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Influence of Tree Density on Vegetation Composition and Soil Chemical Properties in Savanna Rangeland of Eastern Cape, South Africa

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Abstract

The proliferation of woody species alters the vegetation structure, leading to loss of rangeland productivity. It aimed to assess the influence of tree density on vegetation and soil chemical properties at three levels of encroachment; open, moderate and dense. Each level of encroachment was replicated 3 times, a 5000 m² plot was marked per replicate. Four belt transects 200 m² were placed per plot. Woody species within each belt transect per replicate were identified and recorded to evaluate woody species composition. Grass species composition was assessed using a step point method. Soil was sampled per replicate and analysed for chemical properties. Results showed that 71% of grasses were increasers and 29% decreasers. *Digitaria eriantha* and *Eragrostis obtusa* were the most dominant species. *Vachellia karoo* and *Aloe ferox* were the most dominant woody species. The dense had high nitrogen (1.48%) compared to the moderate (0.23%) and the open (0.17%). Increaser species, soil carbon, soil pH increased with the increase of tree density. It was concluded that the replacement of highly palatable grasses with inferior ones was due to improper rangeland management practices. It was recommended that land users form rangeland management associations and set up conservation agreements for proper management of resources.

Keywords

Encroachment, Composition, Density, Rangeland

1. Introduction

Savannas are described as biomes with continuous herbaceous vegetation strata and discontinuous trees or shrubs strata [1]. This biome covers 33% of the surface area of South Africa [2], delivers a wide range of ecosystem services to humans and supports a wide variety of *flora* and *fauna* [3]. Tree-grass interactions in rangeland ecosystems have had a lot of attention from researchers [4]. Tree-grass co-existence is a widely and often controversially discussed concept [5]. Walter's two-layer hypothesis has been used to clarify tree-grass co-existence. Walter's hypothesis proposed that tree roots occupy the surface and deeper layers of the soil whereas grass roots only occur on the top layer [4].

[4] reported that, if the grass layer is over-utilized, it loses its competitive advantage over trees and can no longer use water and nutrients efficiently, thus, leading to a higher water infiltration rate and moving nutrients into the subsoil. This benefits woody plants, allowing them to encroach or dominate in rangeland ecosystems [4]. In South Africa, savanna rangelands ecosystem services have declined as a result of encroachment [6]. Tree encroachment is defined as the thickening of aggressive undesired woody species resulting in an imbalance in the grass to tree ratio which results in a decline in biodiversity and carrying capacity [7]. This phenomenon is associated with the mismanagement of rangelands through overgrazing, suppression or exclusion of fire and the activities of browsers [8].

Tree encroachment is estimated to affect approximately 10 - 20 million hectares of South African rangelands [6]. This is expected to deteriorate over time [9]. Tree encroachment suppresses the growth of grasses and other herbaceous species, thus reducing rangeland productivity [7]. Proliferation of trees in savanna rangelands of the Eastern Cape in South Africa is alarming [10]. However, the effect of such encroachment on the condition and productivity of rangelands in the Eastern Cape Province of South Africa has not been documented. The study aimed to assess the effect of increasing tree density on 1) woody plant composition, 2) grass composition, and 3) soil chemical properties.

2. Material and Methods

2.1. Site Description

The investigation was carried out at Sheshegu communal grazing lands located in Alice Raymond Mhlaba Local Municipality of the Eastern Cape, South Africa (Figure 1). The area is located at coordinates of 32°55'39.30"S, 26°49'30.53"E with an elevation of 544 m. The region has a semi-arid climate and mean annual precipitation ranges from 450 - 600 mm, concentrated in the spring and summer [2]. The mean annual temperatures range from 6.3°C to 25°C. Sheshegu communal rangelands are shared by members of the community and grazed continuously with no restrictions on stocking rates. The vegetation in the area has been classified as Bhisho Thornveld vegetation type [2]. The tree layer in the

study area is dominated by trees and the grass layer. The soils are predominantly mudstone with subordinate sandstone of the Adelaide group and substrate being primary loamy soils [2].

