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A cross sectional comparison of chemical treatment on plant biodiversity at Neudamm farm, Namibia

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Abstract

This study determined the impact of Tebuthiuron application on plant biodiversity over three years at Neudamm farm. A total of 36 quadrats (1 m x 1 m) were collected from three belt transects (50 m x 5 m) per each treatment to record the grasses plant density, species composition, dry matter and ground cover. Woody plant density, heights and canopy diameters were measured in each belt transects (50 m x 5 m). A General Linear Model (GLM) procedure of SAS (2007) was used for analyses. The herbaceous biomass production was significantly higher ($P < 0.05$) in the chemically treated site of 2015 (975 Kg DM ha^{-1}) and least in the other two sites. The chemically-treated site of 2016 had more significant ($P < 0.05$) ground cover percentage than the other treatment sites. The canopy cover and woody plant densities in all woody height categories were higher ($P < 0.05$) in control and chemically treated site of 2017 than the other two sites. The study concluded that the Tebuthiuron had impacted on the plant biodiversity of treated rangelands by improving the grass plant species, biomass yields and reduced bush density. The study recommends that aftercare practices and application of arboricides be carried out routinely to allow herbaceous plants recovery.

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

1. Introduction

Land degradation is a complex phenomenon in Africa (Klintenberg and Gustad, 2002). About 60% of the arid and semi-arid savanna rangelands are degraded (Du Preez et al., 2003) and degradation poses a risk to the ecosystem integrity of these fragile dryland environments (UNDP et al., 2005). One of the most visible forms of savanna rangelands degradation is bush encroachment, which is referred to as the invasion and

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thickening of aggressive indigenous woody species resulting in an imbalance of grass to bush ratio, a decrease in biodiversity and carrying capacity (Wiegand et al., 2005; Von Oertzen, 2009; Rohde and Hoffman, 2011). Bush encroachment also reduces the growth and reproduction of individual plants (Rohde and Hoffman, 2011; Kgosikoma, 2013). The vegetation abilities to compete for space, moisture and nutrients needed for growth and reproduction have for decades been considered as an environmental and economic problem of rangelands in Southern African countries (Skarpe, 1991; Ward, 2005). In Namibia, bush encroachment is a severe environmental and economic threat (Meik et al., 2002), which results in loss of natural resource productivity, loss of agricultural productivity and land degradation. About 67% of Namibia land surface is affected by bush encroachment, which disturbs multiple ecosystems and land uses with up to N$1.7 billion annually, as a result of income losses from reduced beef production on commercial rangelands (De Klerk, 2004; SAIEA, 2015) over which 65% of the National Agriculture Output is produced.

Bush encroachment has adverse effects on livestock production, as a result of the loss of grass production on grazing lands (Woiters, 1994). An estimated 30 to 45 million hectares of Namibia are bush encroached. The main encroaching species are *Senegalia mellifera* (Black thorn) in the central parts of Namibia, *Dichrostachys cinerea* (Sickle bush), *Terminalia sericea* (Silver terminalia), *Terminalia prunioides* (Purple-pod terminalia), *Vachellia erubescens* (Blue thorn), *Vachellia reficiens* (False umbrella thorn) and *Colophospermum mopane* (Mopane) in the northern part of Namibia (SAIEA, 2015). In Namibia, 70% of the country's agricultural output is mainly produced from commercial rangeland of which two-third of the country's population, directly and indirectly, depends on agricultural products for economic well-being primarily through income generation (MAWF, 2009). The generation of profit through cattle farming is under the restriction of the escalation of bush encroacher species, causing a reduction in income generation within the rangelands (Espach, 2006). Bush encroachment is not a permanent phenomenon; therefore, a savannah ecosystem could be changed to its grass-dominated state by favourable management (Doughil et al., 1999; Van Eck and Van der Merwe, 2004).

