COMPARISON OF THE REHABILITATIVE EFFECTS OF MECHANICAL AND CHEMICAL METHODS OF BUSH CONTROL ON DEGRADED HIGHLAND SAVANNA RANGELANDS IN NAMIBIA.

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ABSTRACT

The study was carried out at Spes Bona 207 farm in Hochfeld district, and Neudamm 63 farm in the Khomas Hochland district, Highland savanna in Namibia. The objective of this study was to investigate the rehabilitative effects of mechanical and chemical methods of bush control of an invasive bush species *Acacia mellifera* for achieving long term rehabilitation of a degraded highland savanna rangelands in Namibia. At farm Spes Bona, three belt transects (50 x 5m^2) were laid in chemical treatments and another three belt transects (50 x 5m^2) were laid in mechanical treatments. Moreover, the same method was used in the control experiment. At Neudamm farm, a 200 x 100m^2 plot with 495 *Acacia mellifera* treated stumps were divided into 3 sub-plots for each treatment (mechanical, chemical and control). Each sub-plot was further divided into 3 replicates. In each replicate, stumps were randomly assigned key-tags with sequential numbers from 1-55 per sub-plot, for assessment purpose.

At Spes Bona farm, the grass tuft density of species *Aristida congesta, Cenchrus ciliaris, Chloris vigata, Eragrostis rigidior, Eragrostis viscosa, Melinis repens* and *Melinis villosum* was significantly higher (P<0.05) in chemical and mechanical than in control treatment. Similarly, the total grass density had greater values (P<0.05) high in chemical (36.1 ± 9.6^a), and mechanical (31.7 ± 9.7^a) than in control (25.7 ± 9.0^b) treatment. The soil condition did not show significant difference (P>0.05) between treatments. Total density of woody plants was significantly greater (P<0.05) in the control than chemical and mechanical treatments. At Neudamm farm experiment, mortality of stumps was significantly higher (P<0.001) in chemical than in mechanical and control treatments. On the contrary, coppicing of stumps was significantly lower (P<0.001) in the chemical method than in the control and mechanical treatments. Tuft density of *Schmidtia pappophoroides* showed greater values outside the canopy than underneath the canopy.

Keywords: Bush encroachment, Degradation, Restoration, Highland savanna, Coppicing.

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DEDICATION

I dedicated this thesis to my late father Aluteni Aludhilu Kahumba, who passed away on the 21 April 2010. Daddy, I wish you were still alive, as you taught me the value of education and without your moral and financial support I could not be at this level. I extend this dedication to my entire family and friends for their academic support and inspirational.

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I finally wish to thank my entire family and all those who supported me throughout my study.

DECLARATION

I, Absalom Kahumba, hereby declare that this study is a true reflection of my own research, and that this work has not been submitted for a degree in any other institution of higher education.

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CHAPTER 1

INTRODUCTION

1.1. Orientation of the proposed study

Most parts of 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 degradation is bush encroachment, a term that describes the invasion of whole landscapes by few of several indigenous woody species, which flourish opportunistically under inappropriate management of rangelands (Skarpe, 1991). Bush encroachment results in an imbalance in the ratio of grasses to bush, a decrease in biodiversity and a decrease in carrying capacity, which in turn cause severe economic losses (De Klerk, 2004). Bush encroachment may reduce the grazing capacity of a rangeland by as much as 90% (Adams & Werner, 1990; Bester, 1998).

About 60% of Namibia's land surface and all its savanna rangelands are degraded by inappropriate rangeland management, such as over utilization, prevention of fire and the elimination of mega-browsers (De Klerk, 2004). Such poor management may lead to the weakening of the grass sward, through the overgrazing of the desirable grass species and subsequent replacement by woody plants. One of the effects of bush encroachment is a recurring loss of income to beef ranchers, for example, a recurring loss of foregone income to beef ranchers of about N$700 million per year has been reported in Namibia, as a result of bush encroachment (De Klerk, 2004). This increases rural poverty and decreases food self-sufficiency of the rural population, a large part of which is dependent on extensive livestock husbandry for their livelihood (Moyo *et al*., 1993).

Different methods of bush control have been suggested and applied. In general, bush can be controlled chemically, physically or biologically (Smit *et al.*, 1999; De Klerk, 2004). Chemical treatment of bushes or stumps with arboricides is the most expensive, most rapid and effective but potentially least selective and most disruptive method of control (De Klerk, 2004). Mechanical control by felling and excavation of trees is most selective but take very long time and can be quite expensive if heavy machines rather than manual labour is used (De Klerk, 2004). Thinning of bush thicket has a high visual impact but may not improve the grass-based carrying capacity of the range much in the long term. This method has seed dispersing effect, and has most potential of spreading wealth by the payment of wages and salaries to labourers involved in bush clearing. Biological control can be achieved by fungal-decay (Holz & Bester, 2007) or by controlled burning. Bush control by fire is likely to achieve the highest effect when a fierce fire is applied once to rangeland which is in the process of being encroached by woody saplings below grass-emergent height, because they are most easily killed by a fierce fire (Rothauge & Joubert, 2002). This will interrupt the transition from an open to an encroached rangeland, which only happens occasionally.

Acacia mellifera is the single most invasive woody species over large parts of central and northern Namibia (Bester, 1998). It is a legume that fixes nitrogen, a major plant nutrient in the soil. Removal or killing of the woody individuals in *A. mellifera* encroached areas releases this soil nitrogen and results in a veritable explosion of grass that may last for several years (Smit *et al.,* 1999). However, if the composition of the grass sward is not manipulated, the benefits are soon lost as the thinned savanna will return to a pioneer state that is susceptible to renewed encroachment as soon as a constellation of favourable conditions arises, i.e. a combination of three consecutive years, the successful elimination of fires and mega-browsers and a continuous weakening of the grass sward (Rothauge & Joubert, 2002).

Perennial grasses such as *Schmidtia pappophoroides, Anthephora pubescens, Digitaria eriantha/seriata, Brachiaria nigropedata* and *Panicum spp* are grazed preferentially by large herbivores and have become locally extinct in many bush-encroached savannas (Rothauge & Joubert, 2002). If the savanna is not re-seeded with these grasses after bush thinning, grass recovery may be slow and the superfluous soil nitrogen is used up by pioneer and sub-climax grass species and dicotyledonous weeds. The soil under a tree canopy is an island of fertility compared to "open" soil not covered by tree canopies (Rothauge *et al.,* 2003) and the canopy thus presents an ideal environment in which desirable grasses may be re-sown and protected initially from grazing by the felled thorny canopy, if bush is controlled manually by felling.

1.2. Statement of the problem

Between 12 and 20 million ha of the livestock grazing lands in Namibia are seriously encroached, significantly decreasing the country's ability to raise ruminant livestock (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 and north east (Adams & Werner, 1990). A large part of Khomas Hochland in Highland savanna in Namibia is encroached by a single most invasive woody species, *Acacia mellifera* (Wiegand *et al*., 2005). Due to the extent of bush encroached rangelands and the associated ecological and socio-economic losses, bush control has become a necessity to maintain the ecosystem integrity. Therefore, the ecological impacts of mechanical and chemical bush control methods on the rangeland vegetation and soil were determined. The result of this study was to inform future decisions in the management of savanna rangelands in Namibia.

1.3. Objectives of the study

1.4. General objective

The general objective of this study was to investigate the rehabilitative effects of mechanical and chemical methods of bush control of an invasive bush species *Acacia mellifera* for achieving long term rehabilitation of a degraded highland savanna rangelands in Namibia.

1.5. Specific objectives

1. To compare the ecological and structural effects of mechanical and chemical control of bush in terms of grass layer and soil condition under commercial farming condition.

2. To evaluate and compare the effectiveness of mechanical and chemical stump treatments on stump mortality after felling of encroaching plants.

3. To investigate the effectiveness of re-seeding desirable grass species under felled canopies (inside) and around the overturned canopies (outside).

1.6. Hypotheses of the study

1. There is a significant difference in the ecological effects between the chemical and mechanical methods in rangeland restoration.

2. Bush control treatments have more effects on the rangeland vegetation than the control treatment.

3. The chemical stump treatment is more effective in terms of stump mortality than mechanical stump treatment.

4. Reseeding under felled canopies results in more grass tufts production compared to reseeding outside the canopies.

1.7. Significance of the study

The main purpose of bush control is to improve the productivity of the rangelands and hence the livelihood. It was envisaged that this study would deliver scientific assessment of chemical and mechanical methods of bush control and thus used as a basis for making decisions in rangeland management/bush control programmes. It was also envisaged that the effectiveness of mechanical and chemical methods of stump treatments and re-seeding desirable grass species under felled canopies and in the open space were evaluated and this would provide vital information for those involved in rangeland restoration.

1.8. Limitation of the study

Lack of private transport to go to the research study sites had slowed down the process of collecting data. However, this was delimited by organising for a transport with the farm manager of the University of Namibia, Neudamm Campus on time and prior to the start of data collection.

CHAPTER 2

LITERATURE REVIEW

2.1. Bush encroachment in savanna rangelands

Bush encroachment was defined by De Klerk (1999), as the invasion and thickening of aggressive undesired woody species resulting in an imbalance of the grass to bush ratio, a decrease in carrying capacity.

The problem of bush encroachment threatens many developing countries worldwide, due to the damage on their environments caused by unsustainable agricultural practices. According to Wiegand *et al*. (2005) more than 25% of the African continent is threatened by bush encroachment. The grazing capacity of large areas of the southern African savanna is reported to have declined as a result of being encroached by bush, often to such an extent that many previously economically viable livestock properties have became unviable (Teague & Smit, 1992).

2.2. Causes of bush encroachment

Some factors that lead to bush encroachment, because of the disruption of the natural balance include a low frequency of veld fires, overgrazing of the herbaceous component, selective grazing and certain types of drought.

2.2.1. Overgrazing

Overgrazing refers to the animals grazing on plant material faster than it can naturally regrow leading to the permanent loss of plant cover, a common effect of too many animals grazing limited rangeland (Knight, 2005). Overgrazing extracts an unsustainable yield of floral biomass from an ecosystem. Knight (2005) pointed out that manifestations of overgrazing in landscapes composed largely of native species include reduction of species richness, loss of biodiversity, desertification, loss of native topsoil and increases in surface runoff. In fact, overgrazing can be considered the major cause of desertification in arid drylands, tropical grasslands and savannas, worldwide. Overgrazing of historic human-created pastureland, especially irrigated or non-native grasslands, may lead to soil compaction, reduction in long-term grazing productivity and loss of topsoil (Knight, 2005).

According to Harold & Child (1994) various literatures have indicated that most palatable plant species are normally selected first, continually grazed and closely defoliated. Hence, this practice reduces plant vigour, lessen seed production and eventually cause plant death. Usually, the space vacated by desirable species becomes the expanded home for less palatable nutritious species and invasive woody plants (Harold & Child, 1994). If overgrazing continues, these species give way to annual invaders, many of which are weeds introduced from other continents.

Price (1999) emphasized that the most common practices that produce overgrazing are: (a) excessive animal density on the land; (b) lack of rotation or residence time of grazers on a sub-plot of the landscape unit; (c) grazing at inappropriate times relative to the flora productivity cycle. In the case of essentially native landscapes, there is an additional cause of inappropriate species introduced into the landscape. A common syndrome in less developed countries is the intensive use of marginal rangelands when historically productive adjacent rangeland has become overgrazed and unproductive (Price, 1999).

In many parts of Africa subsistence farmers practice high density animal occupancy that produces sub-optimal yields per animal, with high, even if unsustainable, yields per hectare (Rothauge *et al.*, 2003). Some scientists have argued that there is remarkably little reliable data available to fully understand the syndromes of overgrazing and that some of the most complex issues are in Africa, where data is most scant (Price, 1999).

To complicate the understanding of overgrazing are the complexities of seasonal variation of plant productivity, especially in landscapes with high variations in seasonal precipitation. In the case of semi arid savanna, overgrazing can be seen by wild ungulates, where top-level predator populations have lost their robustness; in particular, wolf, bear and puma populations have generally declined to the point of being ineffective regulators of ungulates over large areas, including some major national parks (Price, 1999).

The ecological impacts of overgrazing are loss of biodiversity, irreversible loss of topsoil, increase of turbidity in surface waters and increased flooding frequency/intensity (Knight, 2005, Price, 1999). It has also been suggested that overgrazing is a significant driver of climate change by reduction of the global photosynthetic carbon dioxide sink; by increasing the production of the potent greenhouse gas, methane; by altering retention of surface waters; and by increasing the albedo of the earth's surface by altering the reflective electromagnetic spectrum (Knight, 2005).

