IMPACT OF RAINFALL ON THE DETERMINATION OF TREE AGE AND ESTABLISHMENT PATTERNS OF *ACACIA TORTILIS* IN THE LIMPOPO PROVINCE, SOUTH AFRICA

BY

MALESELA VINCENT MOKOKA

A MINI-DISSERTATION

Submitted in partial fulfilment of the requirement for the degree of

MASTER OF SCIENCE IN AGRICULTURE

(PASTURE SCIENCE)

in the

FACULTY OF SCIENCE AND AGRICULTURE

Department of Plant Production, Soil Science and Agricultural Engineering

School of Agricultural and Environmental Sciences

UNIVERSITY OF LIMPOPO

SUPERVISOR: DR J.J. JORDAAN

CO-SUPERVISORS: PROF M.J. POTGIETER

2016

DECLARATION

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ABSTRACT

The relationships between tree age, growth rings, and stem circumference correlated with establishment patterns may be a valuable instrument to reveal the functioning of woody species in the Savanna Biome. A study on tree age and establishment patterns of *Acacia tortilis* in the semi-arid regions of the Limpopo Province was conducted to aid an understanding of the causes of encroachment in savanna vegetation.

This study aimed to determine the periodicity of growth ring formation at two study areas, correlate the number of growth rings with different tree characteristics and document tree population establishment patterns of *Acacia tortilis,* using stem circumferences. This was done in order to predict long-term bush encroachment using the interaction between rainfall and soil on the age, growth and establishment patterns of *Acacia tortilis*. Data was collected at three sites representing two study areas, two sites at the University of Limpopo's Syferkuil Agricultural Experimental Farm and one site at the Sondela Nature Reserve in the Limpopo Province. The study incorporated two different soil forms and two rainfall regimes.

Trees were divided into five height classes; namely, <0.5 m, >0.5 – 1.5 m, >1.5 – 2.0 m, >2.0 – 3.0 m and >3m. Fifty trees (ten in each class) were felled at each site, and the following recordings were made: tree height, stem circumference and crown diameter. Furthermore, each felled stump was taken to the laboratory and examined for growth rings.

The results indicated that growth pattern of *Acacia tortilis* stems were more influenced by soil form than the amount of rainfall. Tree height was not significantly affected by soil form. However, rainfall proved to have a significant effect on the final height of the plant. Both rainfall and soil form did not have a substantial effect on the number of growth rings. Crown diameter was affected by soil form but rainfall did not prove to have the same effect. Correlations between growth rings and stem circumferences, tree height and crown diameter, proved to have significant relationships. However, the relationship between stem circumference and the number of growth rings was the most significant.

A prediction model was created using the relationship between stem size and growth rings. Using this model tree age can be determined in a non-destructive manner. However, the absence of a correlation between rainfall and establishment strongly suggests that rainfall cannot be used, on its own, to determine the establishment sequence and the pattern of bush encroachment.

The study suggests that natural developments responsible for establishment patterns and population dynamics of woody species are complex, and their effects are visible after an extensive period. Therefore, to understand these influential processes comprehensively, several seasons of observations and monitoring would be recommended. Future research on this particular topic should include more than one encroaching species, because this will provide a broader perspective on the encroachment patterns of bush communities. However, the focus should be on studying the influence of growth limiting factors such as soil and climatic impacts, as well as area-specific environmental factors on the growth of encroaching species, such as *Acacia tortilis*.

Key words: Bush encroachment, dendrochronology, growth rings, tree age, savanna, stem circumference

Note: The candidate and the supervisors are aware of the fact that the *Acacia* genus has been revised. However, in this dissertation, the genus and species *Acacia tortilis* is still used. Relevant changes will be used in future publications.

DEDICATION

I wholly dedicate this work to my family. My late father, Jonas Malose Mokoka, may his soul rest in the loving arms of eternal peace, my mother, Jacobeth Mmamaropeng Mokoka, who had the strength to raise our family on her own, my brothers Onismus Mokoka, Emmanuel Mokoka and my sister Sylvia Mokoka. I appreciate all the love and support you give me.

ACKNOWLEDGEMENTS

First of all, I thank God and my guardian angels for making my life such a blessing with a beautiful family and the never ending opportunities.

- A very warm thanks to my supervisor, Dr. J.J. Jordaan for giving me a push in the right direction whenever I needed it, I will always be grateful for your support.

- I'm grateful for my co-supervisor's contribution; Prof. M.J. Potgieter, who dedicated his time and ideas into making this study a success.