2.2. Experimental Layout and Sampling

In October 2014, vegetation and soil sampling were carried out in a 5 ha tree-encroached in Sheshegu communal rangeland. According to [2] Sheshegu communal rangeland forms part of the Bhisho Thornveld. The study site was chosen based on vegetation uniformity and similar land use which was mainly for grazing and browsing. Tree density, which is an estimate of the number of individual trees per plot was used to categorize the study area into three tree-encroachment levels as follows: Open (1425 trees/hectare), moderate (2288 trees/hectare), and dense (3300 trees/hectare). In each tree-encroachment level, a 100 m × 50 m plot was marked. Four belt transects (100 m × 2 m) were placed per plot with 15 m distance apart.

2.3. Vegetation Sampling

All woody plant species occurring within each belt transect per tree encroachment level were identified, counted and recorded to evaluate woody plant species composition. Within each belt transect, species composition was evaluated using the step point method along the encroachment gradient [11]. A metal rod was lowered every two steps and herbaceous species nearest to the point were identified. In each belt transect, grasses were identified to species level using the method of [12] other herbaceous plant species were also identified and recorded.

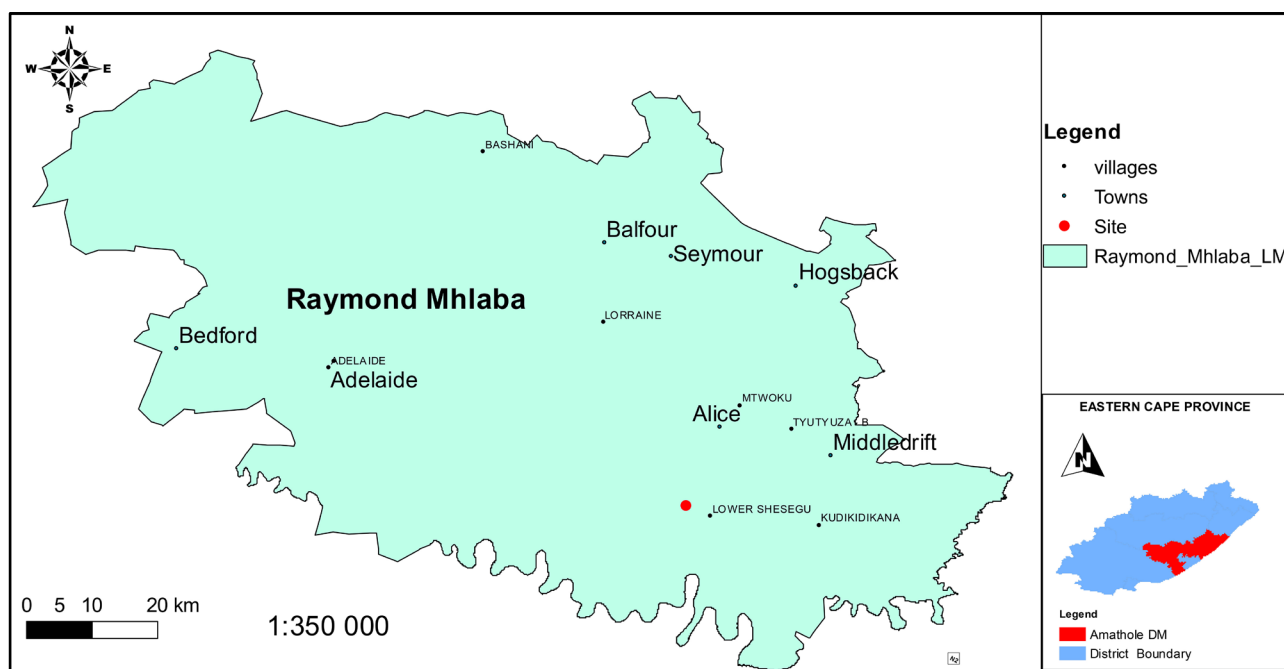


Figure 1. The map of the study site in Raymond Local Municipality under the Amathole District.

