calcium, Magnesium and Sodium were determined by atomic absorption spectroscopy (Jackson, 1958). Phosphorus was detected by ultraviolet spectrophotometer (Olsen and Sommers, 1982).

3.8 Data analysis

The soil and plant data were analyzed using the Statistical Package of Social Science (SPSS) software programme IBM version 21. Soil chemical property data were normally-distributed, a one-way analysis of variance (ANOVA) was used to test whether there was a significant difference in the mean values of measured variables among the different treatment sites. Hierarchy Clustering Analysis (HCA) was used to test for homogeneity of variance between treatment sites and to group sites that were similar. The Shapiro Wilk test was used in analyzing the soil property data because the sample sizes were less than 2 000 (Dytham, 1999; Gauch, (1982). The Kruskal-Wallis test was used to test the null hypothesis that had no significant differences between the median values of the woody cover, grass and herbaceous cover, soil chemical property and the test was done to compare the sites that were treated in 2015, 2015, 2017 and no treatment site (Ashcroft and Pereira, 2003). The HCA was used in line with the linkage between groups method which was performed on sites-by-species matrix consisting of 12 plots and 20 species of grass, using presence and absence data.

3.9. Research ethics

This research did not intend to do harm of any form to the natural environment and never held any confidentiality of whatsoever. It only intended to achieve the objectives stated. The research was based at Neudamm farm, which is part of the University of Namibia and therefore the permission to work on it was firstly obtained.

CHAPTER 4

RESULTS

4.1 Grass plant

4.1.1 Species composition

A total of 20 grass species were identified in all the four sites. Out of all these, 11 were perennials and the remaining 9 were annuals (Table 4.1). Grasses were classified into desirability groups, following Tainton *et al*. (1980) and Vorster (1982). Three species were classified as highly desirable, six as moderately desirable and 11 as less desirable species (Table 4.1). Based on ecological grouping, only 5 species were categorized as decreasers and all others were increasers.

The identified perennial grass species in the study area were *Anthephora pubescens, Aristida meridionalis, Aristida stipitata spicata, Cenchrus ciliaris, Eragrostis echinochloidea, Eragrostis lehmanniana, Eragrostis trichophora, Heteropogon contortus, Microchloa cafra, Stipagrostis uniplumis,* and *Schimidtia pappophoroides.* The identified annual grass species were *Aristida adscensionis, Aristida congesta, Chloris virgata, Enneapogon cenchroides, Eragrostis annulata, Melinis repens, Pogonarthria fleckii, Pogonarthria squarrosa,* and *Schimidtia karahariensis.*

Table 4. 1 Life forms, desirability, ecological grouping and grass species distribution in all four sites

Species	Life form (Desirability)	Ecological status	(2015) %	(2016) %	(2017) %	Control %
Anthephora pubescens	P (HD)	Dec	-	-	0.2	0.2
Aristida adscensionis	A (LD)	Inc IIc	-	0.9	-	-
Aristida congesta	A (LD)	Inc IIc	-	3.9	7.6	4.3
Aristida meridionalis	P (LD)	Inc IIc	12.1	14.0	22.0	41.2
Aristida stipitata	P (LD)	Inc IIc	-	0.5	-	-
Cenchrus ciliaris	P (HD)	Dec	-	-	1.7	3.3
Chloris virgata	A (LD)	Inc IIc	-	3.5	-	0.1
Enneapogon cenchroides	A (LD)	Inc IIc	-	3.5	3.8	0.2
Eragrostis annulata	A (LD)	Inc IIc	0.8	0.3	-	-
Eragrostis echinochloidea	P (MD)	Inc IIb	-	0.4	-	-
Eragrostis lehmanniana	P (MD)	Inc IIb	-	-	0.6	0.2
Eragrostis trichophora	P (MD)	Inc IIb	14.6	6.8	2.9	1.6
Heteropogon contortus	P (MD)	Dec	-	0.7	0.3	2.2
Melinis repens	A (LD)	Inc IIa	44.5	31.7	19.6	16.8
Microchloa cafra	P (LD)	Inc IIa	-	-	21.2	11.9
Pogonarthria fleckii	A(MD)	Inc IIc	1.0	0.2	1.8	-
Pogonarthria squarrosa	A (LD)	Inc IIc	0.9	3.9	-	1.4
Schimidtia pappophoroides	P (HD)	Dec	4.8	10.1	0.6	-
Schimidtia kaharariensis	A (LD)	Dec	5.8	8.1	10.2	3.2
Stipagrostis uniplumis	P (MD)	Dec	4.0	2.4	0.4	0.1

A = Annual, P = Perennial; HD = Highly Desirable, MD= Moderately Desirable, LD = Less Desirable; - =Absent; Dec = Decreaser, Inc IIa = Increaser IIa, Inc IIb = Increaser IIb, Inc IIc = Increaser IIc

4.1.2 Vegetation composition

The Hierarchical Cluster Analysis (HCA) dendrogram (Figure 4.1) below presented the presence/absence representation of species composition across the four treatment sites. Treated sites grouped under the same cluster number indicate species that were present within certain sites (plots) and also show absence of other species within the dendrogram (%). The HCA dendrogram (Figure 4.1) shows a classification of vegetation species richness into 4 main clusters based on chemically treated sites of 2015 (DB-camp6-P1-2015, DB-camp6-P2-2015, DB-camp6-P3-2015); chemically treated sites of 2016 (DB-camp5-P1-2016, DB-camp5-P2-2016, DB-camp5-P3-2016); chemically treated sites of 2017 (DB-camp6-P1-2017, DB-camp6-P2-2017, DB-camp6-P3-2017) and control (DB-Camp5-P1-NT, DB-Camp5-P2-NT and DB-Camp5-P3-NT) sites grass species presence and absence at the Neudamm farm, specifically in camp 5 and 6 in block D.

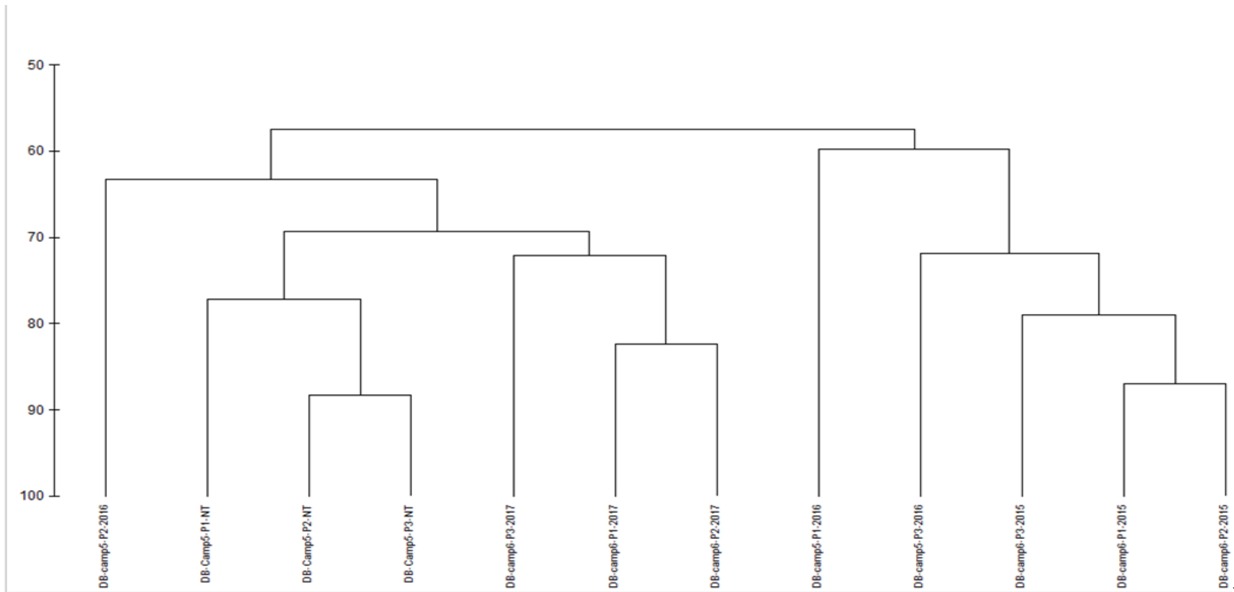
Cluster 1 was confined to plot number 2 in camp 5, which was treated in 2016. Each plot had three belt transects measuring 50m x 5m. The plot had a species composition of *Aristida congesta, Aristida meridionalis, Eragrostis trichophora, Melinis repens, Pogonarthria squarrosa, Schimidtia karahariensis* and *Stipagrostis uniplumis*.

Cluster 2: This was confined to six plots in camps 5 and 6. The plot numbers were 1, 2 and 3 in each camp. They all measured 50 m x 5 m each with an interval of 50 m between plots. All plots maintained had species composition of *Aristida adscensionis, Aristida congesta, Eragrostis trichophora, Heteropogon contortus, Melinis repens, Microchloa cafra* and *Schimidtia karahariensis*. The six plots had diversity in some species that were not common to all, such as *Stipagrostis uniplumis, Schimidtia pappophoroides* and *Eragrostis lehmanniana*. *Eragrostis lehmanniana* that were only found in plot 3 of camp 6, which was treated in 2017. Plot one in camp 6, which was treated in 2016 had higher numbers of grass species, while plot two in camp 5 at the control site (no treatment) had lower numbers of grass species. Furthermore, if this cluster is to be divided again into sub-clusters, one cluster will consist of plots treated in 2017 and the other cluster with plots in the control site.

Cluster 3: this cluster comprised of only one plot, which is plot one in camp 5 which was treated in 2016. It also measured 50m x5 m with a distance of 50 m interval. The plot has the following species composition *Aristida adscensionis, Aristida congesta, Aristida meridionalis, Aristida stipitata spicata, Chloris virgate, Enneapogon cenchroides*, *Eragrostis trichophora, Melinis repens, Pogonarthria fleckii, Pogonarthria squarrosa, Schimidtia pappophoroides* and *Stipagrostis uniplumis.*

Cluster 4: is confined to four plots in camps 5 and 6. The plots in camp 6 which were treated in 2015 are 1, 2 and 3 while the plot in the site that was treated in 2016 is plot 3. The measurements for all plots were also 50 m x 5 m each with a distance between plots at 50m. The plots have the following species composition in common *Aristida meridionalis, Enneapogon cenchroides, Eragrostis trichophora*, *Melinis repens*, and *Stipagrostis uniplumis.* Plot 3 in camp 5 which was treated in 2016 had a greater number of grass species while plot 2 and 3 in camp 6 which was treated in 2015 maintained the same number of grass species.