- Recognitions to the University of Limpopo's Department of Agriculture for granting me this prospect to contribute to the great field of science.

- Gratitude to the National Research Foundation for providing funds throughout my study.

- Furthermore, I'm thankful to Mrs Marie Smith for providing statistical support.

- Also, I would not leave this opportunity to show my appreciation to my colleagues and friends; I thank you all for the support and assistance you contributed to the completion of this study. They are: Baltimore Moketla, Absalom Masenya, Lotanang Mothiba, Michael Mpati, Shiellyboy Mogala, Peter Letsoalo, Johanna Raphala, Ignatius Makwala, Matsobane Thamaga, Ezekiel Mojapelo, Jacob Mashalane and Celestar Maja.

- Last but not least, a warm special word of thanks and appreciation to my entire family, without you none of this would have been possible. In the name of the almighty God, I wish you all excellent health and prosperity.

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CHAPTER 1

INTRODUCTION

1.1 GENERAL INTRODUCTION

Savanna ecosystems are characterised by the coexistence of woody and herbaceous plants with a continuous grass strata (Sankaran *et al*., 2004). In South Africa and Namibia, savannas are referred to as Bushveld (Mucina and Rutherford, 2006). Erastus (2011) indicated that all savannas have at least one key feature in common, which is a climate that has a hot wet season of four to eight-month duration and a warm dry season for the rest of the year. According to Beringer *et al.* (2007), savannas occur in over 20 countries, mostly in the seasonal tropics, with a limited distribution in temperate regions. Grace *et al.* (2006) showed that this ecosystem is extensive, and socio economically important as it is responsible for almost 30% of global net primary production.

The identification of the mechanisms leading to tree-grass co-dominance in savannas is a widely and often controversially discussed (e.g. Sankaran *et al*., 2004, Higgins *et al*., 2000). Generally, the understanding of bush encroachment is based on Walter’s two-layer model, which states an equilibrium explanation for coexistence for savanna trees and grasses. This model relies on vertical niche partitioning and assumed that grasses are more water-use efficient than trees, and use subsurface water while trees also have access to deeper water sources. Thus, in open savannas, grasses are predicted to predominate because of their water use efficiency and access to subsurface water (Ward, 2005).

According to Ward (2005), bush encroachment is the suppression of desirable grasses and herbs by undesirable woody species, often in an area where it previously did not occur, or the aggregation of existing undesirable plants in an area. In pasture context an undesirable plant is one that is less acceptable to domestic livestock, less productive, less nutritious than other plant species in the veld. Furthermore it reduces the production of the more acceptable plant species through its higher competitiveness e.g. bush vs grassland, and it may be physically and/or physiologically harmful to livestock (Breebaart *et al*., 2002). However, it is notable that an undesirable plant will not usually have all the above mentioned characteristics at once. It is typically characterized by a combination, or in some cases, only one of these characteristics.

The study of wood anatomical features in growth rings represents a promising approach in the research of tree biology and climate change (Novak *et al*., 2013), which allows for the determination of relationships between climatic effects and the formation of annual growth rings. Annual rings are the growth layers of wood that are produced each year in the stems and roots of trees and shrubs. They are also reflective (by their range of thickness) of the environmental factors that influence growth rates. In this regard Garcia-Suarez *et al.* (2009) indicated that the width of a growth-ring can be influenced by a variety of factors, some of which relate to the unique location of the tree, its age and management, and others to wider environmental factors such as temperature, rainfall and sunshine.

Stem diameter and subsequently the number of growth rings increases comparatively steadily over a tree's lifespan (Bowman *et al*., 2013). Besides paleontological records, growth rings can also be used over the shorter term to determine establishment patterns of woody plants (Jordaan, 2004). Growth-ring and rainfall data might be sufficiently correlated to permit the estimation of establishment of plant communities. When rings are conspicuous, they may be counted in order to obtain a reasonably accurate approximation of the tree age. The science of dendrochronology is based upon the phenomenon of variability in the thickness of annual rings (Fritts and Swetnam, 1986).

Woody species aggregation affects the growth form of grass species. As encroachment occurs, the total number of individual trees ha^{-1} increases, leading to increase in total canopy cover and total basal cover. However, tree height increases while individual basal cover and stem circumference decreases (Jordaan, 2004). Under mild to moderate encroachment, existing tree populations facilitate the establishment of other tree species due to the development of favourable micro-habitats (Jordaan *et al*., 2004; Jordaan, 2010). This influences the total population dynamics and biodiversity of the existing population (Smit, 2004).

