

# **Brush packing as a restoration technology to restore grazing capacity after bush control in the North West Province**

**J Naudé**



**orcid.org 0000-0003-1250-9894**

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Supervisor: Prof K Kellner

Co-supervisor: Prof PW Malan

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## Abstract

### ***Brush packing as a restoration technology to restore grazing capacity after bush control in the North West Province***

The Savanna Biome covers approximately 35% of South Africa's land area and is considered a precious resource which forms the foundation for livestock production and wildlife-related industries. Evidence accumulated in the past century suggests that savanna ecosystems are being altered by a phenomenon known as 'bush encroachment' which causes an imbalance in the tree/grass ratio. Bush encroachment leads to decreased biodiversity and suppressed biomass production, resulting in significant socio-economic implications on both commercial and communal scale.

The Bush Expert team of the North-West University (NWU) is conducting research, in collaboration with the Department of Environmental Affairs (DEA), on savanna restoration. The research is conducted through the Working for Water (WfW) and the Female Empowerment (FEMpower) programmes. Priority areas include areas stricken by bush encroachment, especially within communal areas.

Brush packing can be implemented as a restoration technology to restore savanna function, which involves covering the degraded soil surface with woody branches and/or other organic material, mostly collected after the control of bush encroachment. This treatment on degraded and denuded soil surfaces simulates the protective cover effect of vegetation, along with various other benefits such as alleviating high soil surface temperatures. Sample plots of 400 m<sup>2</sup> were assigned at a restoration site nearby Goodwood, a rural village situated within the Ganyesa district in the North-West Province.

Six treatments consisting of different combinations of bush clearing, re-seeding, brush packing, and soil disturbance were evaluated. The treatments were evaluated based on its ability to increase biomass production that could serve as fodder for livestock, as well as possibly lead to an increase in biodiversity. Three replicates of each of the six treatments were assigned. These included (1) uncontrolled/still bush thickened, (2) bush controlled only, (3) bush controlled and re-seeding, (4) bush controlled and brush

packing, (5) bush controlled, re-seeding and brush packing, and (6) bush controlled, soil disturbance, re-seeding and brush packing.

Experimental construction was carried out in 2017 in partnership with Land User Initiatives (LUI's) who, appointed by DEA, were tasked to clear woody species within bush encroached areas. Biomass and species data were collected in April 2018. All sample plots, which included brush packing, produced significantly more biomass than the other treatments. Treatments containing brush packing indicated improved grazing capacity by up to a 1000% in a degraded semi-arid communal savanna rangeland. Species diversity also increased within treatments containing brush packing, owing to re-seeding and the protective effect from the brush packing. Further monitoring and soil surveys showed that high soil temperature seems to be alleviated by brush packing and soil moisture content seems to also differ among sample plots containing brush packing compared to sample plots without brush packing. It is recommended that brush packing technology must be utilized in order to restore bush encroached semi-arid savanna rangelands.

**Key Words:** Bush encroachment, tree/grass ratio, biomass production, Department of Environmental Affairs, Land User Initiatives

## Opsomming

### ***Takke pak as 'n restourasietegniek om weidingskapasiteit te herstel nadat bosbeheer uitgevoer is in die Noordwes Provinsie.***

Die Savanna Bioom dek ongeveer 35% van Suid-Afrika se grondoppervlak en word as 'n kosbare hulpbron beskou wat die grondslag vir veeproduksie en wildverwante praktyke vorm. Bewyse wat in die afgelope eeu versamel is, dui daarop dat savanna-ekosisteme deur 'n verskynsel, wat as 'bosverdigting' bekend is, verander word. Bosverdigting veroorsaak 'n wanbalans in die boom/grasverhouding wat tot die afname in biodiversiteit lei asook die biomassaproduksie van weigrasse onderdruk. Dit hou beduidende sosio-ekonomiese implikasies vir kommersiële en kommunale gemeenskappe in.

Die “Bush Expert” span van die Noordwes-Universiteit (NWU) doen tans, in samewerking met die Departement van Omgewingsake (DEA), navorsing aangaande savannarestourasie. Die navorsing word deur die Werking vir Water (WfW) en die Vroue Bemagtigingsprogramme (FEM) uitgevoer. Prioriteitsareas sluit in dié wat deur bosverdigting geaffekteer word, veral binne plattelandse kommunale gebiede.

Die pak van takke kan as 'n restourasietegniek geïmplementeer word om savanna-funksies te herstel. Dit behels grondbedekking met afgekapte takke en/of ander organiese materiale. Hierdie behandeling op blootgestelde oppervlaktes simuleer die beskermende dekkingseffek wat plantegroei bied, tesame met verskeie ander voordele. Behandelings van 400 m<sup>2</sup> was by 'n restourasieterrein in die omgewing van Goodwood, 'n plattelandse dorpie geleë in die Ganyesa-distrik in die Noordwes Provinsie, uitgesit.

Ses behandelings word geëvalueer, bestaande uit verskillende kombinasies van bosbeheer, insaai van grasspesies, grondversteuring en takke pak. Die behandelings word op grond van hul vermoë om grasproduksie sowel as grasspesiediversiteit te verhoog geëvalueer. Drie herhalings van elk van die volgende is toegepas: (1) onbeheerd/nog bos verdig, (2) slegs beheer van die bos, (3) bosbeheer en insaai van grasspesies, (4) bosbeheer en takke pak, (5) bosbeheer, insaai van grasspesies en takke pak, (6) bosbeheer, grondversteuring om grondvogregime te verbeter, insaai van grasspesies en takke pak.

Die eksperimentele uitleg is in 2017 in vennootskap met Grondgebruikersinisiatiewe (LUI's) uitgevoer wat bosverdigting, soos deur DEA aangedui, beheer. Biomassa, spesiedata en grondmonsters is in April 2018 versamel. Alle behandelings wat takke pak bevat, het aansienlik meer biomassa as alle ander behandelings geproduseer. Behandelings wat takke pak bevat, het 'n 1000% toename in weidingskapasiteit getoon, in 'n gedegradeerde semi-ariëde kommunale savanne-weiveld. Grasspesiediversiteit het ook binne die behandelings wat takke pak bevat, weens die insaai van grasspesies asook die beskermende effek wat takke pak vir kruidagtige spesies bied, toegeneem. Verdere monitering en grondopnames het getoon dat grondtemperatuur deur takke pak verlaag word en uit die grondvoginhoud blyk dit ook dat dit tussen die behandelings wat takke pak bevat verskil in vergelyking met behandelings sonder takke pak.

**Sleutelwoorde:** Bosverdigting, boom/grasverhouding, biomassa-produksie, Departement van Omgewingsake, Grondgebruikersinisiatiewe

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## Acronyms and Abbreviations

The following list includes the important acronyms and abbreviations used within this dissertation. Each acronym or abbreviation is declared in full, where mentioned for the first time within the text.

**ANOVA** – Analysis of variants

**BP** – Brush packing

**C** – Carbon

**C** – Control

**C<sub>3</sub>** - Three-carbon molecule

**C<sub>4</sub>** - Four carbon molecule

**Ca** – Calcium

**CAM** - Crassulacean acid metabolism

**CBP** – Control and brush packing

**CCA** – Canonical correspondence analysis

**CEC** – Cation exchange capacity

**CO<sub>2</sub>** - Carbon dioxide

**CRS** – Control and re-seeding

**CRSBP** – Control, re-seeding and brush packing

**CSoRSBP** – Control, soil disturbance, re-seeding and brush packing

**DEA** – Department of Environmental Affairs

**DSS** – Decision Support System

**EC** – Electrical conductivity

**FEM** – Female Empowerment programme

**K** – Potassium

**LUI** – Land User Initiative

**Mg** – Magnesium

**N** – Nitrogen

**N<sub>2</sub>** - Nitrogen gas

**NH<sub>3</sub>** - Ammonia

**NO<sub>3</sub>** - Nitrate

**NW** - North-West

**NWU** - North-West University

**P** – Phosphorous

**RDA** – Redundancy analysis

**S&T Model** – State-and-transition model

**SMT meter** – Soil moisture and temperature meter

**Spp.** – Species

**UC** – Un-controlled

**VMC** – Volumetric moisture content

**WfE** – Working for Ecosystems

**WfW** – Working for Water

# Chapter 1

## 1. Literature review

### 1.1 Savanna ecosystems

The Savanna Biome covers roughly 20% of the earth's terrestrial surface and provides an assortment of ecosystem services to the general population with respect to land use practices, natural resources, and sustained livelihoods, (Van Wilgen, 2009). Savannas are described as biological communities with a continuous herbaceous layer occupied by scattered trees, or potentially as bushes with grasses in the understory (Skarpe, 1992).

Savannas are characterised by great diversity in climate, soil types, biota, human culture, and socio-economic conditions (Young & Solbrig, 1992). Savannas in the Southern Hemisphere are prone to experience wet summers and dry winters. These ecosystems are widely distributed in areas ranging from 300 mm to 1000 mm annual rainfall (Bond et al., 2003). Soil properties greatly differ amongst all savannas: nutrient status, pH, salinity, and texture all influence plant species composition. The most influential factor; however, is soil moisture, which greatly determines spatial distribution and land productivity of savannas and grasslands (Tinley, 1982).

Savanna rangelands cover extensively large areas which make them an essential resource for biodiversity conservation, as well as contributing to sustain the livelihoods of millions of people around the world (Kgosikoma, 2013). Most of the world's savannas are found in Africa, with similar regions in India, South America and Australia (Solbrig, 1996). South African savannas make up 35% of the country's land area (Mucina & Rutherford, 2006). As savannas have existed in Africa for a very long time, they form the foundation for livestock production and wildlife-related industries (Baudena et al., 2015).

Land degradation poses a threat to the integrity and sustainability of savanna ecosystems and can be regarded as an environmental and management issue causing the temporary or permanent loss of ecosystem services (Stocking & Murnaghan, 2001; Schwilch et al., 2012), such as the provision of clean water, food and fodder for livestock production (Havstad et al., 2007). Different types of land degradation that may negatively influence savanna ecosystems exist (Kellner, 2008). These include the

invasion by alien species, bush encroachment (increase in woody density of trees and shrubs) by indigenous species (Kraaij & Ward, 2006), and below average rainfall, which may lead to periods of drought as well as fire suppression (Higgins, 2000). Impacts of land degradation lead to the loss or change in vegetation cover and density and hence a decrease in the functionality of the ecosystem (Tongway & Hindley, 2004).

Savanna rangelands regularly undergo degradation as a result of the mismanagement of livestock farming (Hoffman & Ashwell, 2001). Some nature reserves and wildlife parks in savanna regions endeavor to preserve the integrity of the ecosystems, whereas the more prominent degree of savanna ecosystems concentrated within rural districts are influenced by mismanagement of livestock farming (Young & Solbrig, 1992). With an increase in population densities within these districts, the demand for agricultural land use increases, threatening the remaining non-protected savanna areas (Goldblatt, 2009). In semi-arid savannas, one finds regular low precipitation and high climate variability, where crop cultivation becomes improbable due to low production yields (Jacobs, 2000), leaving livestock farming to dominate semi-arid rangelands (Quaas & Baumgärtner, 2011).

## **1.2 Importance of grasses**

The grass family, Poaceae, is considered the most important plant family on Earth as it occurs on 40% of Earth's terrestrial surface area (Blair et al., 2013). Species from the family Poaceae play an important role in its environment as it, (1) provides food, (2) stabilises the soil surface, and (3) provides shelter material for animals such as birds and rodents to build nests (Nábrádi, 2004). The term "grass species" is often misunderstood by many: for a crop farmer 'grass' is a weed that may occur in the cultivated land, for a cattle farmer grass means fodder for livestock and for others, grass is seen as a regular part of their environment (Van Oudtshoorn, 2002). Thousands of years ago man started cultivating grass and it turned out the most popular food source to date (such as maize, wheat and rice). Almost all domesticated animals and many antelope species, birds, rodents and insects are reliant on grass as a source of nutrition (Barbehenn et al., 2004). The greatest value of grass and probably the most over-looked attribute is the role that it plays in stabilising and protecting the soil surface (Oades, 1992; Porenksy & Veblen, 2012). The growth form and adaptability of grass protects soil from aspects such as high temperatures, water and wind erosion, trampling by

animals, which might lead to compaction, and it is also described as a buffer between the atmosphere and pedosphere (Van Oudtshoorn, 2002).

### **1.3 Bush encroachment**

Evidence accumulated in the past century suggests that savanna ecosystems are being altered by a phenomenon known as ‘bush encroachment’, also referred to as bush or woody thickening (Ward, 2005; O’Connor et al., 2014; Dreber et al., 2017). Bush encroachment involves the rapid increase of woody species, which suppress the growth of herbaceous species, especially grasses, and consequently causes a decrease in the grazing capacity and an increase in the browsing capacity of the palatable woody species in a rangeland (Kerstin, 2005). Bush encroachment is therefore, known to cause an imbalance in the tree/grass ratio which leads to decreased biodiversity and suppressed fodder production (Du Toit et al., 1997; De Klerk, 2004; Smit, 2006; Harmse et al., 2016). The tree/grass ratio is also referred to as the balance of trees and grasses within the savanna ecosystem (Sankaran & Anderson, 2009; O’Connor, 2014).

Bush encroachment is considered an extensive form of land degradation, especially in arid and semi-arid savanna rangelands (Lukomska et al., 2014; O’Connor, et al., 2014; Harmse et al., 2016). With suppressed biomass production, a global problem arises, considering that more than a billion people earn their livelihood directly from livestock farming within arid and semi-arid savanna areas alone (Lukomska et al., 2014).

Bush encroachment can be conceptualised by using the tree/grass balance/ratio as a framework, whereby the disturbance of the tree/grass balance, favouring tree species, gives rise to bush encroachment. The identification of factors causing this disturbance can be used to guide management responses against bush encroachment (Scholes & Archer, 1997; Sankaran et al., 2004).

#### **1.3.1 Models for bush encroachment**

The understanding of the primary causes of bush encroachment is not evident, but literature provides key contemporary models explaining tree/grass interaction in relation to bush encroachment (Scholes & Archer, 1997; Sankaran & Anderson, 2009; De Klerk, 2004; O’Connor et al., 2014).

Only a few conceptual models of bush encroachment take into account all patterns of encroachment by woody species (De Klerk, 2004; Ward, 2005; O’Connor et al., 2014),

and not any individual model can be applied across all environments of southern African's savannas (De Klerk, 2004). The commonly used models include the competition-based models, bottleneck models, and the state-and-transition models (Doughill et al., 1999).

### **1.3.1.1 Competition-based models**

Competition-based models focus on competitive interactions among trees and grasses that may cause its coexistence, resulting from spatial and temporal niche separation (Ferguson, 2013).

The association between different plant species in the same ecosystem greatly modifies the effective growth rates of each species (Teague & Smit, 1992). Different species interfere with one another through acquiring water and nutrients at different depths, at varying rates, and at different times of the year (Westoby, 1980). These interferences can be positive or negative. Some species such as *Senegalia melifera* positions its roots in the upper soil layer, the same as herbaceous species, and as a result competes against grass species for moisture and nutrients (Ferguson, 2013).

Positive effects include the creation of micro climates beneath tree canopies such as *Vachellia erioloba* which positions its roots downwards, up to a depth of 80 m (Neethling, 2018). Most savanna tree species position its roots in the subsoil, allowing for other species (mostly herbaceous species) to utilise the shady nutrient-rich canopy soil. Soil beneath the canopy, generally has a higher nutrient status than soils in the open, often denuded areas (Belsky, 1989). It is also evident that only certain species will occur beneath tree canopies, these species include: *Brachiaria* spp., *Digitaria* spp., and certain *Eragrostis* spp.

Spatial niche separation can be explained by Walter's two-layer model (1970), which is based on competitive root niche separation in savannas, and states that grasses outcompete tree seedlings by absorbing moisture in the upper soil layer and reducing percolation downwards, towards tree roots (Walker et al., 1981; Ward, 2005; Dreber et al., 2017). This model assumes that soil water is the limiting factor in savannas where grass roots and tree roots occupy different soil layers therefore, having different access pathways to the water source (O'Connor et al., 2014). Grasses are therefore, superior to trees in the upper soil layer, but certain trees are able to position its roots into the

deeper soil layers enabling it to access deep soil water, therefore giving rise to tree/grass coexistence.

Competition for moisture in the soil layers thus keeps the tree/grass relationship in a balanced state, and would the grass layer be decreased due to factors such as overgrazing and/or erosion, water will be allowed to infiltrate more freely through to the deeper soil layers, permitting the increase in 'woody species' density and biomass (Walker et al., 1981).

The reduction of the density and cover of the grass layer due to overgrazing may therefore, be a primary causal factor of bush encroachment in arid- and semi-arid savannas where water is considered the limiting resource. Opposed to semi-arid savannas, mesic and tropical savannas have more water to support both trees and grasses if mean rainfall events apply, and drought conditions do not occur.

#### **1.3.1.2 Bottleneck models**

The limitation with the competition-based models is that it fails to address the importance of seedlings in the system. The demographic bottleneck model considers all the effects of climatic variability and disturbances on savanna dynamics, and not only the interaction between trees and grasses, as with the competitive model (Higgins et al., 2000; Sankaran et al., 2004).

Demographic factors such as rainfall variability, herbivory, fire, and land use patterns pose a great impact on the tree/grass coexistence through its effect on germination, growth, and mortality of trees and grasses (Sankaran et al., 2004).

For a particular tree species to germinate, establish and grow in a savanna ecosystem favourable conditions for that specific species are required. Equally, encroacher plant species have to go through a seedling phase and all the elements involved in a savanna ecosystem have an effect on seedling mortality and growth rates (Bengtsson-Sjörs, 2006). Germination is primarily determined by the availability of moisture and changes in temperature after which the chances of survival can vary from very slim to highly probable, given the condition of the ecosystem (Loth et al., 2005). According to the bottleneck model, woody seedling propagation by seed requires seed dispersal via wind or animals (through herbivory) (O'Connor et al., 2014). Such models will then explain that an increase in herbivory will have a definite effect on seed dispersal, as the animals

import/export seeds which may lead to increased bush encroachment (Loth et al., 2005).

Woody seedling establishment can only occur when the seed is dispersed to an area favourable for germination. The dispersed seed's micro-habitat may be a bare soil patch where the grass layer is absent, but enough organic material is available that will cover the seed, and most importantly, soil moisture for the germination to occur (Bengtsson-Sjörs, 2006). Overgrazing usually creates bare patches, giving tree species the space to germinate and seasonal rainfall may promote tree seed germination if seeds are in a favorable micro-habitat.

#### **1.3.1.3 State-and-transition model**

The state-and-transition (S&T) model can also be used to describe the dynamic nature of savanna ecosystems (Doughill et al., 1999; Joubert et al., 2008). This model is based on non-equilibrium ecological theories, predicting that the savanna structure, growth and composition are driven by events such as rainfall, wildfires and drought (Briske et al., 2005). Sullivan (1996) stated that in the case of arid- and semi-arid systems, the biological activity is mainly dependant on soil moisture and to a lesser degree on the nutrient status of the soil.

According to the S&T model, savannas are described as distinct states of vegetation communities with the ability to undergo transitions between different states of existence due to certain events. For example, rainfall may cause more seed development, dispersal and seedling establishment, influencing management actions (Doughill et al., 1999; Joubert et al., 2008). The S&T model; therefore, implies that bush encroachment is just a transition between states and if, for example, management practices would to improve, a grass dominant savanna state can be achieved once again (Stringham et al., 2003).

#### **1.3.2 Drivers of bush encroachment**

Drivers of bush encroachment will vary according to the relation of climate (such as rainfall, temperature and CO<sub>2</sub> levels in the atmosphere) and area specific variables (such as type of soil, nutrient availability, competition with other plants, and management strategies). Walter's two-layer model hypothesis was specifically formulated for semi-arid regions with less than 600 mm annual rainfall and infrequent fires (Ward, 2005).

The fire-trap demographic model was formulated based on mesic and moist environments (O'Connor et al., 2014). These models serve as good explanations for bush encroachment but lacks complexity, as they do not take all variables (climate, disturbances and competition) that could shape the savanna ecosystem into account. Both models ignore browsing by herbivores, which forms a major part of savanna dynamics. The competition-based model also ignores the role of fire, as well as woody seedling establishment (Limberger, 2018). For a comprehensive understanding of bush encroachment and savanna dynamics in general, all factors involved should be considered, such as climatic conditions, parent material, soil quality, biodiversity, ecosystem health, herbivory, fire regimes as well as temporal patterns. These are all factors in a savanna ecosystem which drive the co-existence between woody and herbaceous species and only when considering a holistic approach, can a phenomenon such as bush encroachment be explained (De Klerk, 2004).

Managing natural resources with the aim of increasing land productivity while maintaining sustainability can only be executed with good knowledge of ecological functioning. In order to manage a savanna ecosystem for increased land productivity and sustainable land management, it must be recognised that each system is unique with its own structure, composition and environmental and socio-economic impacts (Bond et al., 2003). Physical determinants (soil and climate) and its biological interactions (especially competition), along with individual species properties make every spatial and temporal savanna situation unique (De Klerk, 2004). Factors determining specific vegetation communities in any given area are diverse and complex and as many factors determine the extent and rate of bush encroachment, each area should be studied separately. Smit (1992) made a distinction between primary and secondary ecosystem drivers.

#### **1.3.2.1 Primary drivers**

Primary ecosystem drivers represent a function of the geographic habitat, which are beyond the influence of management. These include climatic features (e.g. rainfall and temperature) and geology (parent material), which cannot be controlled by management strategies.

Soil moisture balance differs in relation to the texture of a soil. Fine textured soils (high clay soil) are more xeric (drier), meaning that the water holding capacity is much higher due to the strong adsorption forces of the clay particles with less moisture available for plant root uptake (Holdo & Mack, 2014). In similar climatic conditions moisture is more freely available for the plants in coarse textured soils (sandy soils) (Knoop & Walker, 1985).

Sandy soils; however, adsorb less water and are thus susceptible to deep water drainage of which most of it is still available to plants, opposed to the fine capillary pores of clayey soils which are conducive to unsaturated flow (Tinley, 1982). Sandy soils with large pores encourage saturated flow which is also favorable for the establishment of woody plants, as sandy soils allow for greater infiltration and promote greater water percolation which encourages extensive root growth (see section 1.3.1.1 above) (Walker & Noy-Meir, 1982). Given two particular savanna rangelands that have a deep sandy soil classification and a shallow clay/rocky soil classification respectively – bush encroachment will occur quicker in the ecosystem dominated by sandy soils. The water holding capacity of a sandy soil is lower than of clayey soils, which are of a disadvantage for grasses, i.e. water only remains for a short period in the upper soil layers after rainfall events (Dye & Spear, 1982).