2.2.2. Suppression of fire

The suppression of fire on a rangeland normally encourages bush encroachment, as the *A. mellifera* saplings and seedlings turn to establish well without fire control. Moreover, the ecology of *A. mellifera* has been elucidated recently by Rothauge & Joubert (2002), who have postulated that encroachment by this species is not an ongoing process, but rather follows a sleep and leap mode, with many years of a comparatively stable condition and a sudden change in the equilibrium. This sudden change is accordingly brought about by a combination of three consecutive years of above-average rainfall, successful elimination of fires and mega-browse and a continuous weakening of the grass sward (Rothauge & Joubert, 2002). Such opportunities for bush encroachment did not arise regularly during the last century, with only six times of such opportunities occurring during the last 100 years, where most of it witnessed in the last 50 years in the central highland savanna of Namibia due to favourable conditions for *A. mellifera* to encroach landscapes.

According to Hodgkinson (1985), fire can be a double-edged sword for the survival of biodiversity. Without fire some species would be lost while others can be destroyed by fire (Hodgkinson, 1985). Without an appropriate fire regime, fire becomes a threatening process for both individual species and ecosystems. An appropriate fire regime can be either too frequent or too infrequent. A patchy landscape with a range of seral stages found in the mosaic of communities and habitats is the only way of providing for all the species that have evolved within this landscape (Golubiewski & Hall-Beyer, 2007). The relative roles of fire and grazing in the environment have been inverted leading to the increase in shrub populations (Trollope, 1986). However, in a systematic analysis of the impact of fire suppression concluded that the hypothesis that changes to the natural fire regime and the influence of fire in the thickening of woodlands is premature and possibly incorrect.

Trollope (1986) stated that the impact of grazing in reducing fires, through the reduction of fuel by grazing and trampling has been acknowledged by rangeland managers. It is suggested that the fire frequency was 10-20 years, but they are now very uncommon with the lack of fuel as a result of grazing pressure being the most common constraint in addition to active fire suppression (Golubiewski & Hall-Beyer, 2007). In South Africa, it is mostly assumed that there has been a change in fire regime and that this has had a direct impact on the vegetation of the rangelands (Trollope, 1986). The introduction of suppressed or controlled fire as a management tool can play an important role in controlling bush encroachment in rangelands.

2.3. Consequences of bush encroachment

2.3.1. Positive effect of woody plants

According to Walters & Reich (1996), the beneficial effects of woody plants in environments can be great and have in the past sometimes been overlooked by protected areas managers, scientists and conservationists. The role of the woody plants in the local economy and the public perception of its value have to be considered. Possible beneficial effects of invasive woody plants on the rangeland include the following points (Walters & Reich, 1996).

1. Timber; invasive woody plants can produce good quality timber.
2. Wood for use as firewood or charcoal; invasive woody plants can often be a highly productive source, often with higher coppicing ability.
3. Wood plants generate income and it is a source of domestic building materials.
4. As a source of nectar and pollen for bees and insects.
5. Aesthetic values; the public may prefer the pretty flowers or tallness of the woody plant to the more subtle appearance of a native tree, and do not share to such a degree concerns about the ancestry of the plant or how "natural" is its presence.
6. Traditional medicine often uses invasive woody species although it is unclear whether these 'new drugs' have any practical purpose.
7. Biodiversity value; associated with leaf litter, is probably responsible for the survival of an endemic species.

According to Weltzin & Coughenour (1990), woody plant canopies alter the micro-environment, physical and fertility conditions of soil. Trees modify micro-environment in terms of reduced soil and air temperatures, wind speed and irradiation, resulting into reduced soil water evaporation and increased relative humidity (Weltzin & Coughenour, 1990). While woody and herbaceous plants usually compete directly for water, deep-rooted woody plants can benefit the understorey vegetation by transporting water from deeper soil layers to drier surface soils through hydraulic lift, particularly during dry periods (Weltzin & Coughenour, 1990).

Woody plants also acquire nutrients from deeper soil layers and redistribute them at the surface through litter fall which enhances soil carbon and nutrients, benefiting the understorey plants (Weltzin & Coughenour, 1990; Tilman, 1982). Interception of solar radiation is a predominant factor influencing the understorey. In tropical savanna and forest, light reaches perpendicular to the ground, and decreases in a gradient from gap centre to edge to below-canopy locations (Tilman, (1982). Woody plants can either diminish or enlarge grass production by modifying the resource availability to ground flora (Tilman, 1982). Species differ in their response to shading. For example (Walters & Reich, 1996) found that shading reduced the mean dry weights of warm season grasses, but up to 50% shading did not reduce mean dry weights of cool season grasses. Woody plant canopies provide a more stable microhabitat for the understorey, probably because of the protection against direct irradiance and overheating direct solar radiation supplies energy which increases evaporative demand and potential for moisture stress (Walters & Reich, 1996). The increase in radiation is often associated with a reduction in water availability, resulting into reduced species richness.

Wright (1992) found a positive relationship between soil fertility and woody plant richness, the latter tended to increase with radiation; however, this pattern is not universal probably due to interaction with other factors. Studies on the effect of woody canopies on herbaceous diversity in tropical savanna have yielded equivocal results (Wright, 1992). Canopy patches beneath woody plants and the inter-canopy patches experience heterogenous patterns of energy, water, and biogeochemistry, and the level of this heterogeneity should depend on the architecture of woody plant canopies (Wright, 1992).

2.3.2. Negative effects of woody plants

According to De Klerk (1999), some of the highlighted negative effects of woody plants are that woody plants result in an imbalance in the ratio of grasses to bush, a decrease in biodiversity, a decrease in stocking rate and a decrease in carrying capacity, which in turn result in losses of income into rangeland restoration.

Bester (1998) pointed out that some native woody species such as *A. mellifera* and *D. cinerea* have proliferated, and perennial grasses have been reduced throughout semi arid savanna rangeland to the extent that remnant patches of historic open savanna habitat exist only where livestock grazing has been limited. Lubbe (2001) also reported that the carrying capacity of the highly productive and fertile area with an average rainfall of 450 mm p.a. has been reduced by woody plants to that of the dry, low-producing dwarf shrub savanna with 200 mm rainfall p.a.

2.4. Bush encroachment in Namibia

In Namibia, between 12 and 20 million ha of the livestock grazing lands are seriously encroached, significantly decreasing the country's ability to raise ruminant livestock (Stehn, 2008). Bush encroachment has decreased the farms' carrying capacity by 90% (Adams & Werner, 1990, Bester & Reed, 1997). Reclaiming such land will be very expensive as it will not be possible by natural means, and it may take a long time. Unfortunately, the worst affected areas are the most productive livestock grazing areas of Namibia, such as the central highland savanna and savannas of the north and north east (De Klerk, 2004).

Bush encroachment of the savanna rangelands in Namibia is characterised by the following:

(i) In Namibia, the increase in woody component is mainly due to an increase in a limited number of encroaching or primary invasive species, such as blackthorn, sickle bush, terminalia etc. These invasive bush species dominate the savanna rangelands and lead to a decrease in the species diversity of the woody components. Bush density can increase from a normal density of less than 1000 bushes/ha to densities as high as 10000 bushes/ha or more (De Klerk, 2004). Hence, at such high density, the encroaching species kills off not only the herbaceous component of the savanna rangeland, but also many other bushes and trees species, so that a densely encroached area resembles a monoculture of the invader bush species (Stehn, 2008). In a bush thicket, undergrowth cannot survive under the closed bush canopy, because the bush is ruthless competitor for water and to a lesser degree, sunlight.

(ii) This increase happens gradually over a number of years and quite often, bush encroachment is so gradual that the farmer does not notice it, as it follows episodes of veld mismanagement (Rothauge & Joubert, 2002; De Klerk, 2004).

(iii) Lubbe (2001) pointed out that bush encroached Namibia still exhibits a wide variety of woody plant species, but their frequency is much reduced compared to the original species mosaic, due to the overbearing dominance of the primary invasive species.

(iv) A woody component plant is better able to compete for water than a grass plant, because most bush and shrub species have tap-root that reaches deep down into the ground water table not accessible to grasses and shallow root system that absorbs moisture from the top layers of the soil (Teague & Smit, 1992).

(v) A change in the species composition of the herbaceous component due to secondary factors such as the removal of mega-browsers like elephant and black rhino or prevention of veld fires is a rare phenomenon, but does not seem to inevitably include regression of the grass component from climax to pioneer species (Bester & Reed, 1997). However, most instances of bush encroachment or due to veld mismanagement, which is typically associated with a degradation of the soil and regression of the herbaceous layer. Therefore, most instances of bush encroachment in Namibia are characterised by typical pioneer grass species, annual herbs and an increase in poisonous plants (Stehn, 2008).

(vi) One of the effects of bush encroachment in Namibia is a reduction in the carrying capacity of farmland. This effect is the result of the combination of a number of factors, such as the increase in bush, which offers virtually no feed to typical grazing livestock like cattle and sheep, the decrease in grasses on which most livestock species rely predominantly, and a less desirable grass species mosaic (composition). The extent of the decrease in grazing capacity can be dramatic, as in some observed cases, a doubling in the population density of *Acacia mellifera* from 1000 to 10,000 bushes/ha reduces the grass yield 1200 to 300 kg/ha (Bester, 1998). At what density bush encroachment is a subjective issue, but the fact is that the decrease in grass yield is much more dramatic than the increase in bush density. According to Bester & Reed (1997) some experts have estimated that a bush density of 5000 bushes/ha decreases the rangelands' carrying capacity to 10-20% of the original.

(vii) Another effect of bush encroachment is a reduction of biodiversity of natural rangelands. This effect is caused by the increasing dominance of one or two species, resulting in virtual monoculture. A monoculture always offers less habitats and food to a smaller variety of living organisms than a diverse culture. Over the long term, the effect of a monoculture is a much-decreased biomass production and a depletion of the natural resources, making it to the original state virtually impossible (De Klerk, 2004).

If the soil degradation that often accompanies bush encroachment is not too serious, savanna range has a remarkable ability to recover from the bush encroachment after chemical or mechanical treatment coupled with re-seeding of desirable grasses. Such treatment kills or removes the primary invasive species from the area, creating a moisture surplus in following rainy season, which is utilised by the grasses to re-populate the treated area (Smit *et al*., 1999). With good post-treatment aftercare, it is possible to recover the original carrying capacity within three years, the most rapid progress being made in the first year. If, however, the factors that caused bush encroachment in the first place also caused soil erosion and degradation, it will take considerably longer to recover such veld and treatment other than bush control alone might also be required (Van der Westhuizen *et al.*, 1999).

The savannas surrounding the central thornbush savanna in the north, east and south, that is, the mopane savanna, the mountain savanna of the Karstveld, the central Kalahari's camel-thorn savanna, the Hochland savanna and the transition savanna of the northern escarpment zone are seriously affected by this problem (Bester & Reed, 1997). Bush densities vary from 7000-9000 bushes/ha in the north, east and escarpment zone and from 3000-7000 bushes/ha in the south of this area. Initially, the invasion started as localised patches, but has expanded into all-encompassing threat due to the most recent drought, which started in the 1980's. The potential carrying capacity has been reduced from 10ha/LSU to worse than 30ha/LSU.

According to Bester & Reed (1997) the highest bush density occurs in the central thornbush savanna, where populations of more than 10000 bushes/ha are common. This part of savanna should have a carrying capacity of 8 ha/LSU, but this has been reduced on average to 20 ha/LSU and worse in many cases. Lubbe (2001) reported that the carrying capacity of this highly productive and fertile area with an average rainfall of 450 mm p.a. has been reduced to that of the dry, low-producing dwarf shrub savanna with 200 mm rainfall p.a. The primary invasive species in this area is the blackthorn (*Acacia mellifera*).

In those savannas, the primary invasive species varies from the mopane (*Colophospermum mopane*) in the mopane savanna, to sickle bush (*Dichrostachys cineria*) in the northern

Kalahari and mountain savanna, sandveld or yellow terminalia (*Terminalia sericea*) in the central Kalahari and blackthorn (*Acacia mellifera*) in the Hochland savanna. In the northern escarpment zone's transition savanna, several Acacia species act as primary invaders, such as the blue thorn (*Acacia erubescens*), the false umbrella thorn (*Acacia reficiens*) (Vals haak-en-steek or rooihaak) and the blade thorn (*Acacia fleckii*) (Lubbe, 2001; Curtis & Mannheimer, 2005). These encroached areas, together with the central thornbush savanna, represent 52% of commercial farming area and a small part of the communal farming area. The loss in potential stock numbers is enormous and one the country cannot afford.