In heavily encroached situations, trees compete with each other, causing density dependent mortality and regular spacing between individuals (Ward, 2005). As individuals die, due to competition or to factors extrinsic to the population, the resulting gaps will allow either for increased growth of neighbouring individuals or the establishment of new individuals of the same species (De Klerk, 2004). Similarly, Sankaran *et al*. (2004) also indicated that the water regime is also important, with high rainfall years favouring tree recruitment/growth over grasses, and drought periods limiting tree recruitment and growth. Therefore, the existing and constant change in climate, particularly rainfall, will have profound effects on savanna ecosystems.

1.2 BUSH ENCROACHMENT

Bush encroachment is currently a significant problem in the savannas of South Africa, especially in the Limpopo Province. It has led to decreased herbaceous production, diversity and carrying capacity (Trollope, 1983). These adverse effects of bush encroachment ultimately lead to poor animal production, economic losses, and poor farmers' livelihoods.

It is thus critical to study the establishment patterns of woody communities in order to have a clearer understanding on the causes of bush encroachment and ultimately, the control thereof. Furthermore, it is important to study plant population establishment over a long-term period, and to test certain models for establishment prediction, especially in terms of rainfall.

Leguminous woody species are the main encroachers in the African savanna (Mucina and Rutherford, 2006). Therefore, *Acacia tortilis* was used as a representative of this group. This species will therefore be used to determine the establishment patterns of woody plants at two study areas, which include three different sites, in order to make predictions on future encroachment in the province.

1.3 RESEARCH QUESTIONS

i. Can the relative formation of growth rings reflect the effect of rainfall on their development?

ii. Can the relative formation of growth rings reflect the effect of soil on *A. tortilis* development?

iii. Is there any relationship between growth rings and stem circumference of *A. tortilis*?

iv. Will the relationships between growth rings and stem circumference contribute in determining the establishment dynamics of the tree population?

1.4 MOTIVATION FOR THE STUDY

Invasion of woody species in savannas changes the Savanna Biome to a forest/thicket, bringing about a biome shift, usually associated with veld deterioration and decreased carrying capacity (Beringer *et al*., 2007). It is more difficult and costly to reverse the process of forest invasion than to control changes in abundance of savanna trees or shrubs (Khavhagali and Bond, 2008). At the two proposed study areas, bush encroachment has already occurred. The purpose of this study was to establish the relationship between rainfall and soil forms and the occurrence of growth rings, in order to determine past and future establishment dynamics and meteorological effects on woody plant encroachment at the three sample sites occurring at the two study areas.

1.5 AIMS AND OBJECTIVES

The aim of this study was to determine the interaction of climate and soil on the age, growth and establishment of *A. tortilis*.

The objectives of this study were to:

i. Determine the periodicity of growth ring formation of *Acacia tortilis* at two study areas that differ in long-term average rainfall.

ii. Investigate the periodicity of growth ring formation of *Acacia tortilis* between soil forms, namely a Hutton soil form and a Glenrosa soil form.

iii. Correlate the number of growth rings with stem circumferences of *Acacia tortilis*.

iv. Document tree population establishment patterns of *Acacia tortilis* at two study areas using stem circumferences.

1.6 COMPOSITION OF THE DISSERTATION

The purpose of this study was to conclude the effect of both rainfall and soil on bush encroachment in the semi-arid regions of the Limpopo Province. This study sought to simplify the complex phenomenon of bush aggregation in the savanna vegetation types. An introduction, the statement of the problem, research questions, motivation for the study, aim and objectives, scope of the study, limitations of the research and an overview of the dissertation was completed in Chapter 1.

A literature review is presented in Chapter 2. The review of the established literature in the field focused on the contextual history of bush encroachment, a discussion of related literature on the Savanna Biome and progressing theories on population dynamics and growth rings, veld management practices and lastly, strategies for solutions.

Chapter 3 provides a discussion of the study's methodology which is set in a 2 X 5 factorial experiment. Discussion of the research design and its rationale, informed consent procedures, the data collection and data quality procedures and the process for data management and analysis are also presented.

Chapter 4 presents a detailed discussion of the characterization of the study areas, including vegetation description, soil forms and long-term average rainfall of the areas.

Chapter 5 provides results of the study in narrative format, the collective findings of the study, and is organized according to the themes that emerged during the analysis. Furthermore, this chapter introduces the discussion aspect on the findings of the study.