In southern Africa one finds that a peculiar soil and vegetation catena sequence occurs (Walker, 1985). Catena is a term that originated in East Africa to describe a series of different soil classifications that occur in the landscape. Each series differs from another based on the effect of topography on horizontal and vertical water movement and proximity to the water table (Weil, 2003). In southern Africa savannas the coarse-textured upper slopes are dominated by a woodland savanna, the shallower mid-slope by a shrubby mixed savanna, and the alluvial zone representing taller trees such as various *Vachellia* and *Senegalia* species (Walker, 1985).

The effect of soil moisture content is often modified by sunlight, nutrient availability in the soil and atmospheric temperature. Temperature is also an important factor in southern African savannas, since the high altitude of the southern African plateau causes temperatures to reach extremes in the winter and summer seasons, causing

limited productivity at certain times by both woody and herbaceous species (De Klerk, 2004).

### **1.3.2.2 Secondary drivers**

#### **1.3.2.2.1 Fire**

Fire is one of the main contributing factors involving bush encroachment (O'Connor et al., 2014; Dreber et al., 2017). For instance, if a seed successfully germinates and reaches the life stage of a sapling ( $\pm 1$  year old), it still has to endure fire (natural or human induced) which can be treated or naturally occur seasonally in the dry season, depending on fuel loads, and consequently grazing pressure and rainfall. With sufficient fuel loads, preferable rainfall patterns and proper fire management, the sapling will most probably be eliminated by fire. However, in semi-arid savannas where heavy grazing and poor rangeland management is frequent, it is generally found that fuel loads are insufficient for proper fire management. To burn an encroached savanna with a weak fuel load will only worsen the effects of bush encroachment (Van Oudshoorn, 2002).

According to O'Connor et al. (2014) fire suppression is accountable for most of the bush encroachment in recorded history and it may be true that fire suppression alone can account for an increase in woody density and biomass. Fire suppression includes any degree of reduction in fire frequency or intensity in relation to natural fire history, whereas fire exclusion can be considered as an extreme case (Higgins et al., 2007; Dantas et al., 2013; Friedel, 2014).

Early Portuguese explorers who travelled around the Cape of Good Hope in the 15th century wrote of fire in their ship logs by referring to the interior of South Africa as “Terra dos fumos” meaning – the land of fire and smoke (Trollope et al., 2002). The main requirements for wild fires to occur anywhere on earth is to have lightning as the ignition source and preferable climatic conditions permitting the burning and spread of vegetation fires (Trollope et al., 2002). In the Kruger National Park, it was reported that 45% of all unscheduled fires during the years 1977 and 1978 were caused by lightning (Gertenbach & Potgieter, 1979). Africa is highly prone to lightning storms and consists of a fire climate with contrasting dry and wet seasons. High plant fuels are accumulated during the wet, summer season depending on the amount of rainfall, which are then

burnt during the flammable dry, winter season; in the Southern Hemisphere (Trollope et al., 2002).

Beringer et al. (2007) explain that fire may be one of the most important drivers that maintain savanna structure and function and that a change in the fire regime may influence the dynamics of savannas. Reducing the frequency and intensity of fire treatments tend to enhance tree seedling recruitment, which might lead to bush encroachment. With the absence of fire, tree seedlings get the opportunity to compete with grass species for water and nutrients (Smit et al., 2010). However, when fire frequency and its intensity increases, the recruitment of climax grass species such as *Themeda triandra* (red grass) are favoured and the establishment of tree seedlings and/or extensive tree growth is suppressed (Trollope et al., 2002; Smit et al., 2010).

Up until the 19th century, it was still commonly acknowledged that wild fires were a part of the natural process, as reports show that fire events were a widespread phenomenon across South-Africa's savannas and grasslands (Brooks, 1876; Thompson, 1937). The majority of fires predating the 1800's was human induced, a conventional practice for indigenous people of that time (Brooks, 1876). Colonial governments; however, had their own opinion on fire, only focusing on the destruction that it may cause to new settlements (O'Connor et al., 2014). They did not consider the role that fire might play as a natural process in shaping the savanna ecosystems, which lead to the implementation of legislation against the use of fire from as early as the 17th century continuing to the 18th and 19th centuries, in South Africa (Thompson, 1937). The Drought Investigation Commission of South Africa emphasised the negative impacts of fire, developing a national legislation that all soil conservation schemes may include provisions relating to: (1) the regulation or prohibition of rangeland burning, and (2) the prevention, control and extinguishing of rangeland and forest fires (O'Connor et al., 2014).

By the 1920's and 1930's cattle production became a major agricultural income and land owners preferred not to burn the sweetveld vegetation areas since they began to struggle with drought periods and were concerned of having enough fodder biomass production to sustain their livestock (Scott, 1972).

Sweet- and sourveld vegetation areas are broad terms referring to the palatability of the rangeland, which is affected by temperatures and rainfall. Grasses in sweetveld vegetation are regarded as more palatable in both summer and winter seasons and therefore, tend to be overgrazed more quickly, unless proper management is put in place. Examples of sweetveld areas are mostly found in the summer rainfall areas in the western parts of South Africa, which include the Karoo, Grassland and Savanna areas (Van Oudtshoorn, 2002).

Fire, in general, has a strong negative impact on the survival, growth, adult recruitment and seedling regeneration of woody plants. Therefore, fire suppression should promote increased growth and adult recruitment in woody vegetation at a rate determined by annual rainfall and the fire-return period. When travelling along the border between Namibia and Botswana, De Klerk (2004) stated that it is clearly notable that the Namibian side is much more bush encroached, this can be explained by the suppression of rangeland fires on commercial farms in Namibia since the 1950's.

#### **1.3.2.2.2 Grazing pressure**

A savanna vegetation type is made up of two main components; i.e. grasses and trees. If one of the components is removed, the other may increase. High grazing pressure, mainly by livestock and/or wildlife can lead to overgrazing if poor management strategies are implemented. Overgrazing generally leads to a decreased grass sward within the savanna mosaic, thus reducing grazing capacity as well as the fuel load for burning. On the other hand, lack of grazing pressure should have the converse effects. Elimination of grazing pressure would thus promote increased grass biomass and consequently more severe fires (O'Connor et al., 2014).

Grasses are well adapted to defoliation (burning, grazing or cutting), as the growth points are situated at, or very close to the ground level, out of reach of grazers. Grasses also have the ability to store reserve nutrients in its roots and culm bases to be used for regrowth after defoliation (Chirara & Dijkman, 2014). The roots and culm bases provide for regrowth until the leaves have developed up to the stage that the plant can properly function through photosynthesis. After regrowth, the grass plant restores the reserves in the roots for the next defoliation process, it is therefore essential for the plant to have a resting period after defoliation. Should the grass be excluded from any grazing or

burning and defoliation does not occur, excess dead material will accumulate and in severe cases, it may 'suffocate' the tuft of the grass from inside (Van Oudshoorn, 2002).

Overgrazing is thought to be a major cause of soil degradation around the world (Oldemann et al., 1991), representing 35.8% of all types of degradation. Be that as it may, degradation caused by overgrazing is particularly widespread in Australia and Africa, where it represents 80.6% and 49.2% respectively of all soil degradation, and least extensive in Europe (22.7%) (Warren & Khogali, 1992).

Overgrazing can be characterised by repeated utilisation of grasses until the reserve nutrients in the roots and culm bases are exhausted. When this happens, the root system becomes weaker and the grass species can no longer function optimally, especially to take up water and nutrients, and the plant ultimately dies (Warren & Khogali, 1992). The more palatable, perennial and climax grasses are the first to be overgrazed, after which the less palatable species will be grazed, and if this pattern continues, only annual and unpalatable pioneer species will reside in the end. Generally, the lower lying areas are more fertile and the grasses more palatable, which causes grasses in these areas to be overgrazed first. Grassland and savanna areas need to be managed properly and sustainably, especially if the topography divides palatable and perennial grasses from areas in the different ecotones (Van Oudshoorn, 2002). This is especially true during drought years, when the grazing capacity should not be exceeded (Pietikäinen, 2006). The latter is however, a challenge in communally managed areas where the culture is to have as many livestock as possible, as it reflects wealth and prestige (Pietikäinen, 2006).

Bush encroachment in eastern Botswana savannas was identified by van Vegten (1983), claiming overgrazing to be the main causal factor. However, elsewhere in Botswana, low to moderate grazing has shown no significant increase in bush encroachment but in areas with severe overgrazing, bush densities increased dramatically (Skarpe, 1990). Pietikäinen (2006) concluded that it is also very important to not exceed a rangeland's carrying capacity during drought periods.

#### **1.3.2.2.3 Climate change**

According to Smit (1999), Wigley et al. (2009), Ward (2010), and Buitenwerf et al. (2012) increased atmospheric CO<sub>2</sub> (carbon dioxide) concentrations may also have an

effect on savanna ecosystems and that it may be responsible for bush encroachment. Since the Industrial Revolution, CO<sub>2</sub> concentrations have increased significantly and reached 397 ppm in 2014 and is bound to go up to 450 ppm before the year 2030 (Cha et al., 2017). According to Ceulemans (1999) the rising CO<sub>2</sub> concentrations may contribute to global warming, imposing direct impacts on ecosystem function and structure, as well as plant physiology and productivity. The theory of the role that increasing atmospheric CO<sub>2</sub> plays on bush encroachment is based on the physiological understanding of C<sub>3</sub> versus C<sub>4</sub> plants. (Bond & Midgley, 2012).

Three photosynthetic pathways exist among all terrestrial plants i.e. C<sub>3</sub>, C<sub>4</sub> and CAM (Crassulacean Acid Metabolism). The C<sub>3</sub> pathway refers to a 3-carbon molecule as the first product of photosynthesis. The C<sub>3</sub> pathway is known as the ancestral pathway that occurs in all plant groups. In the case of C<sub>4</sub> plants, the initial product is a 4-carbon molecule. C<sub>4</sub> plants are known to be more advanced and are common among monocots, such as grasses and sedges (Ehleringer, 2002). These two pathways react quite differently to increased atmospheric CO<sub>2</sub>. The growth of C<sub>4</sub> plants is enhanced over C<sub>3</sub> plants in low CO<sub>2</sub> and/or high temperature environments, due to the high photorespiration rates in C<sub>3</sub> plants. However, under elevated CO<sub>2</sub> and/or cooler temperature conditions, C<sub>3</sub> plants seem to have an advantage due to the reduction in the photorespiration rate (Ehleringer, 2002). The increase in CO<sub>2</sub> levels in the atmosphere may therefore, promote the increase of woody species, especially in semi-arid regions where competition between herbaceous and woody species are evident (Ward, 2010). It is estimated that the CO<sub>2</sub> levels will increase due to climate change and increased pollution, which might cause the rise in woody species density (e.g. bush encroachment) in all savanna and woodland areas.

## 1.4 Restoring degraded savanna rangelands

### 1.4.1 The five-step restoration procedure

Ecological restoration is the process of assisting the recovery of an ecosystem that has been degraded, damaged or destroyed (SER, 2004). Tongway and Ludwig (2011) proposed a five-step procedure for restoring degraded, damaged or destroyed landscapes, which includes an adaptive learning loop that assists in achieving restoration success by adjusting different restoration technologies as needed (Figure 1.1).

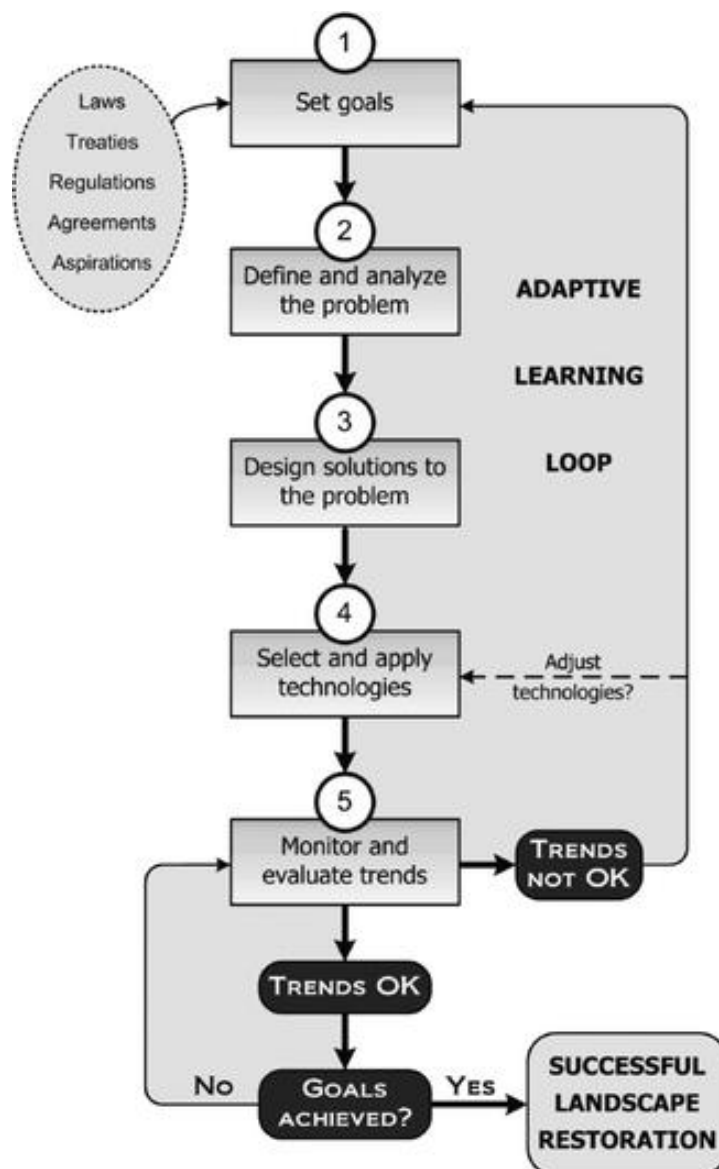


**Figure 1.1** A diagram of the five-step procedure for restoring degraded, damaged or destroyed landscapes (Tongway & Ludwig, 2011).

**Step 1: Setting goals**

Stakeholders, restoration practitioners and all interested parties set goals that define what they want to achieve. Not all groups will share the same view on what the initial state or condition of the ecosystem under restoration was, but it is important that the final use-case for the particular ecosystem is clearly agreed upon (Tongway & Ludwig, 2011).

**Step 2: Defining the problem**

Stakeholders and restoration practitioners will work together to analyse factors causing the deterioration of the ecosystem's functionality. This step involves trans-disciplinary approaches to properly analyse biophysical and socioeconomic causes of the problem. It is important to concentrate on the primary causes of the problem and not the symptoms thereof (Tongway & Ludwig, 2011).

**Step 3: Designing solutions**

Stakeholders and restoration practitioners will examine and discuss possible solutions to address the problem, with an emphasis on identifying biophysical, social and economic processes that need improvement to achieve proposed goals (Tongway & Ludwig, 2011).

**Step 4: Applying technologies**

Stakeholders and restoration practitioners will select appropriate restoration technologies to apply. It is important to choose the technology based on site specific conditions as well as bearing in mind budget constraints and cost-effective analysis in order to facilitate a more sustainable ecosystem (Tongway & Ludwig, 2011).

**Step 5: Monitoring and assessing trends**

Step 5 is very important; it involves ongoing scientific monitoring by the restoration practitioner(s) to evaluate trends in the collected data. The restoration practitioner may also collect data from a reference site which can provide the basis for evaluating the overall trend in the restoration progress. Trend analysis in step 5 may indicate that adjustments need to be made, which will require to go back to the drawing board to change certain methods, and in this feedback loop, it is possible to greatly reduce the cost of repairing future failures (Tongway & Ludwig, 2011).

### **1.4.2 Bush encroachment control**

As previously mentioned; bush encroachment leads to a severe decline in the functionality of a savanna rangeland. In order to restore functionality, a drastic intervention is needed to control the thickening of the woody species (trees and/or shrubs causing bush encroachment) due to certain factors explained above (O'Connor et al., 2014). Mechanical, manual, chemical and biological methods are recognised as possible interventions to control the increase in woody densification in South Africa (Barac, 2003).

#### **1.4.2.1 Mechanical**

Mechanical bush eradication involves the use of heavy machinery such as bulldozers or modified tractor loader backhoes (TLB's) to remove unwanted bush. This method serves very effective as it can clear large areas of land in a relatively short amount of time. It can also be very selective to remove species or roots of species which are left behind by other bush control technologies. The disadvantage is the high running costs associated with using such machinery (Barac, 2003).

#### **1.4.2.2 Manual**

Manual methods rely on 'man-power' to remove unwanted bush. By the use of hand saws, pruning loppers, bush axes, and in advance cases chainsaws, manual working can be very effective in bush clearing practices. This is the most selective method as well as the most sustainable method if applied correctly with a systems approach.

#### **1.4.2.3 Chemical**

Chemical methods involve the application of arborocides (a chemical application for eliminating plant species). This method of application is generally based on the size of the target area, funding, and the availability of a labour force that is properly trained to apply the chemicals (De Klerk, 2004). Tebuthiuron (chemical formula:  $C_9H_{16}N_4OS$ ) is the active ingredient present in many of the arborocides commonly used by rangeland owners and bush clearing contractors. Tebuthiuron is a non-selective 4-photosynthesis inhibitor (Hatzios et al., 1980). Other chemicals used include Picloram and Triclopyr (Van Eck & Swanepoel, 2008).

#### 1.4.2.4 Biological

Biological bush clearing methods regarding savanna ecosystems include the prescribed burning of rangeland. Rangeland is mainly burnt for two reasons: (1) for the removal of accumulated organic material, particularly in areas of high rainfall, and (2) to combat or prevent bush encroachment. It is imperative to burn the rangeland at the right time; timing is not only determined by the seasons (rainfall) but also by the amount of available combustible material (Trollope et al., 2002; Van Oudtshoorn, 2002). The right time for burning is as close to the first spring rains as possible. When burning too early (early winter), the burnt surface is exposed to the elements of nature (wind, frost, sunlight) for too long and fertile surface material may be lost to the wind. In addition, the stimulated burnt grass will have to rely on soil reserves to survive until the rain come. It is important to only burn areas consisting of dense stands of perennial grasses. If a rangeland consisting of primarily pioneer and/or subclimax species is burnt, it will run the risk of further deterioration. When burning to combat bush encroachment, it is very important to make sure that the fuel load (combustion material) will generate enough heat for bush eradication (Trollope et al., 2002; Van Oudtshoorn, 2002).

Other biological control methods to combat bush encroachment include the use of (Coetzee, 2005):

- Browsing animals.
- Fungi such as *Phoma glomerata*.
- Beetles such as *Algarobius prosopis* and *Neltumius arizonensis*.
- Rotational grazing to initiate resting periods.

#### 1.4.3 Brush packing as a restoration technology

It is mandatory to set clear and achievable restoration targets, what's more, to forecast the best possible restoration results by utilising ecological knowledge and different stakeholder perspectives (Figure 1.1) (Higgs, 1997; Ehrenfeld, 2000). Site-specific variables firmly affect the choice of restoration targets on the grounds that it obliges to what is ecologically possible, financially viable, and, socially acceptable (Hobbs, 2007).

The use of brush packing, also referred to as mulching, was selected to serve as the restoration technology for evaluation in this restoration project. This methodology has been studied by Beukes (1999), Beukes & Cowling (2003), Visser (2007), Kellner (2008),

Tongway & Ludwig (2011), and Pelsers (2017), and is carried out by covering the soil surface with organic material, such as woody branches, leaves, crop residue, straw, or reeds. This treatment on exposed surfaces simulates the protective cover effect of vegetation and aids as an effective soil erosion control method (Kellner, 2013).

Brush packing is ultimately an effective method in savanna restoration, due to the following reasons (Coetzee, 2005).

- It functions as a protective layer against rain splash erosion.
- It assists in soil moisture retention.
- It decreases soil temperature and aids in buffering temperature changes through the day.
- It thereby improves the microclimate for soil organisms and seedling plants.
- It restricts soil and organic litter movement through surface run-off by collecting materials against the network of branches.
- It protects the exposed soil against the elements of nature such as wind erosion, surface runoff and severe sunburn.
- It will protect the germinating plants from grazing animals that regularly seek out new growth.
- It traps windblown seeds and serves as a seed production site.
- It creates cover habitat for soil-living animals that burrow, and assists soil aeration.
- Eventually the material used in the brush packing will decay and become part of the organic matter component of the topsoil.



**Figure 1.2** A photograph displaying the appearance of the brush packing technology from an aerial perspective.

## Chapter 2

### 2. Introduction

#### 2.1 Orientation of the study

Degradation occurs on a significantly vast extent of arid and semi-arid savanna rangelands as indicated by Masoudi et al. (2018). Approximately 41% of the Earth's terrestrial surface comprises of drylands, inhabited by more than 38% of the worldwide population (6.5 billion). An estimation of 10 to 20% of these dryland areas are modified by some type of extreme degradation, specifically influencing roughly 250 million individuals (Reynolds et al., 2007). Land degradation poses a risk to ecosystem integrity in dryland environments, which are also susceptible to bush encroachment in the savanna biome (O'Connor et al., 2014). Bush encroachment as the increase in the density of indigenous woody species (trees and shrubs) is enhanced by the mismanagement of rangelands and changes in the climate (Ward, 2005; Dreber et al., 2017). Bush encroachment decreases rangeland grazing capacity; causing financial misfortunes (De Klerk, 2004). Extreme conditions may cause severe bush encroachment in savannas, decreasing a rangeland's carrying capacity (number of livestock units that can be supported for a given time period) by up to 330% (Richter et al., 2001; O'Connor et al., 2014).

Absence of rotational grazing, over utilisation of resources, rangeland fire suppression, and elimination of mega herbivores are some of the major causes of bush encroachment (De Klerk, 2004; McGranahan & Kirkman 2013; O'Connor et al., 2014). Poor rangeland management might be a deciding component leading to bush encroachment, while overgrazing “weakens” the grass sward, decreasing grass species which are then replaced by woody species (Kgosikoma et al., 2012). Loss of income to animal farmers is one of the biggest concerns regarding bush encroachment, for instance in Namibia a repeating annual loss of around N\$700 million has been accounted for in the recent past due to bush encroachment (De Klerk 2004). Annual losses in the livestock production industry increases rural poverty and decreases food self-sufficiency, particularly in rural networks which rely upon broad domesticated animal production for their livelihood (Lukomska et al., 2014).

As discussed in section 1.5.2, different strategies are available for the control of bush encroached areas. These strategies incorporate mechanical, manual, chemical and biological control approaches, used to kill/remove undesirable woody species (Barac, 2003). Bush clearing creates a high visual effect but may not be as effective in the long term with respect to ecosystem succession or re-coppicing of felled tree species (Smit, 2003). Felling and the excavation of woody species add to seed dispersal and coppicing of controlled species, which makes a follow-up treatment mandatory (Barac, 2003). Mechanical and manual control strategies contribute to job creation, which could contribute to improve the livelihoods of the poor.