Lubbe (2001) further pointed out that southern Kalahari and the dwarf shrub savanna are being invaded by *Acacia mellifera*, but currently the density is still relatively low, that is <3000 bushes/ha. Even at this low density though, carrying capacity has been reduced by 50%. Further south, the dwarf shrub savanna is also encroached by the dwarfs *Rhigozum trichotomum* (driedoring) and *Cataphracters alexandri* (ghabba). The eastern part of the central Kalahari is being invaded in patches by the protected camel thorn tree *Acacia erioloba* due to range mismanagement, but the density is less than 5000 bushes/ha. In the far north-eastern parts of the northern Kalahari, sickle bush is starting to encroach, fortunately its density is still less than 5000 bushes/ha. These infestations are still manageable. They threaten about 20% of the tribal and communal farmlands.

The most prominent invasive species are the blackthorn (*Acacia mellifera*) virtually everywhere and the sickle bush (*Dichrostachys cineria*) in the north-eastern parts of Namibia (Bester, 1998). Locally, other acacias and sometimes even thornless trees might be a problem too, depending mainly on climatic factors and soil type. The area and the degree of bush encroachment are accurately correlated with annual rainfall and human activity. In severely encroached area, bush densities of more than 30000 bushes/ha have been measured. Such a thicket is completely impenetrable and reduces former farmland to absolute waste land. The size or height of the bush depends on the age of the stand and the soil type (Stehn, 2008). On shallow soils, half of the bush is less than 1m high and one-quarter is taller than 2m (Lubbe, 2001).

2.5. Methods of bush control

Several tools exist to control bush encroachment in savanna rangelands, but it should be realised that under all circumstances, prevention is better than cure. In order to prevent bush encroachment, scientific and conservative range management are required by every farmer. Once bush encroachment has occurred, methods to treat it are varied, but most are expensive and all depend to a large extent on post-treatment aftercare for complete success (Trollope, 1978; Scifres, 1977).

Methods of controlling bush encroachment are mechanical, biological or chemical control method.

2.5.1. Mechanical control

Mechanical methods such as the bulldozers are destructive and also expensive. Making use of a bulldozer where *A. mellifera* occurs aggravates, rather than solves the problem (Stoddart *et al*., 1995). The aggravating nature of a bulldozer is that it disturbs the topsoil so much (De Klerk, 2004). Felling with the aid of chain saws, machetes and axes is labour intensive, however, not destructive and is also a selective means of thinning bush.

The mechanical control of bush-encroached is very specific, labour-intensive, time consuming and unlikely to have a lasting effect on bush density unless followed by effective aftercare. Mechanical control by slashing or cutting off bush at ground level will temporarily open the canopy without reducing bush density (trees/ha). Unless the remaining tree stumps are treated chemically or killed by a localised fire, they will send out new stems from apical growth points. According to Lubbe (2001) most acacias have the ability to coppice and, if allowed to re-grow, many bush species will form an even denser thicket after slashing than before. Fire-girdling at ground level during the rainy season has a similar effect as slashing, but reduces the stump's coppicing ability.

If mechanical control involves removal of the roots of trees and bushes, the bush density will be reduced permanently. If this is done with a bulldozer, it will be reduced permanently, but it will result in vast ecological damage to the veld, most likely to cause regression and a drop in carrying capacity. To lessen soil disturbance, it is recommended that this operation be carried out with a wheeled and not a tracked vehicle (Tainton, 1999).

In both cases, mechanical control has to be followed up with some kind of after treatment to limit the coppicing ability of the bush (e.g. heavy browsing, "cold fires") and the re-establishment of woody seedling (e.g. light browsing, "cold" fires) within the first two years after de-bushing, coppice growth will be within the reach of goats and browsing game, thereby altering the land use potential of a farm significantly. Mechanical bush clearing has as fringe benefit the possibility of producing charcoal, a product in great demand in urban centres and for export. According to Cunningham (1998) studies have indicated that encroacher species such as *A. mellifera* has been shown to be an appropriate for charcoal production in Namibia. The income earned from the sale of charcoal is more than sufficient to cover the cost of bush control.

2.5.2. Chemical control

Chemical control involves the killing of woody plants by applying a general purpose herbicide (arboricides) or a very specific poison in a localised (spot treatment) or a broadcast manner (Lubbe, 2001). Bush control is unselective if a general purpose herbicide is applied broadly, but can also be very selective if a specific herbicide is applied in spots. Generally speaking, chemical control is more effective, more expensive and less time-consuming than mechanical control (Lubbe, 2001).

Scifres (1977) indicated that herbicides have been integral parts of range improvement and rehabilitation systems for over 25 years. However, until the late 1950's, most herbicide use was as individual-plant treatments and available herbicides were not highly selective. Scifres (1977) emphasised that, it would have been interesting to have observed the reactions of first ranchers who were told, after fighting bush by hand and with heavy equipment for most of their lives, that new chemicals had been developed which, when sprayed in small quantities on the bush, would kill the trees with little or no damage to the grasses.

Bush control on rangeland is basically a management problem that must be approached on an ecological basis within an economic framework. Norris (1971) indicated that effective herbicides are essential tools for the modern rangeland resource managers. Herbicide use for range improvement serves as an ideal example of the increasing complexity of effectively approaching the bush problem in southern Africa, when proper management, ecological requirements and economic criteria are considered (Trollope, 1974).

In the early days, the ultimate fate of herbicides after application to rangeland was a relatively small consideration, especially if the chemicals were known to be non-toxic to grazing animals (Scifres, 1971). Also most herbicides use was concentrated on large areas much of which was privately owned. However, range researchers have made an exceptional contribution to the knowledge base relative to performance of herbicides and their use in range management.

Many different formulations against a wide variety of woody plants or only against a restricted number of species are available in Namibia (Bester, 1985). New plant poisons and applications are developed annually, because of the enormous scale of the bush-encroachment problem in the whole of southern Africa. Most are applied in a dry form and are placed selectively (e.g. by teaspoon-measure) or broadcast by light aeroplane (Bester, 1985; Lubbe, 2001). The latter application is very drastic and should only be used for large areas severely infested by a single species of bush.

Most herbicides do not act via the foliage of the tree, but are absorbed through the roots and seriously interfere with the photosynthesising ability of the plant or its intermediary metabolism. They have to be applied during the active growing season and are slow-acting, with the effect taking several weeks to become apparent (Smit *et al*., 1999). If applied manually or locally, some type of marking is required to prevent double applications and skipping.

Despite the high price of these herbicide poisons, chemical control is very cost-effective. In many of the severely encroached areas are of Namibia, it is probably the only practical method left to eradicate the bush. Lubbe (2001) emphasised that the high cost of treatment should be compared to the potential loss of income from degraded rangelands, alternative to the potential income to be earned from treated areas. Unlike with fire or mechanical control, no immediate post-treatment aftercare is required, although obviously if those grazing practices that caused bush encroachment in the first place are not changed, it will only lead to renewed encroachment in the foreseeable future.

2.5.3. Biological control

Biological control of bush encroachment includes browsing and the spread of stressors amongst the woody component. As mentioned before, browsing alone will not reverse an existing bush infestation, except by mega-browsers. However, browsers play a crucial role along with fire in controlling already established woodland and to maintain recently established woody plants (e.g. young infestation) at a height were the occasional use of fire will promote open grassland. The use of browsers at the regeneration phase offers an extremely cost-effective means of pre-empting bush encroachment, but the grazing system and species mix needs to be adapted accordingly.

A trial performed at Neudamm (Namibia) towards the end of the 1998/9 rainy season showed that goats preferred woody plants, which constituted 51.2% of the total food in the diet (Rothauge *et al*., 2001). Grasses dominated the natural vegetation (51.9%), but formed only 29.4% of the goats' diet. Herbs and forbs made out 23.6% of the veld and contribute to 18.7% of the goats' diet. Only 13 of the 16 woody species present in the feeding area were utilised, compared with over 40 herbaceous species taken. Most preferred forage species were the woody plants *Phaeoptilum spinosum* (13.0% of diet), *Acacia mellifera* (10.7%) and *Catophractes alexandri* (8.0%). This trial indicated that Namibia's Highland Savanna is extremely suitable for goat farming. It also offers conclusive evidence that Boer goat prefer to utilise woody plants, i.e. browse, even during seasons when actively growing, nutritious green grass is available in abundance (Rothauge *et al*., 2001).

Biological methods such as veld-fires and incorporating the Boer goat or game into a management system can be used as an after-care method where bush has been thinned out, rather than an initial method to control bush (Trollope, 1974, Zimmermann *et al*., 2003). When incorporating browsers to control bush, animal numbers must always coincide with the forage availability. Stem burn with dung pats or twigs is inexpensive, very effective and also a selective method of thinning out bush. Herbicides are effective, however the pros and cons should be considered before using them.

Farmers also need to consider the degree of bush control required: The woody component of the savanna provides valuable feed to grazers and especially browsers (Lubbe, 2001). Does he want to completely eradicate all bushes? If so, environment will be left deplete, as there will not be sufficient feed left for browsing animals. Alternatively, does the farmer merely want to thin the bush selectively (either by species or by area), open the canopy, and manipulate the bush to grass balance for the intended land–use but retain the multi-faceted ecology typical of the African savanna? A savanna is at its most productive (in terms of species diversity and biomass produced per ha) if the woody component is retained. Whatever the approach, it should be within the framework of ecological responsibility and economic viability.

Utilisation of bush infestation by browsers, be it domesticated (e.g. goat) or wild (e.g. kudu and other browsing game species), will not reverse an existing bush infestation. The most that can be achieved is to prevent further densification and to utilise the existing feed source. However, browsing is the single most important post-treatment tool to prevent re-infestation, because the browsers top coppice growth and inhibit seedling establishment (Trollope, 1974). Hence, for browsing to prevent re-colonisation by woody seedling establishment, it must be an ongoing process as browsing also aids re-colonisation by the dispersal of seeds.

Any population of living organisms that becomes denser is increasingly susceptible to stress, mostly diseases, so it is with bush as well and a typical infectious biotic disease has recently been identified in *Acacia mellifera* thickets. Dieback is caused directly by stress or more often by several fungi, the potent of which belongs to the *Phoma* genus (De Klerk, 2004). Thousands of hectares of dead blackthorn occur in central Namibia and the disease is spreading north and eastward. If this fungus is released artificially during favourable climatic conditions and after the bush has been stressed by drought, it can devastate the bush population and leave open grassland. The fungus does not seem to affect the seed though and recolonisation is possible.

This *Phoma* fungus is very host–specific (Holz *et al.*, 2007), attacking only blackthorn plants of all ages and sizes but leaving other indigenous vegetable unaffected. No recovery of diseased bush in dead patches has been observed. It has probably always been present in Namibia, but only causes the spectacular dieback when the population density of blackthorn increases to beyond 5000 bushes/ha.

2.6. Fire

Setting fire to veld and range is an unselective tool, affecting all woody plants equally but affecting younger plants more badly than old plants. A certain percentage of woody plants invariably survives a veld-fire. Fire kills bushes by the intense heat and at temperature higher than 95^0 C at ground level and also kills the crown of perennial grass tufts. Annual plants are killed completely by fire (Trollope, 1989) and veldfires can be manipulated to burn “hot” or cold, the latter type only killing off the above-ground parts of plants while a hot fire burns into the ground.

Control of bush encroachment by fire has a variable success rate. The denser the bush infestation, the less grass and other fuel will be available under the bush. Moreover, with a fuel load of less than 2t DM/ha, (Lubbe, 2001) the resulting fire will be too cold to kill the trees and bushes. The top growth will be signed off (top-kill), but the woody plant will survive and coppice from the base of the stem (De Klerk, 2004). More restricted or open infestation will allow a fuel load; of more than 2t DM/ha to build up amongst the woody plants, which will result in a hot fire enough to kill all top growth and the axillary buds and apical meristem at the base of the main shoot near ground level.

2.6.1. Requirements of effective fire control

The available fuel load (grass production) is the single most important factor in determining the success of fire as a bush encroachment management tool (Trollope, 1978; Bester & Reed, 1997). At infestations denser than 5000 bushes/ha, the available fuel load is so small (<2 t DM/ha) that a fire will probably not be effective against the bush, due to insufficient grass production.

As for fire control to yield successful results, selecting the appropriate time to burn represent an important consideration. A successful fire should burn the woody plants into the ground, but not do the same to the grasses. This simply means that fire should preferably be set after the first light rains of spring when the base of the grass is already green, moist and less likely to be damaged by heat. Conversely, when burning to control encroaching plants, fire should be applied before the first spring rains while the grass is very dry and dormant to ensure a high intensity fire (Trollope, 1978). Moreover, grass should be dryer than 40% moisture content and the air should also be dry and warm, otherwise the fire will not be hot enough. Fire should be set to burn with the wind (head fires), because they are more intense than back fires. Head fires will kill top growth very effectively, but will not exceed the critical temperature at ground level (95°C) that would kill the grass tuft's crown (Trollope, 1978). Slightly windy, hot and dry in early spring are the best time to burn.