Similarity (%)



plot

Cluster 1	Cluster 2	Cluster 3	Cluster 4
Camp5_P2_2016	Camp5_P1_NT	Camp5_P1_2016	Camp5_P3_2016
	Camp5_P2_NT		Camp6_P3_2015
	Camp5_P3_NT		Camp6_P1_2015
	Camp6_P3_2017		Camp6_P2_2015
	Camp6_P1_2017		
	Camp6_P2_2017		

Figure 4.1 Hierarchical Cluster Analysis (HCA) dendrogram comparing the composition of herbaceous plants (%) among study sites.

4.1.3 Percentages of ecological grouping

Table 4.2 shows the actual ecological functional type occurrence across the four contrasting sites from the field assessment. The sites that were chemically treated in 2015 and 2017 had higher percentages 44% and 45% respectively of decreaser grass species, followed by the site that was treated in 2016, which had 35%. The control had the lowest percentage (29%) of decreasers. The percentage of increaser IIa was relatively higher on the site that was chemically treated in 2015, than in the other three sites. The increaser IIb species also increased from 15% (2015) to 47% on the control site (Table 4.2).

Table 4. 2 Percentages of ecological grouping of grass species in all four sites

Status	**2015 (%)**	**2016 (%)**	**2017 (%)**	**Control (%)**
Decreaser	44	35	45	29
Increaser IIa	15	7	3	2
Increaser IIb	15	27	32	47
Increaser IIc	15	22	13	9

4.1.4 Total grass tuft density

The mean total grass tuft density was relatively higher ($P < 0.05$) in control site (31 ha) and lower in the chemically treated site of 2016 which was 21 ha (Table 4.3). The other chemically treated sites of 2015 and 2017 also had greater ($P < 0.05$) grass tuft density than the chemically treated site of 2016. There was no significant difference between sites treated in 2015 and 2017. However, there was a significant difference ($P < 0.05$) in total grass tuft density on sites treated in different years as indicated on Table 4.3.

Table 4.3 Total grass tufts density

Treatment year	Grass tufts density
2015	965±2.7^{b}
2016	896±1.95^{c}
2017	925±2.8^{b}
Control	1693±1.2^{a}

4.1.5 Grass species dry matter production

Herbaceous plant dry matter was significantly higher ($P < 0.05$) in the site that was chemically treated in 2015 (975 Kg DM ha^{-1}), followed by the site that was chemically treated in 2016 (925 Kg DM ha^{-1}) and least in the control (575 Kg DM ha^{-1}) and the chemical treatment site of 2017 (350 Kg DM ha^{-1}) (Figure 4.2).

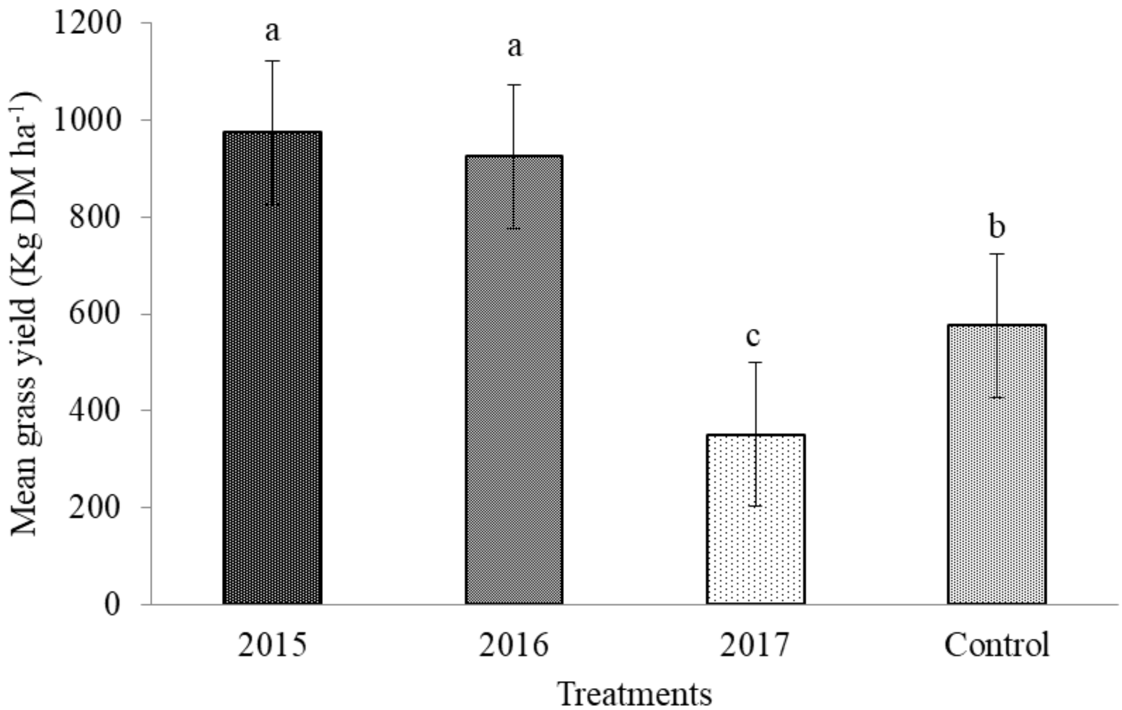


Figure 4. 2 Mean grass dry matter yield (Kg DM ha^{-1}) of all four study sites. Means with different superscripts on the bars differ significantly ($P < 0.05$).

4.1.6 The estimated stocking rate

Table 4.4 below shows the estimated stocking rate of each of the study areas, based on biomass yield. The chemically treated site of 2015 had the greatest potential for small stock with an estimated stocking of 17 SSU (Small Stock Unit)/ha per year. This was followed by the treated site of 2016 at 13 SSU/ha; then the treated site of 2017 (6 SSU/ha) and the control at 8 SSU/ha.

Table 4. 4 An estimation of the stocking rate (SSU) of the four study sites

Year	Camp size (ha)	Grass yield (Kg DM ha^{-1})	SSU/ha	ha/SSU
2015	31	975	17	1.8
2016	26	925	13	2
2017	31	350	6	5.1
Control	26	575	8	3.25

4.1.7 Ground cover (%)

The treated site of 2016 had greater ($P < 0.05$) ground cover percentage than the other three treatment sites (Figure 4.2). However, the chemically treated site of 2017 and the control had equally lower ($P > 0.05$) ground cover percentages.

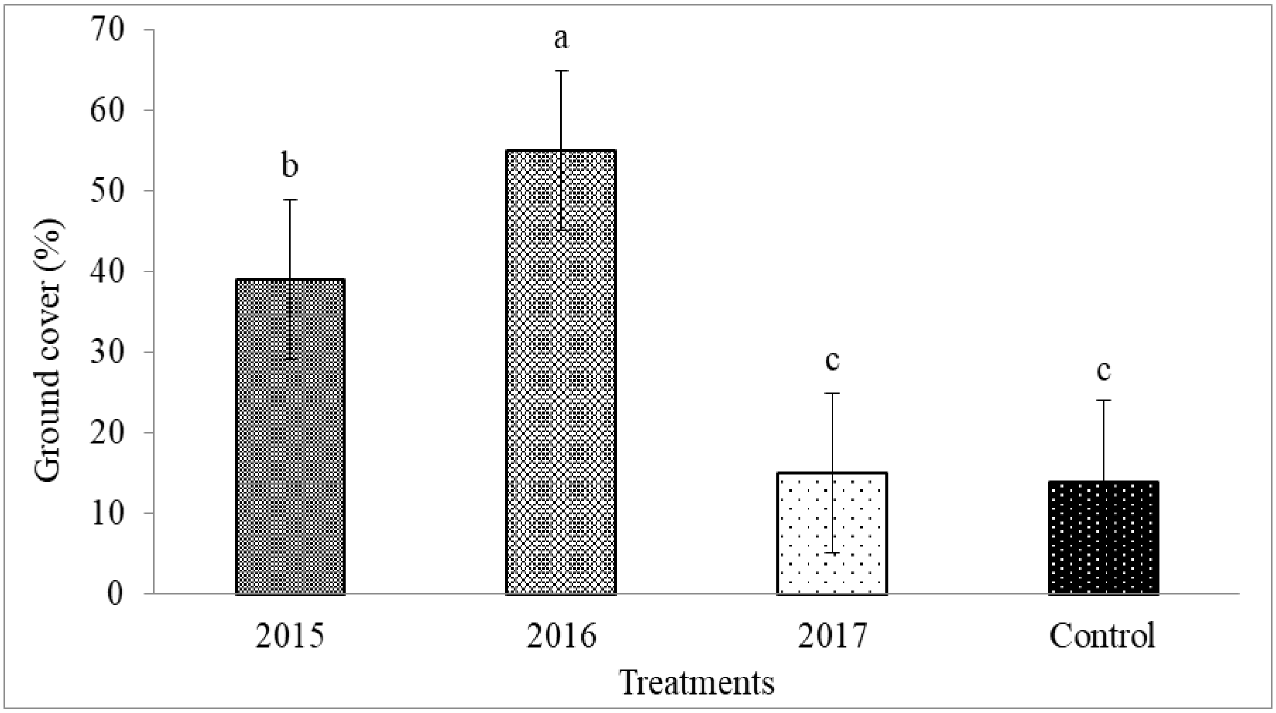


Figure 4. 3 Mean ground cover (%) on the four study sites. Bars indicate standard errors of the means. Means with different superscripts on the bars differ significantly ($P < 0.05$).