The conclusions and recommendations from the study as they were determined in accordance with the overall findings, the research questions and the existing literature are presented in Chapter 6.

1.7 SCOPE OF THE STUDY

The research was conducted at the University of Limpopo’s Syferkuil Farm and Sondela Nature Reserve in the Limpopo Province. However, this study specifically looked at the impact of encroachment at both low and high rainfall, as well as the effect of soil form on the aggregation of woody plant communities.

1.8 LIMITATIONS

This study was primarily limited by its small sample size. The study could have been expanded by including more encroaching woody species of the Savanna Biome. *Acacia tortilis* represented a narrow range of encroaching plants but nevertheless, was used as representative of other *Acacia* species. A larger sample with more diverse species would have benefited our results. Including different kinds of species could have diversified the encroaching plant communities represented in the sample. The encroachment phenomenon would have been better clarified had the study included more extrinsic factors affecting the plant during its life cycle.

CHAPTER 2

LITERATURE REVIEW

2.1 THE SAVANNA BIOME

A savanna is a tropical vegetation type characterized by a grassy ground layer and a distinct upper layer of woody plants (Cowling *et al*., 2007). Where the upper layer is near the ground, the vegetation is referred to as Shrubveld. Where it is dense as Woodland and the intermediate stages are locally known as Bushveld (Mucina and Rutherford, 2006). Beringer *et al*. (2007), however, stated that, in savanna ecosystems, the woody community is 'carbon-rich', and the herbaceous layer, which is usually dominated by grasses, are relatively poor in carbon content. Savanna vegetation occupies the broad region (Figure 2.1) between dry deserts and humid forests in the tropics and subtropics (Okitsu, 2005).

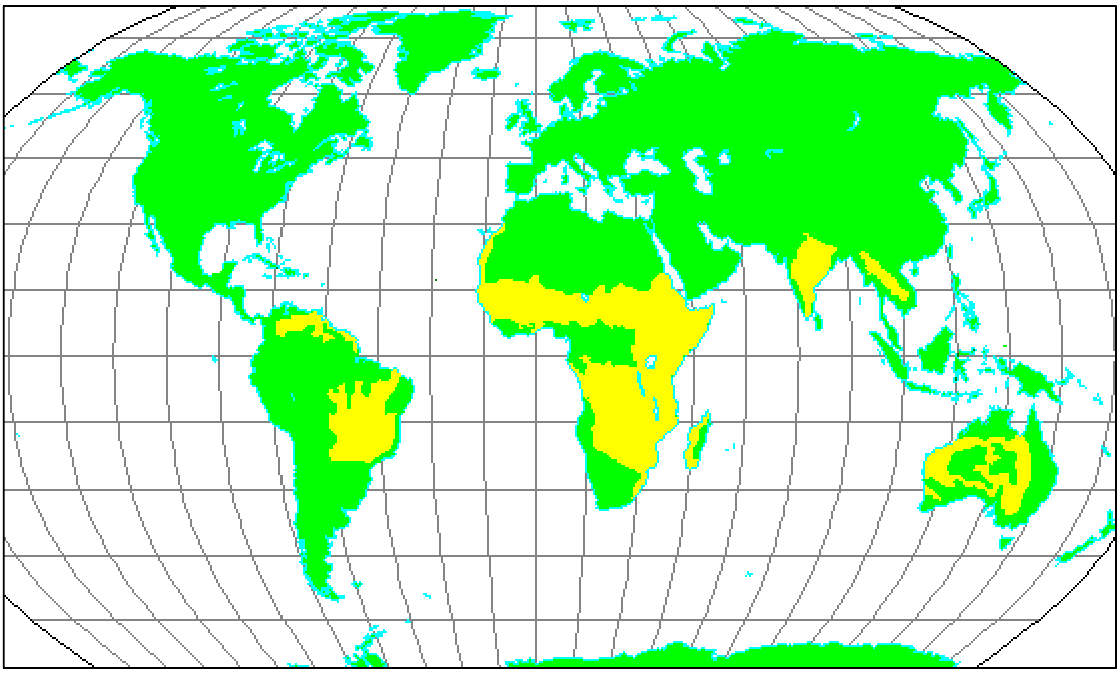

Figure 2.1 The distribution of the Savanna Biome in the world (Low and Rebelo, 1998).