Reactive interventions such as chemical treatment, mechanical and biological control methods are common in combating bush encroachment in Namibia (De Klerk, 2004; Joubert, 2014).
The use of chemical treatment as a way of combating bush encroachment seems to be the most effective and promising since it is easy to use and the reaction is quick although it has some drawbacks (Francina and Smit, 2006). Arboricides such as Tebuthiuron and Bromacil are readily available in Namibia, and these chemicals have active ingredients that are most effective when applied on the surface of the soil to be absorbed later by plant roots. In rangelands, particularly in commercial farming systems, Tebuthiuron based arboricides are commonly used in controlling the invasion of bush encroacher species such as *Senegalia mellifera* (De Klerk, 2004). According to Hatzios et al. (1980), the use of Tebuthiuron in bush control is significant since it is a non-selective inhibitor of photosynthesis. Furthermore, the chemical can be lethal to germinating seedlings up to eight years of post-treatment, but this may depend on the factors associated with the edaphic and seed banks that are locally available in areas treated with Tebuthiuron (Joubert, 2014). Neudamm farm management has been combating bush encroachment for the past several years using chemical treatment. However, no regular rangeland assessment has been conducted to determine if the rangeland has improved in terms of increased grass species composition, density and reduced bush biomass following the chemical treatment. Hence, the objectives of the study were to determine if chemical control

of bushes has significant effects on 1) grass species composition, density, biomass and ground cover and 2) density and canopy cover of woody plants.

2. Materials and methods

2.1. Study area description

The study was conducted at Neudamm 63 Farm in the Khomas Hochland district of the Khomas Region, Namibia, located at an altitude of 1856 m above the sea level, and coordinates 22º27'02″ S and 17º21'38″ E. The Neudamm farm is about 37 km east of Windhoek and was established in 1904. It covers an area of 10 187 hectares, which are demarcated into nine blocks (A, B, C, D, E, F, G, H and I) and subdivided into 197 grazing camps.

The area has an arid to semi-arid climate with the mean annual rainfall ranging from 300 - 360 mm occurring mostly between December to March. The mean minimum and maximum temperatures range from 18 °C to 32 °C in summer, and from as low as -1 °C to 26°C in winter (Mendelsohn et al., 2002). The soil type in the study area is dominated by homogenous Lithic Leptosols and Eutric Regosols, which are generally shallow and contain very little organic matter, which has been attributed to low organic litter input and rapid mineralization (Bertram and Broman, 1999). The vegetation type in this area is categorized as highland savanna that occupies approximately 45 000 km^2 of Namibia's land area (Coetzee, 1998). The highland savanna is dominated by *Senegallia mellifera* and also characterized by shrubs and low trees, mainly *Senegalia and Vachellia* species. The undisturbed rangelands consist of climax grasses such as *Anthephora pubescens, Schmidtia pappophoroides, Brachiaria nigropedata, Heteropogon contortus, Cymbopogon species* and *Digitaria eriantha* (Joubert, 1997).

2.2 Site selection and layout

Neudamm farm was selected for this study, because the farm offers pre-existing ideal conditions, as a result of its previous rangeland manipulation, which is part of the farm management. Before data collection, a preliminary study of the chemically treated sites in different consecutive years was conducted on the farm. The study utilizes two camps (Camp 5 (26 ha) and Camp 6 (31 ha), in block D that is utilized by small stock and had three chemically treated sites in three consecutive years (2015, 2016, 2017) and an untreated camp (control). The selected sites were homogeneous, in terms of vegetation structure, as well as topography. These sites were chemically treated with Bush-Whacker GG (Bromacil 200g/kg) which was manually applied at the stems of the *Senegalia mellifera* woody species. Granules of about 25 grams for small shrubs and 50 grams for big shrubs were applied underneath, at the base of the encroacher species not more than 30 cm from the encroacher species' base. The selected camps were used for open grazing of sheep and goats. The carrying capacity of the chemically treated sites was estimated as follows: 2015 (17 ha SSU^{-1}), 2016 (13 ha SSU^{-1}), 2017 (6 ha SSU^{-1}) and the untreated (8 ha SSU^{-1}). The study was conducted at the end of the rainy season (summer) in April - May 2018.