4.2 Woody botanical vegetation

The Neudamm farm rangeland is mainly inhabited by *Senegalia mellifera, Tarchonanthus camphoratus, Blumea decurens, Grewia flava, Lantana camara, Ziziphus mucronata, Vachellia erioloba, Lycium eenii, Catophractes alexandrii, Searcia marlothii, Searcia ciliate, Maerua parvifolia, Boscia albitrunca* and *Searcia tenuinervis. Senegalia mellifera* was the dominant woody species with *Maerua parvifolia* being the rare woody plant species in the study area.

4.2.1 Total woody plant density

Figure 4.4 shows that total woody plant density was significantly higher ($P < 0.05$) in the control (untreated site) (14160 TE ha^{-1}) than in the three different chemically treated sites of 2015 (1240 TE ha^{-1}), 2016 (5600 TE ha^{-1}) and 2017 (5560 TE ha^{-1}) respectively.

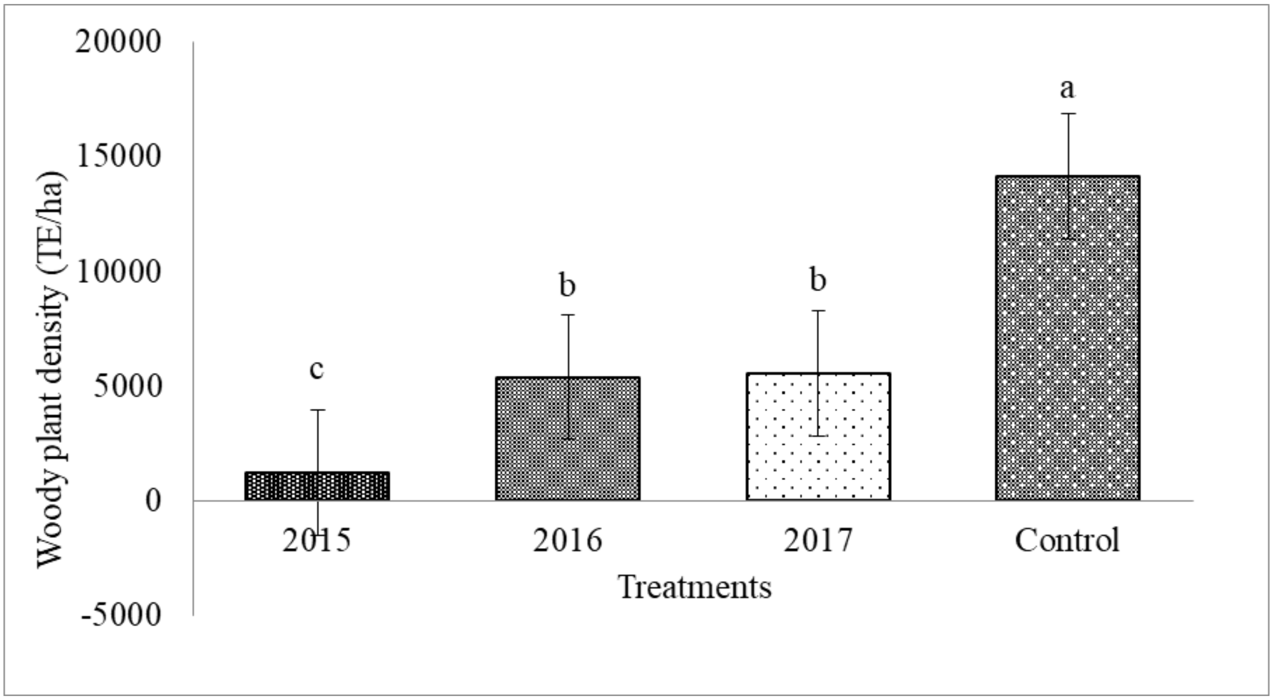


Figure 4. 4 Total woody plant density (TE ha^{-1}) in all four study sites. Bars indicate standard errors of the means. Means with different superscripts on the bars differ significantly ($P < 0.05$).

4.2.2 Woody plant canopy cover

The percent canopy covers for the chemically treated site of 2017 and the control (untreated site) were similar (Fig. 4.5) and these were significantly higher than the % covers of the chemically treated sites of 2015 and 2016. The percentage of canopy cover of the chemically treated sites of 2015 and 2016 were not statistically different.

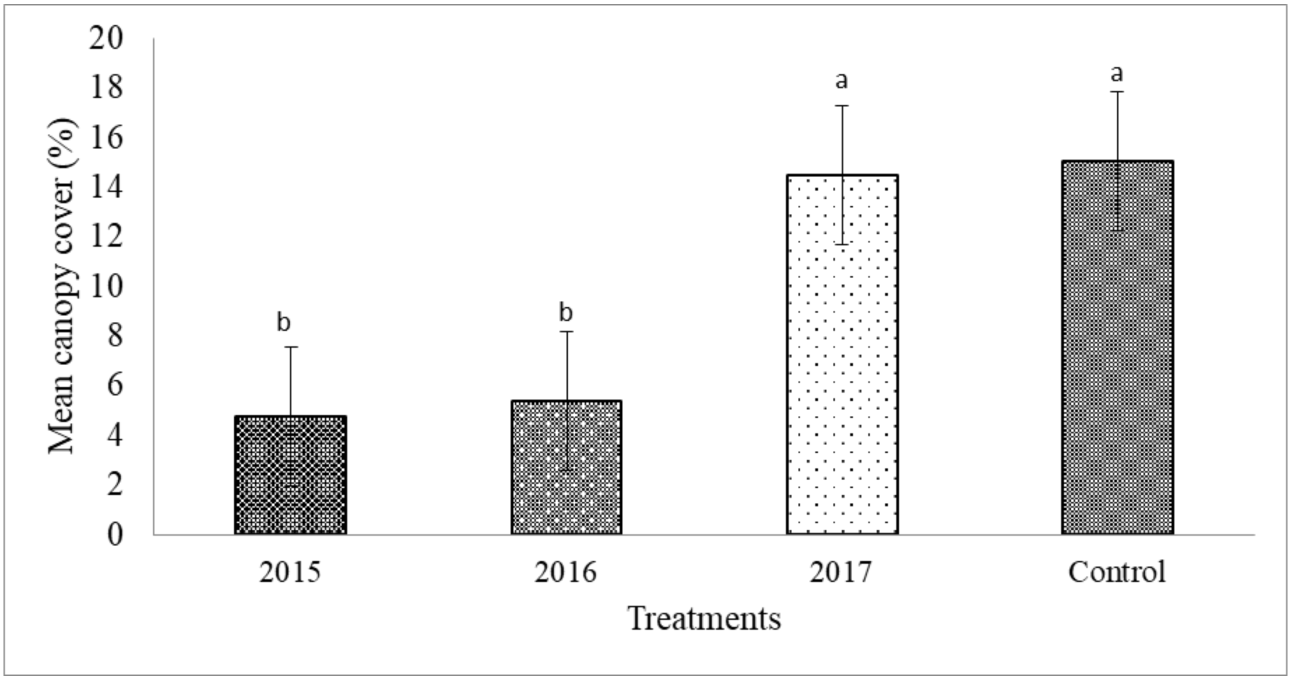


Figure 4.5 Mean canopy cover (%) in the four study sites. Bars indicate standard error of the means. Means with different superscripts on the bars differ significantly ($P < 0.05$).

4. 2.3 Woody plant height class distribution

There was a significant difference ($P < 0.05$) between the four treatment sites (Table 4.5). The control had the highest woody plant densities in all woody height categories, followed by the treated site of 2017 than the other two treatments. The 2015 and 2016 chemically treated sites had no ($P > 0.05$) woody plant density records under the heights of >2 – 3 m and > 3 m categories.

Table 4.5 Densities (mean ± SEM) of woody height classes in the four study sites

Height classes	Treatments	Density
Seedlings (0 - 1m)	2015	920 ± 975.7^{d}
	2016	2920 ± 975.7^{c}
	2017	4280 ± 975.7^{b}
	Control	8840 ± 975.7^{a}
Sapling (>1 – 2 m)	2015	320 ± 0.1^{d}
	2016	$2\ 680 \pm 0.1^{c}$
	2017	1080 ± 0.1^{b}
	Control	3560 ± 0.1^{a}
Young trees (>2 – 3 m)	2015	0^{c}
	2016	0^{c}
	2017	40 ± 13.3^{b}
	Control	1040 ± 13.3^{a}
Mature trees (> 3 m)	2015	0^{c}
	2016	0^{c}
	2017	160 ± 170.8^{b}
	Control	720 ± 170.8^{a}

4.3 Soil chemical properties

4.3.1 Soil pH (H_2O)

The soil pH values of the treatment sites ranged from 5.37 to 6.06 and there were significant differences ($P<0.05$) among the sites. The chemically treated site of 2015 had relatively the highest soil pH (6.06), followed by the control (5.61) and the treated site of 2017 (5.5) (Figure 4.6). The chemically treated site of 2016 had a lower pH (5.37) value than the other sites. The soil pH values in the control and the chemical treatment site of 2017 were not statistically ($P > 0.05$) different.