Fire stimulates biomass production and woody seedling establishment, and therefore post burning aftercare of veld is critical. To encourage regeneration of the grass component, grass should be allowed to advance at least to the reproductive stage before being utilised by grazing; otherwise its competitive ability will be compromised, encouraging recolonisation of woody seedlings. A whole growing season's rest is preferable after a fire. In addition, the burnt veld should be utilised by browsers to control the few coppicing bushes that inevitably survive the fire, as well as the many woody seedlings trying to establish themselves after the fire.

A single fire is unlikely to control bush encroachment and therefore, periodical burning may be required. In savanna areas receiving more than 500 mm of rainfall annually, fire can be included in the veld management program every three to four years, or even less frequently if the situation is well under control (Bester & Reed, 1997). In more arid areas, fire should only be employed after good rainy seasons that resulted in more than 500 mm and a good build up of fuel (grass), i.e. on an opportunistic basis. In all situations, the farmer has to plan for the reduced carrying capacity of his property due to enforced fire–rest.

Fire is also an important management tool as an aftercare of de-bushed area. This is because periodic burning of de-bushed areas will suppress the establishment of bush seedling, because they are very sensitive to fire, and keep mature bushes low and within the reach of browsers (Lubbe, 2001). Under these circumstances, a fuel load of 1.5 t DM/ha will be sufficient. Again, it must be remembered that grassveld needs a lengthy recovery period after every fire.

2.7. A practical approach to the management of woody plants

Tainton (1999) indicated that before any woody plant control programme is embarked on, two alternative approaches to the problem of increasing tree density in savanna areas need to be assessed. One approach is to adapt the livestock system to the existing vegetation. Where tree densities are high and woody plants are palatable, browsers should form an important component of livestock system.

The second approach is to modify the vegetation to suit a specific livestock system and particularly a system based on grazing animals, especially where the vegetation has been greatly modified by past management practice. Since the establishment of woody plants is normally a continuing process in savanna areas, control cannot be achieved with a single thinning operation. Hence, planning and implementation need to be ongoing. Where this option is adopted in areas with a high tree density, the first operation has to be often the drastic one of thinning down to some predetermined density, after which a post-thinning management programme will be needed to keep the area open.

Stehn (2008) stipulates that bush, however important it may be is that it is the main competitor for the soil moisture needed by grass. A balance between bush and grass is regarded as the best solution. Stehn (2008) further noted that it has been calculated that the total number of bush units (one bush of 1.5 m height = one bush unit) should not exceed more than double the amount of the long term rainfall (in mm) per year. (A bush of 4.5 m height is reckoned as three bush units for the calculation). Hence, one has to take various aspects into consideration when eradicating bush. These aspects include that bush eradication should aim to take out only the amount of the bush that is in excess and should also be aimed at those species that are of little value and pose threat to the rangeland.

2.8. Background information of *Acacia mellifera*

Acacia is a genus name from a Greek word Acantha, which means thorn. While the word *mellifera* is a species name, which means “honey bearing” and it refers to its sweet-smelling blossoms of flowers (Milton, 1986). The common names of *Acacia mellifera* include Blackthorn and Swaarthaak (Afrikaans). This tree is an important food resource of both goats and wild animals particularly in dry areas of Africa, as the leaves and young branches contain a high percentage of protein, and thus very nutritious. The flowers are often eaten by kudu and the browsers of *A. mellifera* are goats, black rhino, giraffe and the eland (FAO & UNEP, 1983).

Acacia mellifera is a commonly occurring bush on rangelands throughout the savanna in western, eastern and southern Africa (FAO & UNEP, 1983; ICRAF, 1992). The terrain preference of *A. mellifera* is normally rocky hill parts with rainfall along seasonal watercourses and mixed with other trees. If *A. mellifera* is left unattended, especially if grazing is heavy and no fire controls take place, it spreads and form dense, impenetrable thickets of 2-3 m high or sometimes hundreds of metres across, slowly taking over a good grazing land. This species is drought-tolerant (ICRAF, 1992).

CHAPTER 3

METHODOLOGY

3.1. Description of the study Area

The study was carried out in the Highland savanna (semi-arid savanna) in Namibia (Figure 3.1). The two focal areas, Spes Bona 207 farm in Hochfeld district, Otjozondjupa Region, and the Neudamm 63 farm in the Khomas Hochland district, Khomas Region were used. These farms offer pre-existing ideal conditions to answer the set questions in this study, as a result of previous rangeland manipulation either as part of farm management (Spes Bona) or experimental trials (Neudamm).

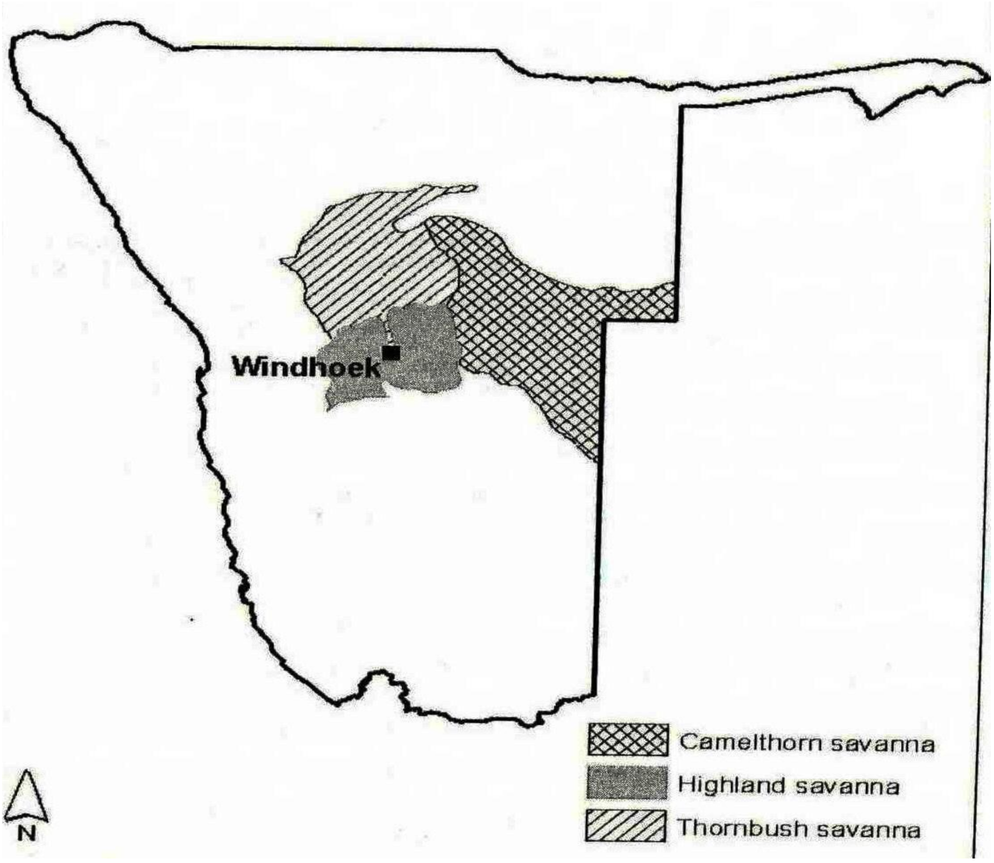

Figure 3.1: Location of Highland savanna (semi-arid savanna) in Namibia (Source: De Klerk, 2004).

3.1.1. Spes Bona farm 207

One part of the study was conducted at Spes Bona 207 farm in Hochfeld district, Otjozondjupa Region. Farm Spes Bona is located at about 142 km east of Okahandja. It is located at latitude 18º11' S and longitude 21º33' E and at an altitude of 1576 m. Farm Spes Bona covers an area of 9618 hectares. It was established in 1963, with only eight camps and two watering points. It was re-zoned later in 1968 in fifty-eight camps with sixteen watering points (Figure 3.2). The farm Spes Bona is primarily a cattle (Bonsmara stud) ranching, though it has other small farming enterprises such as sheep farming, hay production, citrus production, sunflower production, maize and beans production (Von Dewitz, 2009, personal communication). The farm is demarcated in camps which are grazed in a rotational grazing management system. In 2007, this commercial beef rancher was named, as Namibia Agri/Mutual and Federal "Young Farmer of the year" in Hochfeld district through his extensive beef production and rehabilitation of bush encroached rangelands.

As part of his farm management, in 2006 to 2007, this farmer randomly sprayed K-35 and K-51 camps (shaded in Figure 3.2) with a general-purpose arboricide and also mechanically excavated *A. mellifera* plant species with their roots in camps K-2, K-4, K-6 and K-20 (Figure 3.2) (Von Dewitz, 2009, personal communication). Mechanical excavation was done by manual labour. A combination of these chemical and mechanical methods of eradicating bush have been applied and thus presents an ideal canvas on which to study the ecological effect of these bush control methods. This farm (Spes Bona) has also several thousand hectares that are bush-encroached and have not yet been treated (control).

The vegetation type in this area is classified as semi-arid savanna. The mean annual rainfall around Spes Bona and Hochfeld district is about 350-450 mm. The rains are markedly seasonal and occur during summer, from January to April (Mendelsohn *et al*, 2002). Large areas in this vegetation are dominated by *Acacia* species and encroached mainly by *Acacia mellifera* (MÜller, 1984). Moreover, grass cover also varies depending on the soil type. This vegetation is mainly characterised by homogenous ferralic aerosols soil types, though varying slightly in some ecosystems in the same vegetation type (MÜller, 1984).

3.1.2. Neudamm No.63 farm

Part of the study was conducted at Neudamm Agricultural Campus (farm) in the Khomas Hochland district, Khomas region. Neudamm No. 63 farm is about 27 km east of Windhoek. The area is located at latitude 22º27'02″ S and longitude 17º21'38″ E and at an altitude of 1856 m. Neudamm farm was established in 1904-05 and extends over 10187 hectares. The farm maintains Afrikaner stud breed, Karakul sheep, Damara sheep, Dorper sheep, Boer-goats and also game animals on its rangeland (Neudamm farm manager, 2008). It has been one of the important research centres over the years and it is demarcated in nine blocks (e.g. A, B, C, D, E, F, G, H and I), with which each is divided into camps (figure 3.3).

The vegetation type in this area is classified as highland savanna (semi-arid savanna). The average annual rainfall around Neudamm or in Highland savanna of Khomas Hochland ranges from 300-350 mm, with much of the rain experienced during summer seasons (January-April) (Mendelsohn *et al*, 2002). This vegetation is dominated by homogenous Lithic Leptosols and Eutric Regosols soil types. Highland savanna is also characterized by shrubs and low trees, mainly *Acacia* species. The undisturbed rangelands consist of climax grasses such as *Schmidtia pappophoroides*, *Anthephora pubescens*, *Brachiaria nigropedata* and many other palatable grass species (MÜller, 1984). However, in many areas a decline in these valuable grasses can be seen, which is attributed to selective grazing and over-grazing.

In a trial in F-block at Neudamm No. 63 farm (Figure 3.3), 495 *Acacia Mellifera* bushes were felled in camp F-22 (22 ha), during the hot-dry season of 2007 (August-October).

After felling, about 165 of the stumps were left untreated (as control), 165 stumps were randomly treated with the arboricide Galton-4 and the remaining 165 were physically slashed with a cutlass at the top to facilitate rainwater penetration and rotting of the stumps (Rothauge, 2008, personal communication). Differently treated stumps could be identified by the presence of a one-meter piece of metal rod standing beside each stump and painted in a different colour at the top, depending on the treatment.

3.2. Research experimental design

A Completely Randomized Design (CRD) was used, when three belt transects (50 x $5m^2$) were laid randomly on 100 ha of 168 ha in K-35 and the of whole K-51 camps (shaded in Figure 3.2) which were chemically treated with a general-purpose arboricide, leading to a complete eradication of most microphyllous *Acacia* species (*A. mellifera*). Another three belt transects (50 x $5m^2$) were randomly laid for mechanical treatments in camps K-6 and K-20 (shaded in Figure 3.2). The other two mechanically treated camps (K-2 and K-4) were not used for the study, as the farmer had already harvested the grasses before the study was conducted. Moreover, the farm Spes Bona has thousand hectares in all other remaining camps that are bush-encroached and had not yet been treated and the same design (Completely Randomized Design) was used in K-50 and K-6 camps, in order to compare what untreated rangeland looked like (the "experimental control").