2.3 Data collection

2.3.1 Grass species composition assessment

Three belt transects of the size 50 m x 5 m each was laid in each study camp. Grass species composition was determined from 50 points within each belt transect in the three chemically treated sites, treated in 2015, 2016 and 2017 and untreated camp (control) using a step point method (Hardy and Walker, 1991). The nearest plant and basal strikes were recorded from 50 points of observation per belt transect. Based on range monitoring and evaluation principles, the sample size of 250 observations is deemed adequate for reliable, detailed scientific studies in semi-arid savannas (Hardy and Walker, 1991; Chmura and Salachna, 2016). If the tip of the 1 m metal rod struck on a tuft of the grass plant, it was recorded as a basal strike. When the distance of the nearest plant was further than 30 cm from the marked step point, it was recorded as ‘bare ground’. Point observations were spaced at approximately 1 m intervals, and records were made over the length of the belt transect once.

2.3.2 Grass plant density and biomass

1 m^2 quadrat was used to estimate density, cover and biomass of the grasses in all the four sites. A total of 36 quadrats (1 m x 1 m) were collected from three 50 m x 5 m transects at an interval of 3 m, in each camp. A total of 144 quadrats were assessed for the four sites. In each quadrat, all grass plant tufts were identified, counted and clipped at about 10 cm stubble height. The grass species that could not be identified were prepared and taken to the National Herbarium of Namibia in Windhoek. All herbaceous plant materials were air-dried in a warehouse for ten days until completely dry, and the dry matter yield was determined.

Grass species were classified based on their palatability and ecological status using secondary sources of information. The classification of grasses was based on the succession theory described by Dyksterhuis (1949), for the ecological information of the arid and semi-arid areas (Tainton et al., 1980; Vorster, 1982). The species were grouped into (i) highly desirable species: those which occur in rangeland in good condition and decrease with overgrazing (decreasers); (ii) moderately desirable species: those which occur in rangeland in poor condition and increase with slight and moderate overgrazing (increaser IIa and IIb), and; (iii) less desirable species: those which occur in rangeland in poor condition and increase with severe/extreme overgrazing (IIc). Grass species were also grouped into their life forms (annuals and perennials). Plant identification was made in the field and species that could not be identified in the field, a full-plant sample with inflorescences and other vegetative parts were collected, prepared and taken to the National Herbarium of Namibia in Windhoek for further identification.

2.3.3 Woody vegetation

All live woody plants within each of the 250 m^2 belt transects (50 m x 5 m) in all four sites were recorded and counted for the estimation of the woody plant density. Plant height and canopy diameters were measured for each woody plant. When multiple stems occurred in the belt transect, an arbitrary decision was made to count a stem as a separate individual. The classification of woody species was made based on the description by (Curtis & Mannheimer, 2005). All woody plants of height >0-1 m were grouped as seedlings; >1–2 m as saplings or young shrubs; >2–3 m as young trees; and >3 m as mature trees. Canopy diameter of every woody plant was measured along two axes (length, L, and width, W) perpendicular to each other. Percentage canopy cover was calculated using the formula: Percentage canopy cover = $(n\pi r^2)/(2.5)$, where n is the number of woody plants and r^2 is equivalent to $LW/4$ (Beyene, 2015). Woody plant data were standardized to tree equivalent (TE ha^{-1}) (1 TE = 1 tree, 1.5 m high) (Teague et al., 1981).

2.4 Data analysis

The plant vegetation data were analysed using a General Linear Model (GLM) procedure of SAS (2007). The density, biomass and ground cover of grasses, density and canopy cover of woody plants data were subject to a two-way analysis of variance to test variations between different treatment sites. Means were separated following the PDIFF option of the least-squares means statement of the GLM procedure of SAS. The Kruskal-Wallis test was also used to test the null hypothesis that had no significant differences between the median values of the woody canopy cover and grass cover, and the test was done to compare the sites that were treated in 2015, 2016, 2017 and no treatment site (Ashcroft and Pereira, 2003). For grass species composition that did not require analysis, simple descriptive statistics and percentages were used where appropriate.