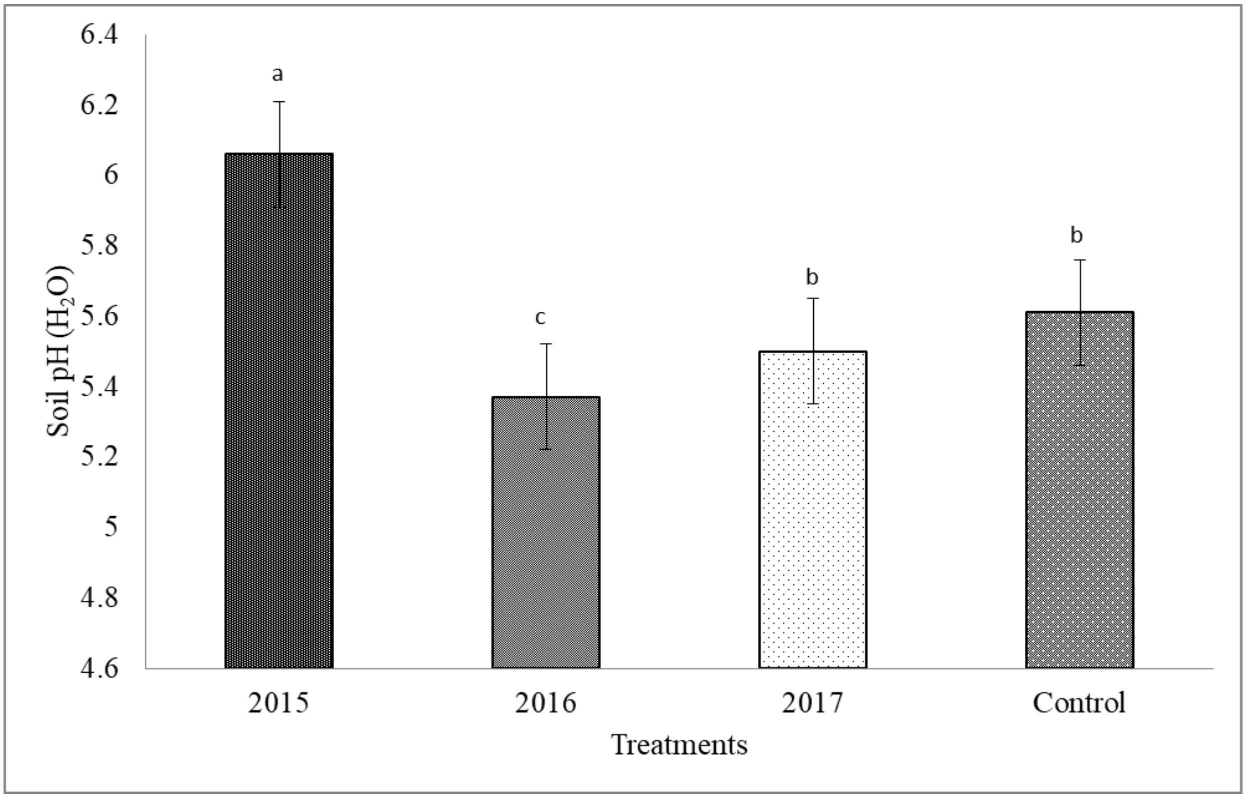


Figure 4.6 Soil pH in all four study sites. Bars indicate standard errors of the means. Means with different superscripts on the bars differ significantly ($P < 0.05$).

4.3.2 Organic carbon and organic matter

Organic carbon and organic matter percentages were significantly ($P < 0.05$) higher in the chemically treated site of 2015 than in all the other treated sites (Figure 4.7). The chemically treated site of 2017 had the lowest OM and OC percentages, but the OM and OC percentages were insignificantly ($P > 0.05$) different in the control and the chemical treatment site of 2016.

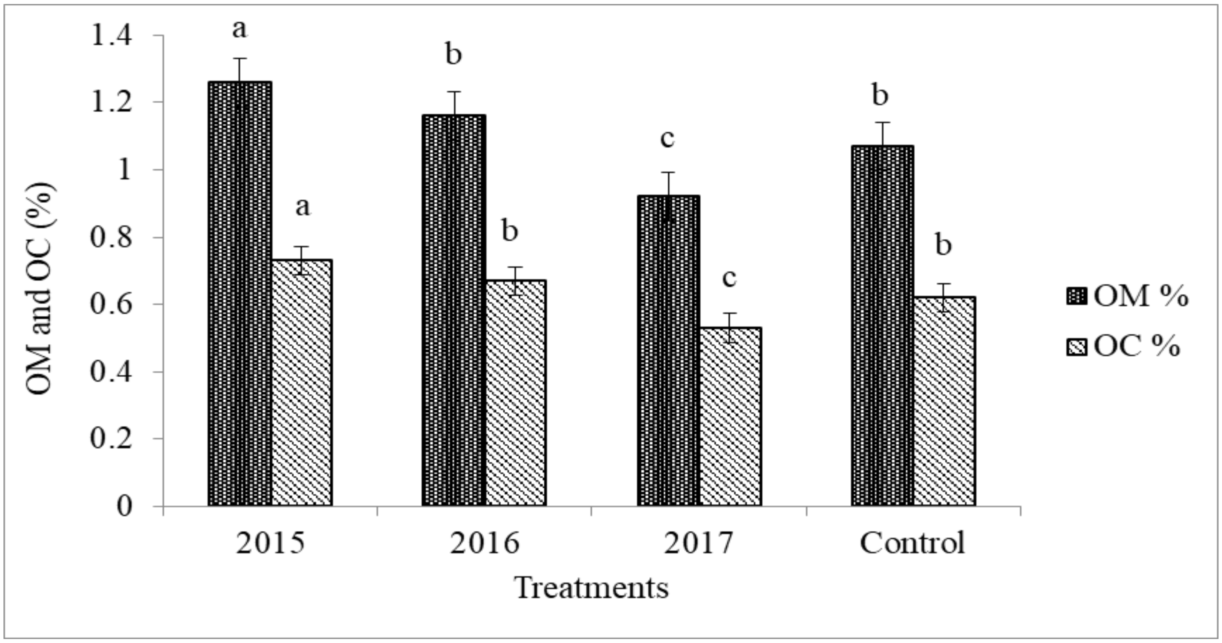


Figure 4. 7 Organic Carbon and Organic Matter (%) in all four study sites. Bars indicate standard errors of the means. Means with different superscripts on the bars differ significantly ($P < 0.05$).

4.3.3 Soil minerals

The results in Figure 4.8 showed that the soil Calcium (Ca), Potassium (K), Magnesium (Mg) and Sodium (Na) concentrations were significantly ($P < 0.05$) different among different treatment sites. The soil in the chemically treated site of 2016 had the highest Ca (551 ppm), K (197.3 ppm), Mg (76 ppm), P (23.3) contents, followed by the site of 2015 than the soil of all other sites. The soil P, K, Ca and Mg contents were slightly lower in the control and the treated site of 2017. The soil of the treated site of 2015 had higher Na (6 ppm) concentration than the soil of other treated sites.

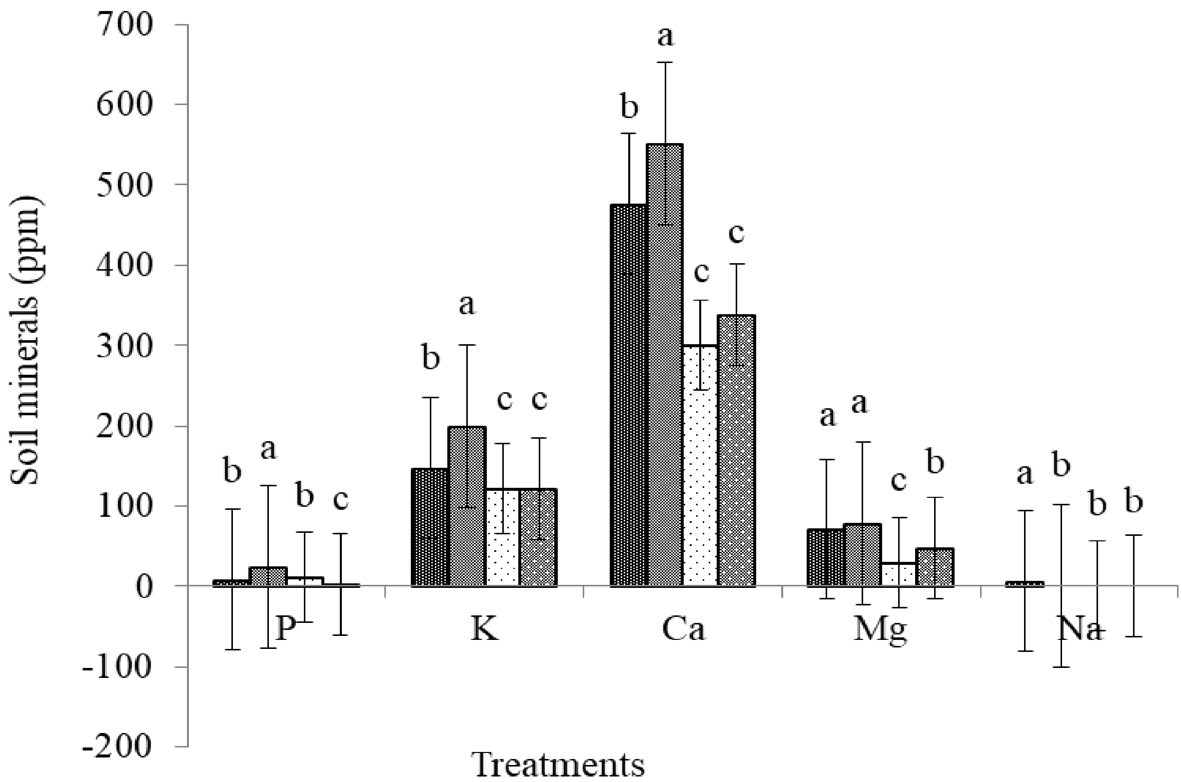


Figure 4. 8 Soil minerals in all four study sites. Bars indicate standard errors of the means. Means with different superscripts on the bars differ significantly ($P < 0.05$).

CHAPTER 5

DISCUSSION

5.1 The herbaceous plant species composition

The study findings indicated that out of the twenty plant species that were identified, eleven were perennials and the remaining were annuals. The higher percentage perennial grass species could be attributed to the removal and control of bushes that opened up spaces, which boosted the germination and vegetative growth of various grasses on the treated rangelands. The current study results are consistent with the study by Tainton (1999), which emphasized that removal of bushes could boost the germination and growth of various grasses on the rangeland.