2.1.1 Relationship between trees and grasses

Sankaran *et al*. (2004) stated that explanations for the persistence of both trees and grasses in savannas fall into two categories: those that emphasize the fundamental role of competitive interactions in fostering coexistence and those that focus on the limiting roles of demographic bottlenecks to tree establishment and persistence. Stochastic events such as fire and climatic variation are the main forces maintaining tree-grass coexistence in savanna, although a unifying ecological explanation for the wide range of observed savanna physiognomy is yet to emerge (Patrick, 2008). Therefore, when fire and climatic variations are limited, change in the tree-grass equilibrium occurs. Such changes in the grass-tree balance influence rangeland use, biodiversity and ecosystem function including hydrology and nutrient cycling, at both the local and landscape scale (Bond, 2008).

According to Cowling *et al*. (1997), theoretically, there are two main mechanisms that allow competitors to coexist: equilibrium theories based on niche separation; and disequilibrium theories, in which disturbance prevents competitive exclusion from proceedings to its logical conclusion. For tropical savannas, carbon uptake by the woody component largely occurs via the C3 photosynthetic pathway and via the C4 pathway for the grass layer. The two coexisting life forms (trees and grasses), thus have differing responses to available moisture and nutrient, light, changes to atmospheric CO_2 concentration and temperature (Beringer *et al*., 2007). Thus, trees and grasses may co-exist due to their morphological differences and method of resource use.

2.1.2 Importance of the savanna vegetation

According to Mucina and Rutherford (2006), the Savanna Biome is the largest biome in southern Africa, occupying 46% of its area, and over one-third the area of South Africa (Figure 2.2). Furthermore, Smit (2004), indicated that the Savanna Biome of southern Africa extends from north of 22^{o}S into northern Namibia, Botswana, Zimbabwe, Mozambique and South Africa. It is well-developed in the lowveld and Kalahari region of South Africa, and is also the dominant vegetation in neighbouring Botswana, Namibia and Zimbabwe (Mucina and Rutherford, 2006).

In the southernmost savannas goats are the major livestock (Yakubu *et al*., 2010). Therefore, this vegetation must be properly managed and conserved to allow profitable and sustained animal production in order to ensure good farmer’s livelihoods and economic stability. However, one of the most intractable problems in savanna management is the thickening up or invasion by trees (bush encroachment), which then suppress productivity of the grass layer (Erastus, 2011). This phenomenon is further discussed under 2.4 (Bush encroachment). According to De Klerk (2004) as grass species die, due to competition or to factors extrinsic to the population, the resulting gaps will allow either the increased growth of neighbouring woody species or the establishment of new individuals.

Savannas are extensive and socio-economically important ecosystems. Approximately 20% of the world's land surface is covered with savanna vegetation. This biome is responsible for almost 30% of global net primary production (Grace *et al*., 2006). Most of the savanna vegetation types are used for grazing, mainly by livestock or game (Mucina and Rutherford, 2006). Furthermore in Africa, savannas have an intrinsic sentimental value because they are home to most of the world's last remaining mega herbivores (animals > 1000 kg) (Bowman *et al*., 2013).