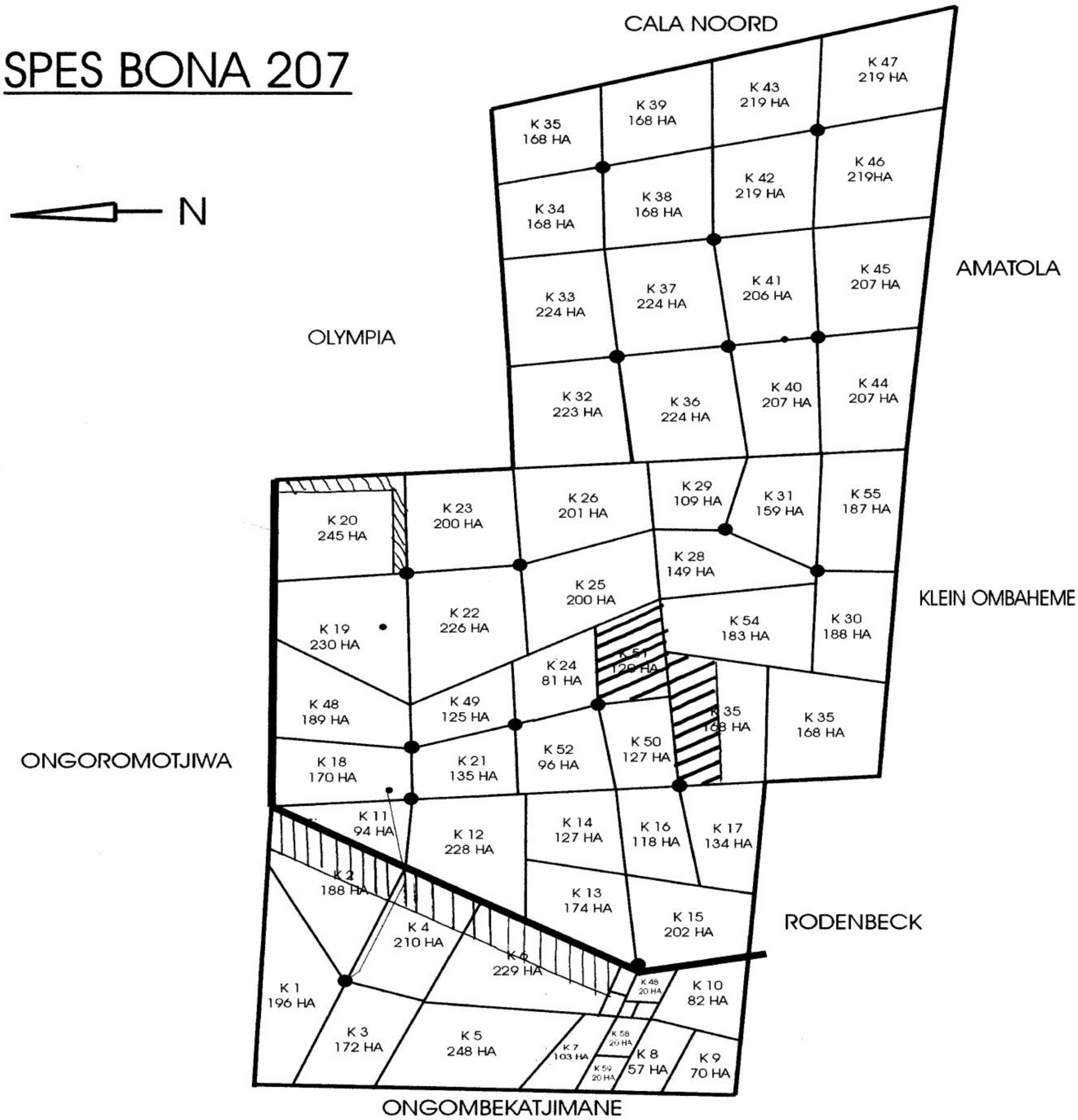

Figure 3.2: The map of farm Spes Bona 207 showing the treated camps (shaded).

In a study trial at Neudamm, in F-block (Figure 3.3), a Complete Randomised Design (CRD) was as well used in a 200 x 100m^2 plot (2ha). This plot of 2ha was identified and divided into 3 sub-plots for each treatment (mechanical, chemical and control). Each sub-plot was further divided into 3 replicates. In each replicate, stumps were randomly assigned key-tags with sequential numbers from 1-55 per sub-plot. The numbered key-tags were randomly placed at the top of the metal rods at the stumps in different treatments. This was to enable the study to reseed desirable grass species underneath and around canopies at the stumps and also to investigate effects of different stump treatments on stump mortality and coppicing.

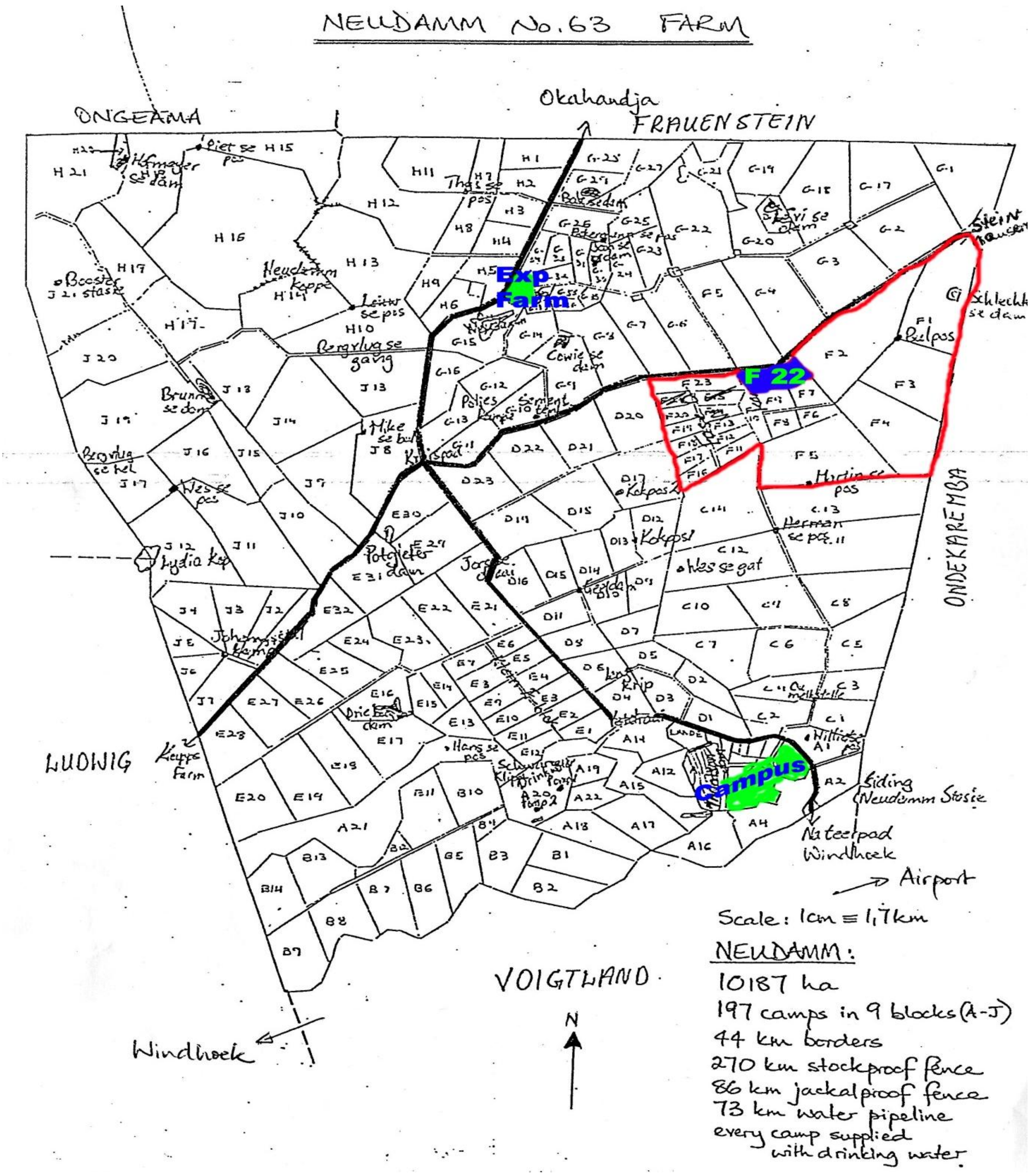

Figure 3.3: The map of Neudamm 63 farm showing the location of the study site camp F-22 in block F. (source: Neudamm farm manager).

3.3. Population

The population of the study was the whole farm of Spes Bona 207 that covers an area of 9618 hectares (divided in 58 camps) and the whole of Neudamm No. 63 farm, which covers an area of 10187 hectares (demarcated in nine blocks, e.g. A, B, C, D, E, F, G, H and I).

3.4. Sample

A total study sample of seven (7) camps was used in this current study. A sample of six (6) treated and untreated camps was randomly selected from Spes Bona 207 farm. These are some of the camps that have been heavily encroached by *Acacia mellifera* on this farm. At Neudamm No. 63 farm, a sample of one (1) most heavily encroached camp was randomly selected for the study from (F-block) (Figure 3.3), which has been one of the heavily encroached blocks by *Acacia mellifera* at Neudamm No. 63 farm.

3.5. Study of the effect of bush control treatments on the grass species, soil layer and woody plant density at Spes Bona farm.

3.5.1. Site selection and data collection

At the farm Spes Bona, different treatment sites (chemical, mechanical and control) as described in section 3.4 above were randomly selected for data collection, in April 2009. As a sampling method of the vegetation, in each site, three belt transects (50 x $5m^2$) were laid in the treated and untreated camps. Sites were randomly identified according to woody plant communities in the camp and the accessibility of being able to pass through the impenetrable woody plants. After the site had been randomly identified, a 50m tape was laid on the ground in order to mark off the site by putting up pieces of metal rods in each corner of the belt transect and tied on a string around the corners. The first belt transect in each camp was set up at about 50m away from the fence of the camp, with the second belt transect set towards the middle and the third towards the other end side of the camp, depending on the camp size. In each belt transect, every woody plant was identified, measured for its height.

For data on herbaceous plants, 1m x 1m quadrats was used within each belt transect at an interval of 10m along the 50m tape (i.e. 5 quadrats). In each of these quadrats, all tufts of different grass species, as well as forbs were recorded and counted. Individuals that could not be identified in the field were kept in paper-bags and got identified the same day after data collection using the grasses of Namibia and grasses of southern Africa books (MÜller, 1984; Van Oudtshoorn, 1999). In addition, the condition of the soil surface at each 10m interval along the 50m tape was examined whether covered by any vegetation or bare. If the soil was bare, it was further categorized as crust, loose or capped.

3.6. Effects of bush control methods on coppicing and mortality of *Acacia Mellifera* stumps at Neudamm farm

3.6.1. Site selection and data collection

Camp F-22 at Neudamm farm was used to collect data on effects of different stump treatments on stump mortality. For each treatment (mechanical, chemical and control), stumps in all three sub-plots were assigned key-tags with sequential numbers from 1-55. The numbered key-tags were randomly placed at the top of the metal rods at the stumps in different treatments. The assessment of the coppicing and mortality of the stumps was done after the 2009 rainy season (from April 2009), by counting stumps coppicing or dead. Moreover, the basal diameter and height of each stump in subplots among all treatments were measured using a ruler and a 1 meter tape and recorded.

3.6.2. Re-seeding of desirable grass species experiment

This experiment took advantage of the felled and overturned canopies of *Acacia mellifera* bushes at Neudamm farm. The assessment on the site was done during mid-February 2009 to evaluate the result of the 2007 reseeding and identify treatments that had to be reseeded. These treatments were then reseeded based on the condition that there was no desirable grass species found underneath and around the overturned canopies. During the process of reseeding (end of February 2009), the broadcasting of desirable grass species (at the density of 200 seeds/stump) was used through manual spreading of seeds on top of the felled canopies and in the surrounding area of the felled canopies. During data collection, only tufts for *Schmidtia pappophoroides* were counted and recorded underneath and outside the canopies ($2m^2$), as other two reseeded desirable grass species (*Anthephora pubescens* and *Brachiaria nigropedata)* could not germinate at the site.

3.7. Research Instruments

The key research instruments that were used in the study were the 50 x $5m^2$ belt transects, 1 x $1m^2$ quadrats, 50m long measuring tape, 5m and 1m tapes, grasses of Namibia and grasses of southern Africa books. These instruments were used in the study, as has been described in sections 3.5.1 above.