It is important to note that classifications of grass species into desirability and ecological categories rely mostly on the qualities of species with respect to their life forms and acceptability. The chemically treated site of 2015 and 2017 had higher proportions (44% and 45% respectively) of decreaser grass species. These results could be associated with improvement in the rangeland management. The finding of this study agrees with the study of O'Connor (1991), who reported that ecologically decreaser species are the most important key species in the semi-arid grasslands of southern Africa and good indicators of the health status of rangelands. The lower percentages of decreasers species in the treated site of 2016 and control may be an indication of poor health status of these rangelands, as increaser species are normally associated with rangeland degradation. These findings are in agreement with the study of Smet and Ward (2005) who indicated that variations in grazing pressure and rangeland history could be the primary factor that influences the composition of grasses and forbs in semi-arid rangelands of Africa. In agreement to the findings in this study, Tainton (1999), also stated that increasers (less palatable grass species) may not be grazed and increase if they are over utilized in the rangeland.

5.1.1 Grass species tuft density, dry matter production and cover.

The significantly higher mean total grass tuft density in the control site could be to small annuals and perennials that inhabit denuded rangelands. Kahumba (2010) indicated that grass species such as *Aristida meridionalis*, *Pogonarthria fleckii*, *Pogonarthria squarrosa Aristida congesta*, *chloris virgata* could be abundant in degraded rangeland because they are hardy grasses with low leaf production and may be poorly utilised by livestock if there is abundant forage choices from which animals could select, especially during the rainy season. The lower mean total grass tuft density in the chemically treated site of 2016, could be associated with recurrent drought situations and overgrazing coupled with leaching of soil minerals due to rainfall. These findings also corresponded with Tainton (1999) who indicated that retrogression of the grass component is common in the savanna rangelands and which inevitably reduces the productive capacity of savanna rangelands for herbivores.

The herbaceous plant dry matter significantly higher in the chemically treated sites of 2015 and 2016 and least in the other two sites. This could be due to differences in defoliation rate in different rangelands. Low herbaceous biomass in rangelands is associated with high grazing intensities that could have led to decreased standing biomass, as more biomass is consumed by livestock and this is consistent with the findings of Kahumba (2010) and Solomon *et al*. (2007). Conversely, Tainton (1999) supported that a decline in the condition of the grass layer is typically accompanied by the increase in the density of encroacher bushes. The ground cover percentages were significantly greater in the chemical treatment sites of 2016 and 2015. This could be because grass species had larger and wide tufts that could protect and prevent the top-soil from being blown away by wind or washed away by the rain water. The findings of the current study are in agreement with the study of Angassa (2002), which emphasized that the ground coverage with wide and larger herbaceous layers reduces the level of soil erosion on the rangeland, which enables the soil to retain its nutrient contents. Generally herbaceous biomass increases with time from date of chemical treatment, which simply means that the 2015 sites, which were treated earlier and had more years to recover after treatment than the sites that were treated year (2017 and 2018) later.

5.2 Total woody plant density

The total woody plant density was significantly higher in the control (untreated site) than in the three chemically treated sites. This higher woody plant density could be associated with the encroachment of the highland savanna of Namibia, particularly by *Senegalia mellifera.* The finding of this study is consistent with O'Connor and Watkinson (2001) who demonstrated that rangeland degradation in the form of bush encroachment causes major ecological transformations of savanna ecosystems grazed by livestock and the consequent bush encroachment negatively impacts on the livelihoods of farmers. Similarly, Abule *et al*. (2005) and Solomon *et al*. (2006) indicated that overgrazing due to overstocking, has been frequently reported as the major anthropogenic cause of rangeland degradation, which necessitates opportunities for encroacher bushes. The lower woody densities in the chemically treated sites reflect the effectiveness of the arboricide in killing the bushes.

5.2.1 Canopy cover and woody plant height classes distribution

The study findings on canopy cover indicated that percentage of canopy cover was significantly higher in the control (untreated site) and chemically treated site of 2017. This could be attributed to live standing woody plant densities, which could vertically provide a wide coverage and protection of the soil surface under the crown. The control had the highest woody plant densities in all woody height categories. The higher woody plant densities in the chemically treated site of 2017, could be due to that treated woody plants were still in the process of dying back. The study revealed that the further recruitment of seedling and bushes in the control was increasing and could in the future result in advanced and severe bush encroachment, which would be impermeable to grazing livestock (Kahumba, 2010). This study also showed that there is greater association between woody plant heights and woody plant densities. Friedel (1985) and Solomon *et al*. (2007) reported that the supremacy of small size growing plants in rangelands of Southern Africa signifies suppression of the herbaceous plant production, which demonstrates the competitive ability of woody plants at a young stage.

5.3 Soil chemical properties

5.3.1 Soil pH (H_2O (pH)

The high soil pH in the chemically treated site of 2015 could be attributed to mineralization characteristics of the soil. The pH level is the most important soil factors measured in terms of acidity or alkalinity. These results are in agreement with the report of previous studies (Wang *et al*., 2001; Nsinamwa *et al*., 2005; Solomon *et al*., 2007), that reported that complex spatial patterns of soil nutrients in rangelands have been commonly presumed to develop over time as a result of interactions of animal activities, parental material, vegetation type and topography. Variations in grazing pressure, history of site, effects of grazing on litter cover, and on soil structure and fertility also influence the soil pH of grazing rangelands (Snyman and du Preez, 2005; Smet and Ward, 2005; Solomon et al., 2007). The soil pH variations of the current study could also be closely associated with plant densities (Gough *et al.,* 2000), differences in carbon dynamics of the area and mineralization characteristics of the soil (Hobbie and Gough 2002).

5.3.2 Organic carbon and organic matter

The chemically treated site of 2015 had higher organic carbon and organic matter percentages than all the other treatment sites. This could be because of the dense level and accumulation of dead plant material (especially from the high biomass) which on decomposing are converted into soil organic carbon and soil organic matter (Smet and Ward, 2005). The least soil organic carbon and organic matter levels in the site of 2017 could be attributed to reduced input of organic matter and the reduced physical protection of soil from erosion. Franzluebbers (2002) reported that low soil organic carbon and organic matter levels can be associated with a degraded process (vegetation losses and unsustainable soil management) resulting in continuous impoverishment in the organic matter content causing low soil productivity.

5.3.3 Soil minerals (P, K, Ca, Mg and Na)

The highest soil contents of Ca, K and P in the chemically treated sites of 2016 and 2015 could be associated with the presence of dead woody plant density and increase in the concentrations of some soil nutrients. The greater concentration of these soil minerals might also be associated with the inherent nature of parent materials of savanna soils. This is in consistent with the studies of Vourlitis *et al.* (2015) and Rolo *et al.* (2012), that indicated that vegetation enhances surface P and K ions availability but not Ca and Mg ions because it contains calcium ions (Ca^{2+}), and this may reveal the reason of greater amounts of Ca, P and K ions concentrations in the sites of 2016 and 2015 soils that had high density of woody vegetation. In contrast, Boyazoglu, (1997) reported that the Phosphorus level in soils of most of the semi-arid rangelands are low and this is attributed to the fact that this element is stored in unavailable forms to plants (Juo, 1978). In natural rangeland ecosystems, the Phosphorus cycle is virtually closed and most plant Phosphorus is recycled by microbial breakdown of litter and organic debris (Berliner and Kioko, 1999).

The high soil contents of Mg in the chemically treated sites of 2015 and 2016 could be attributed to the soil magnesium (Mg^{2+}) cations attracted to the negative exchange sites of organic matter (cation exchange complex of the soil) (Sawyer, 2003). The finding of this study is inconsistent with the results of McDowell (1985) and Tiffany *et al.* (2001) who reported that the soil Mg deficiency results in low rangeland and animal productivity. The lowest soil levels of Na could be related to the high concentration of calcium in the soil. Calcium, just like magnesium, generally competes for the exchange sites occupied by sodium thereby reducing the amount of sodium that will be bound to soil (Hanson *et al*., 1999).

CHAPTER 6

CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

Based on the findings of the current study chemical treatments have impacted on the plant biodiversity of the treated rangelands by improving the herbaceous plant density, increased biomass yields, reduced bush density and enhanced the soil health status in terms of ground cover. The woody plant density and height categories were drastically lowered in the treated sites of 2015 and 2016. There was an indication of the need for aftercare to control the recruitment of seedlings. This study therefore rejects the null hypotheses and concludes that there is significant difference in woody plant composition in chemically treated sites compared to the untreated (control) site. The study also concluded that bush control improved the soil chemical properties (P. K. Ca. Mg. Na. organic matter and organic carbon) as exemplified by the treated sites of 2015 and 2016. Generally, chemical treatments improved the health state of rangelands through increasing perennials in the rangeland for livestock production.

6.2 Recommendations

1. The researcher would like to recommend that there should be a regular assessment of rangeland conditions at Neudamm farm, especially after arboricide application, as this will provide information to the farm management to improve their farm management and decision making. Bush thinning through the use of chemical treatment should not be considered as a once off operation, hence, aftercare measures and continuous monitoring of the rangeland are recommended. The farm management should consider the practice of aftercare routinely.

2. Arboricide application should be well planned in order to accommodate treatment and resting cycles of affected areas so that the treated areas should be rested for at least two rain seasons to provide perennial grass species with an opportunity to recover and replenish sufficient seeds and stabilize growth.

3. It is recommended that other long-term studies should be conducted, to assess the long term effects of arboricide application. The present study only served as a baseline study in the Highland Savannas, thus further investigations are required to assess the effectiveness for a period of at least five years.