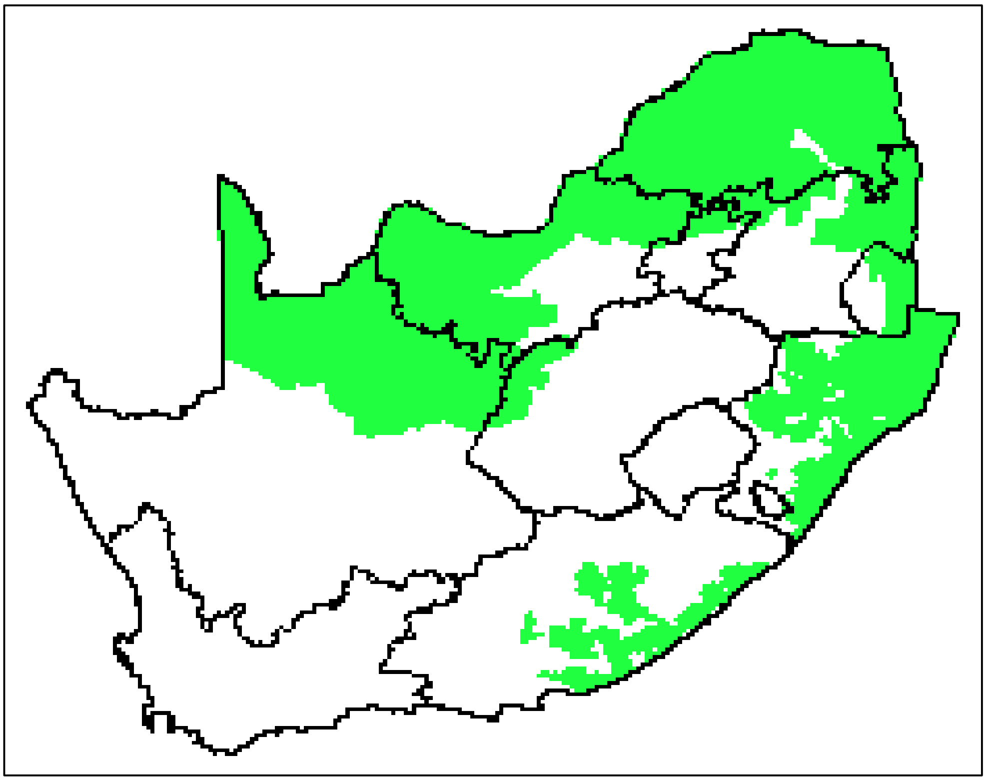

Figure 2.2 Distribution of the Savanna Biome in South Africa (Low and Rebelo, 1998).

2.2 VELD TYPES OF THE STUDY AREAS

Two veld types were examined in the study; Pietersburg Plateau False Grassveld and Turf Thornveld. These veld types are described in detail by (Acocks, 1988).

2.2.1 Pietersburg Plateau False Grassveld

The climax of this plateau is clearly open, clumpy Sourish-Mixed Bushveld, with *Acacia rehmaninana* as the typical dominating tree. Altitude ranges from 1200 – 1500 m, and rainfall from 200 – 600 mm per annum, falling in summer. Geologically, the parent material is predominantly granite. The principal grass species are *Andropogon schirensis*, *Aristida congesta, Aristida diffusa*, *Brachiaria serrata*, *Brachiaria nigropedata*, *Cymbopogon pospichilli, Cymbopogon excavatus, Digitaria argyropgrapta, Eragrostis chloromelas*, *Eragrostis racemosa*, *Eragrostis superba, Elionurus muticus, Heteropogon contortus*, *Hyparrhenia hirta*, *Schizachyrium sanguineum, Sporobolus nitens*, *Themeda triandra*, *Trachypogon spicatus* and *Triraphis andropogonoides*.

Acacia rehmanniana, *Acacia tortilis* subsp. *heteracantha*, *Acacia hebaclada* subsp. *hebaclada* and *Gymnosporia senegalensis* occur as scattered individuals through it, with *Acacia permixta* along its northern margin where it merges into the open *Schlerocarya* Veld.

2.2.2 Springbok Flats Turf Thornveld

This veld type occupies the plains between the Waterberg and the Elands-Olifants valley, with a northward extension past Mokopane. It is extremely flat and hot, with an average summer rainfall of 450 – 750 mm per annum. It is naturally an open thornveld, but tends to thicken up when the grass cover is reduced by grazing mismanagement.

Two main variations can be distinguished: (i) Red Turfveld, and (ii) Black Turfveld.

i. Red Turfveld

This is a fairly dense thornveld, the principal species being *Acacia gerrardii* var. *gerrardii, Acacia nilotica* subsp. *kraussiana*, *Acacia tortilis* subsp. *heteracantha*, *Dicrostachys cinerea* subsp. *africana*, *Grewia flava* and *Ziziphus mucronata*. The grass is of a mixed type, dominated by *Themeda triandra*, often in combination with *Cymbopogon pospichilii.* The principal species are; *Aristida canescens, Bothriochloa insculpta, Brachiaria nigropedata, Cymbopogon pospichilii, Digitaria argyropgrapta, Elionurus muticus, Eragrostis superba,* various *Eragrostis* spp., *Heteropogon contortus, Hyparrhenia hirta, Panicum coloratum, Pogonathria squarrosa* and *Themeda triandra.*

ii. Black Turfveld

This is a more open thornveld, in low-lying areas. The principal trees are *Acacia karroo*, *Acacia nilotica* subsp. *kraussiana* and *Ziziphus mucronata*, scattered throughout a dense, tall, coarsely-tufted grassveld. The principal species are; *Bothriochloa insculpta, Digitaria* spp., *Elionurus muticus*, *Enneapogon scoparius, Eragrostis* spp., *Fingerhuthia africana, Ischaemum afrum*, *Panicum coloratum, Sehima galpinii*, *Setaria woodii* and *Themeda triandra*.