3.8. Data analysis

Data from Spes Bona experiment, stump mortality and coppicing at Neudamm farm were analysed using a one-way ANOVA according to General Linear Model (GLM) procedure of SAS (1999). The means of each treatment were compared following the PDIFF option of the least squares means statement of the GLM procedure of SAS. For reseeding experiment, data were first tested for normality before applying the statistical t-test, using the GenStat programme.

3.9. Research ethics

Farmers would be informed with concert. This study would take cognisance of animal welfare issues by ensuring that the people, animals and the rangelands are not adversely affected in the process.

CHAPTER 4

RESULTS

4.1 Ecological and structural differences between three bush control treatments

4.1.1. Grass species tuft density

The mean density of total grass species density was relatively slightly high in chemical (36.1 ± 9.6[a]), mechanical (31.7 ± 9.7[a]) and low in control (25.7±9.0[b]) treatments, respectively. There was no significant difference (P>0.05) in the density of *Aristida congesta, Cenchrus ciliaris, Chloris vigata, Eragrostis rigidior, Eragrostis viscosa, Melinis repens* and *Melinis villosum* grass species among the three bush control treatments. The density of *Aristida congesta* was significantly higher in chemical and mechanical than in control treatment, compared to the density of *Melinis villosum* which was significantly higher among all three bush control treatments (Table 4.1). However, there was a significant difference (P<0.05) in the density of *Aristida meridionalis, Enneapogon cenchroides, Eragrostis rotifer, Pogonarthria fleckii, Stipagrostis uniplumis, Urochloa brachyura* and forbs species among all three bush control treatments.

Table 4.1. Presents the mean grass and forbs density per 1m^2 among three bush control treatments at farm Spes Bona.

	Treatments		
Grass species	**Chemical**	**Mechanical**	**Control**
A. congesta	6.5 ± 1.8[a]	6.3 ± 2.8[a]	3.2 ± 1.8[a]
A. meridionalis	2.7 ± 0.7[b]	1.1 ± 0.8[a]	1.7 ± 0.7[ab]
C. ciliaris	0.1	0	0.4
C. vigata	1.9	-1.3	0
E. cenchroides	7 .0 ± 0.7[a]	6.2 ± 0.7[a]	3.2 ± 1.5[b]
E. rigidior	1.3 ± 0.6[a]	1.7 ± 0.9[a]	2.4 ± 0.5[a]
E. rotifer	1.0 ± 0.6[ab]	1.9 ±0.6[b]	0.4 ± 0.5[a]

E. viscosa	0.4	0	0
M. repens	1.7 ± 1.3[a]	2.7 ± 0.8[a]	1.5 ± 1.3[a]
M. villosum	6.2 ± 0.9 [a]	5.9 ± 0.9 [a]	6.1 ± o.9[a]
P. fleckii	3.5 ± 1.6[ab]	1.4 ± 0.9[b]	3.8 ± 0.8[a]
S. uniplumis	2.5 ± 1.0[ab]	3.5 ± 0.9[b]	0.8 ± 0.9[a]
U. brachyura	0.4 ± 0.1[a]	0.6 ± 0.06[b]	0.5 ± 0.09[ab]
Forbs	0.9 ± 0.3[a]	1.7 ± 0.3[b]	1.7 ± 0.0[b]
Total grass tufts (13 sps)	**36.1 ± 9.6[a]**	**31.7 ± 9.7[a]**	**25.7±9.0[b]**

Means with different superscripts within the rows differ significantly (P<0.05) and vice versa.

4.1.2. Soil condition

Three levels (1=low, 2=medium, 3=higher) were used in the assessment of soil erosion among three bush control treatments at Spes Bona farm. The low level indicated that the soil was covered by grass tufts and the medium level indicated that the soil was not covered by herbaceous tufts and the soil was loose. The higher level indicated that the soil was not covered by herbaceous tufts and it was crust.

There was no significant difference (d.f.=15, P>0.05) in the mean of soil condition among the three bush control treatments (Figure 4.1). This shows that the soil among the three treatments was covered by herbaceous layer.

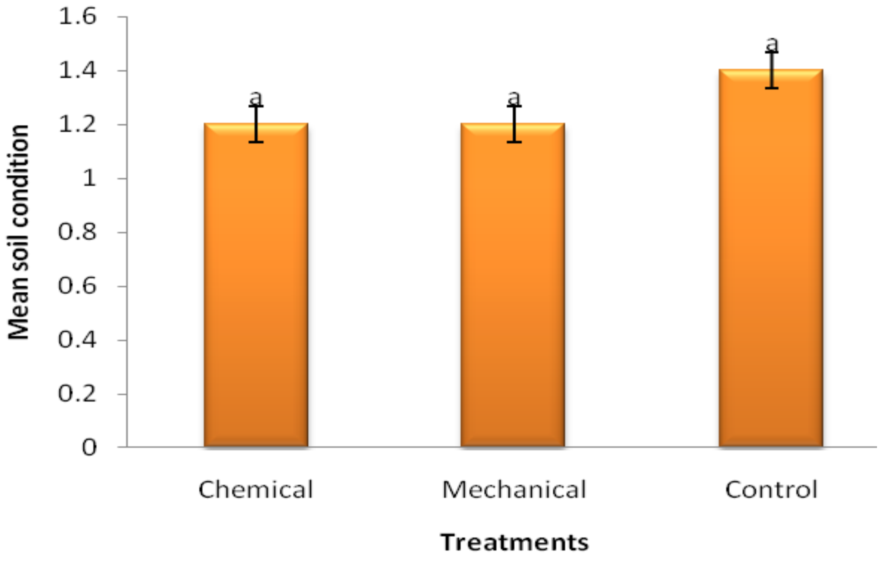

Figure 4.1. Comparison of the mean difference of the soil condition among three treatments at Spes Bona farm. Bars indicate SEs. Means with similar superscripts on the bars show no significant difference (P>0.05).

4.1.3. Woody plant density

Woody plant density under the three bush control treatments at Spes Bona is presented in Table 4.2. There was no significant difference (P>0.05) in the density of *Acacia hebeclada, Boscia Albitranca*, *Dichrostachys cinerea* and *Grewia flavescens* among the three bush control treatments, although *A. hebeclada* had a significantly higher density in the control and chemical than mechanical treatments, compared to other woody plant species. However, there was a significant difference (P<0.05) in the density of *Acacia Mellifera*, *Grewia flava, Catophractes alexandri and Acacia hereroensis* among the three bush control treatment, with *C. alexandri* and *A. Mellifera* recorded significantly less in the mechanical and significantly higher in both control and chemical treatments.

Table 4.2. Mean woody density per ha among three bush control treatments at farm Spes Bona.

Woody species density	Chemical	Treatments Mechanical	Control
A. mellifera	150.0 ± 42.5^{b}	40.0 ±85.0^{a}	173.3 ± 34.7^{b}
A. hebeclada	60.0 ±44.7^{a}	40.0 ± 63.2^{a}	100.0 ±44.7^{a}
A. hereroensis	40.0 ± 0.0^{a}	0.0	160 ± 0.0^{b}
B. albitranca	56.0 ± 8.0^{a}	0.0	40.0 ± 10.0^{a}
C. alexandri	280.0 ± 61.1^{a}	93.3 ± 35.3^{b}	320.0 ± 61.1^{a}
D. cinerea	60.0 ± 10.0^{a}	40.0 ± 20.0^{a}	40.0 ± 14.1^{a}
G. flava	40.0 ± 75.0^{a}	80.0 ± 106.1^{ab}	224.0 ± 47.5^{b}
G. flavescens	0.0	80.0 ± 40.0^{a}	80.0 ± 23.1^{a}
Ouma boom	0.0	40.0	0.0
T. camphorates	0.0	40.0	0.0
R. nersii	0.0	0.0	40.0
Total woody density	**686 ±241.3^{b}**	**453.3 ±349.6^{b}**	**1137.3 ±235.2^{a}**

Total woody plant density was significantly lower in the chemical and mechanical than the control treatment. Means with different superscripts within the rows differ significantly (P<0.05) and vice versa.

4.1.3.1. Woody plant heights

Figure 4.2 shows the density of the different height class in the three treatments. The density of seedling (>0-1) showed a slight significant difference (P<0.05) among the treatments. However, the density of shrubs or saplings (>1-2) and trees (>2-3) showed significant difference (P<0.05), with the highest value being recorded in the control treatment.

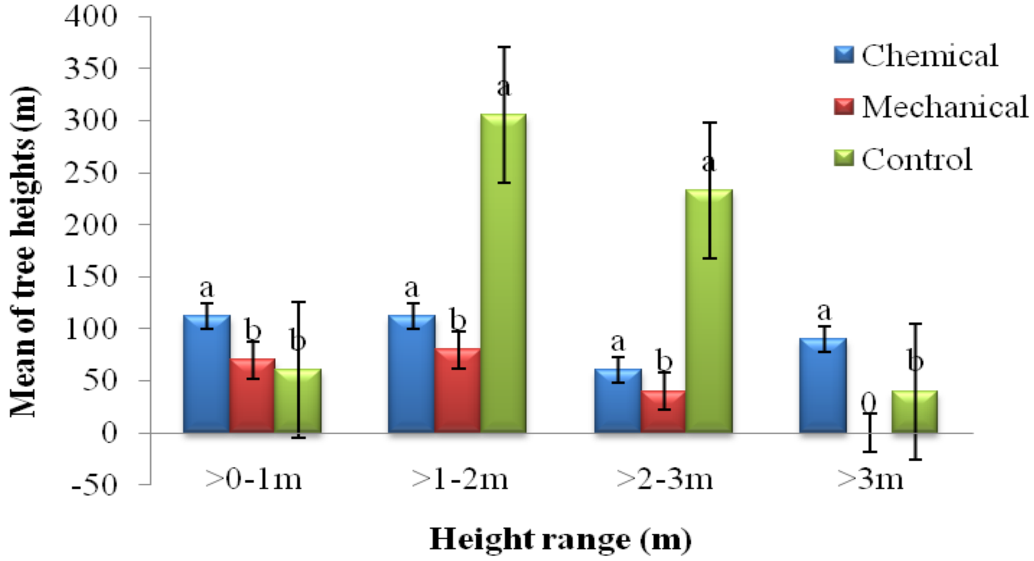

Figure 4.2. Mean heights of woody plant species among three bush control treatments at Spes Bona farm. Bars indicate SEs. Means with different superscripts on the bars differ significantly (P<0.05) and vice versa.

4.2. Effects of bush control methods on coppicing and mortality of *A. Mellifera* stumps at Neudamm farm.

4.2.1. Coppicing and mortality of *A. Mellifera* stumps

There was a significant difference (d.f.=6, P<0.001) in the mean proportions of stump coppicing among the three stump control methods (chemical, mechanical and control). A larger population of coppicing stumps was recorded in the control and mechanical treatment methods than in the chemical method, (Figure 4.3).

There was also a significant difference (d.f.=6, P<0.001) in the mean proportions of stump mortalities among the three stump control methods. More proportion of dead stumps (83% of stumps) in chemical control method was dead than in mechanical (32% of stumps) and control (23% of stumps) methods.

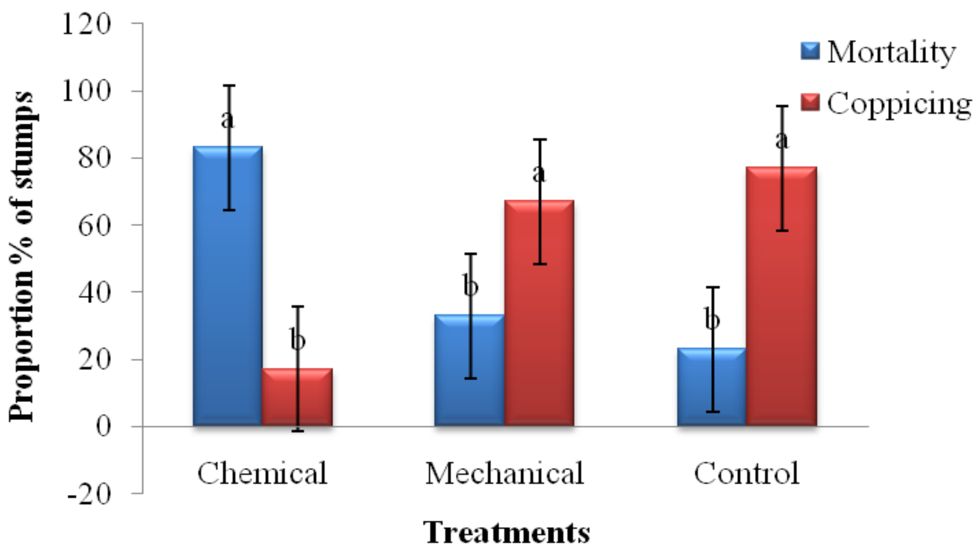

Figure 4.3. Mean Proportion (%) of stump coppicing and mortalities among three stump control methods at Neudamm farm. Bars indicate SEs. Means with different superscripts on the bars differ significantly (P<0.001) and vice versa.