4. Cost- benefit analysis of chemical control of bush needs to be evaluated.

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APPENDICES

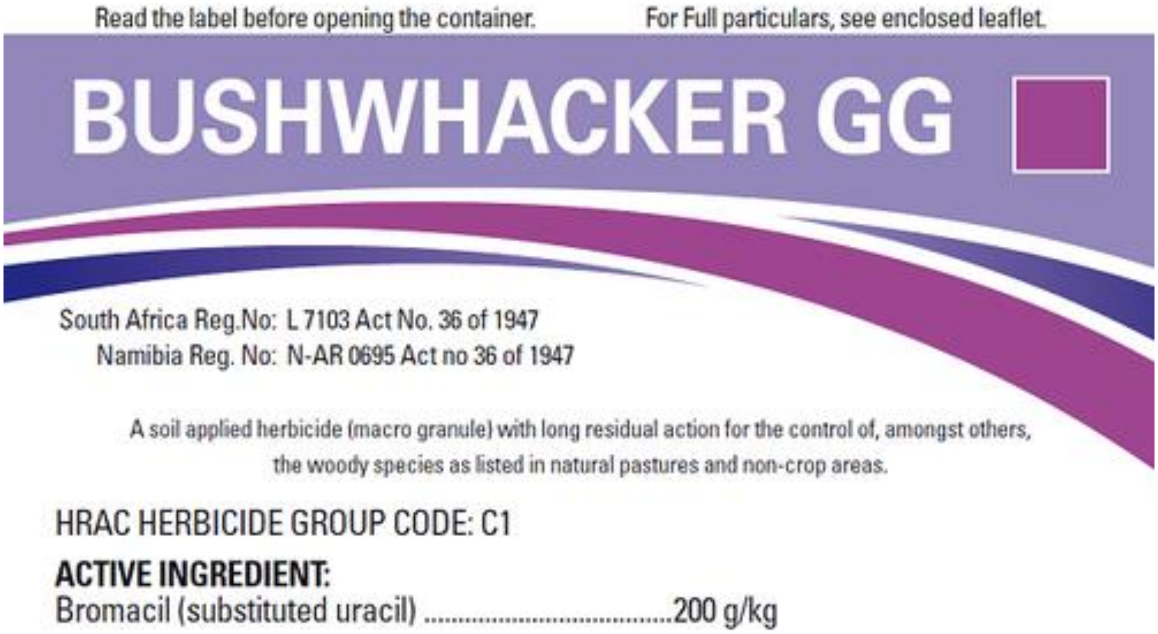
Appendix 1: Grass species composition

Species	Life form	Ecological status	2015 %	2016 %	2017 %	Control %
Anthephora pubscens	P (HD)	Inc IIc	0	0	0.2	0.2
Aristida adscensionis	A (LD)	Inc IIc	0.0	0.9	0.0	0.0
Aristida congesta	P (LD)	Inc IIc	0.0	3.9	7.6	4.3
Aristida meridionalis	P (LD)	Inc IIc	12.1	14.0	22.0	41.2
Aristida stipitata spicata	P (LD)	Inc IIc	0.0	0.5	0.0	0.0
Cenchrus ciliaris	P (HD)	Dec	0.0	0.0	1.7	3.3
Chloris virgata	A (LD)	Inc IIc	0.0	3.5	0.0	0.1
Enneapogon cenchroides	A (LD)	Inc IIa	0.0	3.5	3.8	0.2
Eragrostis annulata	A (LD)	Inc IIc	0.8	0.3	0.0	0.0
Eragrostis echinochloidea	P (D)	Inc IIb	0.0	0.4	0.0	0.0
Eragrostis. lehmanniana	P (D)	Inc IIb	0.0	0.0	0.6	0.2
Eragrostis trichophora	P (D)	Inc IIb	14.6	6.8	2.9	1.6
Heteropogon contortus	P (D)	Dec	0.0	0.7	0.3	2.2
Melinis repens	A (LD)	Inc IIa	44.5	31.7	19.6	16.8
Microchloa cafra	P (LD)	Inc IIa	0.0	0.0	21.2	11.9
Pogonarthria fleckii	A(D)	Inc IIc	1.0	0.2	1.8	0.0
Pogonarthria squarrosa	P (LD)	Inc IIc	0.9	3.9	0.0	1.4
Schimidtia pappophoroides	P (HD)	Dec	4.8	10.1	0.6	0.0
Schimidtia karahariensis	A (LD)	Dec	5.8	8.1	10.2	3.2
Stipagrostis uniplumis	A (D)	Dec	4.0	2.4	0.4	0.1
Forbs			11.4	8.9	7.3	13.6

Appendix 2: Trees species identified during the study

Scientific name	**Common name**
Acacia erioloba	Camel-thorn
Blumea decurrens	
Boscia albitrunca	Witgat
Catophractes alexandrii	Ghabbabos
Grewia flava	Velvet raisin
Lantana camara	Lantana
Lycium eenii	Broad-leaved honey-thorn
Maerua parvifolia	Small-leaved maerua
Searcia ciliata	Sour karee
Searcia marlothii	Bitter karee
Searcia tenuinervis	Kalahari currant
Senegaria mellifera	Kunene swarthaak
Tarchonanthus camphoratus	Camphor bush
Ziziphus mucronata	Buffalo-thorn

Appendix 3: Description of arboricide that is used at Neudamm farm



Appendix 4: Soil chemical analysis results sheet

Name: Diina Shigwedha	**Date:** 07/08/18	**Serial No.** 18/25	**Enquiries to:** Soil Laboratory 061 2087752
Address: Neudamm farm	**Phone:**0812694977		Mrs Sipapo: 061 208 7073

Soil analysis results

	pH(H2O)	Ecw (uS/cm	OM %	OC %	P (ppm)	K (ppm)	Ca	Mg (ppm)	Na (ppm)
DB-camp6-P1-2015	6.06	49	1.26	0.73	8.6	147	476	71	6
DB-camp6-P2-2015	6.02	50	1.28	0.75	8.5	149	478	69	7
DB-camp6-P3-2015	6.04	50	1.24	0.71	8.8	145	477	72	5
DB-camp5-P1-2016	5.37	384	1.16	0.67	23.4	199	551	78	0
DB-camp5-P2-2016	5.43	388	1.14	0.65	23.4	196	554	76	0
DB-camp5-P3-2016	5.21	372	1.18	0.69	23.2	197	552	74	0
DB-camp6-P1-2017	5.5	147	0.92	0.53	11.7	122	300	30	0
DB-camp6-P2-2017	5.41	149	0.94	0.54	11.8	120	298	28	0
DB-camp6-P3-2017	5.6	145	0.9	0.52	11.1	124	302	29	0
DB-Camp5-P1-NT	5.61	65	1.07	0.62	2.2	122	338	47	0
DB-Camp5-P2-NT	5.65	67	1.05	0.63	2.4	121	337	46	0
DB-Camp5-P3-NT	5.51	66	1.09	0.65	2	124	338	48	0

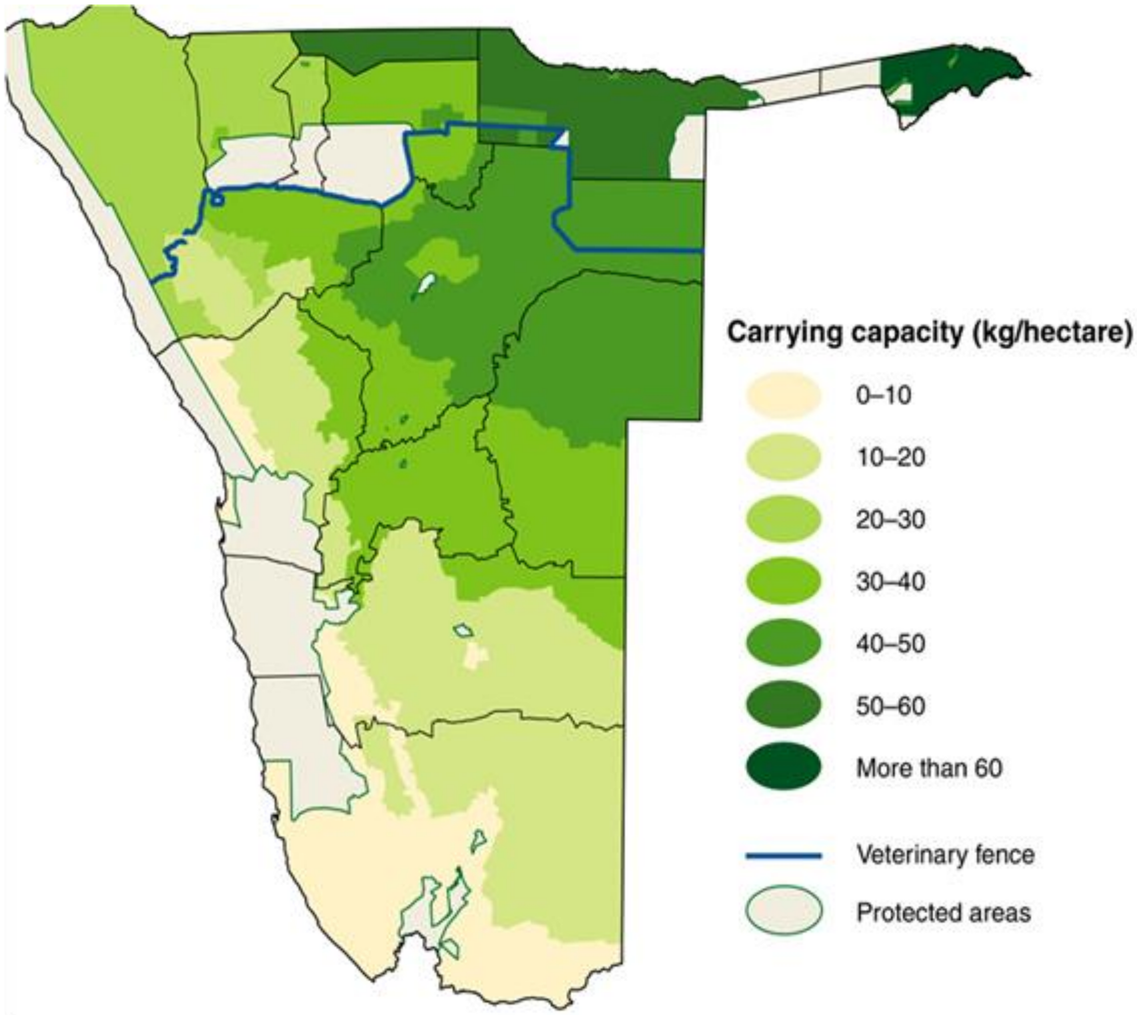
Appendix 5: Description of the methods used for soil analysis

Description of the methods used for soil analysis	
SAMPLE PREPARATION	Soil samples are dried at a temperature not greater than 35^o C. The part of the sample retained on a 2 mm sieve, called the fine earth fraction, is used for analysis. The fraction >2mm is referred to as stones and gravel.
AVAILABLE PHOSPHORUS	Ohlsen method: Extraction with sodium bicarbonate. Phosphate measured Spectrophotometrically using the Phosphomolybdate blue method.
EXTRACTABLE CATIONS	Extraction with 1M ammonium acetate at pH 7. Measurement of Calcium, Magnesium, Potassium and Sodium (K,Mg,Ca) by Inductively coulped plasma(ICP).
EXCHANGEABLE CATIONS	Extraction with 1M Ammonium acetate at pH 7 if pH(H2O)<6.8 & EC<0.4 mS/cm.
CATION EXCHANGE CAPACITY(CEC)	Extraction with 50:50 Ammonium acetate (1M) and Ethanol at pH 7 if pH(H2O)>6.8 & EC>0.4mS/cm. Calcium, Magnesium, Sodium and Potassium measured by atomic absorption spectrophotometry.
ORGANIC CARBON (ORGANIC MATTER CONTENT)	Walkley-Black method (Sulphuric acid-potassium Dichromate oxidation). A factor is included in calculations to take account of incomplete oxidation. Organic matter content calculated as organic-C x 1.74.
ORGANIC MATTER (by loss on ignition)	Organic matter is estimated by measuring the weight loss when dried samples are heated in a muffle furnace at 360 degrees C for 4 hours.