The Department of Environmental Affairs (DEA) facilitates numerous bush control projects within the Working for Water (WfW) and the Working for Ecosystems (WfE) programmes (Gibson & Low, 2003). These programmes aim to reduce the density of woody invasive plants (shrubs and trees), and alien plants (terrestrial and aquatic) through labour intensive projects by at least 22% per annum (Gibson & Low, 2003). This study was done in accordance with DEA and conclusions made from this study will provide restoration advice towards bush clearing projects in the future.

A number of woody species causing bush encroachment hold the ability to fix nitrogen ( $N_2$ ) from the atmosphere, converting it to ammonia ( $NH_3$ ); a major plant accessible nutrient (Bustamante et al., 2006). Typical N fixing plants include those from the legume family (Fabaceae). These plants select for rhizobia in the soil through its root systems – a type of N producing bacteria assisting the plant in growth and competition with other plants (Abubakar & Yusuf, 2016). When the plant dies, the fixed N stored in its roots, leaves, stems and pods are released and fertilize the soil, which can be utilised by other plants. Nitrogen fixing species such as *Vachelia tortilis*, *V. karroo*, *Senegalia mellifera*, and *Dichrostachys cinerea* are found to be some of the main encroaching species in southern African savannas, especially within arid and semi-arid regions (O'Connor et al., 2014). The control of these species may result in an increase of grasses and other herbaceous species and may last for several years, but only if the process of bush encroachment can be reversed (De Klerk, 2004).

Perennial grasses such as *Digitaria eriantha*, *Schmidtia pappophoroides*, and *Panicum* spp. are palatable for grazing animals, especially large herbivores. Mismanagement can

lead to a reduction of these species caused by overgrazing (O'Connor et al., 2014). Grasses need to produce seed for sustained populations in savanna ecosystems, as seed dynamics form a major part of grass life cycles (Johannsmeier, 2009). The production, viability, dispersal, germination and establishment of grasses play a significant role in the survival of the species. Mismanagement of savanna rangelands by e.g. overgrazing may disrupt the seed dynamics of grasses, causing a decrease in the seed bank which has drastic effects on the sustainability of the species in the long-term (Johannsmeier, 2009). If the woody species are mechanically controlled in a heavily bush encroached savanna, the recovery of the perennial grass will probably be slow due to the lack of viable grass seeds in the soil (Johannsmeier, 2009). Tree seedlings will dominate the area which may also re-initiate the process of bush encroachment.

Trees with deep root systems such as *V. erioloba* create an 'island of fertility' under its canopies, enriching the soil with nutrients while providing shade on days with extreme temperatures (Isichei & Muoghalu, 1992). The canopy presents an ideal environment for certain grass species such as *Brachiaria marlothii* and *Eragrostis biflora* to flourish. Woody cover in this manner additionally provides beneficial outcomes respective to the survival of grass species, desirable grasses may be re-sown and shielded from grazing by felled thorny woody branches. Research into re-seeding in combination with alternative restoration technologies such as brush packing may provide solutions to repair degraded savanna ecosystems and provide resourceful management suggestions for sustainable livestock production on savanna rangelands.

For this restoration experiment woody branches ("brush") gained from bush encroaching species were used as packing and mulching material to cover bare patches in the degraded areas. This procedure ('brush packing') can easily be implemented by local community members. Such procedures do not only restore the degraded areas, but also provide jobs, which is one of the main aims of the DEA. This is achieved through the Working for Water (WfW) and Working for Ecosystems (WfE) programmes of the DEA, by restoring the water and grazing resources in the degraded ecosystems, often caused by the encroachment of alien and/or indigenous woody species.

This project also forms part of a bigger research project funded by the DEA to develop a Decision Support System (DSS) for bush control in semi-arid savanna areas of South

Africa (so-called “Bush Expert DSS”), regarding the implementation of restoration technologies for the improvement of grazing capacity after bush clearing caused by bush encroachment. The experimental process is carried out in collaboration with the LUI’s that were appointed by DEA. The LUI’s working in their respective areas must use local manpower to clear the woody species and help with the implementation of the restoration treatments. LUI’s are contractors that focus on eradicating and controlling woody species in bush encroached areas. LUI’s also ensure proper training to the participating community members in order to safely use brush cutters, chain saws and chemical application of arborocides for bush eradication. The timing of the bush clearing operation by the LUI and application of the restoration practices had to be carefully synchronised. This required good communication between the LUI and scientists of the NWU, which resulted in participation sessions held between all stakeholders to create awareness regarding the bush clearing and restoration activities as suggested in Figure 1.1.

Feed-back sessions also took place between all stakeholders (LUI’s, communities, scientists and traditional leaders) as the project progressed. A scientific A0 poster, addressing the full range of studies led inside the Bush Expert DSS was made to fill in as a visual clarification to be utilised in networking input sessions and general gatherings held between the different stakeholders partaking in restoring degraded savanna rangelands in the North-West and Limpopo provinces

## **2.2 Problem statement**

Between 10 and 20 million hectares of savanna land in South Africa is altered by bush encroachment, negatively affecting agricultural productivity and biodiversity of these precious savanna ecosystems (Ward, 2005). The worst affected areas are those utilised for livestock production where overgrazing is recurrent and proper rangeland management is lacking, these areas are also frequently found within arid and semi-arid regions where rainfall is considered to be the limiting factor (O’Connor et al., 2014).

Rural communal areas are most susceptible to bush encroachment, as proper rangeland management is often lacking, and grasses are overgrazed, due to a lack of fencing and paddocks in order to implement rotational grazing (Kgosikoma, 2012). Rural communities participate in sharing their land with numerous ranchers that depend on

livestock farming as an important part of their livelihood. Sharing rangeland for livestock production can become problematic considering ecosystem integrity: the more ranchers utilising a particular rangeland area, the higher is the stocking rate (the number of animals on a given amount of land over a certain period of time). Due to the extent of bush encroached rangelands and associated ecological and economic losses, bush clearing practices have become a priority to maintain ecosystem integrity as well as economic prosperity. Bush control on its own; however, will not restore the ecosystem functions to a previous desirable state. Further intervention and after care will thus be needed for proper restoration.

### **2.3 Aim and objectives of the study**

The aim of the study is to restore a degraded semi-arid savanna area, characterised by bush encroachment, by using brush packing as a restoration technology which serves as an effective method for restoring degraded areas. Restoration is implemented to improve the grass biomass production for increased grazing capacity for livestock production. The result of this study will inform future decisions in the management of savanna rangelands in southern Africa.

The objective of this study was to evaluate the restoration technology of brush packing after bush control in a communally managed rangeland area in the North-West Province, South-Africa.

#### **The specific objectives include:**

1. Determine the effectiveness of brush packing as a restoration technology on some ecological functions after bush control in degraded areas, and
2. Study the effects of brush packing to increase the grass biomass and diversity in degraded areas where bush encroachment has been controlled.

## **2.4 Hypothesis of the study**

1. Experimental plots treated with the brush packing technology will produce significantly more grass biomass than plots without brush packing.
2. Experimental plots treated with a combination of bush clearing, soil disturbance, re-seeding, and brush packing will produce the highest amount of grass biomass of all the treatment combinations.
3. The microclimate created by brush packing will facilitate the recruitment of more grass species when compared to plots without brush packing.
4. Soil moisture and temperature evaluations will be different in plots treated with brush packing compared to plots without brush packing.

## **2.5 Significance of the study**

The main purpose of restoration applications is to improve the productivity of rangelands and hence the livelihood of the affected communities. It was envisioned that this study would deliver a scientific assessment of restoration methods pertaining to bush control. The results should be used by DEA as a basis for making decisions in the restoration of degraded areas characterised by bush encroachment where woody species have been controlled. The effectiveness of re-seeding will favour grass species development beneath packed brush in the brush-packed plots and could provide vital informative advice for stakeholders involved in rangeland restoration after the control of bush for improved grazing capacity.

## Chapter 3

### 3. Study area

#### 3.1 Location

The western region of the North-West Province is partitioned into 3 sub regions: (1) Vryburg/Ganyesa, (2) Kudumane, and (3) Taung. This study is concentrated in the Ganyesa district. It forms part of the semi-arid region and is situated between 26° 00'- 26° 40' S and 23° 50'- 24° 22' E (Figure 3.1). The region is portrayed by undulating to flat sandy plains with an average elevation of 1070 m above sea level (Dapaah et al., 2001). The riverbed zone is at approximately 1040 m, representing only 5% of the total land area of the region (Dapaah et al., 2001). The particle size distribution indicates that the study site consists of a predominant sand fraction with little clay and silt particles (Figure 5.4). Soils with high sand and low clay fractions also have high soil permeability for water infiltration but is characterised by a lower water holding capacity than soils with higher clay content (McCauley et al., 2005). Sandy soils are prone to deep water drainage which can negatively affect seedling recruitment if drought periods occur (McCauley et al., 2005).

The study site is found near the Goodwood rural village situated at 26° 27' 14.62" S and 24° 15' 10.12" E, which is approximately 23-km along the road from the town of Ganyesa in the North-West Province (Figure 3.1). Ganyesa is occupied by almost 20 000 people in an area of 2200 ha. Ganyesa is located 70 km north-west of Vryburg and is considered the administrative hub of the north-western part of the province, home to a number of provincial and national governments (Dapaah et al., 2001). The study site was selected by DEA and is a priority area regarding the control of bush encroachment within communally managed regions. Ganyesa, formally part of the Kagisano/Molopo district, is a rural town inside the conventional domain of the Tswana tribe. This region was part of the former Bophuthatswana, a self-governing state that existed between the years 1977 and 1994, after which it was reincorporated into South Africa. Local people that lived here preceding colonialism in the 1800's were hunter/gatherers, living of the produce of the land, making an existence of self-subsidy (Agenbag, 2012).

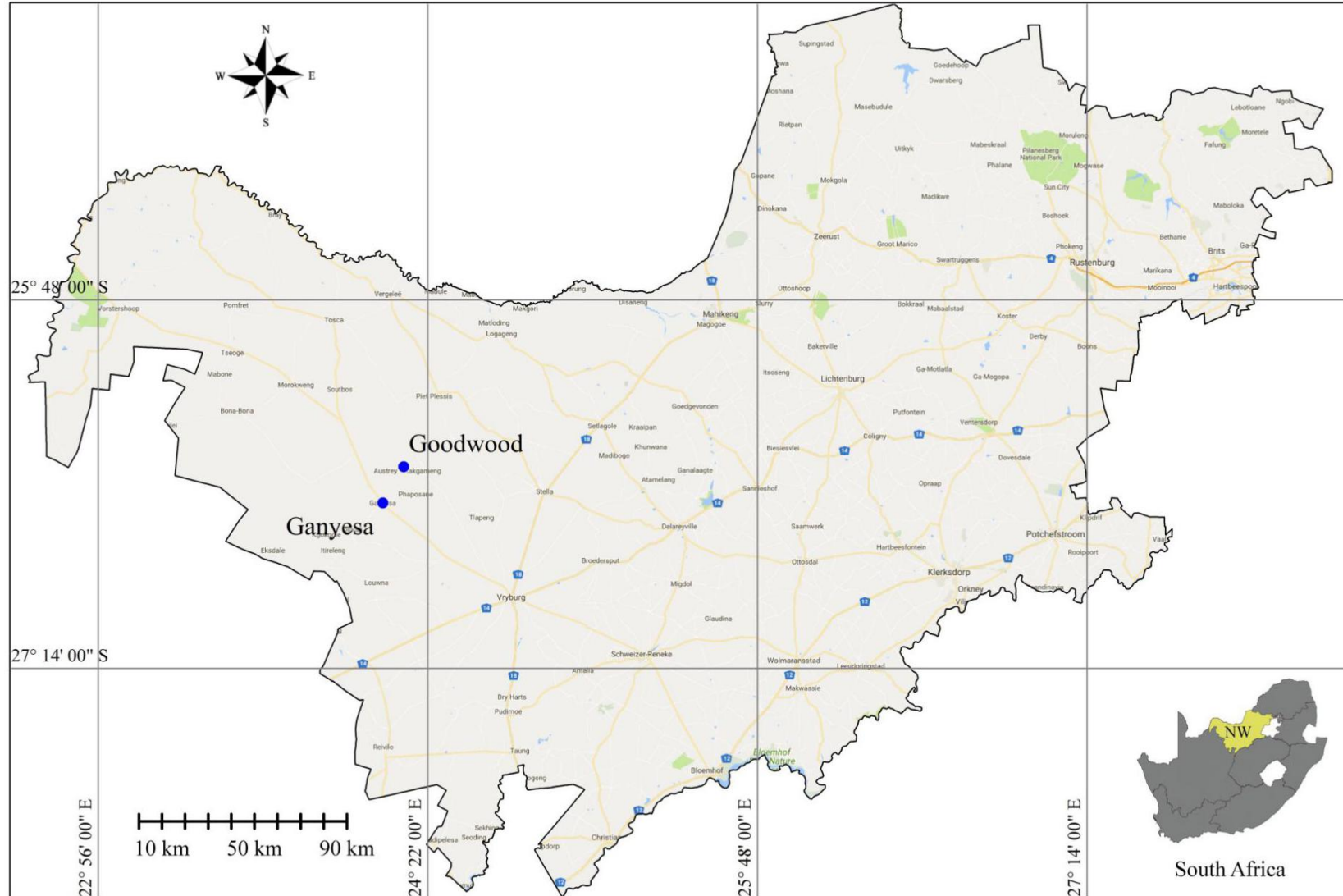


**Figure 3.1** A map showing the locality of the research area at Goodwood in the North-West Province (NW), South Africa.

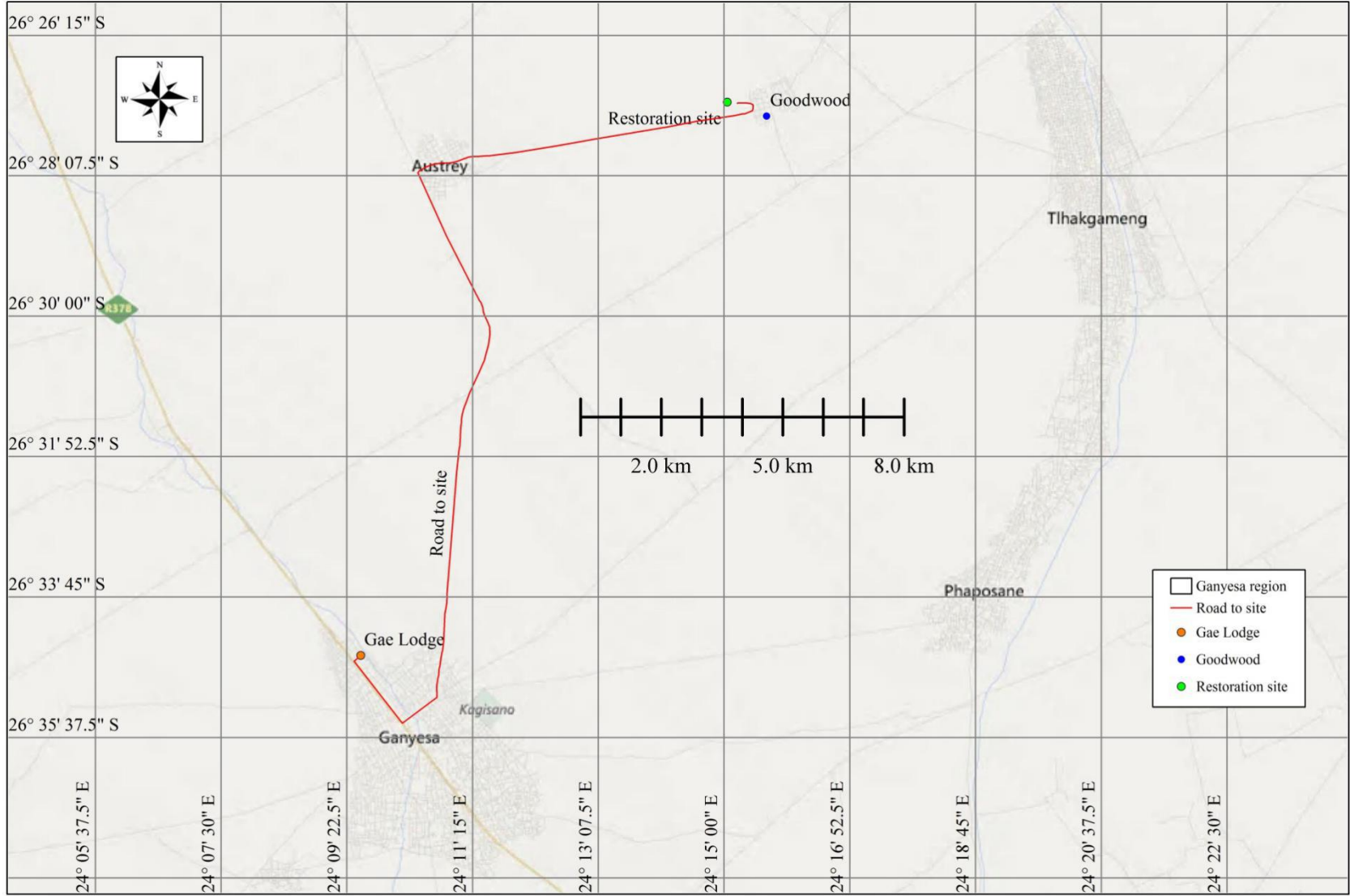


**Figure 3.2** A Street map indicating the restoration site in relation to nearby villages and towns.



**Figure 3.3** A photograph facing the eastern direction, displaying the restoration site situated next to the village of Goodwood.

### 3.2 Climate

The study area is characterised as semi-arid with hot and dry conditions, especially during the summer months (September – April), especially when temperatures can rise above 33°C during January (Figure 3.4), while the temperature in winter can drop to approximately -2°C (Figure 3.4). The average annual precipitation is approximately 350·mm (Figure 3.4), which is very low, rendering dry land cultivation generally nonviable. The land is; therefore, mainly used for keeping livestock.

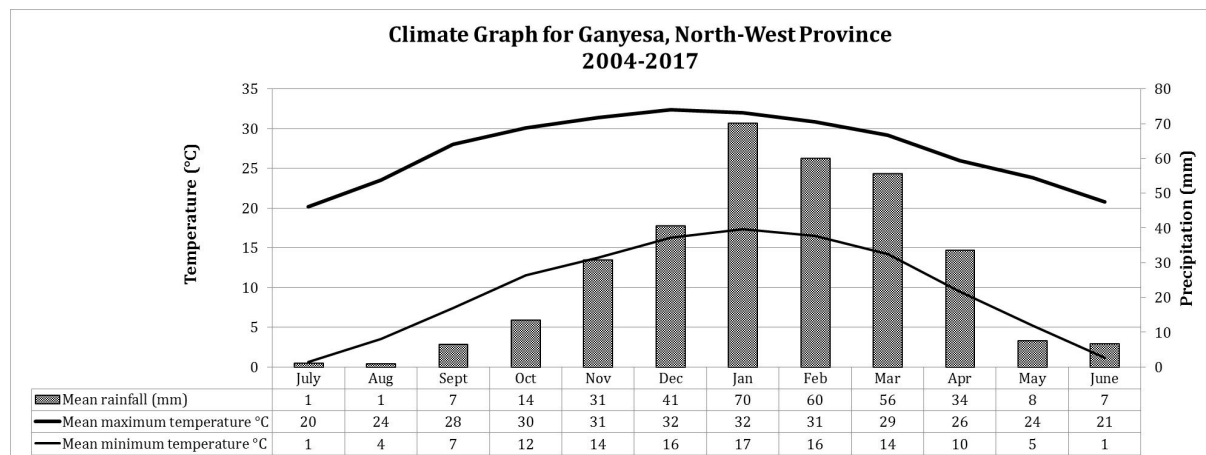


**Figure 3.4** Climate graph for Ganyesa, North-West Province, indicating the mean monthly rainfall (mm) and minimum and maximum temperatures (°C) from the past 14 years (2004 to 2017).

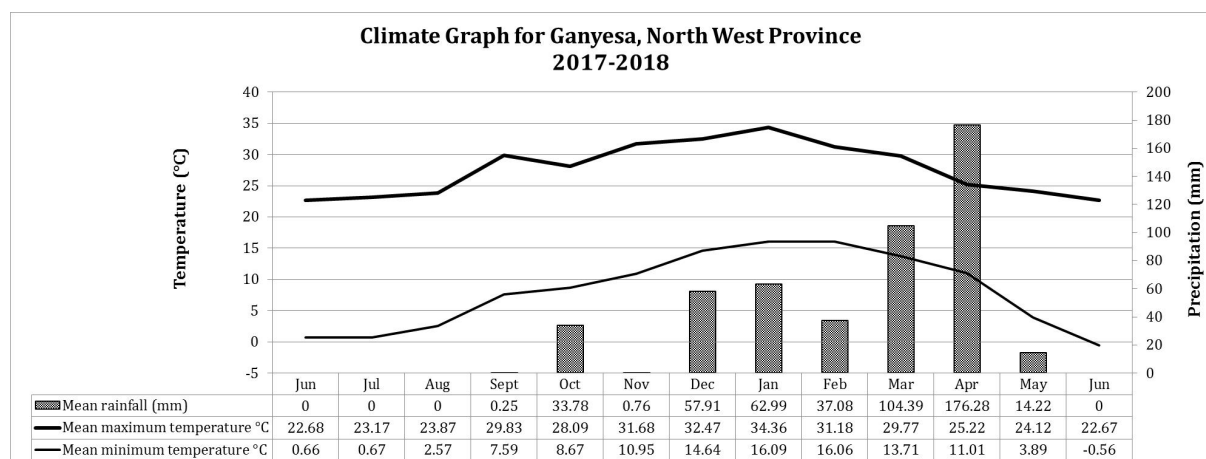


**Figure 3.5** Climate graph for Ganyesa, North-West Province, indicating mean monthly rainfall (mm) and minimum and maximum temperatures (°C) during the study period (June 2017 to June 2018).

From Figure 3.5 it is clear that the precipitation pattern in 2018 differs from the normal precipitation pattern of the past 14 years (Figure 3.4). The average rainfall precipitation pattern from the past 14 years shows that this area received most of its rain during January, February, and March (Figure 3.4). Precipitation during the study period (2017/2018) was however, different from the past 14 years with very little precipitation between December and March but high rainfall during April 2018 (Figure 3.5). The temperature however, does compare to the average maximum and minimum temperatures from the past 14 years; however, spikes in maximum temperatures were recorded in September and January 2018 (Figure 3.5).

### 3.3 Rangeland and management

The study site is found on the boundary between the Molopo Bushveld and the Mafikeng Bushveld which are grouped in the Eastern Kalahari Bushveld Bioregion (Mucina & Rutherford, 2006). The savanna is encroached by various invasive woody species such as *Vachellia tortilis*, *Vachellia hebeclada*, and *Tarchonanthus camphoratus* (O'Connor et al., 2014). It is a communally managed area with no, or only a few fences to make paddocks to keep out the abundance of donkeys, cattle, sheep and goats. The grass sward in the area is generally overgrazed due to the high livestock numbers.