4.2.2. Stump sizes

4.2.2.1 Stump height and diameter

There was no significant difference (P>0.05) in the mean of stump heights among the three different stump treatment methods. The mean stump heights were relatively similar in mechanical (20.02 cm) and chemical (19.64 cm) and lower in the control (14.1 cm) treatments (Figure 4.4), respectively. No significant difference (P>0.05) was found in the mean of stump diameters among the three different sump treatment methods (Figure 4.4). The means of stump diameters were also relatively similar in mechanical (5.63 cm) and chemical (5.08 cm) and small in the control (4.28 cm) treatment methods (Figure 4.4), respectively.

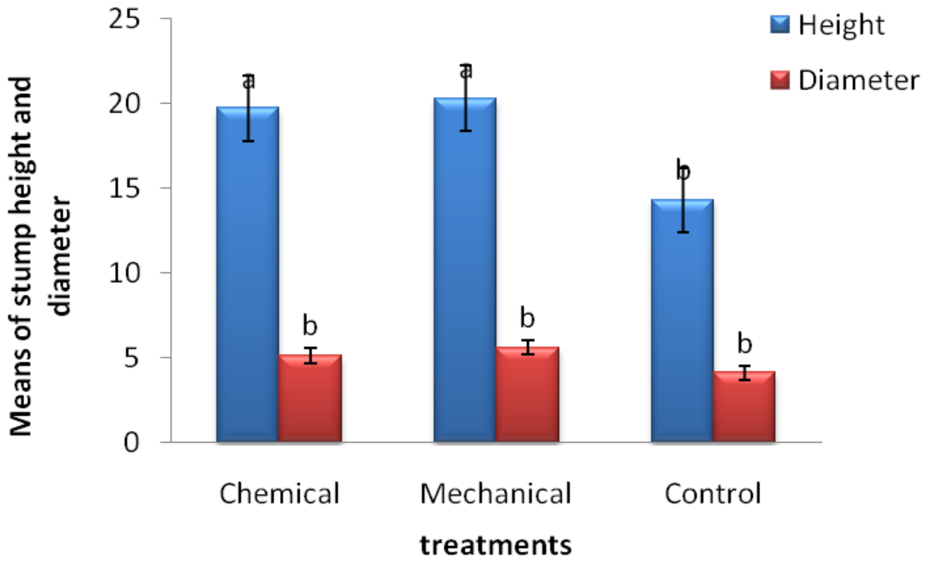

Figure 4.4. Mean of stump heights and diameter among three stump treatment methods at Neudamm farm, in highland savanna, Namibia. Bars indicate SEs. Means with different superscripts on the bars differ significantly ($P<0.05$) and vice versa.

4.3. Re-seeding desirable grass specie (*Schmidtia pappophoroides*) underneath the (inside) and around the overturned canopies (outside).

4.3.1. *Schmidtia pappophoroides* tuft count density at positions.

The mean of *Schmidtia pappophoroides* tuft count density was significantly higher (d.f.=984, $P<0.001$) in the outside position of the canopies than in the inside position of the canopies (Figure 4.4).

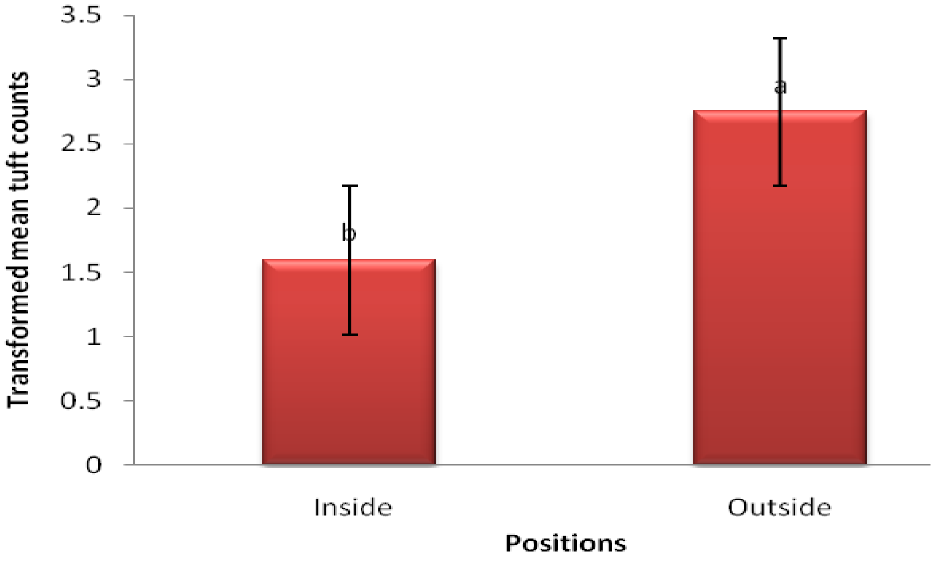

Figure 4.5. Mean of *Schmidtia pappophoroides* tuft density among the two positions (inside and outside the canopy) at Neudamm farm. Bars indicate SEs. Superscripts indicate significant (P<0.001) mean differences between positons.

CHAPTER 5

DISCUSSION

5.1. Comparison of ecological and structural effects of mechanical, chemical control treatments of bush in terms of grass layer and soil condition under commercial farming condition.

This study indicated that a total number of about 13 grass species (Appendix 2) found on farm Spes Bona were not different in all three bush control treatments. The results have statistically shown that there was no significant difference (P>0.05) in the density of *A. congesta, C. ciliaris, C. vigata, E. rigidior, E. viscosa, M. repens* and *M. villosum* grass species among the three bush control treatments. The density of *Melinis villosum* was significantly higher among all three bush control treatments, compared to the density *Aristida congesta* which was only significantly higher in chemical and mechanical than in control treatment (Table 4.1).

The study also showed that the rangeland of Spes Bona farm was dominated by both annual and perennial grass species, such as *Melinis villosum, Enneapogon cenchroides* and *Aristida congesta*, *Stipagrostis uniplumis* and *Eragrostis rigidior* (Appendix 2). A similar study conducted by Tainton (1999) indicated that the condition of the semi-arid savanna type is reflected particularly in changes in herbaceous layer brought about by poor management. There is bush encroachment in many of the savanna types and the application of chemical and mechanical methods are usually practised (Tainton, 1999). Retrogression of the grass component inevitably mainly reduces the productive capacity of savanna rangelands for herbivores. Productive capacity is reduced when preferred grasses like *Schmidtia pappophoroides, Panicum maximum* and *Anthephora pubescens* are replaced with less desirable annual grasses and other *Eragrostis* species, and with species of *Aristida* (Tainton, 1999).

In the current study, grass species found in mechanically and chemically treated camps were relatively the same as those in encroached and untreated camps, but the difference was only mainly in the density of the grass tufts. Tainton (1999) supported that a decline in the condition of the grass layer is typically accompanied by the increase in the density of trees and shrubs. Sensitivity of savanna to this process increases as aridity increases. Walter (1971) emphasised that in a savanna ecosystem, grasses are superior competitors for water in the upper soil, while trees have exclusive access at deeper layers. However, woody species compete more successfully than grasses for the resources needed for growth, and tolerate utilization better (Tainton, 1999). It is therefore believed that, this is because trees have exclusive use of soil water at depth in the profile (Walter (1971). While grasses cannot survive in a dense woody community because they are denied water, trees can survive in a dense grass community (Tainton, 1999). In this study, the mechanical treatment method yielded high grass density and low woody plant density.

The results of the soil condition showed that there was no significant difference (d.f.=15, $P>0.05$) in the mean of soil condition among the three bush control treatments (Figure 4.1). This showed that the soil among the three treatments at farm Spes Bona was covered by herbaceous layer and that has reduced the level of soil erosion on the rangeland, which enables it to retain its nutrients content. The level of erosion at few patches that experienced erosion was not severe and this indicated that the state of the rangeland was perfectly sustainably managed. This is a clear indication that the encroached rangelands are still in a good and reversible state, though biodiversity has been affected, the soil degradation still appears minimal. A study conducted by Angassa (2002) has also pointed out that farming methods that result in a minimal amount of soil disturbance and allow selectivity are preferred to prevent soil erosion and degradation of plant communities. Walter (1971) postulated that rangeland condition reflects changes in vegetation composition, productivity and soil stability. The condition of the arid savanna type is reflected particularly in changes in herbaceous layer brought about by poor rangeland management.

Thrash (1997) stressed that the idea of bush control by indicating that vegetation improves the structure and water-holding capacity of the soil preventing crust formation through the interception of raindrops. When the intensity of a rain shower exceeds the maximum infiltration rate of the soil, run-off occurs. This run-off eventually causes accelerated soil erosion and flooding. The moisture content of the soil is also adversely affected and thus also the production of herbage (Thrash, 1997).

Animals on a farm may alter the structure of the soils by loosening the soil surface or they may deform or compact the soil, depending on the type of soil and its moisture content (Thrash, 2000). Clayey soils are more easily capped by livestock trampling than sandy soils (Thrash, 2000). Without disturbance, the soil surface may seal off and, in at least some soils, animal hooves may break up this seal, particularly when soils are dry, promoting infiltration (Owen-Smith, 1999). The loosening of soil may, however, also lead to increased soil loss associated with either wind or water erosion (Owen-Smith, 1999). When soils are relatively wet there is a tendency for trampling to compact rather than loosen its surface, particularly where the clay content is high (Owen-Smith, 1999). This compaction causes a loss of soil structure, increased bulk density and reduced pore space, which in turn will result in reduced infiltration, aeration and water holding capacity, making the general conditions less favourable for plant growth (Owen-Smith, 1999). Grazing, trampling, and dung deposition by large herbivores often result in a zone of decreasing impact on many vegetation and soil parameters, including herbaceous vegetation basal cover and soil bulk density and penetrability, away from watering points (Thrash, 1997). It is therefore reasonable to assume that excessive trampling resulting from high grazing and browsing pressures will have a detrimental long-term effects on the vegetation and soil, as is readily apparent in bush encroach rangelands (Owen-Smith, 1999)

The current study has shown that among all 11 woody species found on farm Spes bona, *Acacia mellifera*, *Catophractes alexandri* and *Grewia flava* (Table 4.2) were the most abundant species in the control and chemical and less in mechanical bush control treatment. Hence, the statistical results have similarly shown that there was no significant difference ($P>0.05$) in the density of *A. hebeclada, B. Albitranca, D. cinerea G. flavescens* among the three bush control treatments, although *A. hebeclada* had a significantly higher density in the control and chemical than mechanical treatments. However, there was a significant difference ($P<0.05$) in the density of *A. Mellifera* and *G. flava, C. alexandri, A. hereroensis* among the three bush control treatment, with *C. alexandri* and *A. Mellifera* recorded significantly less in the mechanical and significantly higher in both control and chemical treatments. Woody species are normally protected, at least partially against exclusive utilization, because part of their canopy is usually beyond the reach of browsing animals (Tainton, 1999). In most cases changes such as bush encroachment are irreversible because of the effect on the grasses of the woody species, which compete strongly for moisture (Tainton, 1999). The low fuel loads in areas where the grass layer has degraded also mean that fire cannot be used to help control the bush. Tainton (1999) recommended that expensive mechanical or chemical methods must be resorted to if these areas are to be cleared.

According to Angassa (2002), bush control and management method is often necessary to maintain and improve the quality of rangelands for livestock grazing and habitat for wildlife. Angassa (2002) supported the mechanical control of bush by stating that initial treatments may require mechanical methods such as hand cutting or spot treatment with herbicides. Hence, in this study, the mechanical treatment was more effective in the control of bush encroachment on degraded rangeland too compared to chemical treatment.

Roques, O'Connor & Watkinson (2001) elaborated that rangeland degradation is causing major ecological transformation of savanna ecosystems grazed by livestock and the consequent of bush encroachment is considered a serious issue for the livelihoods of farmers.