3 Results

3.1 Grass species composition

A total of 20 grass species were identified in all the four sites. Out of all these, 55% were perennials, and the remaining 45% were annuals (Table 1). Grasses were classified into desirability groups, following Tainton et al. (1980) and Vorster (1982) methods. Three species were classified as highly desirable, six as moderately desirable and 11 as less desirable species (Table 1). Based on ecological grouping, only five species were categorized as decreasers, and all others were increaser species

3.2 Total grass tuft density (ha)

There was a significant difference ($P < 0.05$) in the total grass tuft density of sites treated in different years (Table 2), with the mean total grass tuft density being significantly higher ($P < 0.05$) in control site (31 ha) and lower in the chemically treated site of 2016 (21 ha). The other chemically treated sites of 2015 and 2017 had greater grass tuft density ($P < 0.05$) than the chemically treated site of 2016. However, the grass tuft density was no significantly different ($P > 0.05$) between sites treated in 2015 and 2017.

Table 1. Life forms, desirability, ecological grouping and grass species composition (%) in all four sites.

Species	Life form (Desirability)	Ecological status	2015 %	2016 %	2017 %	Control %
Anthephora pubescens	P (HD)	Dec	-		0.2	0.2
Aristida adscensionis	A (LD)	Inc IIc	-	0.9	-	-
Aristida congesta	A (LD)	Inc IIc	-	3.9	7.6	4.3
Aristida meridionalis	P (LD)	Inc IIc	12.1	14	22	41.2
Aristida stipitata	P (LD)	Inc IIc	-	0.5	-	-
Cenchrus ciliaris	P (HD)	Dec	-	-	1.7	3.3
Chloris virgata	A (LD)	Inc IIc	-	3.5	-	0.1
Enneapogon cenchroides	A (LD)	Inc IIc	-	3.5	3.8	0.2
Eragrostis annulata	A (LD)	Inc IIc	0.8	0.3	-	-
Eragrostis echinochloidea	P (MD)	Inc IIb	-	0.4	-	-
Eragrostis lehmanniana	P (MD)	Inc IIb	-	-	0.6	0.2
Eragrostis trichophora	P (MD)	Inc IIb	14.6	6.8	2.9	1.6
Heteropogon contortus	P (MD)	Dec	-	0.7	0.3	2.2
Melinis repens	A (LD)	Inc IIa	44.5	31.7	19.6	16.8
Microchloa cafra	P (LD)	Inc IIa	-	-	21.2	11.9
Pogonarthria fleckii	A (LD)	Inc IIc	1	0.2	1.8	-
Pogonarthria squarrosa	A (LD)	Inc IIc	0.9	3.9	-	1.4
Schimidtia pappophoroides	P (HD)	Dec	4.8	10.1	0.6	-
Schimidtia karahariensis	A (LD)	Inc IIc	5.8	8.1	10.2	3.2
Stipagrostis uniplumis	P (MD)	Dec	4	2.4	0.4	0.1

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

Table 2. Total grass tuft density (ha)