Within communal rangeland, livestock farming often provides non-market value, such as cultural and spiritual resources (Dovie et al., 2006). A variety of livestock breeds are often found on communal rangeland, as many indigenous breeds such as Nguni cattle are better suited to low-input management systems (Mapiye et al., 2009). Different types of livestock as well as different breeds may have unique dietary requirements that have to be considered when managing communal rangeland. Stocking rates might be more or less flexible, depending on the number of livestock owners, their incentives for raising animals and their access to alternative fodder during times of drought.

The rangeland in the research area, as well as other areas belonging to traditional leaders, is shared among community farmers of the area. Numerous livestock owners will utilise the rangeland as fodder for their livestock, but with different livestock owners utilising the same area, it may become unsustainable considering that minimal fencing infrastructure exists, which makes rotational grazing difficult to implement.

## **Chapter 4**

### **4. Methodology**

#### **4.1 Research procedure**

The research procedure is designed to provide both qualitative and quantitative results. Major activities are divided into six phases, i.e. (1) baseline survey prior to restoration, (2) experimental design, (3) maintaining the experimental plots, (4) monitoring and surveys, (5) glass house trials, and (6) data interpretation. The experiment makes use of a cost-effective method, i.e. brush packing with woody branches after the clearing of unwanted trees and shrubs to restore degraded savanna rangelands, mainly to improve the grazing capacity of the land.

#### **4.2 Phase 1: Baseline survey**

The first objective was to conduct a baseline vegetation and soil survey to better understand the bio-physical processes functioning within the ecosystem of the proposed study site and to get a better understanding of the vegetation and soil conditions of the environment. Vegetation and soil conditions can be used as parameters to determine the state in which a given ecosystem resides, as similar ecosystems can exist in different states due to interactions between biota and its environment (Crop & Gabric, 2002).

As environmental conditions change, plants and animals will adapt to constraints imposed by factors such as overgrazing and bush encroachment. The vegetation (trees, shrubs and grass) in the ecosystem, thus, adapts to the current conditions, which is influenced by management practices, soil type and climate variability. Knowledge about the state and condition of the ecosystem can be used to determine the type of restoration technology needed to restore lost ecosystem functions and services.

#### 4.2.1 Vegetation survey:

Three 20 m belt transects with a 4 m buffer (100 m<sup>2</sup>) were used to record the composition, density and height classes of the woody tree- and shrub species (Figure 4.1). The following height classes were identified (Table 4.1):

**Table 4.1** Height classes identified for height measurements of tree and shrub species during the baseline survey

|                |         |
|----------------|---------|
| Height class 1 | 0-1 m   |
| Height class 2 | 1-1.5 m |
| Height class 3 | 1.5-2 m |
| Height class 4 | 2-2.5 m |
| Height class 5 | > 2.5 m |

The experiment focussed mostly on the grass component of the savanna and not so much the woody component, height classes of woody species were determined only to give an indication on the overall height of woody species occurring in the study area.

Five 20 m transects were used to record the frequency of the grass species using the descending point method, at every 1 m interval (Figure 4.1) (Kent, 2012). The nearest grass species within a 30 cm radius was recorded to determine the frequency or, if the pointer touched the grass tuft, it was recorded as a “hit” to determine the grass basal cover (Kent, 2012). A 1 m<sup>2</sup> quadrant was used at five locations positioned in the 400 m<sup>2</sup> sample plot (Figure 4.2) to determine the density and composition of the grass species.

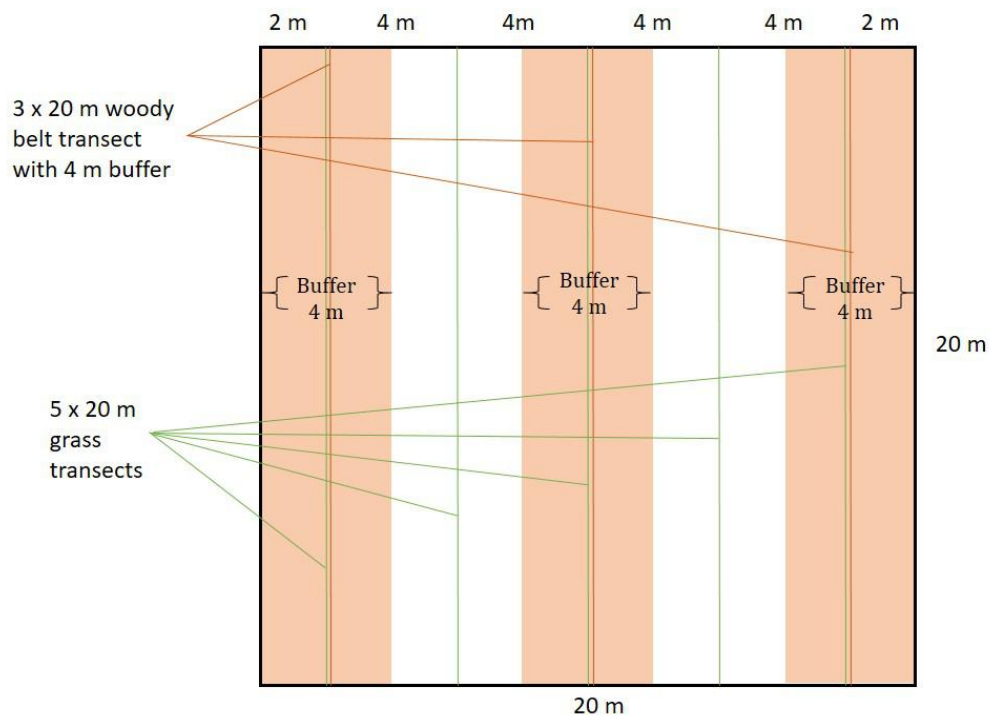


**Figure 4.1** A diagram showing 20 m transects for grass and woody components at specific positions; 3 woody belt transects with 4 m buffer and 5 grass transects.

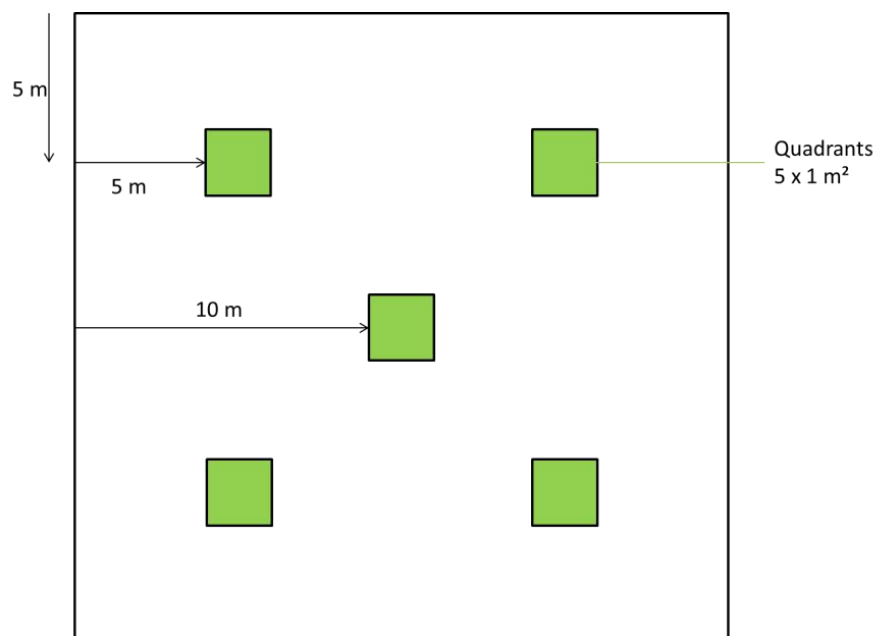


**Figure 4.2** A diagram showing 1 m<sup>2</sup> quadrants for grass surveys in the 20 x 20 m sample plot.

#### **4.2.2 Soil sampling:**

Three random soil samples, using a soil auger, were taken in each experimental plot to a depth of 30 cm, mixed and combined in a composite sample. The soil samples were analysed at the Eco Analitica laboratory<sup>1</sup>, chemical and biophysical analyses were carried out to determine the soil quality of the proposed research area. Soil quality refers to the ability of the soil to function as a major component of an ecosystem and determines the capacity of a certain soil type to function within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and well-being (Snyman & Du Preez, 2005).

#### **4.3 Phase 2: Experimental design**

The methodology entails the implementation of brush packing as a restoration technology on bush cleared areas. A total of 18 sample plots were developed, each with a size of 400 m<sup>2</sup> (20 m x 20 m) (Figure 4.3 and Figure 4.4). The plots consisted of six different treatments, which were replicated three times. Treatments consist of different combinations of bush clearing, soil disturbance, re-seeding and brush packing (Figure 4.3). The following treatments were applied:

1. C – Clearing of bush.
2. UC – Un-cleared (The control plot).
3. CRS – Clearing and Re-seeding.
4. CBP – Clearing and Brush packing.
5. CRSBP – Clearing, Re-seeding and Brush packing.
6. CSoRSBP – Clearing, Soil disturbance Re-seeding and Brush packing (Full treatment).

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Eco Analitica laboratory, North-West University, Potchefstroom 2531, +27 (18) 285 2732.

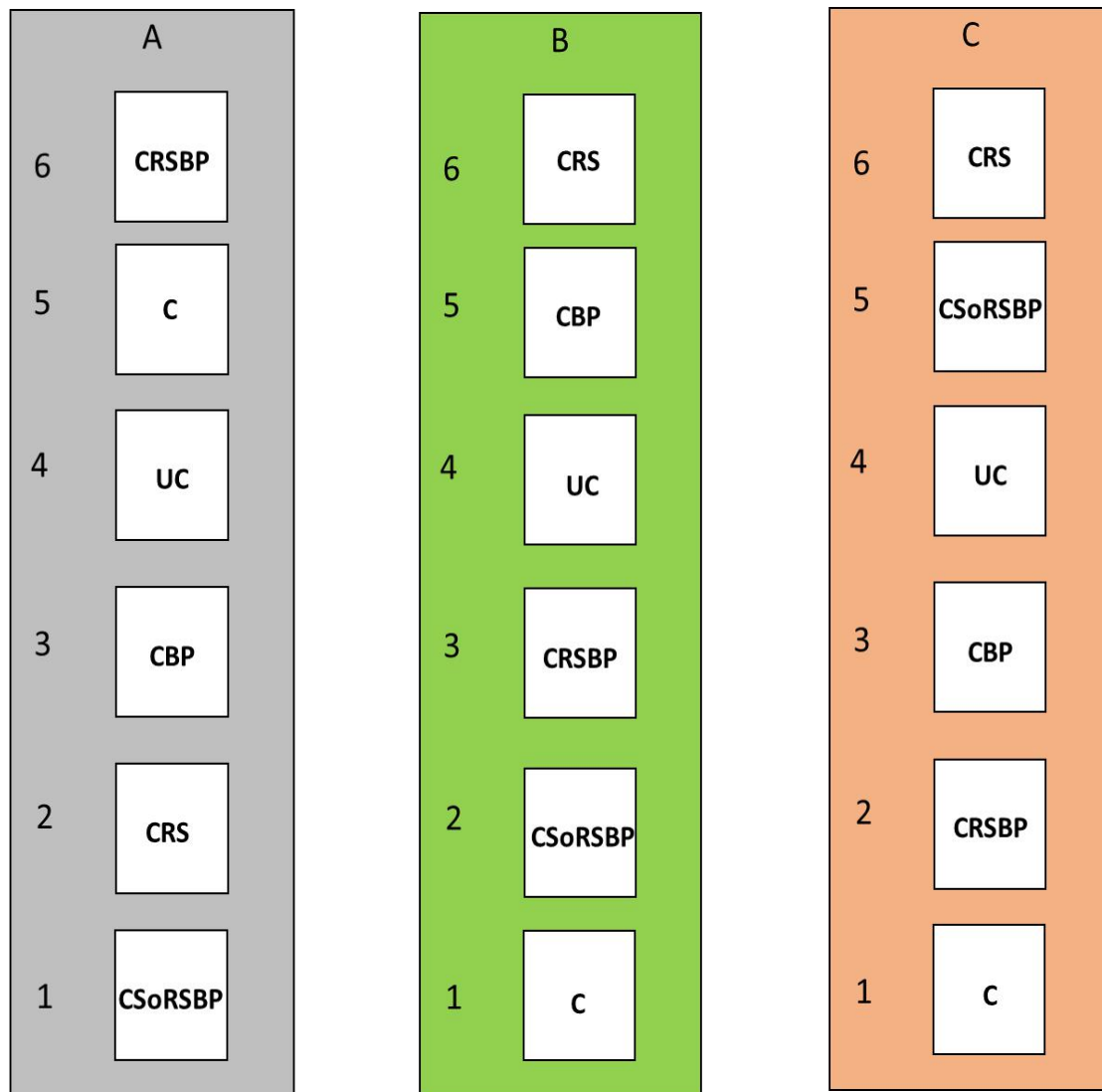


**Figure 4.3** Schematic diagram indicating the randomly placed six restoration treatments (1-6) in three blocks (A, B & C).

The experimental design phase depended on the cooperation of the involved LUI's and commenced at the end of May 2017 with the LUI's cutting down woody species ("bush") at the study area according to the bush clearing standards of DEA (cut 75%, leave 25% and cut all woodies with stem diameter smaller than 10 cm at knee height). The bush was cut by means of manual methods (using chainsaws, handsaws and pruning loppers), after which arboricides (chemical herbicide for woody species) were applied on the cut stumps. All "bush" occurring inside the experimental plots were cut down, except those occurring in the control plots.

A team of the local community assisted in setting up of the restoration experiment in June 2017. A mixture of *Eragrostis curvula*, *Chloris gayana*, *Digitaria eriantha*, *Cynodon dactylon*, and *Cenchrus ciliaris* seeds were sown in to the assigned plots at a ratio of 5 kg/ha and brush was strategically packed on the assigned sample plots. One of the treatments i.e. CSoRSBP (See meaning of abbreviation in section 4.3) involved the soil being disturbed with pitch forks and shovels prior to sowing, this treatment opposed to all other, also involved stamping (stamp means to forcibly strike down with the foot) the ground after sowing.

These procedures were carefully supervised by the scientist involved in the project. To sow the seed in the months of October or November would have been a more appropriate time, however the time allocated for this experiment, as well as the fact that the experiment was dependant on the LUI's assistance, sowing already commenced in the month of June.

The reason why the specific grass species were chosen, depended on their palatability to livestock, suitability of the certain soil type and that they are generally used for restoration purposes. Other reasons for choosing these species was that large amounts of seed were available from the seed merchant and that the results of this experiment could be compared with restoration trials carried out in other regions where the same grass species were used. Other reasons for using these grass species included their effectiveness when using the brush packing technology, as well as their ability regarding recruitment, growth and survival in restoration trials. Figure 4.4 displays the experimental design as seen from an aerial perspective.



**Figure 4.4** Photographs displaying all the experimental plots (6 treatments, replicated 3 times) from an aerial perspective (see section 4.3 above for the abbreviations of the treatments).

The total surface area under scientific monitoring is 7200 m<sup>2</sup> (18 x 400 m<sup>2</sup>). Nine out of the eighteen sample plots consist of brush packing technology, which equals to almost half a hectare of brush packing. The whole construction phase took four days to complete with a team of five “brush packers” (Figure 4.5).



**Figure 4.5** A photograph portraying the implementation of brush packing by the local community from the nearby village of Goodwood. Brush packing was carried out on 13 June 2017.

#### **4.5 Phase 3: Maintaining the experiment plots**

Maintaining the experimental plots is very important in order to formulate quality long-term scientific data. The experimental plots were maintained in a “good” condition, especially the plots with brush packing. In order to ensure successful restoration, the brush must be kept intact throughout the research period. The research area in Goodwood is situated approximately 200 m from the border of the village. Having the research site close to a village, has positive and negative effects on the experiment. Local people who co-operate with the sustainability of the research project may contribute to maintaining the experimental plots, while others might remove the packed branches for fire wood and construction purposes.

Communication with community members and awareness played a significant role in ensuring research integrity. The tribal office (“chief”) has the final say in all activities occurring in the village. In order to conduct the research successfully, meetings were held with the tribal offices of Austrey and Goodwood beforehand. The tribal authority was cooperative and when the plots were checked by the scientist in November 2017, the research site was still in a good condition, meaning that there was successful collaboration with the nearby community, contributing to science (Figure 4.6).

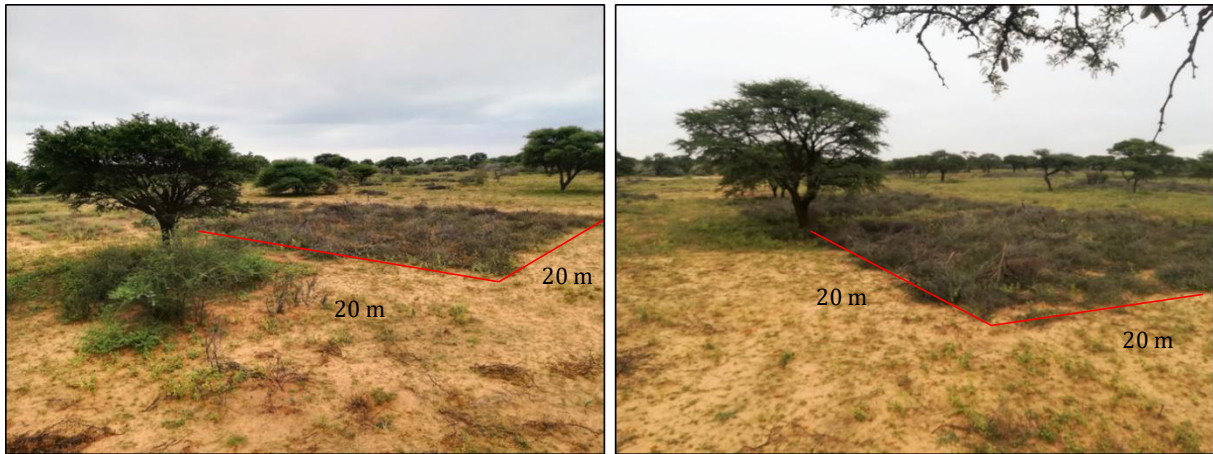


**Figure 4.6** Photographs displaying successful preservation of brush packing through the growing season of 2017 and 2018.

#### **4.6 Phase 4: Monitoring and surveys**

During April 2018, vegetation and soil surveys were carried out. The main purpose of the experiment was to provide scientific evidence concerning the brush packing restoration technology, and whether it contributes to a significant increase in grass biomass production for improved grazing in semi-arid savanna rangelands.

A number of interns, commonly referred to as “Groen Sebenzas” by DEA, were employed to create awareness, build capacity and contribute to training procedures. The interns assisted with data capturing (soil and vegetation parameters) during the field visits and also assisted in data analysis that were carried out.

With the help of the “Groen Sebenzas”, the composition, density and biomass of the different grass species, as well as the soil temperature and moisture were recorded within five 1 m<sup>2</sup> quadrants in each of the eighteen 400 m<sup>2</sup> experimental plots at specified positions (Figure 4.7). Composite soil samples were also taken to analyse for physical and chemical parameters that may have changed during the restoration period.

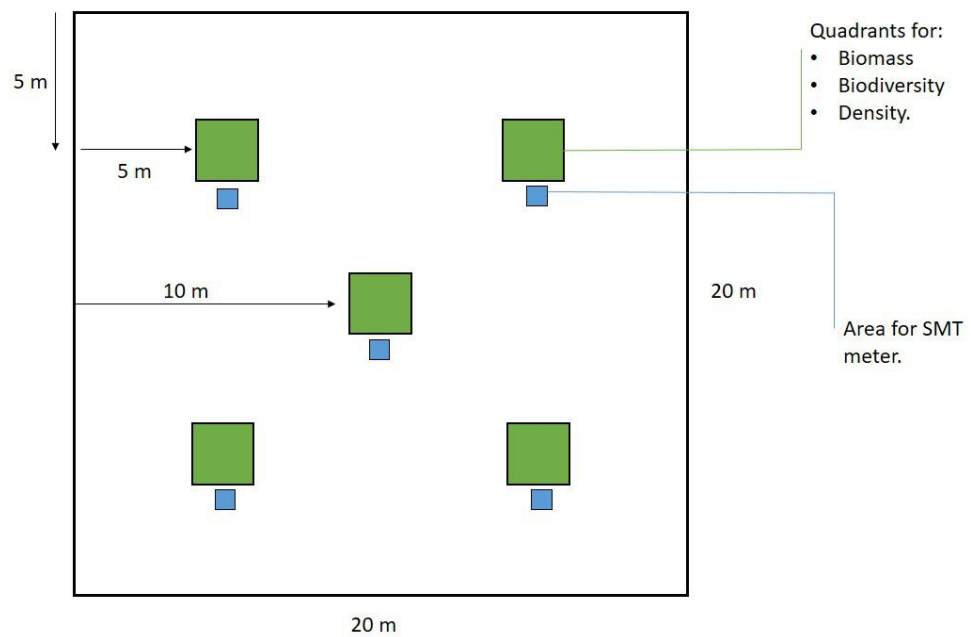


**Figure 4.7** A diagram representing the experimental sample plot, indicating the positions where the vegetation and soil samples were taken. The green squares indicate the position for placing 1 m<sup>2</sup> quadrants in which grass biomass, diversity and density were measured. The blue squares indicate the positions where soil moisture and temperature were measured using the Soil Moisture meter (SMT meter).



**Figure 4.8** Photographs displaying the use of the Soil Moisture meter (SMT meter).

The soil moisture meter, also referred to as the SMT meter (Figure 4.8) was used to measure both the soil moisture and temperature across all sample plots. Soil moisture and temperature were measured three times daily during the time of surveying (4 days) only (morning, midday, and afternoon). A probe is vertically inserted into the soil at the specified position to measure the soil temperature and moisture, which is then digitally displayed on the SMT meter screen. Moisture is given as volumetric moisture content

(VMC), measuring the volume of moisture present and not the weight of moisture (gravimetric soil moisture) as with drying-weighing techniques (Bilskie, 2001). The specifications of the SMT meter include:

- Moisture range: 0.0 to 100.0% VMC
- Temperature range: -40.0~ 80.0°C
- Measurement type: Volumetric soil water content
- Accuracy: Temperature:  $\pm 0.5^{\circ}\text{C}$ , Moisture:  $\pm 3\%$  (within 0-53%)
- Measurement: Insert or buried
- Pin length: Approx. 70 mm
- Average power consumption:  $<0.5\text{ mA}$

Soil moisture and temperature in all plots were measured to quantify brush packing as a grass recruitment facilitator through its effects on surface temperature and the soil-moisture regime (Visser et al., 2017). Semi-arid savannas are prone to experience very high temperatures during summer, which means that the shade created by brush packing may be beneficial for the recruitment and production of grasses that are in the soil seed bank or have been re-seeded during the restoration treatments.