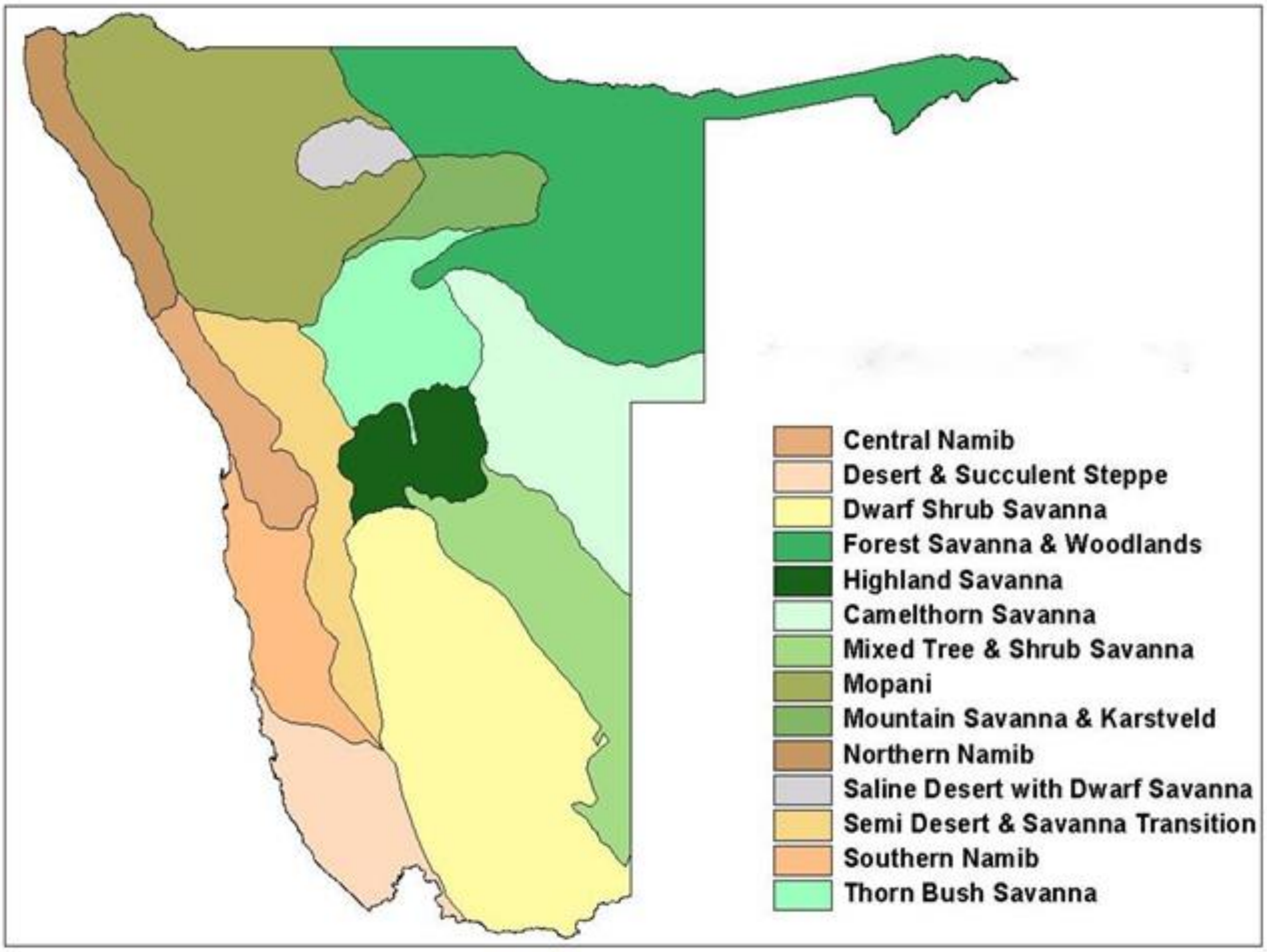
pH (KCl)	Measured in a 1:2.5 soil: IM Potassium chloride ratio suspension on a mass to volume basis.
pH(water)	Measured in a 1:2.5 soil: water suspension on a mass to volume basis.
ELECTRICAL CONDUCTIVITY (SOLUBLE SALT CONTENT)	Measurements in the supernatant of the 1:2.5 soil:water suspension prior to measurement of pH. Units of measuremnt are mS/cm (1 mS=1000 uS). High results indicating possible salinity hazard are repeated on the extract of a saturated soil paste.
TOTAL NITROGEN	The sample is then introduced to the furnace containing only pure oxygen, resulting in a rapid and complete combustion (oxidation). Nitrogen present is oxidized to NOx respectively. The NOx gases are passed through a reduction tube filled with copper to reduce the gases to N and onto a thermal conductivity cell (TC) utilized to detect N2.
CARBONATE (as Calcium Carbonate)	Reaction of soil with hydrochloric acid and estimation of acid consumed by titration with Sodium hydroxide.
CARBONATE (estimation)	Treatment of dry soil with 10% Hydrochloric acid and observation of effervescence.
AVAILABLE SULPHUR (as SULPHATE)	1:2 weight:volume extraction of soil with 0.01M Calcium chloride. Sulphate-S estimated by measuring turbidity at 600 nm following treatment with acidified Barium chloride.
SULPHATE (estimation)	Soil: water extract from pH/EC measurement made 0.01M with respect to calcium by addition of 1M Calcium chloride. Filtered extract reacted with acid Barium chloride and turbidity visually compared with standard solution of Sulphate-S.

Notes: 1 ppm (part per million) = 1 mg/kg = 1 ug/g 1 % = 10 000 ppm

Appendix 6: Carrying capacity map of Namibia (Mendelsohn et al., 2002)

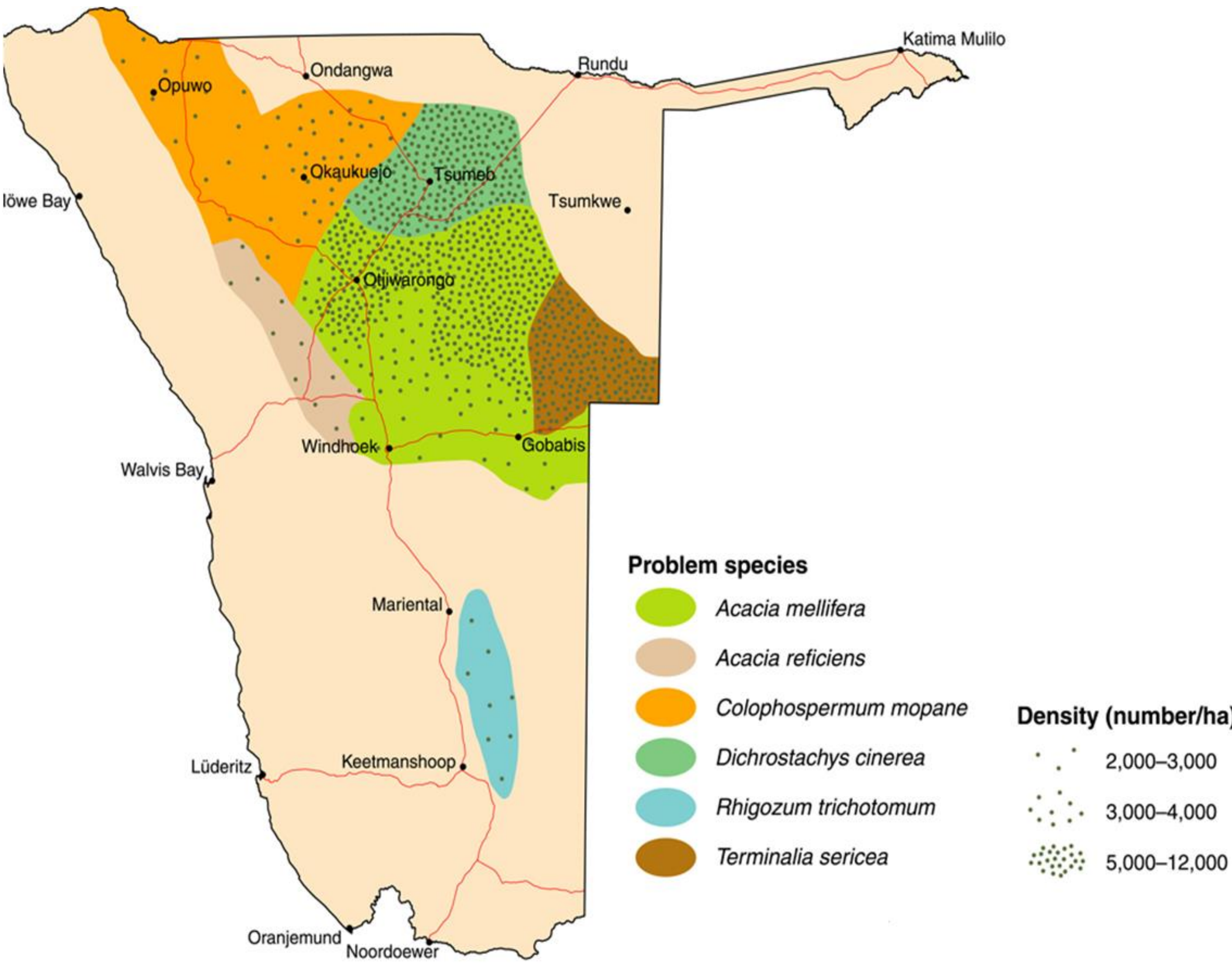


Appendix 7: Vegetation types of Namibia (Mendelsohn et al., 2002)



Appendix 8: Problem woody species and their distribution in Namibia

(Mendelsohn et al., 2002)



Appendix 9: Ground cover estimation form

PLOT SAMPLING DATA FORM

GRASS PERCENTAGE COVER

Complete one form for each plot.