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

3.3 Grass species dry matter production

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

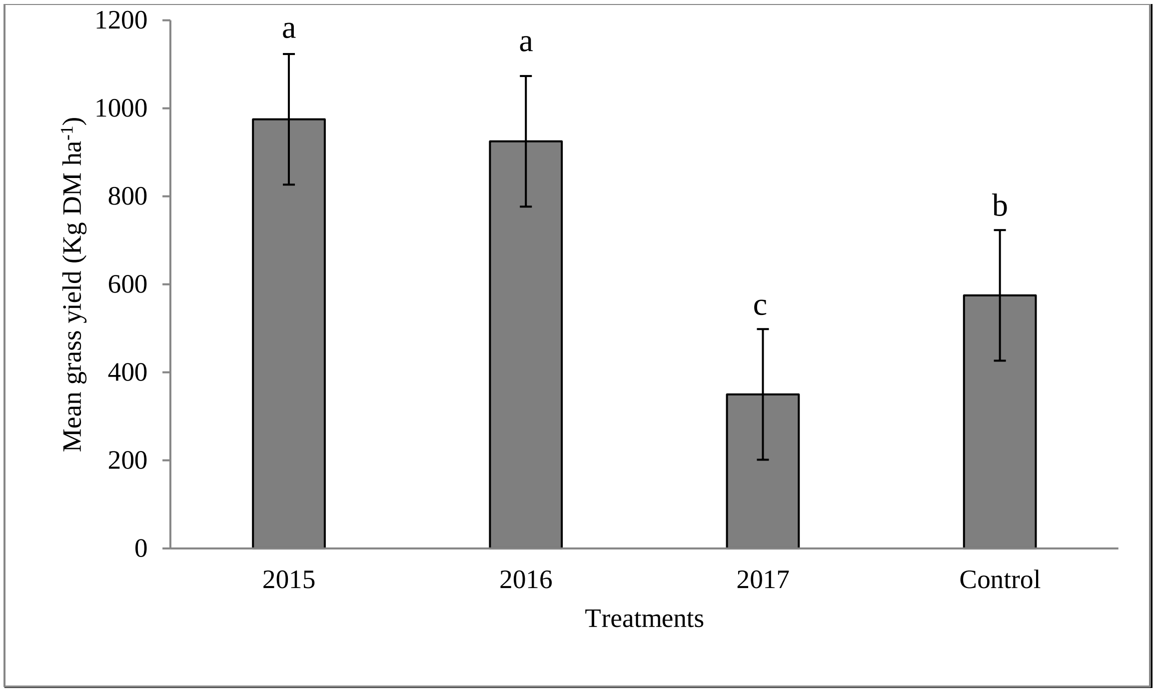

Figure 1. Mean grass dry matter yield (Kg DM ha^{-1}) of all four study sites. Means with different superscripts on the bars differ significantly ($P < 0.05$).

3.4 Ground cover (%)

The chemically-treated site of 2016 had significantly greater ($P < 0.05$) ground cover percentage than the other three treatment sites (Figure 2). However, the chemically-treated site of 2017 and the control had significantly lower ($P > 0.05$) ground cover percentages.

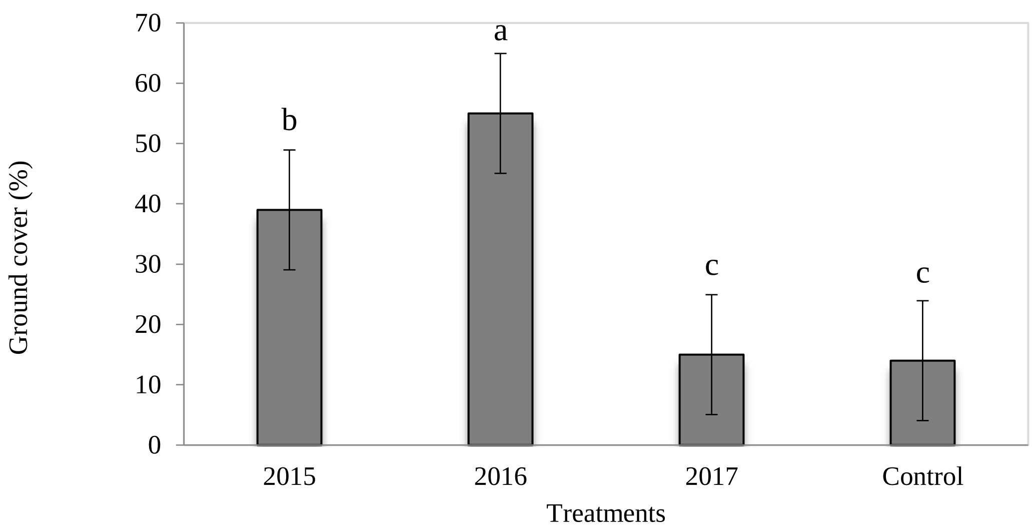

Figure 2. Mean ground cover (%) on the four study sites. Bars indicate standard errors of the means. Means with different superscripts on the bars differ significantly ($P < 0.05$).

3.5 Total woody plant density and canopy cover %

The total woody plant density was significantly higher ($P < 0.05$) in control (untreated site) (14160 TE ha^{-1}) than in the three different chemically treated sites of 2015 (1240 TE ha^{-1}), 2016 (5600 TE ha^{-1}) and 2017 (5560 TE ha^{-1}) (Figure 3), respectively.