Figure 4.9 indicates how biomass production was measured by cutting grass with sheep shears to a height of 1 cm. Although the norm height for grass sampling is at 5 cm, 1 cm was used for the reason that certain treatment plots (mainly those without brush packing) would have indicated close to if not zero biomass due to the severity of overgrazing occurring at the study area. The process of acquiring grass survey data was as follows: (1) five positions within the sample plot, as described above, were marked (see Figure 4.7), (2) the species were identified and counted in each marked position within the quadrant to obtain the density of the different species, and (3) grass biomass were harvested with sheep shears, and then put in bags and weighed to determine biomass production (Figure 4.9).

One composite grass biomass sample was taken at each plot. Biomass samples were air dried and weighed by the Department of Rural, Environment & Agricultural Development<sup>2</sup> in Potchefstroom.



**Figure 4.9** Photographs showing vegetation sampling and biomass collection in the 1·m<sup>2</sup> quadrants in each of the experimental plots. The photograph on the left shows the process of species identification and counting, and the photograph on the right shows grass biomass collection with the use of sheep shears.

#### 4.7 Phase 5: Glasshouse trials

An experiment in the glasshouse at the NWU was conducted to simulate the brush packing technology in a controlled environment. The glasshouse is equipped with a ventilating system connected to an automatic thermostat which regulates a daytime temperature of 24°C and night time temperature of 17°C. The same seed batch used in the field were used for the glasshouse trial, these seeds were sponsored by AGT Foods<sup>3</sup>, which included the five different species mentioned: *Eragrostis curvula*, *Chloris gayana*, *Digitaria eriantha*, *Cynodon dactylon*, and *Cenchrus ciliaris*.

Figure 4.10 shows the glasshouse trial as conducted within 30 cm x 30 cm buckets with a depth of 10 cm. Three soil treatments were collected at the Goodwood site: soil from underneath tree coverings (canopy soil) and soil from open areas (open soil) and additionally little thorny twigs from *Acacia* species were collected which were used for

<sup>2</sup> Department of Rural, Environmental & Agricultural Development, 114 Chris Hani St, Potchefstroom, 2520, 018 299 6500.

<sup>3</sup> AGT Foods, 8 Jacobs Street, Krugersdorp, 1740, +27 011 762 5261/2.

the brush packing simulation. Buckets received a seed mixture of the five grass species, as conducted in the field. Seeds were sowed in on the 21<sup>st</sup> of May 2018 with a ratio of 1 g/bucket and surveys were conducted 25 July and 21 August 2018. The surveys included species identification, counting of individuals and measuring the growth height of the species in the buckets to compare open soil with canopy soil, as well as the soil covered with brush.

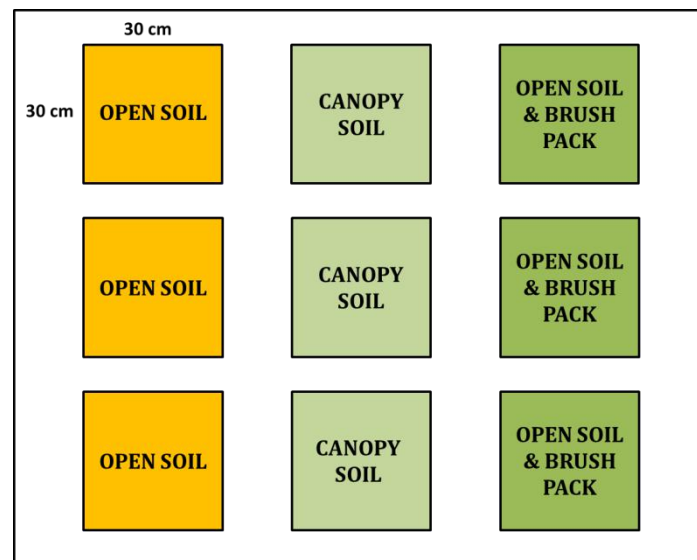


**Figure 4.10** A schematic diagram depicting the three soil treatments with three repetitions that were used in the glasshouse experiment, conducted in 30 cm x 30 cm buckets.

#### 4.8 Phase 6: Data interpretation

Soil chemical and physical analysis, vegetation studies (woody and grass species), soil temperature and moisture, seed viability, soil fertility and grass biomass production studies were conducted. These data sets were investigated and shown through tables and diagrams utilising Microsoft Excel, to indicate certain patterns and trends of savanna restoration in the data. Statistical analysis was directed utilising the Statistica software, particularly processing the information through the ANOVA (analysis of variance) statistical method, keeping in mind the end goal to showcase practical and statistical significance of the effect of brush packing on grass biomass production and species recruitment. Furthermore, the statistical software Canoco 4.5 was also utilised, specifically interpreting the data through the Redundancy Analysis (RDA) and the canonical correspondence analysis (CCA) constrained ordination methods using the CANOCO data analysis program (Ter Braak & Smilauer. 1997; Okullo & Moe, 2012).

## Chapter 5

### 5. Results and discussion

#### 5.1 Baseline survey

The baseline survey gave the researchers an indication of the condition of the proposed ecosystem. The woody species component reflects on the degree of bush encroachment in the region, while the grass species component reflects on the usefulness of the area for livestock production. Soil parameters were determined through soil sampling and analysis, which gave an indication of the agricultural production capabilities of the regions soil.

##### 5.1.1 Woody species

The woody species diversity, (i.e. the composition and abundance of woody species) showed that *Diospyros lycioides* (Blue Bush) was the dominant species, occurring within plots 1-6 (Chapter 4, section 4.2) especially within plots 4, 5 and 6 (Figure 5.1).

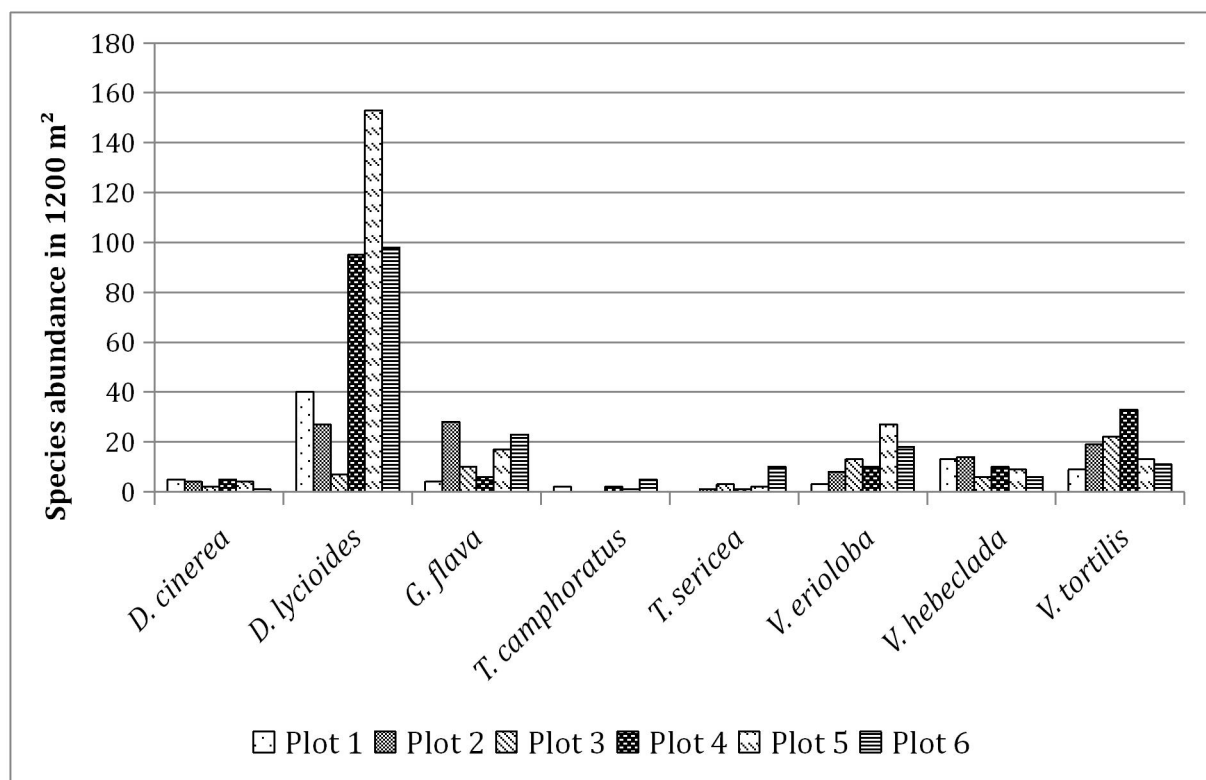


**Figure 5.1** A graph showing the abundance of the major woody species (see Annexure 1 for full names of species abbreviations) composition within sample plots 1-6 (values are summed together for all three replicates of the sample plots for an area of 1200 m<sup>2</sup>).

*Diospyros lycioides* outweighs the other species by number of individual occurrences. The high abundances of *D. lycioides* can be attributed to the patch formation of this species in the savanna mosaic. *D. lycioides* is considered a highly palatable species that is frequently browsed by goats in South Africa (Owen-Smith & Cooper, 1987).

The main encroaching species in the study area include *Vachellia tortilis* (Umbrella Thorn), *V. hebeclada*, (Candle-pod Thorn), *Terminalia sericea* (Silver Cluster-leaf) *Tarchonanthus camphoratus* (Camphor Bush), and *Dichrostachys cinerea* (Sickle Bush) (Figure 5.1). *V. tortilis* can be regarded as the main encroacher species, as it occurred in all the experimental plots (Figure 5.1). It is evident that the number of individuals for all the woody species in this area is not very high, suggesting that the process of bush encroachment for this area is probably in an early stage. *V. erioloba* occurs in all the plots and can be regarded as a typical woody species occurring in deep sandy soils in the Savanna Biome (Figure 5.1) (Mucina & Rutherford, 2006).

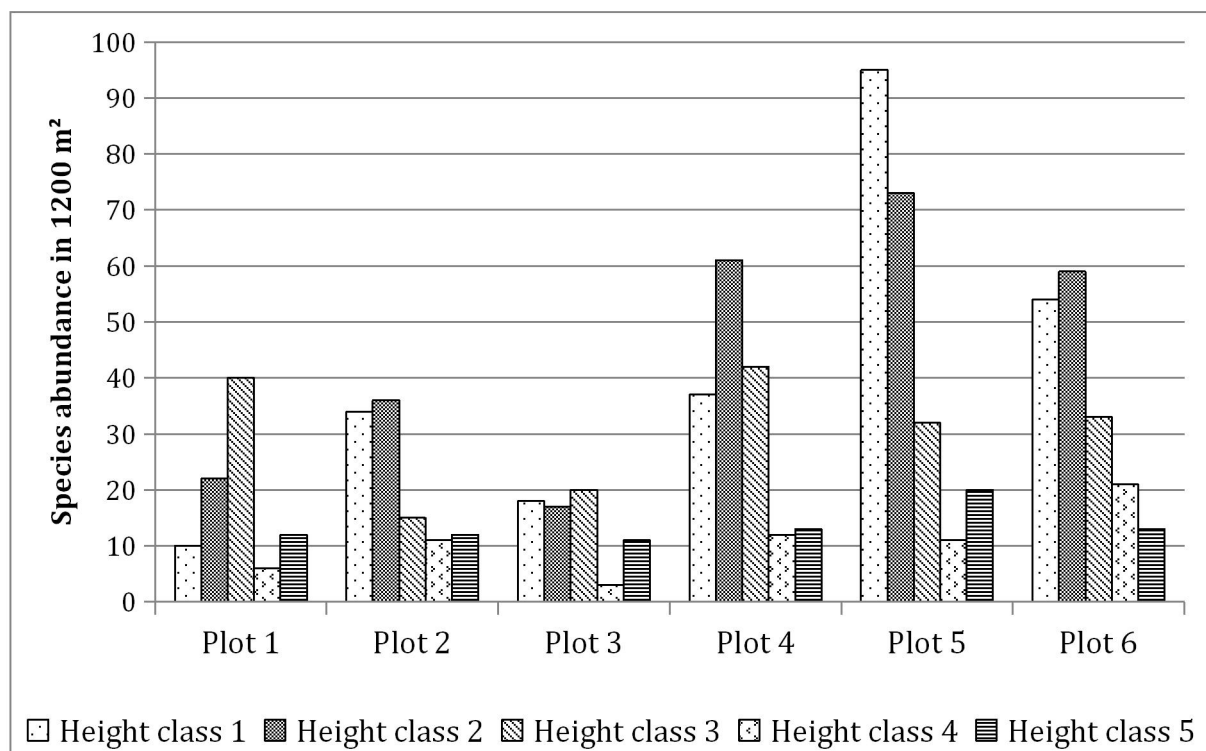


**Figure 5.2** A graph showing woody species abundances (number of individual species) for the 5 height classes identified within sample plots 1–6 (values are summed together for all three repetitions). See Chapter 4, section 4.2.1 where the height classes are explained.

The number of woody plants per height class may give an indication of the extent of bush encroachment (Van Rooyen, 2016). Most of the woody species are abundant in the lower height classes (1 and 2), but less abundant in the higher height classes (3–5) (Figure 5.2; See Chapter 5, section 4.2.1 where the five different height classes are explained). This could also be an indication that bush encroachment may be in an early stage as the majority of woody species are within the lower height classes.

### 5.1.2 Grass species

The grasses *Eragrostis trichophora* (Atherstone's Grass), *Brachiaria marlothii* (Creeping Grass), and *Aristida congesta* (Cats-Tail Three-Awned Grass) are the dominant species that occurred within all the sample plots (Figure 5.3). However, *B. marlothii* only occurred underneath *V. erioloba* tree canopies.

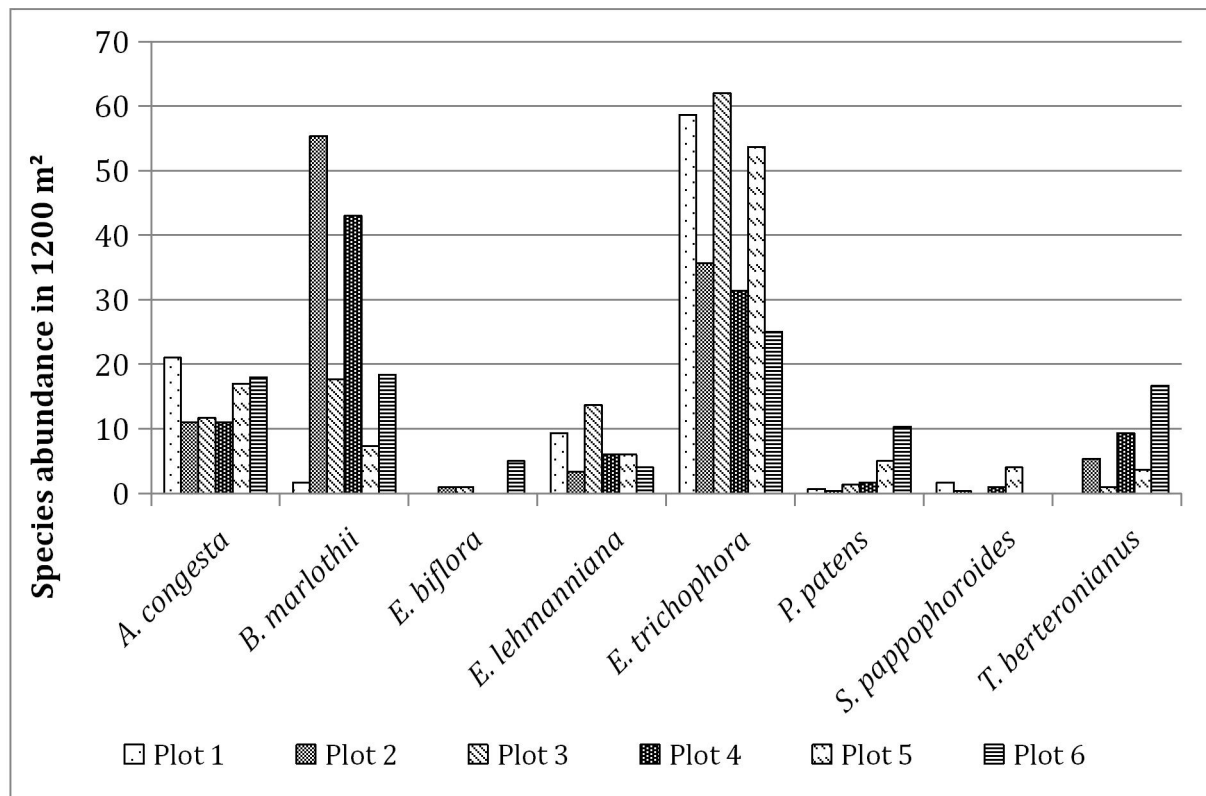


**Figure 5.3** A graph showing the occurrence of the major grass species diversity within sample plots 1-6 (values are summed together for all three repetitions for an area of 1200·m<sup>2</sup>).

This occurrence gives rise to the positive cover effect that canopies of larger tree species have on the underlying herbaceous species. *Eragrostis trichophora* and *A. congesta* are classified as sub-climax and pioneer species in this region respectively

(both increaser II species). These species frequently occur in disturbed, overgrazed or degraded areas (Van Oudtshoorn, 2002). The only significant climax, palatable grass species found was *Schmidtia pappophoroides* (Blue Grass), a perennial decreaser grass species, indigenous to southern and western Africa and the Cape Verde. This species is very useful in making thatch roofs and is a valuable fodder grass for grazing purposes (Van Oudtshoorn, 2002).

The high abundance of pioneer and sub-climax species may be an indication that the study area was frequently overgrazed in the past (van Oudtshoorn, 2002). Climax species are almost absent, only growing between spiny shrubs and trees where livestock (cattle, donkeys, sheep and goats) cannot reach it. See annexure 2 for complete list of grass species involved in the study.

### 5.1.3 Soil analysis

The soil texture of the study area is illustrated in Figure 5.5 below, indicating the extremely high sand fraction in the soil.

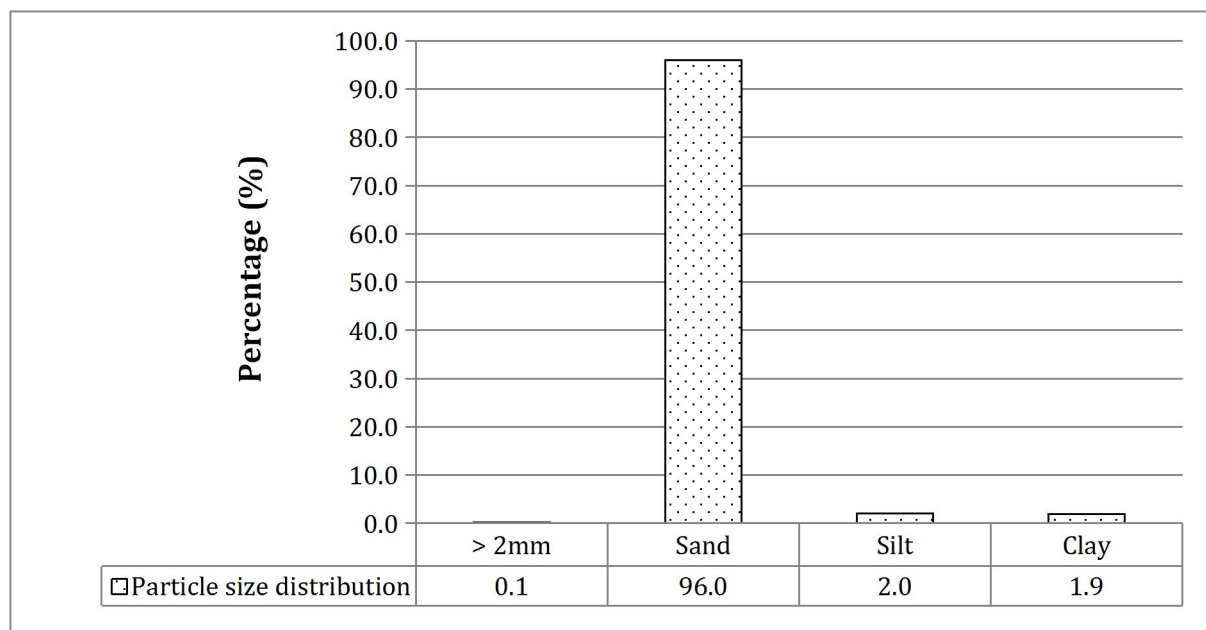


**Figure 5.4** A graph indicating the particle size distribution of the soil at Goodwood, which include sand, silt, clay and particles larger than 2 mm represented as a percentage.

### 5.1.3.2 Nutrient status of the soil

The nutrient status of the soil was analysed for the following elements (Ca, Mg, K, P, CEC, pH, EC, N and C). The results of the mineral elements are given in Table 5.1, and the chemical and organic analysis for Goodwood study site, showing the pH, EC, N, and C levels in the soil are given in Table 5.2.

**Table 5.1** Soil nutrient status at the Goodwood study site, showing Ca, Mg, K, N, and P as mg/kg as well as the CEC

| Nutrient status & CEC | (mg/kg) |      |      |     |     | CEC |
|-----------------------|---------|------|------|-----|-----|-----|
|                       | Ca      | Mg   | K    | Na  | P   |     |
|                       | 115.6   | 23.4 | 25.7 | 0.5 | 5.0 |     |

#### Calcium (Ca) to magnesium (Mg) ratio:

The Ca to Mg ratio is the single most important ratio in a soil analysis (Table 5.1) (Dinkins & Jones, 2007). This ratio determines gas exchange capacity of the soil. The more efficiently a soil can take in oxygen and then release CO<sub>2</sub> for photosynthesis (gas exchange), the better the agricultural production capabilities of the soil (Moser, 1933).

Soil gas exchange is dependent on the ratio between Ca and Mg in the soil and this, in turn, depends on the CEC of the soil (Moser, 1933). CEC is a measure of the clay component of the soil (McCauley et al., 2005). A sandy soil might have a CEC of 4 cmol(+)/kg, while a heavy clay soil might have a CEC of 40 cmol(+)/kg. In the heavy clay soil more Ca is needed to help push apart the high clay component. Here, the ideal Ca:Mg ratio might be 7:1. Conversely, in the sandy soil a Ca:Mg ratio of 3:1 will be adequate, since more Mg is needed to help create structure in the soil (Moser, 1933).

The soil at Goodwood site has a Ca:Mg ratio of 5:1 (115.6/23.4). The Mg seems to be in a deficit, which implies that there is not much structure in the soil which is; however, a common phenomenon among deep sandy soils (Table 5.1).

#### Potassium (K) to magnesium (Mg) ratio:

The second most important ratio is the K to Mg ratio (Table 5.1) (Dinkins & Jones, 2007). Whenever there are equal parts of K and Mg in the soil, it seems to enhance the plant uptake of these elements, as well as the uptake of P. Phosphorus is one of the essential minerals for photosynthesis, and the most critical mineral for plant immunity (Mullen,

2013). Hence, this ratio directly influences plant resilience, creating a reduced need for chemical intervention.