Grass species were later grouped into 1) Decreaser species, 2) Increaser I species and 3) Increaser II species using the procedure of Trollope (1989). Grass species were also grouped into annuals and perennials [13].

2.4. Soil Sampling and Analysis

In each belt transect, five soils samples were randomly collected at a depth of 0 - 10 cm. Soil samples were oven-dried for 48 hours at 60°C and milled to pass through a 2 mm sieve. Soil samples were analysed for macro-elements as nitrogen (N), magnesium (Mg), potassium (K), phosphorus (P) and soil organic carbon (OC), microelements zinc (Zn), manganese (Mn), copper (Cu), iron (Fe) and soil pH. Available soil P, Mg and K were determined by the Inductively Coupled Plasma analysis of soil with 1% critic acid [14]. N was determined by using the standard Kjeldahl method using a block digester [15]. OC was analysed using the Walkley-Black method [16]. Zn, Mn and Cu were determined by using Inductively Coupled Plasma in 0.02 M DI-ammonium EDTA (ethylenediamine-tetraacetic) acid soil extracts [14]. Soil pH was determined in 1M potassium chloride (KCL) [14].

2.5. Statistical Analysis

A general linear model procedure of the Statistical Analysis System (SAS, 2009 version) was used to compare the effect of tree encroachment on soil properties along the encroachment gradient [17]. Significant mean differences ($P \leq 0.05$) between tree encroachment levels were separated using the least significant difference (LSD) at ($P \leq 0.05$). Description statistics were employed where appropriate.

3. Results and Discussion

3.1. Woody and Grass Species Composition along Encroachment Gradient

Seven dominant grass species were identified, 71% were increasers and 29% decreasers grass species (Table 1). In terms of grazing value grass species contribute 14% of medium, 42% both (high and low) but, all were perennials (Table 1). *Digitaria eriantha* (open: 34%, moderate: 23%, and dense: 15%), *Eragrostis obtusa* (open: 21%, moderate: 19%, and dense: 35%) and *Eragrostis chloromelas* (open: 18%, moderate: 18%, and dense: 12%) showed high percentage of relative abundance compared to other grass species (Table 1). Open had more decreasers species compared to moderate and dense, respectively. This indicated that the frequency of *Digitaria eriantha* and *Themeda triandra* decline with the increase of tree density, except for *Panicum maximum*. Similar results were reported by [18], who demonstrated that an abundance of decreasers species in an openly encroached site is an indicator of the good condition but their proportion decline as encroachment worsens.

Table 1. Relative abundance (%), ecological status, grazing value and life form of grasses in open, moderate and dense tree encroached rangeland.

Species	Ecological Status	Grazing Value	Life form	Open	Moderate	Dense
				Relative abundance (%)		
<i>Aristida congesta</i>	Increaser II	Low	Perennial	5	8	11
<i>Digitaria eriantha</i>	Decreaser	High	Perennial	34	23	15
<i>Eragrostis obtusa</i>	Increaser II	Low	Perennial	21	19	35
<i>Eragrostis chloromelas</i>	Increaser II	Moderate	Perennial	18	18	12
<i>Panicum maximum</i>	Decreaser	High	Perennial	2	10	16
<i>Sporobolus africanus</i>	Increaser II	Low	Perennial	6	12	3
<i>Themeda triandra</i>	Decreaser	High	Perennial	14	10	8

Dense had a high percentage of *Aristida congesta* and *Eragrostis obtusa* compared to moderate and open, respectively (Table 1). These results indicated that *Digitaria eriantha* and *Themeda triandra* declined with an increase in tree density. The gradual decline of these species at dense and moderate tree densities could be a result of continuous grazing, competition between grasses and trees in terms of soil resources. Loss of decreaser species was a clear indication of veld deterioration due to negligence of veld management practices by farmers. Van Oudsthoon (1992) argued that decreaser species can only dominate in good veld condition but could decline because of selective grazing, climate factor, overutilization and manipulation of veld management practices. Overutilization and exclusion of prescribed burning and browsers can accelerate the change of grass species to woodland [19].