2.3 VELD CONDITION ASSESSMENT

2.3.1 Grass and veld condition

One of the most important aspects to be considered during veld management is grass (Tainton, 1999). This is due to the fact that grasses are good indicators of veld condition. Furthermore, grasses differ in their grazing value. Therefore, grasses can easily be used to determine the condition of veld. The most used method of determining veld condition is the ecological status or grazing status (Du Toit, 1998). Van Oudtshoorn (2012) stated that the ecological status of grasses refers to the grouping of grasses according to their reaction to different levels of grazing.

A grass species reacts to grazing in one of two ways: it can either increase in number or it can decrease in number (Van Oudtshoorn 2012). Following this criterion grasses are classified into the following groups:

- **Decreasers** - Grasses that are abundant in good veld, but decrease in number when the veld is overgrazed or under-grazed. These grasses are palatable climax grasses preferred by grazing animals, such as *Digitaria eriantha* and *Themeda triandra*.

- **Increaser I** – Grasses that are abundant in underutilized veld. These grasses are usually unpalatable, robust climax species that can grow without any defoliation, such as *Hyperthlia dissoluta* and *Trachypogon spicatus*.

- **Increaser II** – Grasses that are abundant in overgrazed veld. These grasses increase due to the disturbing effect of overgrazing and include mostly pioneer and subclimax species such as *Aristida adscensionis* and *Eragrostis rigidior*. This group is common in lower-rainfall areas.

- **Increaser III** – Grasses that are commonly found in overgrazed veld. These grasses are usually unpalatable, dense climax grasses such as *Aristida junciformis* and *Elionurus muticus*. These grasses are strong competitors and increase when palatable grasses are weakened through overgrazing. In addition, it is possible that they are stimulated by light grazing during overgrazing. This group is more common in higher-rainfall areas.

- **Invaders** – invaders are all plants that are not indigenous to an area. These plants are mostly annual weeds or perennial invasive species such as Khaki weed (*Tagetes minuta*), Nassela tussock (*Nassela trichotoma*), Spanish reed (*Arundo donax*), Lantana (*Lantana camara*) and many more.

2.3.2 Terminologies used in veld condition assessment

In order to understand the ecological status of grasses, the following concepts are important (Van Oudtshoorn 2012):

- **Grazing capacity** – Grazing capacity refers to the number of grazers that can be sustained on a property without deterioration of the veld condition. Grazing capacity is expressed as hectare/livestock unit/year (ha/LSU/yr) where one livestock unit is a grazing animal of 450 kg.
- **Plant succession** – is the progressive succession of plant communities. When a disturbance takes place in an area, the area is re-colonized by a new, better adapted plant community. This progressive succession of plant communities is called plant succession and continues until the climax community has been established. However, when the succession is disturbed once more, the veld will revert towards the first stage, the pioneer stage. This process is called retrogression
- **Pioneer stage** – Pioneer plants are hardened, annual plants that can grow in very unfavourable conditions. Examples of pioneer grasses are *Aristida adscensionis*, *Melinis repens* and *Tragus berteronianus*, usually plants with advanced seed dispersal strategies.
- **Subclimax stage** – Subclimax plants are denser than pioneer plants and offer even more protection to the soil. More moisture now becomes available, that leads to a denser plant structure, which deposits more organic material on the surface. Examples of subclimax grasses are *Bothriochloa insculpta* and *Eragrostis rigidior*. These are mainly weak perennials with a life span of approximately two to five years.
- **Climax stage** – Climax grasses are strong perennial plants that are adapted to normal, optimal growth conditions and will grow in an area as long as these conditions prevail. These grasses offer excellent protection against wind, sun and flooding. Examples of such grasses are *Anthephora pubescens, Digitaria eriantha* and *Themeda triandra*, all dense perennial tufted grasses.

2.4 *ACACIA TORTILIS*

2.4.1 Taxonomy and nomenclature

Recently, there has been a dispute over the botanical name of the *Acacia* genus, and all African *Acacias* were divided into two and renamed either *Vachellia* or

Senegalia in 2014. However, for the purpose of this study, due to the lack of clarity on this matter during the study, the species will sustain the name *Acacia tortilis* in this dissertation.