The K/Mg ratio at the Goodwood site is 1.09:1 which is almost 1:1. It is considered as a good ratio for the plant uptake of K, Mg, and P (Figure 5.1).

However, as the amount of P in the soil is only 5 mg/kg, it indicates that the study area has a P deficit (Table 5.1). According to Dinkins and Jones (2007), medium levels of P will be in the range of 8-16 mg/kg, high levels >16 and low levels <8.

#### **Potassium (K) to sodium (Na) ratio:**

The elements K and Na (Figure 5.1) are two of the major cations that are stored in high abundance on the clay colloid in soils (Eckert, 1987). Sodium should never occur in higher amounts than K in the soil. Should this occur, the plant may have problems differentiating between these two minerals due to the fact that these molecules are similar in size (Eckert, 1987). The plant seems to assume that K will naturally be present in higher amounts, so it simply extracts the mineral that is present at the higher percentage at the time. The key is to always maintain a higher percentage of K than Na. The ideal K/Na ratio may be around 4:1.

At the study site near Goodwood, the K/Na ratio was 51:1 which is very high, but as mentioned above, this ratio becomes problematic when Na exceeds the amount of K. In this case; however, one see the opposite, which is good for healthy plant growth.

**Table 5.2** Chemical and organic analysis for Goodwood study site, showing the pH, EC, N, and C levels in the soil

| pH, EC & organic component | pH (H <sub>2</sub> O) | pH (KCl) | (mS/m) | %N   | %C   |
|----------------------------|-----------------------|----------|--------|------|------|
|                            |                       |          | EC     |      |      |
|                            | 5.37                  | 4.22     | 5.39   | 0.00 | 0.45 |

#### **5.1.3.4 Soil pH**

Soil pH is very important; it influences soil factors such as soil bacteria, nutrient leaching, soil structure, toxic elements, and as mentioned nutrient availability (Perry, 2003). According to Gilbert (2013), the desirable soil pH in rangelands is between 6 and 7. At these pH values the plants and soil organisms fair best and this is also the range

where nutrient availability is the highest to plants. For example, N availability drops at a pH lower than 5.5 and P availability rises at a pH level of 6 (Gilbert, 2013). As seen in Table 5.2, the pH (KCl) of the study area is 4.22, which is below the optimal level for plant growth in rangelands.

Rhizobium (the bacteria that release N from soil organic matter) is also dependant on soil pH. These bacteria operate best at pH levels between 5.5 and 7 (Perry, 2003). When the pH drops to a level below 5, it may cause nutrients to leach out of the soil substrate, where values between 5 and 7.5 will keep nutrients from leaching out (Perry, 2003).

Certain grass species are more hardened in terms of tolerance to acidic conditions, low water availability, extreme temperatures, and saline conditions. Therefore, according to the soil analysis that was carried out for the baseline study, it can be interpreted that hardy grass species, such as *Aristida congesta*, will be able to occur in the study area near Goodwood.

#### **Soil electrical conductivity:**

Electrical conductivity refers to the ability of a material to transmit or conduct an electrical current between the elements and is commonly expressed in units of millisiemens per metre (mS/m) (Grisso et al., 2009). Figure 5.5 gives an indication of electrical conductivity values respective to different soil types, i.e. sand, silt or clay soils. The study site where the restoration was carried out has an electrical conductivity value of 5.39 mS/m, which falls within the classification of a typical sandy soil.

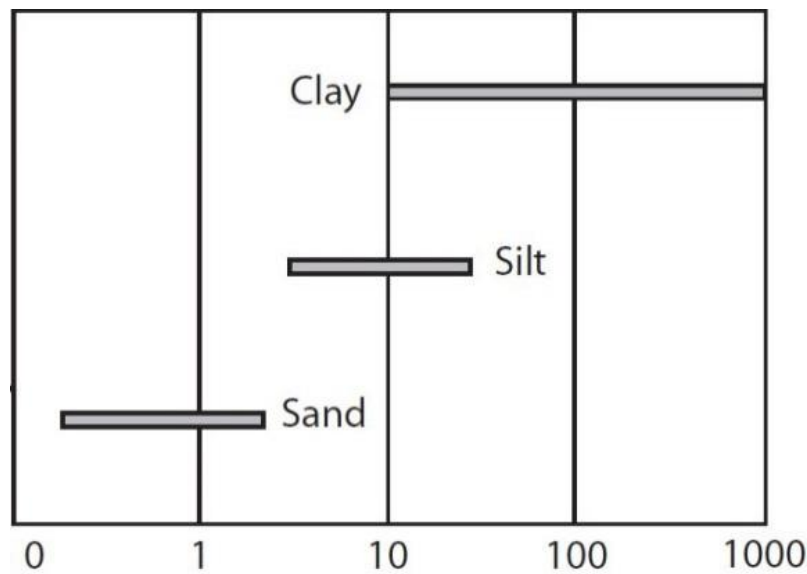


**Figure 5.5** Classification of Electrical conductivity (EC) for sandy, silt and clay soils, presented as millisiemens per metre (mS/m), as described by Grisso et al. (2009).

#### **Soil carbon (C) and nitrogen (N):**

Organic C in soil improves water and nutrient holding capacities, improves soil structure which promotes root growth and aeration, provides desirable habitat for soil organisms, and also acts as a reserve for plant nutrients (Weidemann 1914). Organic C levels in soils are considered low when it is less than 4% (Dinkins & Jones, 2007). According to the soil analysis at the study site, the C content was considered very low with a value of 0.45% before restoration treatments were carried out (baseline study) (Table 5.2). Medium organic C levels are between 4-8%, which is preferred for optimal plant growth (Wang et al., 2009).

Nitrogen, on the contrary, forms part of all living cells and is a contributor for promoting green leafy plant growth. A lack of N will limit plant growth (Dinkins & Jones, 2007). Nitrogen is taken up by plants in the form of nitrate ( $\text{NO}_3$ ) or ammonium ( $\text{NH}_4$ ) (Mullen, 2013). These forms of N are fixed from N gas by soil organisms such as the rhizobium bacteria which utilise C as an energy source (Weidemann 1914). As seen in Table 5.2 the N of the soil in the study area is 0% before restoration treatments were carried out (baseline study), but for optimum plant growth the N level is required to be at least 0.4% (Wang et al., 2009).

The low levels of P, C, and N can be explained by the overgrazing that occurred in this rangeland. Livestock over utilise the rangeland's grass production, consuming all the land's biomass and leaving very little organic matter, such as dead leaves, seeds and other plant residue for important nutrient cycles to occur (Du Preez et al., 2011). In other words, organic matter is removed from the land through overgrazing but not returned. Only some organic matter is returned in the form of animal dung, but the distribution thereof is unpredictable as it may occur on unproductive areas.

Soil sampling and analyses was also carried out after the application of the different restoration treatments. It was; however, found that the soil chemical and biophysical parameters did not change considerably in a period of one year. It should thus be suggested that soil monitoring should be carried out over a longer period of time to see a change in soil quality by implementing brush packing as a restoration technology.

## 5.2 Outcomes after the application of the different restoration treatments

During the study period the rainfall pattern of the Ganyesa region was inconsistent when compared to the average precipitation times of the region (See Chapter 3, Figure 3.4). The rainfall came later than expected but with sufficient amounts to facilitate the restoration process (Chapter 3, Figure 3.5). Rainfall is a noteworthy determinant of restoration success especially within semi-arid regions where rainfall greatly influences the dynamics of vegetation growth and restoration outcomes (Warren & Khogali, 1992; Snyman, 2003).

During the sampling period (2017-2018), it was found that the implementation of brush packing significantly increased grass biomass production ( $p < 0.001$ ), and to a lesser extent the grass species diversity ( $p = 0.049$ ).

**Table 5.3** The effect sizes between the three replicates (N=3) of the six different treatments, considering the standard deviation and mean values of biomass (g) of each treatment (e.g. UC & CSoRSBP = 11.68).

| Treatment | N | Mean<br>boimass<br>(g) | Std.<br>Deviation | Effect Size |      |       |       |            |
|-----------|---|------------------------|-------------------|-------------|------|-------|-------|------------|
|           |   |                        |                   | UC &        | C &  | CRS & | CBP & | CRSBP<br>& |
| UC        | 3 | 21.400                 | 7.9674            |             |      |       |       |            |
| C         | 3 | 42.433                 | 41.9636           | 0.50        |      |       |       |            |
| CRS       | 3 | 39.800                 | 22.3812           | 0.82        | 0.06 |       |       |            |
| CBP       | 3 | 248.533                | 70.7323           | 3.21        | 2.91 | 2.95  |       |            |
| CRSBP     | 3 | 252.867                | 34.5209           | 6.71        | 5.01 | 6.17  | 0.06  |            |
| CSoRSBP   | 3 | 285.867                | 22.6460           | 11.68       | 5.80 | 10.87 | 0.53  | 0.96       |

Comparing different treatments can verify the practical significance of certain treatments according to its effect sizes. See Chapter 4, Section 4.3 for the abbreviations of the treatments.

Effect sizes are the most imperative result of empirical studies (Table 5.3). Researchers need to know whether an intervention or restoration treatment has an effect more noteworthy than zero, or how big the effect is (when it is evident an effect exists – see Table 5.4). Scientists are frequently reminded to report effect sizes, since it is helpful for

reporting discoveries made from scientific experiments (Lakens, 2013). It enables specialists to introduce the greatness of the reported effects in a standardised metric which can be understood without knowing the scale that was utilised to quantify the dependent variable. Such standardised effect sizes enable researchers to communicate the practical significance of their outcomes (what are the practical outcomes of the discoveries for day by day life), rather than only reporting the measurable significance (Lakens, 2013).

**Table 5.4** Table indicating the parameters for practical significance for effects sizes

|     |                                              |
|-----|----------------------------------------------|
| 0.2 | Small, no practically significant difference |
| 0.5 | Medium, practically visible difference       |
| 0.8 | Large, practically significant difference    |

The highlighted area in Table 5.3 indicates that there is a substantial practical significant difference between treatments UC, C, CRS and treatments CBP, CRSBP, CSoRSBP. All treatments containing BP (brush packing) thus indicate significant increases in grass biomass production.

According to Table 5.4 a substantial practical significant difference requires an effect size above 0.8. It was found that the effect that brush packing treatments had on increasing the grass biomass production compared to treatments without brush packing had an average effect size of 6.1 (Table 5.3). The largest effect size was 11.68 and is the result of comparing treatment UC with treatment CSoRSBP, which shows that bush clearing combined with soil disturbance, re-seeding and brush packing contributed the most to an increase in the grass biomass production.

Disturbing the upper soil layer with shovels or pitchforks assist in improving the soil-water regime which improves the water infiltration capacity of the soil i.e. more water will be available for plant growth in treatments that include soil disturbance (Thomas et al., 2006).

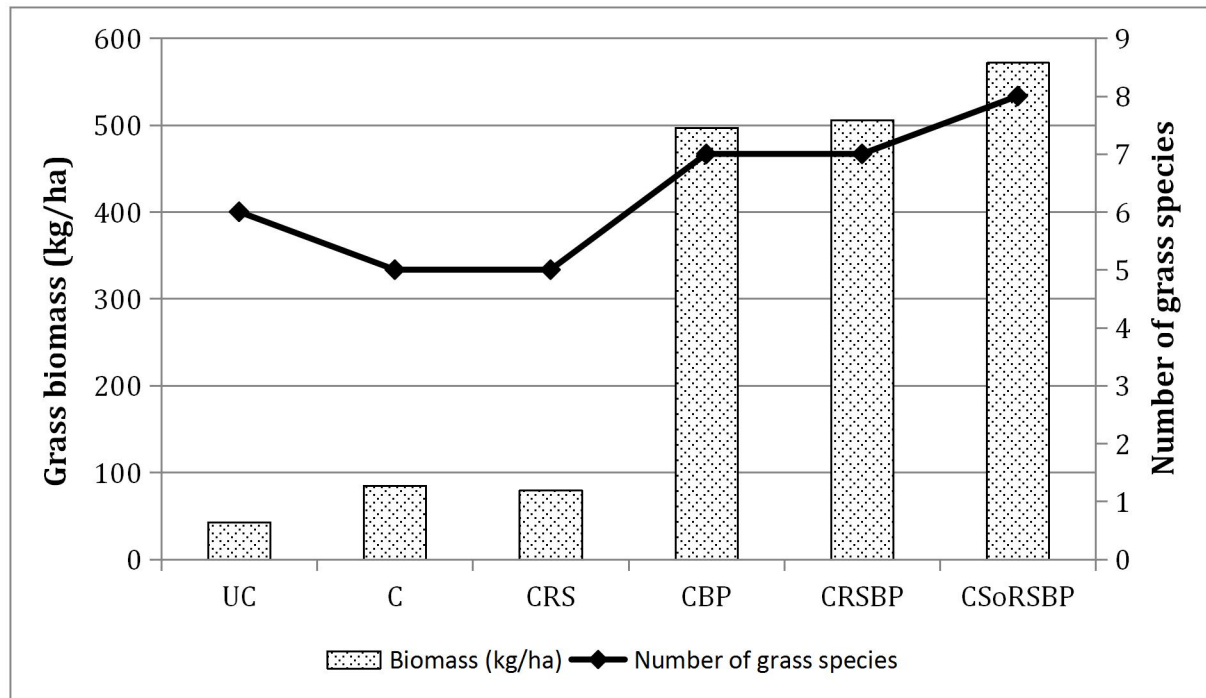


**Figure 5.6** The grass biomass production (kg/ha) and grass species richness (number of grass species) for the six different restoration treatments at the end of the sampling period in April 2018. (See Chapter 4, Section 4.3 for the abbreviations of the treatments).

The differences in grass species richness (number of species) and biomass production (kg/ha) across the six different treatments are shown in Figure 5.6, indicating that all treatments where BP (brush packing) was applied, produced more than 500 kg/ha grass biomass. Treatments where no brush packing was applied (i.e. UC, C and CRS) produced less than 100 kg/ha.

Treatment CSoRSBP (bush clearing, soil disturbance, re-seeding and brush packing) produced the most biomass (570kg/ha) of all treatments applied. From Figure 5.6 it is also clear that the number of grass species (species richness) is higher in BP treatments compared to the non-brush treatments.

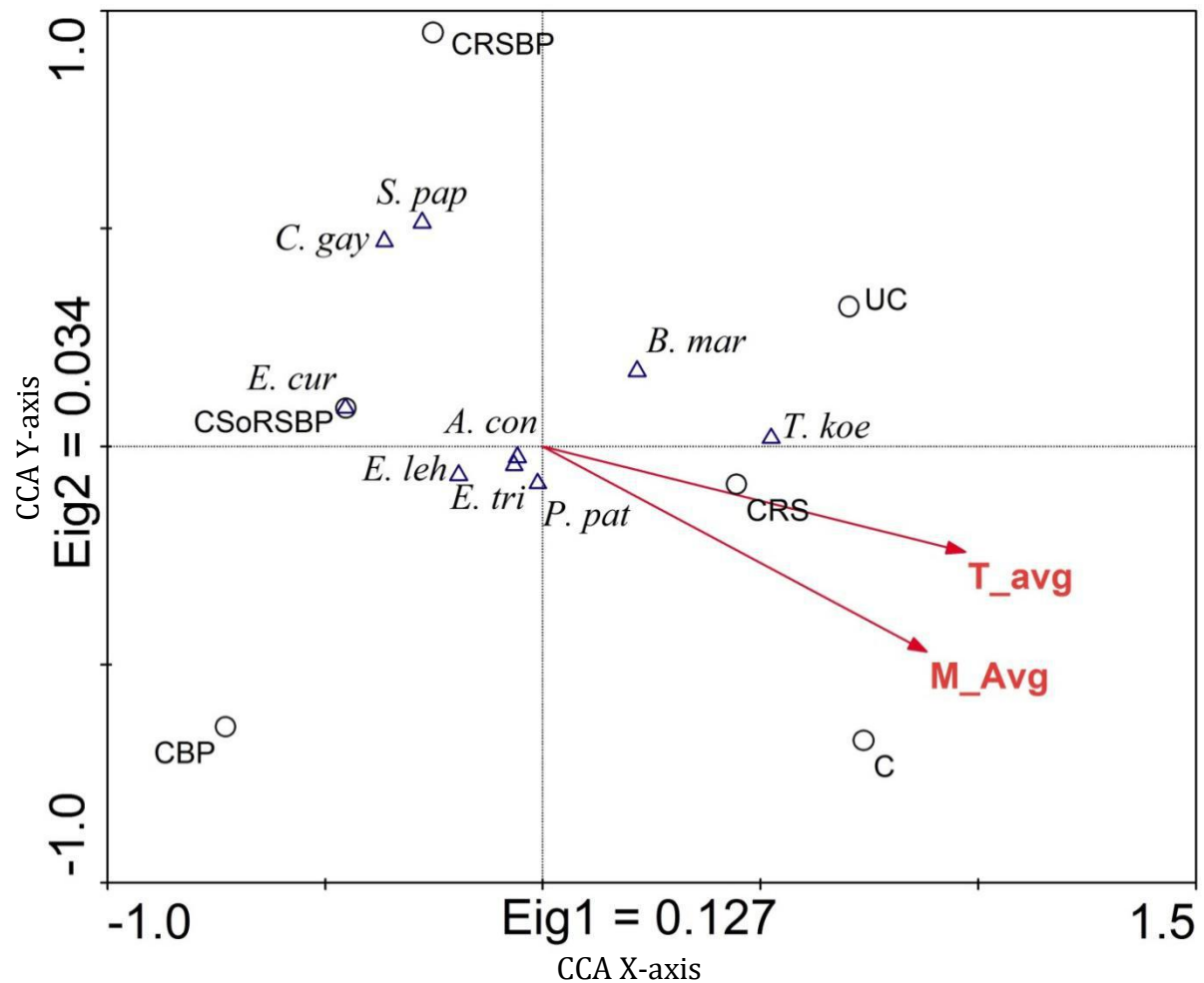


**Figure 5.7** Canonical Correspondence Analysis (CCA) ordination for treatments (UC, CRS, C, CBP, CRSBP and CSoRSBP) related to the most important grass species that occurred at the restoration site as well as soil temperature (T\_avg), and soil moisture (M\_avg). (Annexure 1 for the abbreviations of the species and see Chapter 4, Section 4.3 for the abbreviation of the treatments).

Species presented in Figure 5.7 were chosen as representatives of the study area. *Schmidtia pappophoroides* (*S. pap*), *Chloris gayana* (*C. gay*), and *Eragrostis curvula* (*E. cur*) were the most palatable perennial species recorded during the sampling period in the field. *Chloris gayana* and *Eragrostis curvula* were sowed in during the experimental construction phase within treatments CRS, CBP, CRSBP and CSoRSBP. Figure 5.7 also shows that *S. pap*, *C. gay*, and *E. cur* only occurred within treatments containing BP (i.e. treatments CBP, CRSBP and CSoRSBP), suggesting that brush packing creates a favourable micro-habitat for the recruitment and growth of palatable perennial grass species. Re-seeding frequently forms part of restoration projects (Milton & Dean, 1995). Re-seeding on bare patches (treatment CRS) showed zero recruitment of sowed-in species, but where re-seeding in combination with soil disturbance and brush packing

was applied (treatment CSoRSBP), a high recruitment of grasses occurred including those that were re-seeded (Figures 5.6 and 5.7).



**Figure 5.8** A collage of photos taken during field surveys in April 2018 displaying the effects of brush packing on grass species recruitment, survival and growth, seen as healthy green grass foliage (see explanation of A-D below).

The use of brush packing as a restoration technology showed that it facilitates the recruitment, survival, and growth of grass species within communal rangeland (Figure 5.8):

- A) This photograph shows healthy *Eragrostis curvula* specimens that were sown-in during the month of June 2017.
- B) This photograph shows a *Chloris gayana* specimen thriving underneath brush packing branches. The *C. gayana* seed was also sown-in during June 2017.
- C) This photograph shows that the spiny branches used in the BP treatments will restrict livestock (donkeys, cattle, sheep and goats), allowing them to only graze the upper parts of the grass sward that is in reach when seeking for palatable greenish

foliage. Brush packing therefore; serves as an effective protection barrier to shield off new growth from herbivory, providing plants with a rest period to re-grow and create new seed after heavy grazing periods.

D) This photograph shows a *Perotis patens* specimen flourishing underneath the branches used for the brush packing. Although not palatable, this species will help to restore the nutrient reserves in the soil.

The effect of brush packing to improve the grazing capacity is illustrated in Figure 5.10. Grazing capacity is defined as ha/LSU (hectare per large stock unit), i.e. the total area required to sustain one large stock unit of approximately 450 kg for 1 year, that consumes on average 10 kg DM (dry matter) per day (Meissner et al., 1983). The formula used to calculate the grazing capacity as presented by Van der Westhuizen et al. (2001) is illustrated in Figure 5.9.

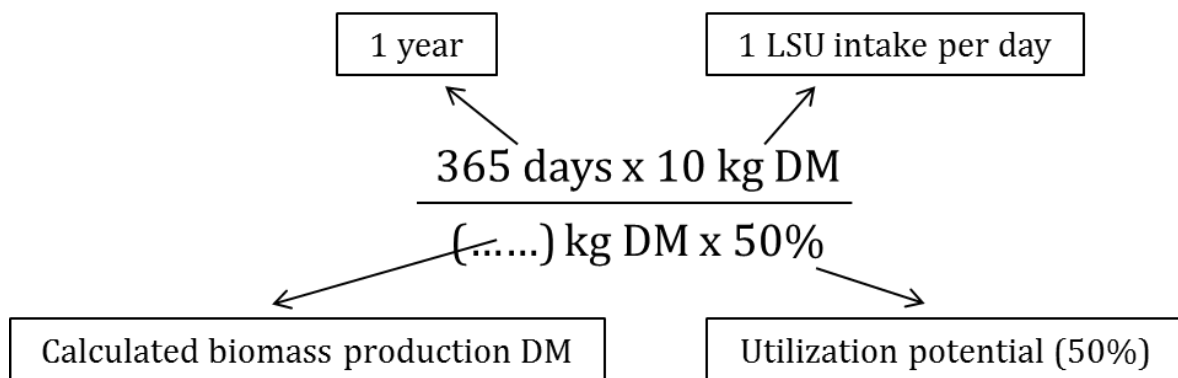


**Figure 5.9** Formula for calculating annual grazing capacity as ha/LSU, considering 365 days, average DM intake of one LSU per day (10 kg), divided by the biomass production (DM) from the different treatments multiplied by the utilisation potential of the grasses in the area (e.g. 50%).