These results well compared to that of [4], who states that if grasses are over-utilized they lose its competitive advantage and can no longer use soil resources efficiently. Dense tree density had more *Panicum maximum* compared to open and moderate, the abundance of this species in dense tree density could be influenced by its tolerance to shading effect. *Panicum maximum* maintained higher soil resources potentials and was adapted to water stress in the shaded habitat compared to *Themeda triandra* [20]. This study showed that an increase of tree density favours the abundance of less palatable at the expense highly acceptable. The loss of perennial plants arises from the fact that perennial species are more sensitive to overgrazing. Overutilization of grasses promotes the removal of the apical meristems through overgrazing may limit the regrowth grasses [21].

The gradual replacement of decreasers by increasers at dense and moderate densities could be influenced by veld management practices in particularly uncontrolled grazing and competition of water and soil nutrients. Mismanagement of veld management practices such as uncontrolled grazing might cause a replacement or complete disappearance of palatable species with less palatable ones [22]. Similar results reported by [21], who noted that there is a gradual shift

of plant species composition consequently strong perennials could be replaced by weak perennials such as *Aristida congesta*.

3.2. Woody Species Composition along Encroachment Gradient

In this study, six dominant woody plant species were identified, 42% were acceptable (*Vachellia karoo*, *Erehia Rigida* and *Maytenus polycantha*) and 58% unacceptable (*Grewia occidentalis*, *Diospyros lycioides*, *Aloe ferox*, *Coddia rudis* and *Lucas capensis*) to browsers (Table 2). Unacceptable woody plant species might increase in their abundance and such can result in reduced carrying capacity. [23] demonstrated that survival of unpalatable woody species could lead to more recruitment. [24] suggested that tree management must be the main focus, rather than financial benefits of the controlled woody plants.

Vachellia karoo (open: 46.0, moderate: 62.2, dense: 63.8) was dominant species followed by *Aloe ferox* (open: 6.0, moderate: 1.5, dense: 3.3) and *Coddia rudis* (open: 4.3, moderate: 2.0, dense: 4.5), respectively. Mean abundance of *Aloe ferox* and *Coddia rudis* were significantly different whereas *Vachellia karoo* was not different. Abundance of *Vachellia karoo* across all levels of tree densities could be caused by climatic factors such as drought and rangeland management practices. [25] demonstrated that overgrazing and frequent burning of grasses have a positive influence on the recruitment of *Acacia* species and scarifying of woody plant seed through fire. Rainfall availability may also play a major role in the colonization of woody plants [26].

The proliferation of woody plants in communal grazing lands may have influenced by free access to rangeland resources. Moreover, [25] suggested that increased colonies of woody plants may be ascribed to low densities of grasses competing against trees. High grazing pressure due to uncontrolled grazing is the key determinant of trees invasion because it creates an opportunity for colonization, thus, permitting woody recruitment in grass-dominated ecosystem.

3.3. Soil Chemical Properties along the Encroachment Gradient

Dense had high concentration of nitrogen (1.48%) followed by moderate (0.23%)

Table 2. Mean $\pm$ SE abundance of common woody species in open, moderate and dense tree encroached rangeland.

Species	Acceptability	Thorns	Open	Moderate	Dense
<i>Vachellia karoo</i>	+	+	46.0 $\pm$ 3.3 ^a	62.2 $\pm$ 3.3 ^a	63.8 $\pm$ 3.3 ^b
<i>Aloe ferox</i>	–	+	6.0 $\pm$ 1.4 ^a	1.5 $\pm$ 1.4 ^c	3.3 $\pm$ 1.4 ^b
<i>Coddia rudis</i>	–	–	4.3 $\pm$ 1.4 ^a	2.0 $\pm$ 1.4 ^b	4.5 $\pm$ 1.4 ^a
<i>Lucas capensis</i>	–	–	4.5 $\pm$ 1.0 ^a	2.7 $\pm$ 1.0 ^b	2.5 $\pm$ 1.0 ^b
<i>Erehia rigida</i>	+	–	3.3 $\pm$ 1.3 ^a	1.0 $\pm$ 1.3 ^b	4.0 $\pm$ 1.3 ^a
<i>Maytenus polycantha</i>	+	+	2.2 $\pm$ 2.4 ^b	3.0 $\pm$ 2.4 ^a	2.0 $\pm$ 2.4 ^b