Date _______________

Year of treatment_________________________________

Plot ID____

Species name	Density (# of individuals in plot)	Percent cover (% of plot covered by species)

Appendix 10: Determination of the grazing capacity

Determination of the stocking rate and grazing capacity for site treated in 2015:

The estimation of the grazing capacity and stocking rate of each of the study sites

Assumptions in the determination of the grazing capacity:

1. Dry matter intake of an animal (sheep) is 3 % of body weight of (75 kg) per day.

2. Losses by termites, trampling, grasshoppers and wind was estimated to be 10 %.

3. Only 50 % of the available grass material was grazeable.

Animal live weight = 75 kg

Available grass yield = = 975kg DM ha^{-1}

Camp size = 31 ha

1 Animal requirement

Small stock daily requirement (Kg) = 75 kg x 3% = 2.25 Kg DM/ Day

Small stock yearly requirement (Kg) = 365 day x 2.25kg/day= 821.25 Kg DM/year

2. Calculating grazing capacity (kg live body weight/ha)

= 975 kg DM/ha – (975 Kg DM x 0.1) = 877.5 Kg DM/ha

= 877.5 Kg DM/ha – (877.5 Kg DM x 0.5) = 438.75 Kg DM

= 438.75 Kg DM x 31 ha = 13 601.25 Kg DM

Total number of animals that can be kept

Stocking rate (SSU) = 13 601.25 kg DM / 821.25 Kg DM/year = 17 SSU

Grazing capacity (ha/SSU) = 31 ha / 17 SSU = 1.8 ha/SSU

Determination of the stocking rate and grazing capacity for site treated in 2016:

Animal live weight = 75 kg

Available grass yield = = 925kg DM ha^{-1}

Camp size = 26 ha

1 Animal requirement

Small stock daily requirement (Kg) = 75 kg x 3% = 2.25 Kg DM/ Day

Small stock yearly requirement (Kg) = 365 day x 2.25kg/day= 821.25 Kg DM/year

2. Calculating grazing capacity (kg live body weight/ha)

= 925 kg DM/ha – (925 Kg DM x 0.1) = 832.5 Kg DM/ha

= 832.5 Kg DM/ha – (832.5 Kg DM x 0.5) = 416.25 Kg DM

= 416.25 Kg DM x 26 ha = 10 822.5 Kg DM

Total number of animals that can be kept

Stocking rate (SSU) = 10 822.5 Kg DM / 832.5 Kg DM/year = 13 SSU

Grazing capacity (ha/SSU) = 26 ha / 13 SSU = 2 ha/SSU

Calculating stocking rate and carrying capacity for site treated on 2017

Animal live weight = 75 kg

Available grass yield = 350 Kg DM

Camp size = 31 ha

1. Animal requirement

Small stock daily requirement (kg) = 75 kg x 3% = 2.25 Kg per day

Small stock yearly requirement (kg) = 365 day x 2.25 Kg/day= 821.25 kg DM/year

2. Calculating grazing capacity (kg live body weight/ha)

= 350 Kg DM/ha – (350 Kg/ha x 0.1) = 315 Kg DM/ha

= 315 Kg/ha – (315 Kg/ha DM x 0.5) = 157.5 Kg

= 157 kg x 31 ha = 4 867 Kg DM

Total number of animals that can be kept

Stocking rate (SSU) = 4 867 Kg DM / 821.25 kg DM/year = 6 SSU

Carrying capacity (ha/SSU) = 31 ha/ 6 animals = 5.1 ha/SSU

Calculating stocking rate and carrying capacity for control site

Animal live weight = 75 kg

Available grass yield = 575 Kg DM/ha

Camp size = 26 ha

1. Animal requirement

Small stock daily requirement (kg) = 75 kg x 3% = 2.25 kg per day

Small stock yearly requirement (kg) = 365 day x 2.25kg/day= 821.25 kg DM/year

2. Calculating grazing capacity (kg live body weight/ha)

= 575 Kg DM/ha – (575 Kg/ha x 10%) = 517.5 Kg DM/ha

= 517.5 Kg/ha x 0.5 = 258.75 Kg

= 258.75 Kg x 26 ha = 6 727.5 Kg DM

Stocking rate (SSU) = 6 727.5 Kg DM / 821.25 Kg DM/year = 8 SSU

Carrying capacity (ha/SSU) = 26 ha/ 8 animals = 3.25 ha/SSU

Appendix 11: Grass cover analysis

Oneway

Descriptives

Grass cover (%)

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
DB-camp6-P1-2015	13	52.31	9.268	2.571	46.71	57.91	40	70
DB-camp6-P2-2015	13	34.62	14.356	3.982	25.94	43.29	15	60
DB-camp6-P3-2015	13	31.54	14.632	4.058	22.70	40.38	10	60
DB-camp5-P1-2016	13	53.85	13.868	3.846	45.47	62.23	30	80
DB-camp5-P2-2016	13	61.54	12.142	3.368	54.20	68.88	40	80
DB-camp5-P3-2016	13	49.23	13.821	3.833	40.88	57.58	30	70
DB-camp6-P1-2017	13	11.92	4.804	1.332	9.02	14.83	5	20
DB-camp6-P2-2017	13	22.69	8.807	2.443	17.37	28.01	10	40
DB-camp6-P3-2017	13	10.00	4.564	1.266	7.24	12.76	5	20
DB-Camp5-P1-NT	13	13.08	7.511	2.083	8.54	17.62	5	30
DB-Camp5-P2-NT	13	15.15	8.385	2.326	10.09	20.22	2	30
DB-Camp5-P3-NT	13	11.15	4.634	1.285	8.35	13.95	5	20
Total	156	30.59	21.080	1.688	27.26	33.92	2	80

Test of Homogeneity of Variances

Grass cover (%)

Levene Statistic	df1	df2	Sig.
3.804	11	144	.000

Test of Homogeneity of Variances

Grass cover (%)

Levene Statistic	df1	df2	Sig.
3.804	11	144	.000

ANOVA

Grass cover (%)

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	53201.436	11	4836.494	44.422	.000
Within Groups	15678.308	144	108.877		
Total	68879.744	155			

Post Hoc Tests

Multiple Comparisons

Dependent Variable: Grass cover (%)

Tukey HSD

(I) Distribution of grass cover	(J) Distribution of grass cover	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
DB-camp6-P1-2015	DB-camp6-P2-2015	17.692*	4.093	.002	4.09	31.29
	DB-camp6-P3-2015	20.769*	4.093	.000	7.17	34.37
	DB-camp5-P1-2016	-1.538	4.093	1.000	-15.14	12.06
	DB-camp5-P2-2016	-9.231	4.093	.513	-22.83	4.37
	DB-camp5-P3-2016	3.077	4.093	1.000	-10.52	16.68
	DB-camp6-P1-2017	40.385*	4.093	.000	26.79	53.98
	DB-camp6-P2-2017	29.615*	4.093	.000	16.02	43.21
	DB-camp6-P3-2017	42.308*	4.093	.000	28.71	55.91
	DB-Camp5-P1-NT	39.231*	4.093	.000	25.63	52.83
	DB-Camp5-P2-NT	37.154*	4.093	.000	23.56	50.75
	DB-Camp5-P3-NT	41.154*	4.093	.000	27.56	54.75

Homogeneous Subsets

Grass cover (%)

Tukey HSD[a]

Distribution of grass cover	N	Subset for alpha = 0.05		
		1	2	3
DB-camp6-P3-2017	13	10.00		
DB-Camp5-P3-NT	13	11.15		
DB-camp6-P1-2017	13	11.92		
DB-Camp5-P1-NT	13	13.08		
DB-Camp5-P2-NT	13	15.15		
DB-camp6-P2-2017	13	22.69	22.69	
DB-camp6-P3-2015	13		31.54	
DB-camp6-P2-2015	13		34.62	
DB-camp5-P3-2016	13			49.23
DB-camp6-P1-2015	13			52.31
DB-camp5-P1-2016	13			53.85
DB-camp5-P2-2016	13			61.54
Sig.		.092	.147	.117

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 13.000.

Means for groups to test for homogenous subsets

Appendix 12 Calculation of canopy cover (%)

Canopy diameter of every woody plant species was measured along two axes (length, L, and width, W) perpendicular to each other. Percentage canopy cover was calculated using the formula percentage canopy cover = $(n\pi r^2)/(2.5)$, where n is the number of woody plants and r2 is equivalent to LW/4 (Beyene, 2015).

Canopy cover for site treated on 2015

canopy cover = $(n\pi r^2)/(2.5)$

31 x 3.14 x 0.122/2.5

4.75 %

Canopy cover for site treated on 2016

canopy cover = $(n\pi r^2)/(2.5)$

130 x 3.14 x 0.033/2.5

5.38 %

Canopy cover for site treated on 2017

canopy cover = $(n\pi r^2)/(2.5)$

139 x 3.14 x 0.083/2.5

14.49 %

Canopy cover for control site

canopy cover = $(n\pi r^2)/(2.5)$

31 x 3.14 x 0.082/2.5

15.036 %