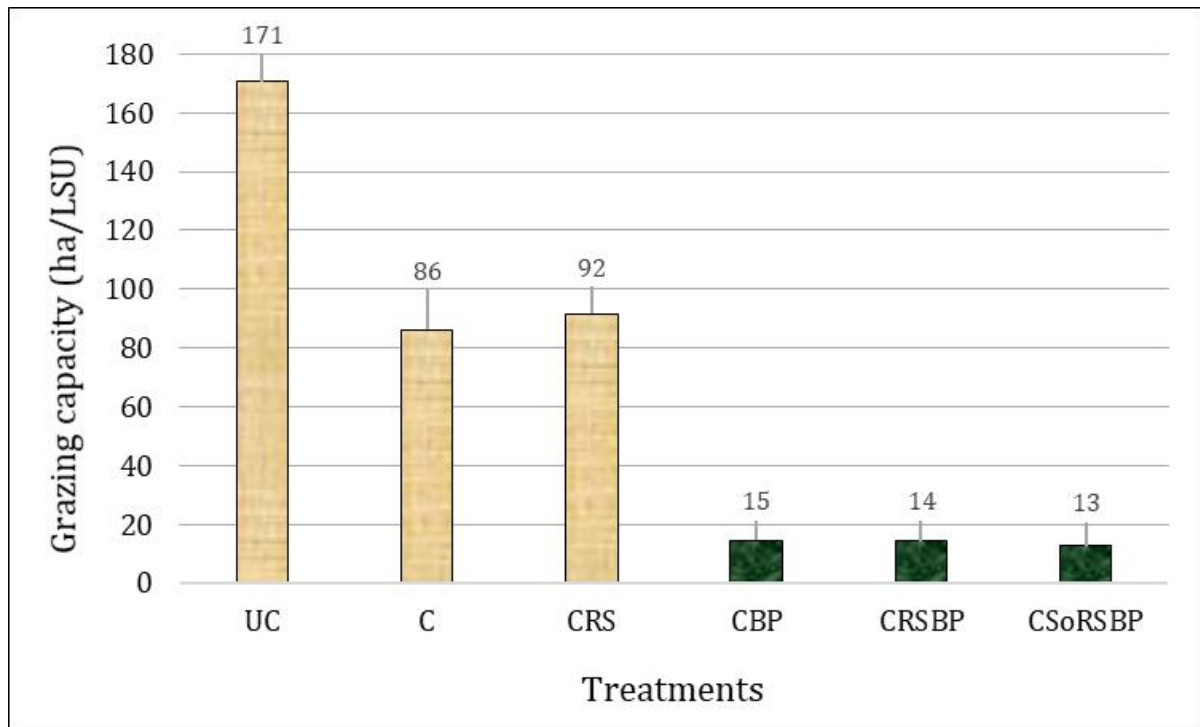


**Figure 5.10** Grazing capacity as ha/LSU calculated for all six treatments. (See Chapter 4, Section 4.3 for the abbreviation of the treatments).

The utilisation potential was selected to be 50%, meaning that half of the DM grass biomass production would be consumed by the livestock in the area which included different livestock types (i.e. cattle, sheep, goats and donkeys).

Treatment UC (control treatment) has a grazing capacity of 171 ha/LSU compared to brush packing treatments having an average grazing capacity of 14 ha/LSU (Figure 5.10). Treatments CBP, CRSBP and CSoRSBP thus indicated that brush packing can improve grazing capacity by up to a 1000% in a semi-arid communally managed savanna rangeland.

The variance between different treatments as well as the soil moisture and temperature results collected during field surveys is shown in Figure 5.11. The fundamental difference in variation can be noted that on the left-hand side between -1.5 and 1 on the X-axes, only restoration treatments that included brush packing occur and on the right-hand side between 1 and 1.5 on the X-axes, only treatments where no brush packing was used, occur (Figure 5.11).

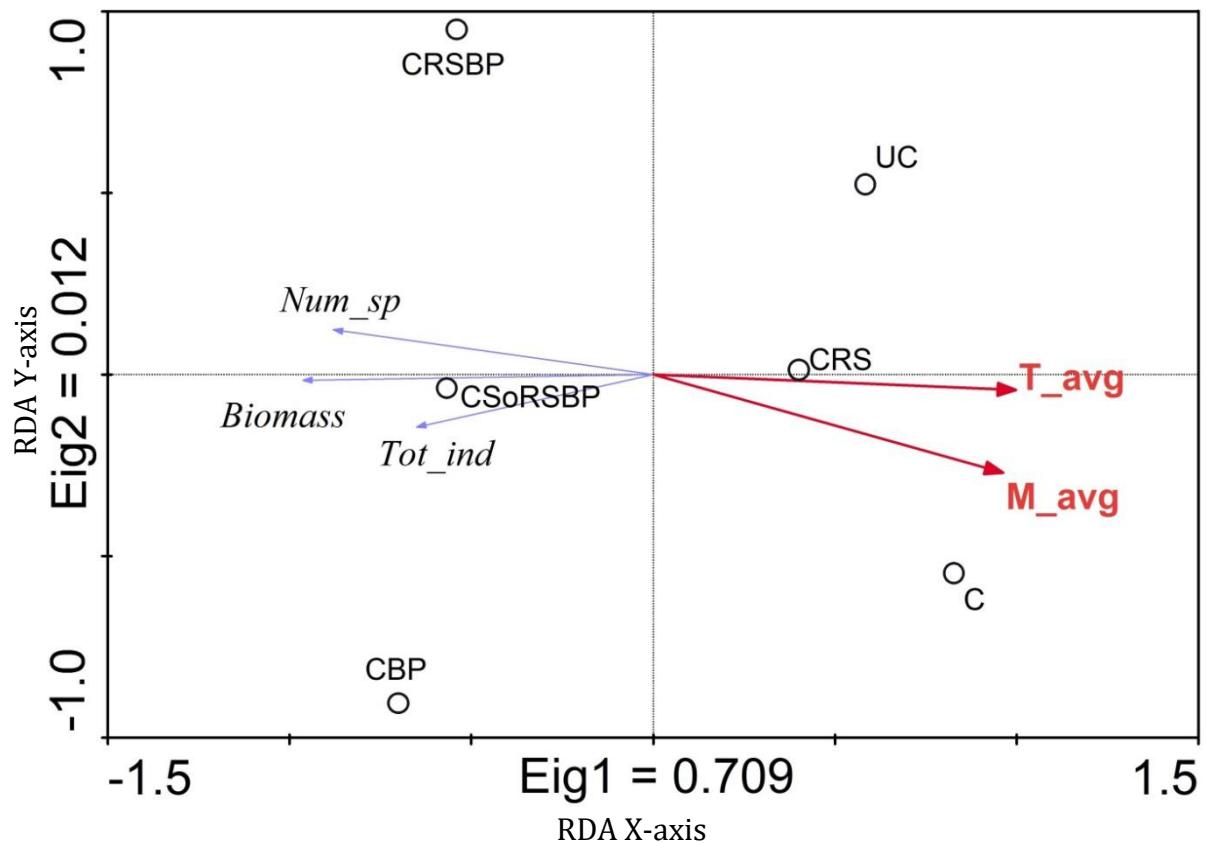


**Figure 5.11** Redundancy ordination analysis (RDA) for treatments (UC, CRS, C, CBP, CRSBP and CSoRSBP) in relation with biomass production (*Biomass*), number of species (*Num\_sp*), total individuals (*Tot\_ind*), as well as soil temperature (*T\_avg*), and soil moisture (*M\_avg*). See Chapter 4, Section 4.3 for the abbreviations of the treatments.

The RDA ordination indicates that a positive correlation exists between treatments containing brush packing, especially treatment CSoRSBP, with grass species diversity (which includes the number of species as well as the total individuals of each species) and biomass production (Figure 5.11). This clearly indicates that brush packing had a significant effect on the increase of grass biomass production, as well as grass species diversity, opposed to other treatments that did not include brush packing (Figure 5.11).

Soil temperature and moisture are shown as red arrows (Figure 5.11) indicating a positive correlation with treatments C, UC and CRS where no brush packing was implemented. This suggests that the soil moisture and temperature was higher in treatments C, UC and CRS i.e. treatments containing brush packing had lower soil temperature and moisture readings (Figure 5.11). The lower soil temperature inside brush packing treatments could be due to the shade effect caused by the overlying brush, whereas the lower soil moisture content in brush packing treatments might be

due to the higher abundances of grass species and higher biomass values of brush packing plots as more soil moisture will be utilised by the grasses occurring in these treatments (Figure 5.11). It might be accepted that more soil moisture is utilised by the more abundant plant species that happen to occur in brush packing treatments opposed to treatments without brush packing which had less biomass and less plant species to utilise soil moisture.

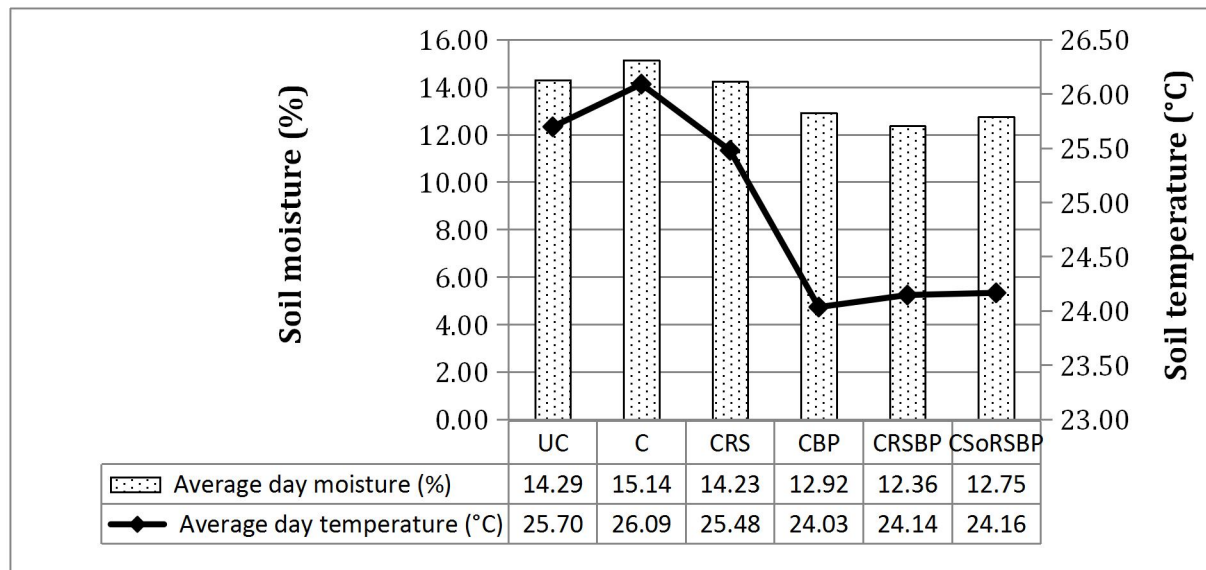


**Figure 5.12** The average day values for soil temperature and moisture contents within the upper soil layer of the six different restoration treatments. (See Chapter 4, Section 4.3 for the abbreviations of the treatments).

Figure 5.12 shows that the daily soil temperatures and moisture contents differ among the restoration treatments (also see Figure 5.11). The daily soil temperature ranged between 24.03 °C and 24.16 °C in BP treatments, opposed to treatments without BP where the temperature ranged between 25.48 °C and 26.09 (Figure 5.12).

Worldwide surface temperatures have ascended by approximately 0.8 °C in the course of the last century and are anticipated to increase by 1.4–5.8°C in the 21st century (Intergovernmental Panel on Climate Change [IPCC], 2007). Increasing temperatures are probably going to have various consequences for plant communities globally (De Boeck et al., 2007). In Africa, this increase in temperature is anticipated to result in longer growing periods, higher soil fertility, higher biomass allocation towards roots, and a conceivable shift towards tree-dominant biomes (Scheiter & Higgins 2009). Brush packing has shown that it can alleviate daytime temperature by up to 2°C as observed

within this study (Figure 5.12). Soil moisture seems to only slightly differ among BP and non-BP treatments as indicated by Figure 5.12. Treatment C (bush clearing only) had the highest daytime temperature, which can be a result of the higher exposure of the soil with more open space and little/no cover for a shade effect to possibly alleviate high temperatures (Figure 5.12).

### 5.3 Glasshouse experiment

The experiment conducted in the glasshouse provided an observation of brush packing simulated in a controlled environment. It also gave an indication of the fertility of the soil in terms of growth height of grasses where three different soil treatments were assigned: (1) soil from underneath tree canopies, (2) soil from open areas, and (3) soil from open areas supplemented with brush packing (Figure 5.13).



**Figure 5.13** A photograph showing grass species emergence in soil collected from the Goodwood restoration site for the three soil treatments, i.e. (1) open soil, (2) canopy soil, and (3) open soil with brush packing twigs.

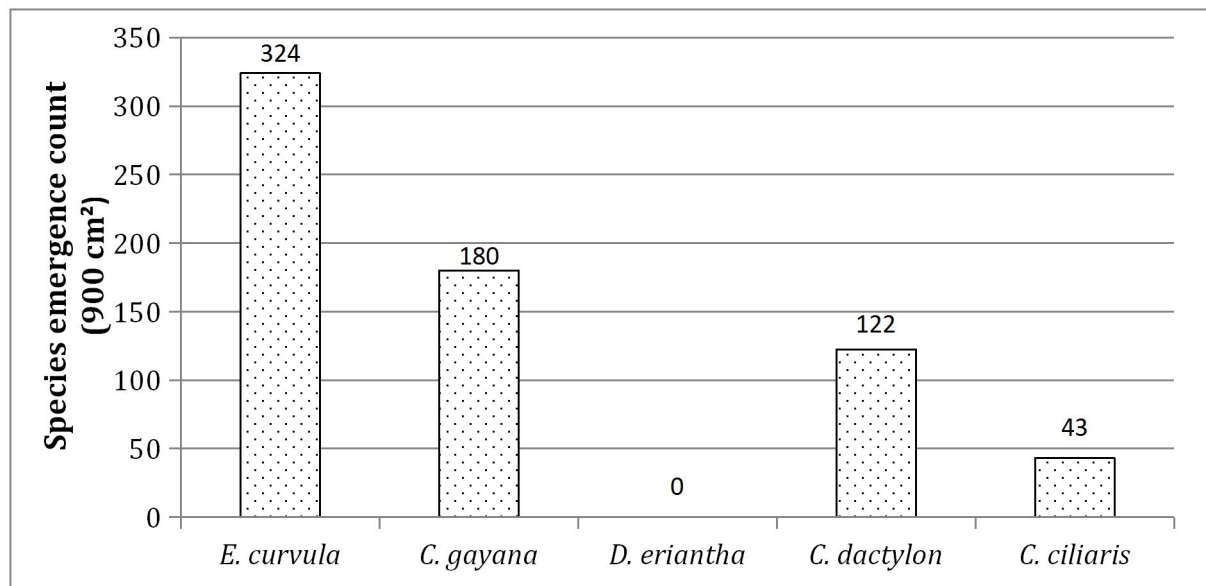


**Figure 5.14** The species emergence (considering the average emergence in all three soil treatments) of the five grass species used for re-seeding in the field sown in 30 x 30 cm (900 cm<sup>2</sup>) experimental buckets in the glasshouse experiment (See Annexure 1 for the abbreviations for the grass species).

From Figure 5.14, it is evident that *E. curvula* (*Eragrostis curvula* or Lovegrass) had the highest average seedling emergence with 324 individual grass seedlings counted for these species. *Chloris gayana* or Rhodes grass had the second highest average emergence with 180 individuals counted. The high emergence rate of *E. curvula* and *C. gayana* is consistent with the results obtained at the Goodwood restoration site, which indicated that only these two sown-in species were recorded in the field (Figure 5.7).

The average emergence of *D. eriantha* (*Digitaria eriantha* or Finger grass) was 0%, which could be due to a poor seed batch which only comprised of dead seed. *Digitaria eriantha*; however, has the tendency to take longer to germinate, especially if the seed batch is immature, suggesting that the seed may still have been in its dormant phase (Stanisavljević et al., 2014).

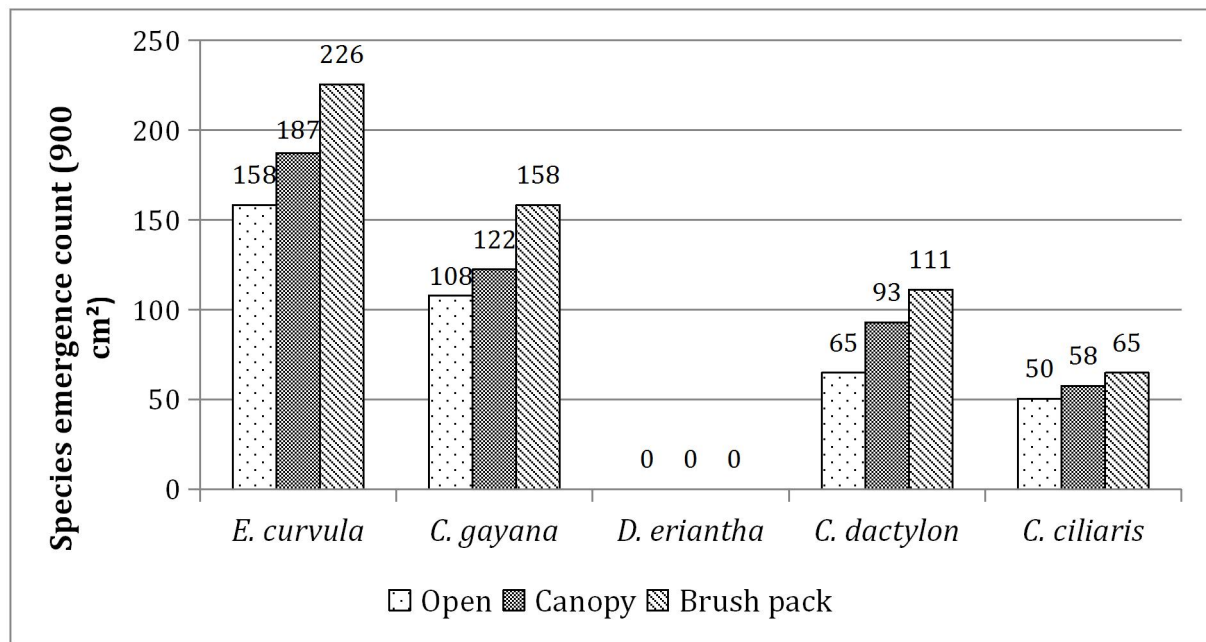


**Figure 5.15** The seed viability (seedling emergence) count of species sown in 30 cm x 30 cm (900 cm<sup>2</sup>) experimental buckets containing the soil of three different soil treatments: (1) open (soil obtained from open areas in the field), (2) canopy (soil obtained from underneath *Vachellia erioloba* trees in the field), and (3) brush packed (soil obtained from open areas supplemented with small thorny twigs to simulate the effects of brush packing). (See Annexure 1 for the abbreviations for the grass species).

The average emergence of grasses in the three different soil treatments was the highest in the BP treated soils (65, 111, 158 & 226 individuals for species *C. ciliaris*, *C. dactylon*, *C. gayana* and *E. curvula* respectively) (Figure 5.15). This result is consistent with the field sampling results, as the average seedling emergence in the brush packing restoration treatments in the field sites was also the highest where brush packing had a significant ( $p = 0.049$ ) impact on increasing grass species diversity, as well as increasing the total number of individual grass species (Figure 5.11) Soil obtained from underneath *V. erioloba* trees (2 - under canopy cover) had the second highest species emergence on average when compared to the soil collected from the open areas (Figure 5.15).

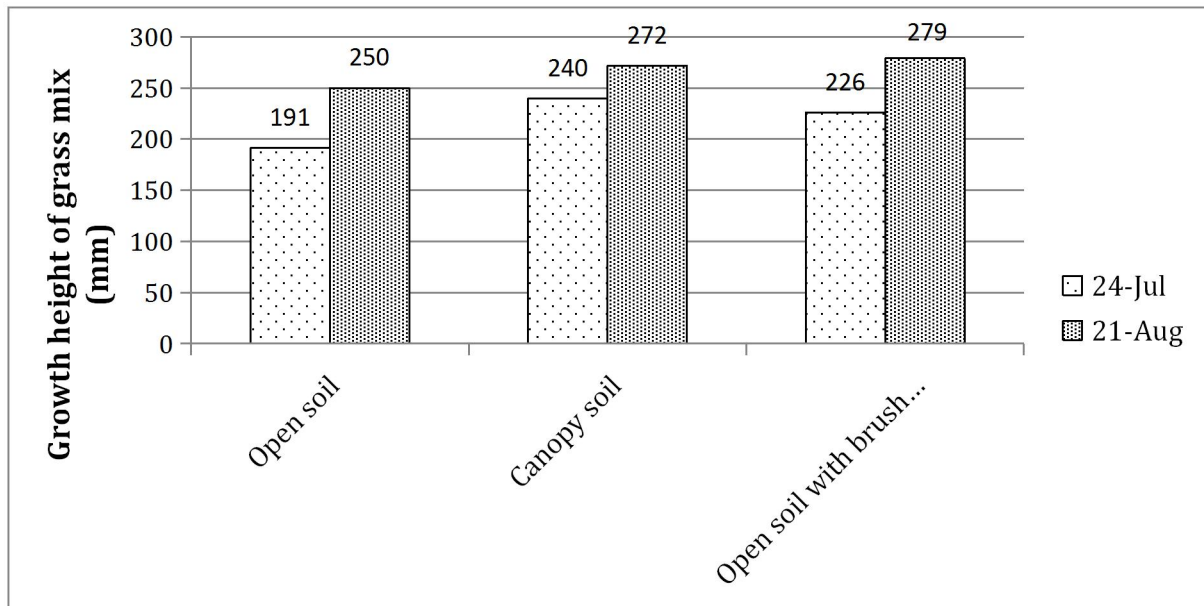


**Figure 5.16** The average growth height of grasses sown-in in the 900 cm<sup>2</sup> buckets in relation to the three different soil treatments: (1) open soil, (2) canopy soil, and (3) open soil with brush packing, measured on the 24<sup>th</sup> of July and the 21<sup>st</sup> of August 2018.

All three treatments showed an increase in growth height between 24 July and 21 August 2018 (Figure 5.16). The average grass was; however, found to be the highest in the soil treatment where brush packing was simulated (279 mm), compared with the open soil (250 mm), and canopy soil (272 mm) treatments (Figure 5.16, Figure 5.17).