Different superscript in a row denote significant differences at ($P < 0.05$). Plus (+) denotes acceptability and presence of thorns, Minus denotes unacceptability and absence of thorns.

and open (0.17%) respectively. This study showed that soil nitrogen increases with an increase in tree density. Dense was significantly different compared to open tree density (Table 3). In agreement with [27], who reported high nitrogen concentration at dense habitat was double compared to open habitat. The abundance of soil nitrogen at dense could be attributed by triggered by in all encroached sites were dominated by the leguminous tree (*Vachellia karoo*). Correspond with [19], who stated that *Vachellia karoo* previous known as *Acacia karoo* can fix nitrogen, in so doing *Vachellia* brings additional nitrogen into soil ecosystem.

Table 3 & Table 4 indicated that there was a positive relationship between soil pH and nitrogen. Soils with acid ranged between 5 to 7 pH tend to have more nitrogen because such soil pH favours soil microbial activities and nitrogen fixation [28]. Open had less concentration of soil organic carbon (1.03%) compared to moderate (1.20%) and dense (1.27%) tree densities, respectively. Soil carbon showed no significant difference in all levels of tree densities. Soil carbon content could be influenced by the quantity of litter and rainfall, which plays a significant role in soil organic matter accumulation. [29] demonstrated that soil carbon increases from open to dense tree densities. Densely encroached tends to have high soil moisture and the accumulation of dead materials as opposed open tree density [19]. Open rangeland had fewer trees and such allow grazing animal to freely, as results of uncontrolled grazing grass layers were very sparse. Over-utilization of rangeland resources through uncontrolled grazing had a potential of reducing soil carbon because it's of impact on grass sward [30].

Open rangeland had high phosphorous concentration measured at 24.0 mg/kg

Table 3. Effect of tree encroachment on macro elements and soil organic matter in open, moderate and dense tree encroached rangeland.

BE-Level	Nitrogen (%)	Organic Carbon (%)	Potassium (mg/kg)	Phosphorous (mg/kg)	Magnesium (mg/kg)
Open	0.17 ± 0.3 ^b	1.03 ± 0.5 ^a	2.10 ± 0.4 ^a	24.0 ± 2.6 ^a	1.40 ± 0.5 ^a
Moderate	0.23 ± 0.3 ^b	1.20 ± 0.5 ^a	1.84 ± 0.4 ^b	22.0 ± 2.6 ^a	1.50 ± 0.5 ^a
Dense	1.48 ± 0.3 ^a	1.27 ± 0.5 ^a	2.20 ± 0.4 ^a	18.0 ± 2.6 ^b	1.50 ± 0.5 ^a

BE-tree encroachment; Different superscripts across the column indicate significant difference ($P < 0.05$).

Table 4. Effect of tree encroachment on micro minerals and soil pH in open, moderate and dense tree encroached rangeland.

BE-Level	Copper (mg/kg)	Iron (mg/kg)	Manganese (mg/kg)	Zinc (mg/kg)	pH (KCL)
Open	2.4 ± 0.3 ^a	123.0 ± 5.2 ^a	243.0 ± 14.2 ^a	0.85 ± 0.2 ^a	5.4 ± 0.3 ^a
Moderate	1.6 ± 0.3 ^b	117.0 ± 4.3 ^a	228.0 ± 14.2 ^a	0.99 ± 0.2 ^a	5.9 ± 0.3 ^a
Dense	1.4 ± 0.3 ^b	8.9 ± 1.3 ^b	160.0 ± 7.1 ^b	0.82 ± 0.2 ^a	6.0 ± 0.3 ^a