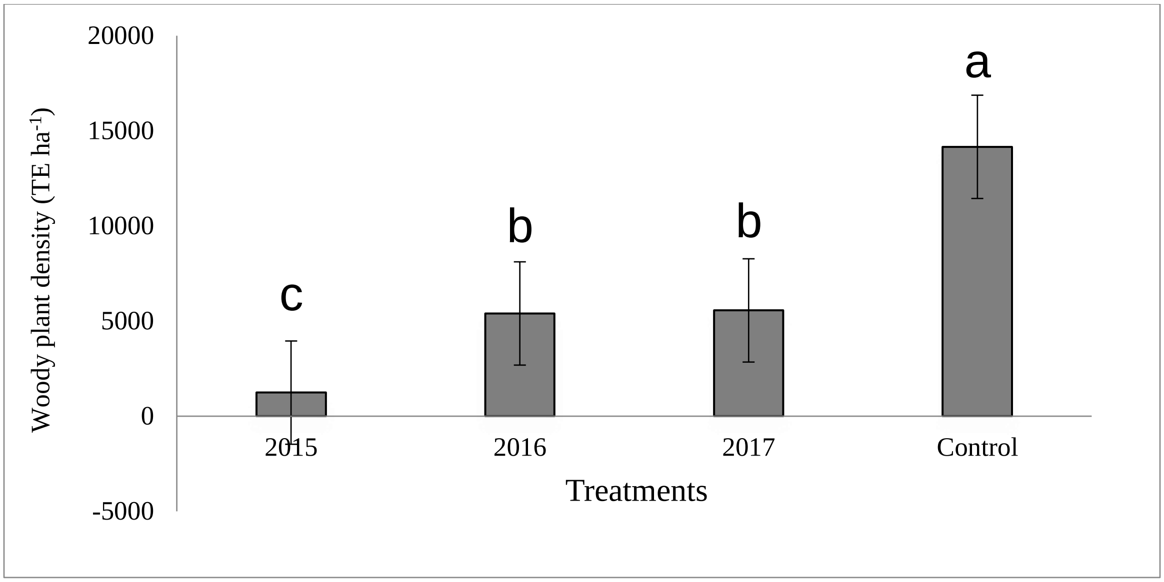

Figure 3. Total woody plant density (TE ha^{-1}) in all four study sites. Bars indicate standard errors of the means. Means with different superscripts on the bars differ significantly (P < 0.05).

The percentage of canopy covers of the chemically treated site of 2017 and the control were similar (P > 0.05) (Figure 4), but significantly higher than the canopy cover percentages of the chemically treated sites of 2015 and 2016 that were not statistically different (P > 0.05).