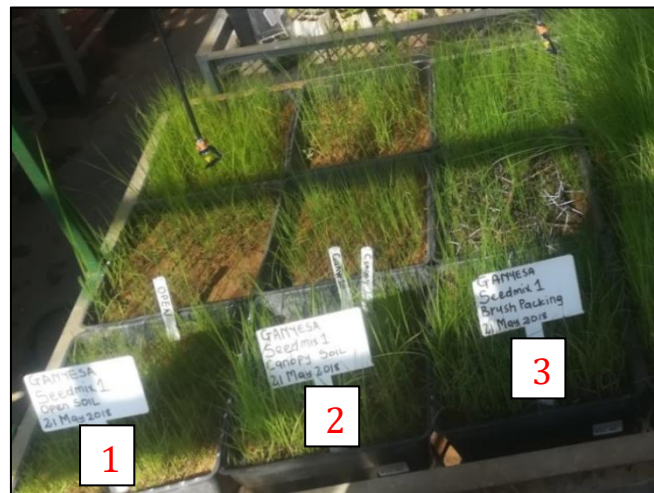


**Figure 5.17** A photograph showing the difference in growth height of grasses sowed in the three different soil treatments, i.e. (1) open soil, (2) canopy soil, and (3) open soil with brush packing twigs retrieved from the Goodwood site.

Soil from underneath tree canopies are influenced by the microclimate created by the canopy, these soils generally contain more nutrients and soil organic matter due to the

falling of leaves at the end of the season which over time are decomposed into the soil (Isichei & Muoghalu, 1992; Holdo & Mack, 2014). This may explain the higher seed emergence and higher average growth height in the soil that was collected underneath *V. erioloba* trees, as this tree sheds its leaves during the winter season. The comparison between C, N, pH, Ca, and Mg levels in soil occurring underneath tree canopies and soil occurring in open areas at the Goodwood site is illustrated in Figures 5.18, 5.19 and 5.20. The percentage N component was higher in the soils collected from under the canopies than in the soil collected in the open areas, i.e. 0.04% and 0.00% respectively (Figure 5.18). Likewise, the percentage C was also higher in the soils from under the canopies than for the soil collected in the open areas, i.e. 0.84% and 0.39% respectively (Figure 5.18). These results can be explained by the falling of leaves each season which will increase the C and N content of the soils after decomposition over time (Isichei & Muoghalu, 1992; Holdo & Mack, 2014).

Soil pH also differs among these two soils, where pH levels are higher in soil from underneath tree canopies than in open areas (Figure 5.19). This is for the pH levels for both analyses (pH -KCl) and (pH – H<sub>2</sub>O) (Figure 5.19). Gilbert (2013) possess that a pH level for optimal plant growth should be in the range of 5.5 to 7, meaning that the pH levels of these soils are somewhat acidic which may introduce stress the growth levels of the plants. The amount of Ca (mg/kg) in the soils collected below the canopy is considerably higher than in the soils collected from the open sites, i.e. 258 mg/kg and 127mg/kg respectively (Figure 5.20). Although Ca is higher underneath tree canopies, the Ca/Mg ratio indicates that the soils from under the canopy has a ratio of 5.5:1 compared to the soils from the open areas with a ratio of 3.3:1. Open soils thus have a more balanced Ca/Mg ratio than soils from beneath the canopy, especially in these sandy soils with lower pH values. The presence of more Ca underneath tree canopies can be explained by foliage that intercepts Ca from wind-blown dust or dust generated by ploughing activities (Ahmad-Shah & Rieley, 1989). During rainfall events the Ca is leached from the leaves, enriching the soil underneath the canopy. The percentage of other minerals, such as Fe, Mn, Zn, SO<sub>4</sub>, PO<sub>4</sub> and Cl<sup>-</sup> may also increase through the leaching effect (Ahmad-Shah & Rieley, 1989).

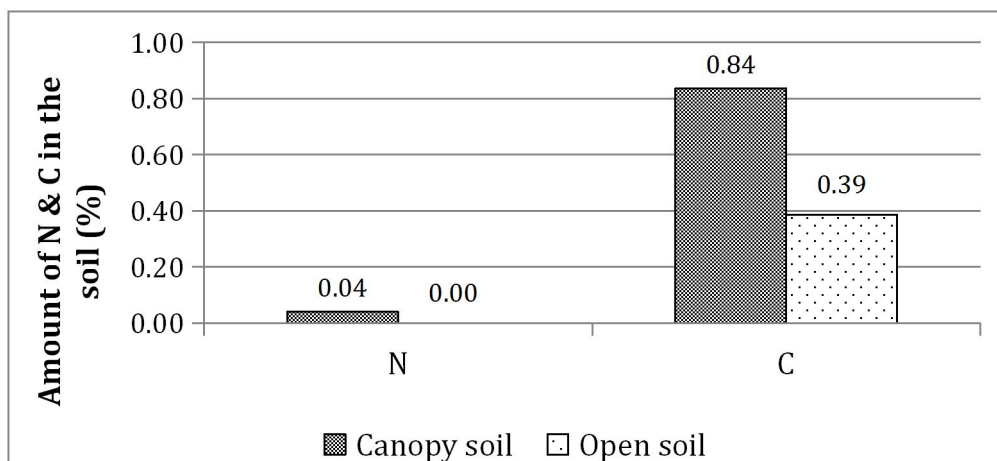


**Figure 5.18** A comparison of nitrogen (N) and carbon (C) levels between soil collected under the woody canopy and soil collected from open areas at the Goodwood site.

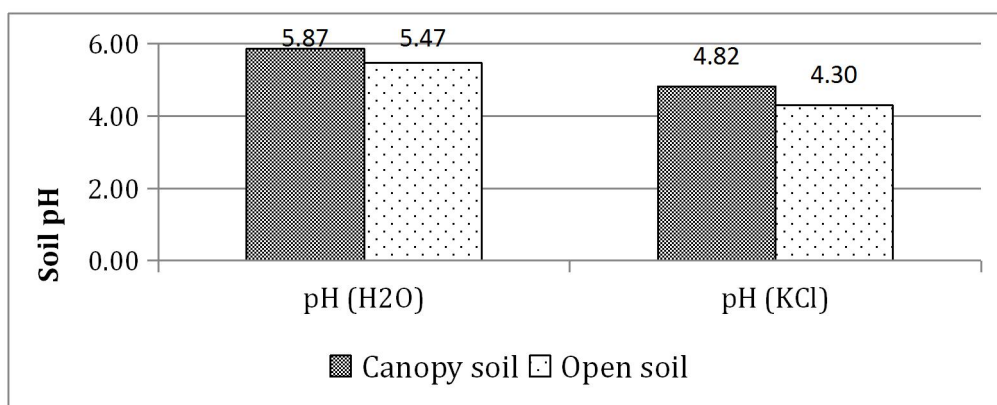


**Figure 5.19** A comparison of soil pH between canopy soil and bare soil at the Goodwood site.

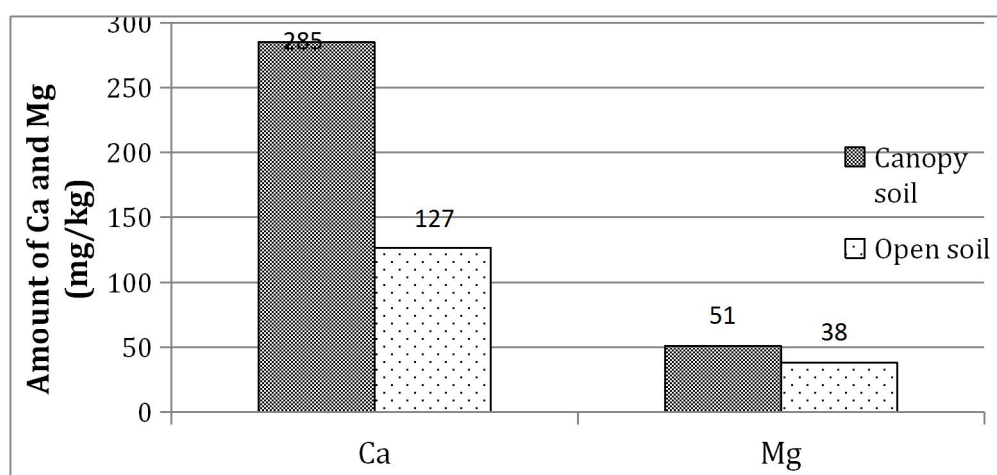


**Figure 5.20** A comparison of calcium (Ca) and magnesium (Mg) between canopy soil and bare soil at the Goodwood site.

## Chapter 6

### 6. Conclusion

The Savanna Biome in South Africa is a precious resource, providing a variety of benefits to people in the form of ecosystem services. One of which is the production of grass biomass that serves as fodder for livestock farming practices. Bush encroachment (i.e. the invasion of woody species that disrupts the tree/grass balance, and consequently eliminates herbaceous species, including grasses) poses a threat to existing and future livestock keeping and farming practices in South Africa.

To reverse or prevent bush encroachment, an active restoration plan must be followed, especially if factors such as overgrazing and low rainfall conditions are present. An experiment was led by the North-West University to evaluate the effect of using brush packing (placing of woody twigs/branches on denuded and/or bare areas) as a restoration technology to improve the grazing capacity (number of hectares needed to sustain one large stock unit for one year) in a savanna rangeland, situated nearby Goodwood, a rural village in the Ganyesa region in the North West Province. Grazing capacity includes aspects of grass biomass production, grass species diversity and soil parameters (temperature, moisture), which were monitored in the experiment.

This experiment forms part of the Bush Expert Decision Support System (DSS) which includes a database of case studies of technologies to control or combat bush encroachment and woody thickening. The North-West University currently has four active restoration sites where research is conducted on possible methods to restore degraded rangelands caused by bush encroachment in South Africa. The four sites include: (1) Goodwood near Ganyesa, (2) Manthe near Taung, both in communally managed areas in the North-West Province, (3) D’Nyala Nature Reserve, and (4) Shongwane, a communally managed area, near Lephalale in the Limpopo Province. The restoration methodology (i.e. brush packing after the control of bush encroachment) and research procedures to monitor vegetation and soil parameters are the same for all four study sites, which facilitates future comparison between sites, which will ultimately feed into the Bush Expert DSS.

For this project, a baseline survey was conducted at Goodwood in April 2017, before the restoration experiment was established in June 2017 with the cooperation from the

Land User Initiative (LUI), which was appointed and commissioned by the Department of Environmental Affairs (DEA). The LUI had to control the woody species causing bush encroachment in the areas following the instructions from DEA, which included manual and chemical bush control methods. Local people from Goodwood village, which was near the restoration experimental plots, were appointed by the LUI to control the woody species in the area. The local community were also involved in the establishment of the restoration plots, which included a team of five local workers that were hired by the North-West University to assist in setting up the experiment. The experiment consisted of 18 sample plots of 400 m<sup>2</sup> each, which included six different restoration treatments replicated three times. The six treatments consisted of different combinations of bush control, soil disturbance, re-seeding and brush packing.

Vegetation and soil surveys were conducted in April 2018 at the end of the 2017/2018 growing season to evaluate the effectiveness of the treatments regarding the improvement of the grazing capacity. All treatments that contained brush packing produced much more grass biomass (more than 500 kg/ha) than treatments that did not contain brush packing (less than 100 kg/ha). Treatments containing bush control, soil disturbance, re-seeding and brush packing produced the most biomass with 570·kg/ha. Treatments that included brush packing also increased the grass species diversity, especially in plots that were re-seeded. Although re-seeding is often an expensive method of re-vegetation, the results can be much more satisfactory when combined with brush packing. Brush packing thus facilitates the recruitment, survival and growth of grass species, which in turn improves the grazing capacity as well as the biodiversity. The control treatment (still occupied by trees and shrubs, thus where no bush control was carried out) had a grazing capacity of 171 ha/LSU, compared to brush packing treatments having an average grazing capacity of 14 ha/LSU. This experiment indicated that brush packing can improve grazing capacity by up to a 1000% in a controlled bush encroached savanna rangeland.

The researchers found that brush packing presumably creates a micro-habitat that is favourable for the growth and recruitment of grass species and additionally serves as an effective protection barrier to shield off new growth from herbivory, providing plants with a rest period to re-grow and create new seed. It was also evident that brush packing had a distinctive effect on soil temperature and moisture in the upper soil layer,

alleviating higher surface temperature through the shade effect created by the woody branches. Soil moisture content also differs among sample plots containing brush packing and plots without brush packing. As this experiment was only conducted over one growing season, further research and monitoring is required to formulate a comprehensive conclusion on the effect of brush packing on soil moisture content.

A glasshouse experiment was also conducted to simulate the brush packing experiment in a controlled environment. The results obtained in the glasshouse experiment were consistent with the field results, indicating that brush packing had a positive effect on increasing grass biomass production.

Conclusions made from this study can be used to improve existing restoration practices in semi-arid regions and especially where people are dependent upon the environment for their livelihood regarding livestock production. If the grazing capacity and biodiversity is improved, it will contribute to the ecosystem services of the surrounding communities and improve the well-being of the people.

Restoration of degraded land is one of the most important fields of modern environmental science and much needs to be done regarding restoration of lost or degraded ecosystems in South Africa. Individuals and organisations of various societies are making decisions today that will have profound consequences on future generations to come. There should be a need among scientists, politicians, governments, Non-Government Organizations (NGO's), and most importantly the vast number of human beings occupying this earth. This need should be to find a balance between consuming the Earth's resources and preserving its plants, animals and precious ecosystems. A lot of the Earth's resources are being depleted at an alarming rate, and together with land degradation, often caused by over-population and erratic rainfall patterns, especially in arid- and semi-arid areas, are at the core of this problem. Brush packing technologies can be utilised, and can even be improved, to restore many hectares of degraded land in South Africa, and at the same time expand production yields and contribute to the conservation of biodiversity in savanna ecosystems.

## **Chapter 7**

### **7. Recommendations**

#### **7.1 Brush packing guideline**

To restore degraded savanna rangelands in South Africa on a large scale, a restoration plan must be followed. A general procedure of activities can serve as a guideline for restoration practitioners, land owners, and contract workers, including the Land User Initiatives (LUI's), to assist in building a framework for restoration projects across South African savannas. Procedures are divided into major activities that can determine the outcome of restoration success:

##### **7.1.1 Procedure 1 – Site identification**

Within the Savanna Biome certain areas are more degraded than others and decisions regarding the priority of sites must be made, mostly depending on the rate and extent of degradation; i.e. which sites require restoration first. The condition of the ecosystem, as well as the land use of the area, including the socio-economic aspects of the people utilising the land, must be considered beforehand. Collaboration with the land users via meetings and workshops must form part of the site identification procedure. Geographic information systems (GIS) and remote sensing (RS) technology can be utilised to identify priority areas, as well as determining site boundaries and calculate surface areas.

##### **7.1.2 Procedure 2 – Bush control**

Bush control as the removal or clearing of woody invasive species includes manual, mechanical, chemical, biological, or a combination of these methods. Manual bush clearing by using apparatus, as focused upon in this investigation, can be carried out with great efficiency when good site management and proper quality control methods are implemented. Manual tools that can be used to remove woody species include:

- Chainsaw
- Handsaw
- Brush cutter
- Pruning lopper
- Bush axe

Invasive tree and shrub species need to be manually controlled as close to the ground as possible, where-after all the stumps need to be chemically sprayed or smeared with an arborocide that is registered for that species, to prevent regrowth. Various arborocide products are available on the market, including products with active ingredients including: Picloram, Tebuthuiron, and Triclopyr. If possible, environmentally friendly products should be used. An in-depth investigation should be carried out, regarding which arborocide to use on which species to prevent regrowth.

Various tree and shrub species are characterised by diversified stumps, it is thus mandatory that all the stumps be treated with the arborocide. For example, if a tree or shrub has four/five stumps, every stump should be chemically treated, as the remaining stump/s will re-coppice (regrow) if not treated properly, leading to further bush encroachment. The bush control project would have been in vain, and lots of resources (financial and manpower) wasted.

As savannas are characterised as biological communities with a continuous herbaceous layer occupied by scattered trees, it is best to leave some tree species individuals undisturbed. A ratio of 75:25 will serve well in restoring these ecosystems, i.e. remove 75% of the trees and/or shrubs, and leave 25% undisturbed. Tree stems with a diameter of 10 cm or more at breast height should also not be controlled. Instructions for the correct control methods for bush encroachment, set by DEA, should be followed.

### **7.1.3. Procedure 3 – Brush packing**

After bush control the site is characterised by open spaces, and frequently areas with bare soil patches. Bush control creates a high visual impact with lots of open spaces in the short term, but given the same disturbances that caused bush encroachment in the first place, the site will only return to its bush encroached state as time goes by. To properly restore a degraded savanna, the woody (tree/shrub), as well as the herbaceous (mainly grasses) layers must be considered. A balance between these plants must be created in a savanna to restore the energy flux of the ecosystem. Therefore; with a degraded savanna ecosystem one finds that both the woody component and the herbaceous component must be actively restored. After bush control of the trees and shrubs (woody layer), the often-depleted grassy layer can be restored by introducing brush packing technologies on the bare and denuded patches. It is better to use

branches/twigs from spiny trees that were controlled in the area, as these will help prevent further herbivory by livestock so that re-growth of species can occur which will presumably produce new seed that will ultimately improve the biodiversity. Restoring large areas of degraded land can become very expensive, technologies such as brush packing provides alternative solutions to restore thousands of hectares of degraded land with materials that are freely available. Bush encroachment is a problem that reduces South Africa's land productivity. This problem can be overturned by using the bush as restoration material, which will ultimately increase South Africa's land productivity.

The proposal is to only restore patches of degraded land within a savanna ecosystem. It is impractical and unfeasible to restore the whole ecosystem all at once, therefore; the focus must be to create so called 'brush packing plots' of 20 m x 20 m (400 m<sup>2</sup>) in size (also referred to as 'brush packing islands'). A suggestion is to create 10 'brush packing plots' for each 1 ha of bush controlled. These 'brush packing plots' will serve as a favourable habitat for the regrowth of herbaceous species, which will be protected by the thorny brush against herbivory, allowing for the production of new seed that will spread to adjacent areas, improving the seedbank of the area's soil and ultimately restore the herbaceous/grass layer of the savanna ecosystem.

#### **7.1.4 Procedure 4 - Monitoring**

After the brush packing technology has been implemented, regular scientific monitoring will be required. The brush packed plots need to be kept in a good condition, and if, for some reason, branches are removed or trampled by animals, after-care need to be implemented to sustain the restoration project.

Restoration practitioners and/or researchers will conduct frequent surveys of vegetation and soil parameters to measure the restoration progress, as well as report on restoration success. It is important to note that soil samples need to be taken at the exact same location and at the same time each year to retrieve scientifically accurate data. Regular monitoring will reflect on restoration effectiveness, and in some cases, scientific feedback may recommend that the restoration technique must be adjusted or improved to achieve better restoration results.

## 7.2 Recommendations for further research

It is recommended that further research be conducted on the following aspects:

- The effect of brush packing on soil parameters such as:
  - Soil moisture,
  - Soil temperature,
  - Soil organic matter, and
  - Soil chemical properties.
- The use of different grass species for re-seeding in combination with brush packing, in different regions.
- The effect of brush packing on the biodiversity of savanna ecosystems, which includes all living organisms.
- Methods to improve manual labour force with specialised equipment to control bush encroachment more efficiently.
- Methods to improve brush packing technologies to restore savanna rangelands more efficiently.
- The effect of eco-guards i.e. local people that herd cattle and other livestock animals (donkeys, goats and sheep), to protect certain areas from grazing (allowing grass species a rest period to promote regrowth) to assist in restoring degraded areas.

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## Annexure 1

### Species abbreviations -Chapter 5:

**A. con** – *Aristida congesta*

**A. congesta** – *Aristida congesta*

**B. mar** – *Brachiaria marlothii*

**B. marlothii** – *Brachiaria marlothii*

**C. cil** – *Cenchrus ciliaris*

**C. dac** – *Cynodon dactylon*

**C. gay** – *Chloris gayana*

**D. cinerea** – *Dicrostachys cinerea*

**D. eri** – *Digitaria eriantha*

**D. lycioides** – *Diospyros lycioides*

**E. biflora** – *Eragrostis biflora*

**E. cur** – *Eragrostis curvula*

**E. leh** – *Eragrostis lehmanniana*

**E. lehmanniana** – *Eragrostis lehmanniana*

**E. tri** – *Eragrostis trichophora*

**E. trichophora** – *Eragrostis trichophora*

**G. flava** – *Grewia flava*

**P. pat** – *Perotis patens*

**P. patens** – *Perotis patens*

**S. pap** – *Schmidtia pappophoroides*

**S. pappophoroides** – *Schmidtia pappophoroides*

**T. berteronianus** – *Tragus berteronianus*

**T. camphoratus** – *Tarchonanthus camphoratus*

**T. koe** – *Tragus koeleroides*

**T. sericea** – *Terminalia sericea*

**V. erioloba** – *Vachellia erioloba*

**V. hebeclada** – *Vachellia hebeclada*

**V. tortilis** – *Vachellia tortilis*

## Annexure 2

List of grass species that were involved in this study with ecological and grazing attributes

| <b>Grass species</b>            | <b>Annual/Perennial</b> | <b>Grazing value</b> | <b>Plant succession</b> | <b>Ecological status</b> |
|---------------------------------|-------------------------|----------------------|-------------------------|--------------------------|
| <i>Aristida congesta</i>        | Annual                  | Low                  | Pioneer                 | Increaser II             |
| <i>Aristida stipitata</i>       | Annual                  | Low                  | Pioneer                 | Increaser II             |
| <i>Brachiaria marlothii</i>     | Perennial               | Average              | Sub-Climax              | Increaser II             |
| <i>Cenchrus ciliaris</i>        | Perennial               | High                 | Climax                  | Decreaser                |
| <i>Chloris gayana</i>           | Perennial               | High                 | Sub-Climax              | Decreaser                |
| <i>Chloris virgata</i>          | Annual                  | Average              | Pioneer                 | Increaser II             |
| <i>Cynodon dactylon</i>         | Perennial               | High                 | Sub-Climax              | Increaser II             |
| <i>Digitaria eriantha</i>       | Perennial               | High                 | Climax                  | Decreaser                |
| <i>Eragrostis biflora</i>       | Annual                  | Low                  | Pioneer                 | Increaser II             |
| <i>Eragrostis curvula</i>       | Perennial               | High                 | Climax                  | Decreaser                |
| <i>Eragrostis lehmanniana</i>   | Perennial               | Average              | Sub-Climax              | Increaser II             |
| <i>Eragrostis trichophora</i>   | Perennial               | Average              | Sub-Climax              | Increaser II             |
| <i>Melinis repens</i>           | Perennial               | Low                  | Pioneer                 | Increaser II             |
| <i>Perotis patens</i>           | Perennial               | Low                  | Pioneer                 | Increaser II             |
| <i>Pogonarthria squarrosa</i>   | Perennial               | Low                  | Sub-Climax              | Increaser II             |
| <i>Schmidtia pappophoroides</i> | Perennial               | High                 | Climax                  | Decreaser                |
| <i>Tragus berteronianus</i>     | Perennial               | Low                  | Pioneer                 | Increaser II             |
| <i>Tragus koelerioides</i>      | Perennial               | Low                  | Pioneer                 | Increaser II             |
| <i>Urochloa mosambicensis</i>   | Perennial               | High                 | Sub-Climax              | Increaser II             |

(Van Oudtshoorn, 2002)