BE-tree encroachment; Different superscripts across the column indicate significant difference ($P < 0.05$).

followed by moderate (22.0 mg/kg), even though dense tree density showed less phosphorous content but were significantly different compared to open and moderate tree densities (**Table 3**). The study indicated that soil phosphorous concentration declines with an increase in tree density (**Table 3**). *Vachellia karoo* tends to have a suppressive effect on the abundance of phosphorous concentration [31]. [32] argued that the concentration of phosphorous can be suppressed by high calcium content in the soil. *V. karoo* have deeper lateral root system and have an advantage over grass sward to access available soil phosphorous in deeper soil profiles [1].

Dense had high potassium content (2.20 mg/kg) compared to open (1.84 mg/kg) and moderate (2.10 mg/kg) tree densities, respectively (**Table 3**). The concentration of soil potassium showed no clear trend. [33] reported a positive relationship between soil potassium and woody densities. In contradicting the results of [19], who reported that concentrations of potassium tend to be higher under encroached areas. Dense (1.5 mg/kg) and moderate (1.5 mg/kg) had the same values for magnesium concentration (**Table 3**). The magnesium concentration showed no clear trend in all levels of tree densities. Soil magnesium could be influenced by soil pH, depth and leaching rate. [34] demonstrated a positive correlation between magnesium soil content and tree density [35] reported individual woody plants tend to have high content of Magnesium and Potassium under dense trees compared to open grasslands trees.

Open had high values of copper (Cu), Iron (Fe), Manganese (Mn) (Cu; 2.4 mg/kg, Fe; 123 mg/kg, Mn; 243 mg/kg) as compared to moderate (Cu; 1.6 mg/kg, Fe; 117 mg/kg, Mn; 228 mg/kg) and dense (Cu; 1.4 mg/kg; Fe; 8.9 mg/kg; Mn; 160 mg/kg), respectively (**Table 4**). Dense tree density was significantly different as compared to moderate and open tree densities for iron and manganese. This implies that soil copper, iron and manganese content declines with increase of tree density (**Table 4**). Zinc showed no clear trend but, moderate (0.99 mg/kg) had high content of zinc compared to dense (0.82 mg/kg) and open (0.85 mg/kg), respectively (**Table 4**). [36] reported high values of micro elements at dense tree density as compared to open habitat. [24] argued that falling of tree leaves and animal excretion may contribute to high soil copper and Manganese. [35] argued that acceptable zinc (Zn) concentration for conducive environment for plant growth ranged between 0.15 to 6.56 mg/kg and such amounts cannot lead plant retardation.

Dense tree density had of value of soil pH (6.0) as compared to moderate (5.9) and open (5.4) (**Table 4**). Soil pH at open and moderate tree densities were slightly acidic as opposed to dense tree density, statistically, soil pH in all levels of tree densities were not different. [37] reported a high soil pH values in dense tree site as opposed to open habitat. *Acacia* species possessed some beneficial properties such as leaf litter which contributes positively to the increase of soil pH [38].

4. Conclusion and Recommendations

An increase of tree density has resulted in a gradual change of both herbaceous vegetation and soil nutrients. This has led to a gradual decline of grazing capacity and replacement of highly palatable grass species by less palatable ones. An increase of increasers grass species at Sheshegu communal was a clear indication of rangeland deterioration. However, uncontrolled access to rangeland resources, uncontrolled grazing and unplanned burning may influence the vegetation composition and soil properties. It is recommended that farmers should formulate rangeland rules and regulations for proper management of rangeland resources. These rules and regulations should be based on the collective management of encroaching species in terms of density and access to rangeland resources. Correct application of veld management practices such as burning, rational grazing, stocking rate is also recommended for providing good soil cover with edible perennial grass plants that ensure long-term sustainable production with maximum financial return. Further research is needed to explore the influence of veld management practices on the change of vegetation and soil nutrient content in a communal environment.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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