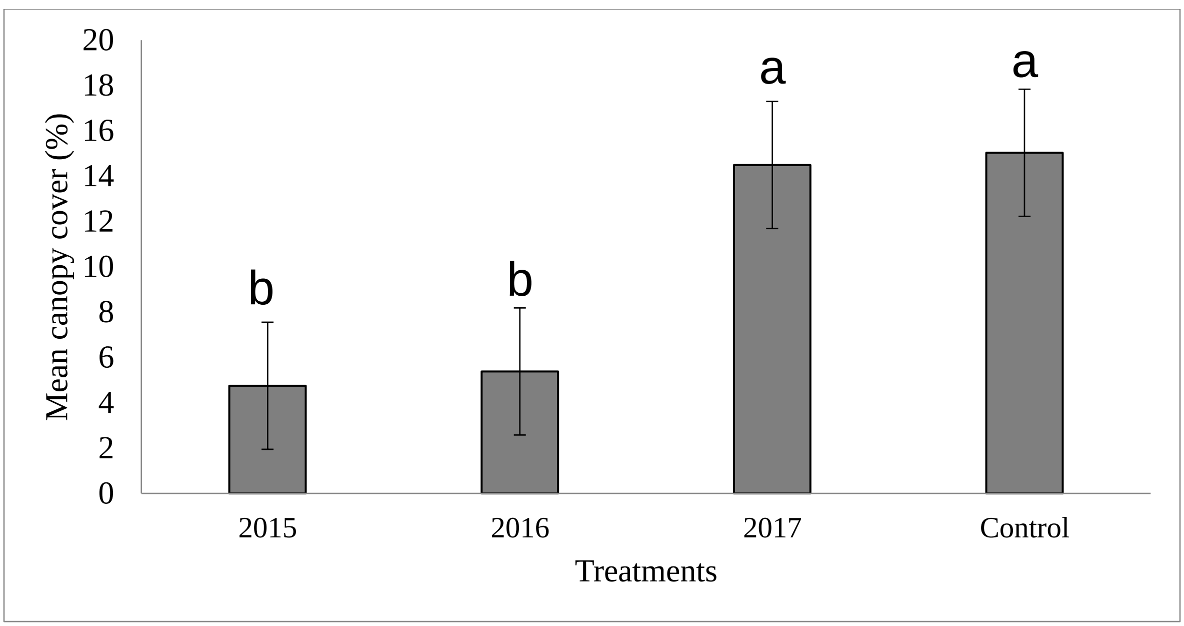

Figure 4. Mean canopy cover (%) in the four study sites. Bars indicate standard errors of the means. Means with different superscripts on the bars differ significantly (P < 0.05).

3.6 Woody plant height class distribution

There was a significant difference (P < 0.05) between all four treatment sites (Table 4). The control had the highest woody plant densities in all woody height categories, followed by the chemically treated site of2017 than the other two treatments. The 2015 and 2016 chemically treated sites had no ($P > 0.05$) woody plant density records under the heights of >2 – 3 m and > 3 m categories.

Table 3. Densities (mean ± SEM) of woody height classes in the four study sites

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

4. Discussion

4.1 Grass species composition

The study found that, out of the twenty plant species that were identified, 55% were perennials, and the remaining were annuals. The higher percentage of perennial grass species could be attributed to the removal and control of bushes that opened up spaces, which boosted the germination and the vegetative growth of various grasses on the treated rangelands. The results of the current study are consistent with the study by Tainton (1999), which accentuated that the removal of bushes could hastily boost the recovery and growth of various grasses on the rangeland.

It is important to note that classifications of grass species into the desirability and ecological categories rely mostly on the qualities of species concerning their life forms and acceptability. The higher proportion of decreaser species in the chemically treated sites of 2015 and 2016 could be associated with enhancement and manipulation of rangeland management. The finding of this study is in agreement with the study of O'Connor (1991), who reported that ecologically decreaser species are the essential critical species in the semi-arid rangelands of southern Africa and good indicators of the health status of rangelands. The lower percentages of decreasers species in the treated site of 2017 and control may be an indication of the low health status of these rangelands, as increaser species are generally associated with rangeland degradation.

This study is supported by Solomon et al. (2007), They indicated that a decrease in decreaser species had been commonly reported to occur as a response to bush encroachment and heavy grazing. These findings are in agreement with the study of Smet and Ward (2005), who showed that variations in grazing pressure and rangeland history could be the primary factor that influences the composition of grasses and forbs in semi-arid rangelands of southern Africa. In agreement with the findings of this study, Tainton (1999), stated that increasers (less palatable grass species) might not be grazed and increase if they are not over-utilized in the rangeland.

4.2 Grass tuft density, dry matter production and cover

The significantly higher means of total grass tuft density in the control site could be attributed to a higher density of small tufts of annuals and perennials that inhabit denuded rangelands. The study results were in agreement with the study of Kahumba (2018), which indicated that grass species such as *Aristida meridionalis*, *Pogonarthria fleckii*, *Pogonarthria squarrosa Aristida congesta*, *Chloris virgata* could be abundant in degraded rangelands, because they are hardy grasses with low leaf production and maybe poorly utilised by livestock if there are abundant forage choices from which animals could select, especially during the rainy season. The lower mean total grass tuft density in the chemically treated site of 2016, could be associated with recurrent drought situations and overgrazing coupled with low soil fertility and minerals due to leaching and runoff. These findings were comparable to studies of Tainton (1999) and O'Connor (1991), who indicated that retrogression of the grass component is expected in the savanna rangelands and inevitably reduces the productive capacity of savanna rangelands for herbivores grazing.