The results of height classes showed that the density of seedling (>0-1) showed a slight significant difference ($P>0.05$) among the three bush control treatments. However, the density of shrubs or saplings (>1-2) and trees (>2-3) showed significant difference ($P<0.05$), with the highest value being recorded in the control treatment then in chemical and mechanical treatments. This is an indication that recruitment of bushes is the same in treated and untreated plots. It entails that treating the plot is not enough to keep the rangeland from getting encroached again in the future, without any after-care to suppress the recruitment of seedlings. However, abundance of grass in treated sites may provide a degree of suppressing seedlings, but when these seedlings pass the seedling stage, they can become more competitive and eventually the rangeland will be back to its thickets.

5.2. Effectiveness of mechanical and chemical stump treatments on stump mortality and coppicing.

A larger population of coppicing stumps was recorded in the control and mechanical treatment methods than in the chemical method, (Figure 4.3). This means that chemical treatment method is the best treatment method that achieves highest stump mortality.

This was an indication that chemical method was more rapid and effective in the killing of stump than in comparison to mechanical and control stump treatments. The findings in this study are in with the results of Troth *et al.* (1986), who stated that chemical stump treatment is particularly useful in preventing the vigorous regrowth, which is the characteristic response of many invasive species such as *Acacia mellifera* after cutting. Moreover, killing the stump is the first step towards encouraging it to rot. Troth *et al.* (1986) further stressed that in many cases, it is more desirable to remove existing bushes manually than to spray it and leave the dead material standing.

Coppicing of stumps was significantly higher in control and mechanical control methods than in chemical (Figure 4.3). Troth *et al.* (1986) has also observed however that, under some conditions, mechanical removal and killing of stumps may not be practical. In these cases, herbicides may be applied to freshly cut stumps to effectively kill the plant and prevent them from coppicing. When the top is removed, many bushes and shrubs respond by producing new shoots from adventitious buds at ground level (Troth *et al.*, 1986; Walter, 1971). These shoots, sometimes called stump sprouts, will regrow vigorously using stored energy from the existing root system.

There are multiple methods that can be used to prevent coppicing of woody plant stumps (Walter, 1971). The most basic and labour intensive mechanical method is hand removal of the stump using a shovel, axe, and digging bar. Stump grinders are also available, but work best on relatively open, level sites. Both of these mechanical removal methods are effective on species that do not resprout from large root fragments left in the soil (Walter, 1971).

Bester (1998) has supported the chemical stump control and indicated that general use of herbicides can be used to effectively prevent regrowth of encroaching bushes and shrubs that resprout after cutting. General use herbicides are not likely to harm the environment when used according to label directions. These products can be advantageous because the herbicide is translocated to the entire root system therefore preventing regrowth from roots that may be some distance from the cut stump (Bester, 1998).

Ecological value of stumps is that stumps are a food source and a habitat which is difficult to find in many community landscapes (Dahl & Nepembe, 2001). In most cases, creatures which inhabit and use the decaying stump change as the stump changes. Energy concentration in a decaying stump represents a rare and essential resource to a number of animals and micro/meso-organisms (Dahl & Nepembe, 2001). If a stump can be simply left in-place and not disturbed, interesting things may happen, especially when the stump is surrounded by a healthy soil. The pieces and chips of a stump can also be used to enrich the site and provide unique, wood centered habitat.

Dahl & Nepembe (2001) have criticised the use of herbicide by emphasising that one of the main threats associated with the use of herbicides in general is the possibility that the export market will reject Namibian beef on the grounds that grazing has been polluted by the active ingredients of applied herbicides. Therefore, great care needs to be taken, therefore, to ensure no misperceptions cause a negative impact on the export of beef to the European Union (Dahl & Nepembe, 2001).

The study has found that there was no significant difference (P>0.05) in the mean of stump height and diameter among the three different stump treatment methods. The mean stump height was relatively similar in mechanical and chemical than in the control. Similarly, the mean stump diameter was also relatively similar mechanical and chemical than in the control treatment methods.

This indicates that the level of cutting the encroaching woody stem may not matter. However, Friedel (1991) noted that the problem species do not die after being chopped down. Many woody species have a strong ability to resprout from the roots. This was already also reported in 1971 by Walter, who stated that it was necessary to remove Acacia species trees to a depth of about 20 cm underground due to "sleeping buds" at the base of the stem (Friedel, 1991. Various reports from farmers indicated that the season of treatment is important in the coppicing ability/ survival rate of such plant.

According to Khan *et al*. (1989), many studies have found that stump height is a key factor influencing the occurrence and vigour of sprouting and also that the number and height of sprouts was related to the parent tree diameter. Sprout number may not be the best indicator of establishment success from stumps; in many circumstances the growth rate of the largest sprout is more significant and in some cases this is negatively correlated with sprout number (Khan *et al*., 1989). However, sprout number becomes more important if sprouts suffer significant mortality. Tall stumps have a better chance of surviving fire, browsing and weed competition as the vulnerable sprouts are produced above the height of disturbance (Khan *et al*., 1989).

5.3 Effectiveness of re-seeding desirable grass species under felled canopies (inside) and around the overturned canopies (outside).

The results indicated that there was a significant difference in reseeding *Schmidtia pappophoroides* under the overturned canopy and around the canopy. The position of reseeding *Schmidtia pappophoroides* plays a great role in its establishment and survival in a rangeland. According to Stoddard *et al.* (1975), when a grazing rangeland is disturbed by climate, weed invasion or encroached by bushes, a rangeland manager needs to evaluate improving the production capability and condition of a site by reseeding. Rangers may have to consider many factors when deciding to reseed including the cost to benefit ratio, reseeding method, place of reseeding, available equipment, selection of grass species, timing the effort and what to expect after reseeding (Stoddard *et al.*, 1975). Environmental and social values for re-establishing good rangeland condition are always high but often fiscally difficult. Strong healthy rangeland filter water, provide wildlife habitat, establish aesthetic view and reduce airborne dust in addition to providing a stable grass production location for agriculture (Stoddard *et al.*, 1975).

Schmidtia pappophoroides tufts managed to recover and improve outside the canopy, when the intensity of use and competition for nutrients and water at a site are reduced (Quan *et al.* 1994). For this reason, it is always advisable to undertake an integrated management plan and reduce the intensity of grazing use on a site until desirable grass species fully recover. This only happens when a rangeland manager constantly monitors whether such a combined approach allows the desirable grasses to recover or whether additional undesirable species or accelerated erosion begin on the site.

According to Quan *et al.* (1994), the density of reseeded perennial grass species is estimated to increase by 200–400% after treatment, depending on the condition of the rangeland before. Grazing days per annum have been reported to increase by 100% over a period of seven years after tuft establishment. Hence, this would allow the production to rise more than N$7 per kilogram live weight, resulting in a net financial gain of N$56 per hectare (Quan *et al.* 1994).

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1. Conclusions

The study was carried out at Spes Bona 207 farm in Hochfeld district, Otjozondjupa Region and Neudamm 63 farm in the Khomas Hochland district, Khomas Region, both in the Highland savanna in Namibia. The objective of this study was to investigate the rehabilitative effects of mechanical and chemical methods of bush control of an invasive bush species *Acacia mellifera* for achieving long term rehabilitation of a degraded highland savanna rangelands in Namibia. At farm Spes Bona, three belt transects (50 x 5m^2) were laid randomly on 100 ha of 168 ha in K-35 and the of whole K-51 camps which were chemically treated with a general-purpose arboricide. Another three belt transects (50 x 5m^2) were randomly laid for mechanical treatments in camps K-6 and K-20. Moreover, the same method was used in camp K-50 and K-6, as control experiment. At Neudamm farm, a 200 x 100m^2 plot with 495 *Acacia mellifera* treated stumps was divided into 3 sub-plots for each treatment (mechanical, chemical and control). Each sub-plot was further divided into 3 replicates. In each replicate, stumps were randomly assigned key-tags with sequential numbers from 1-55 per sub-plot. This was to enable the study to reseed desirable grass species underneath and around canopies at the stumps and also to investigate effects of different stump treatments on stump mortality and coppicing.

At Spes Bona farm, the grass tuft density of species *A. congesta, C. ciliaris, C. vigata, E. rigidior, E. viscosa, M. repens* and *M. villosum* was significantly higher (P<0.05) in chemical and mechanical than in control treatment. Similarly, the total grass species tuft density had greater values (P<0.05) high in chemical (36.1 ± 9.6[a]), mechanical (31.7 ± 9.7[a]) than in control (25.7±9.0[b]) treatment. The soil condition did not show significant difference P>0.05) between treatments. Total woody plant density was significantly greater (P<0.05) in the control than chemical and mechanical treatments. At Neudamm farm experiment, stump mortalities was significantly lower (P<0.001) in chemical than in mechanical and control treatments. On the contrary, coppicing of stumps was significantly lower (P<0.001) in the chemical method than in the control and mechanical treatments. Tuft density of *Schmidtia pappophoroides* showed greater values outside the canopy than underneath the canopy.

The current study concludes that the chemical method was effective in terms of grass species tuft density and also in the killing of *Acacia mellifera* stumps. The mechanical method of treatment was also effective in terms of bush clearing and establishment of grass species than control treatment. However, the mechanical and control treatments were not effective in the killing of *Acacia mellifera* stumps in this study.

6.2 Recommendations

a) I recommend that the degraded highland savanna rangelands to be totally prohibited from grazing livestock long enough for plants to become well established and reproduce through improving rangeland revegetation by means of animal few animals trampling and reseeding desirable grass species such as *Schmidtia pappophoroides*.

b) All pesticides (including herbicides) used for bush control should be carefully selected and applied in strict accordance with label directions. Read the labels of any product carefully before purchasing to ensure, it is labelled for cut stump application and appropriate for the intended use. Once a product is selected, it is recommended that the user buy the smallest container that can complete the treatments for a given situation.

c) Based on the current study, it can be recommended that a further research study should be done in other regions of the country in order to assess the effectiveness of the same treatment methods.

d) Future studies should as well consider researching on the financial implications involved in the chemical and mechanical control of bushes, under commercial and communal farming enterprises.

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APPENDICES

Appendix 1. Vegetation species composition from farm Spes Bona

Number	Species	Growth form
1	*Aristida congesta*	Grass
2	*Aristida meridionalis*	Grass
3	*Cenchrus ciliaris*	Grass
4	*Chloris vigata*	Grass
5	*Enneapogon cenchroides*	Grass
6	*Eragrostis echnochloidea*	Grass
7	*Eragrostis rigidior*	Grass
8	*Eragrostis rotifer*	Grass
9	*Eragrostis viscosa*	Grass
10	*Melinis repens sub repens*	Grass
11	*Melinis villosum*	Grass
12	*Pogonarthria fleckii*	Grass
13	*Stipagrostis uniplumis*	Grass
14	*Urochloa brachyura*	Grass
15	Forbs	Forbs
16	*Acacia mellifera*	Woody
17	*Acacia hebeclada*	Woody
18	*Acacia hereroensis*	Woody
19	*Boscia albitranca*	Woody
20	*Catophractes alexandri*	Woody
21	*Dichrostachys cinerea*	Woody
22	*Grewia flava*	Woody
23	*Grewia flavescens*	Woody
24	Ouma boom	Woody
25	*Ronchocareus nersii*	Woody
26	*Tarchonanthus camphorates*	Woody

Appendix 2. Total number of grass species and their classification from different treatments at farm Spes Bona

Grass	Classification	Chemical	Mechanical	Control
Aristida congesta	Annual	194	110	96
Aristida meridionalis	Perennial	81	23	51
Cenchrus ciliaris	Perennial	5	0	2
Chloris vigata	Annual	38	1	0
Enneapogon cenchroides	Annual	138	65	1
Eragrostis echnochloidea	Perennial	10	17	0
Eragrostis rigidior	Perennial	31	27	65
Eragrostis rotifer	Perennial	18	42	10
Eragrostis viscosa	Annual	2	0	0
Melinis repens sub repens	Annual	30	176	184
Melinis villosum	Annual	186	80	23
Pogonarthria fleckii	Annual	22	47	114
Stipagrostis uniplumis	Perennial	55	105	24
Urochloa brachyura	Annual	3	11	2
Total		**813**	**704**	**572**

Appendix 3. Class height of woody plants at farm Spes Bona

	Treatments		
Height range	**Chemical**	**Mechanical**	**Control**
>0-1m	112.0 ± 42.0^{a}	70.0 ± 47.0^{a}	60.0 ± 66.4^{a}
>1-2m	112.0 ± 29.6^{a}	80.0 ± 38.2^{a}	306.7 ± 27.0^{b}
>2-3m	60.0 ± 42.3^{a}	40.0 ± 84.7^{a}	233.3 ± 34.6^{b}
>3m	90.0 ± 14.8^{a}	0	40.0 ± 17.1^{b}
Total mean height	**374 ± 128.7^{ab}**	**190 ± 170^{a}**	**640 ± 145.1^{b}**