The significantly higher grass dry matter in the chemically treated sites of 2015 and 2016 and least in the other two sites could be because of the differences in the defoliation rate in different rangelands. Low herbaceous biomass in rangelands is associated with high grazing intensities that could have led to the decreased standing biomass, as more biomass is consumed by livestock and this is consistent with the findings of (Kahumba, 2010; Solomon et al., 2007). Conversely, Tainton (1999) is in support of the current study by highlighting that a decline in the condition of the grass layer is typically accompanied by the increase in the density of encroacher bushes. The significantly greater grass cover percentages in the chemical treated sites of 2016 and 2015 could be attributed to grass species that had more extensive and broad tufts that could protect and prevent the top-soil from being blown away by wind and washed away by the rainwater. The current study findings concurred with the study of Angassa (2002), which stressed that the ground coverage with broad and more extensive herbaceous layers reduces the level of soil erosion on the rangeland, which enables the soil to retain its nutrient contents. Generally, grass biomass increased with time from the date of chemical treatment, as the sites that were treated earlier had more years to recover after treatment than the site that was treated in 2017.

4.3 Total woody plant density and canopy cover (%)

The significantly higher total woody plant density in the untreated site than in the three chemically treated sites could be associated with bush encroachment of the highland savanna of Namibia, particularly by *Senegalia mellifera.* The findings of this study were consistent with O'Connor and Watkinson (2001) who revealed that rangeland degradation in the form of bush encroachment causes major ecological transformations of savannah ecosystems grazed by livestock, and the consequent bush encroachment negatively impacts on the livelihoods of farmers. Similarly, Abule et al. (2005) and Solomon et al. (2006)

indicated that overgrazing due to overstocking had been frequently reported as the significant anthropogeniccause of rangeland degradation, which necessitates opportunities for encroacher bushes. The lower woody densities in the chemically treated sites reflect the effectiveness of arboricides in the killing the bushes. The study found that the percentage of canopy cover was higher in control (untreated site) and chemically treated site of 2017. This could be attributed to living standing woody plant densities, which could vertically provide comprehensive coverage and protection of the soil surface under the crown as ascribed by (Solomon et al., 2006).

4.4 Woody plant height classes distribution

The control had the highest woody plant densities in all height categories. The higher woody plant densities in the chemically treated site of 2017, could be due to that treated woody plants were still in the process of dying back. The study revealed that further recruitment of seedling and bushes in control was increasing and could in the future result in advanced and severe bush encroachment, which would be impermeable to grazing livestock (Kahumba, 2010). This is in agreement with studies of Friedel (1985) and Solomon et al. (2007), who reported that the supremacy of small size growing plants, particularly seedlings and saplings in rangelands of southern Africa signifies the suppression of the herbaceous plant production, which demonstrates the competitive ability of woody plants at an early stage.

5. Conclusion

Based on the findings of the current study, chemical treatments have impacted on the plant biodiversity of the treated rangelands by improving the grass density, increased biomass yields and reduced bush density. The woody plant density and height categories were drastically lowered in the treated sites of 2015 and 2016. There was an indication of the need for aftercare to control the recruitment of seedlings and saplings. This study, therefore, concludes that there is a significant difference in woody plant density in chemically treated sites compared to the untreated (control) site. Based on the study results, it is recommended that there should be a regular assessment of rangeland conditions at Neudamm farm, especially after arboricides application, as this will provide information to the farm management to improve the management of the farm and decision making. Arboricides application should be well planned in order to accommodate treatment and resting cycles of affected areas so that the treated areas should be rested for at least two rain seasons to provide perennial grass species with an opportunity to recover and replenish good seeds and stabilize growth. Furthermore, bush thinning through the use of chemical treatment should not be considered as a once-off operation; hence, aftercare measures and continuous monitoring of the rangeland are recommended. The outcomes of the study can be applied to similar environments, with similar problems.

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Disclosure of conflict of interest

The authors declare no conflict of interest.

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