Acacia tortilis commonly known as the “umbrella thorn”, is one of the most distinctive and widespread African acacias. *Acacia tortilis* belongs to the family Fabaceae (Mimosoideae). It has a number of subspecies, namely; *Acacia tortilis* subsp. *heteracantha* (Burch.), *Acacia tortilis* subsp. *raddiana* (Savi), *Acacia tortilis* subsp. *spirocarpa* (*A. Rich*), and *A. tortilis* subsp. *tortilis*. It has the following synonyms; *A. fasciculata Guill*. and *Perr.*, *Acacia heteracantha Burch*., *A. litakunensis Burch.*, *A. maras*, *A. raddiana Savi, A. spirocarpa, A. Rich*., *A. spirocarpoides* and *Mimosa tortilis Forssk* (Joker, 2000). Vernacular or common names include Apple ring acacia and Umbrella thorn.

Its distribution and habitat are widespread throughout the savanna biome and dry zones of Africa, from Senegal to Somalia and south to South Africa (Figure 2.3), in Asia, in Israel, Jordan and southern Arabia to Iran. *Acacia tortilis* subsp. *raddiana* has successfully been introduced to India from Israel. *Acacia tortilis* is a drought-resistant species that grows in areas with as little as 40 mm rain annum^{-1} and in temperature regimes up to 50°C. In the countries that fringe the Sahara it is often this species that extends furthest into the desert. It is found growing from below sea level up to 2000 m altitude and tolerates light night frost. It favours alkaline soils and avoids waterlogged sites, but apart from that it will grow on a wide range of sites (Hegazy and Elhag, 2006).

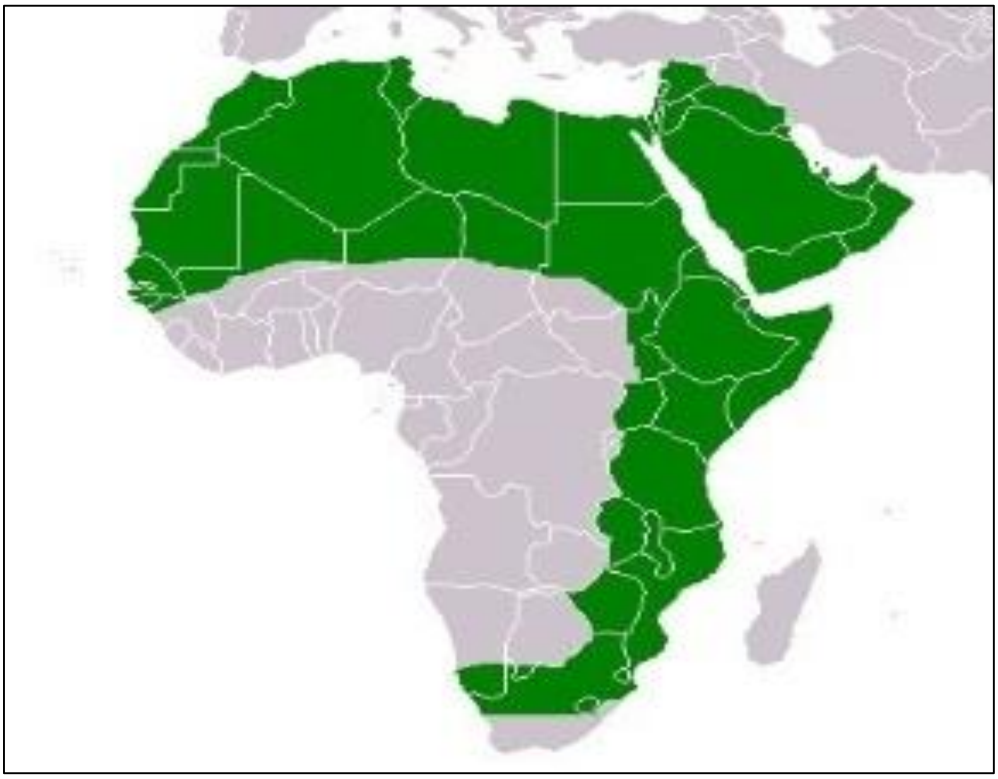

Figure 2.3 Distribution of *Acacia tortilis* in Africa (Kyalangalilwa *et al.*, 2013).

2.4.2 Botanical description

Acacia tortilis is morphologically variable species. It can be multi-stemmed shrubs (ssp. *tortilis*), or single stemmed trees up to 20 m tall with rounded (ssp. *raddiana*) or flat-topped (ssp. *heteracantha* and *spirocarpa*) crowns. It is a slow-growing dryland species, with deep rooting habits, and a spreading umbrella-shaped crown, growing up to 20 m in height. The foliage is feathery and typically *Acacia*-like (Rachie, 1979). The bark is grey-brown-black, rough and fissured. The spines are in pairs, some short and hooked up to 5 mm long, mixed with long straight slender spines up to 10 cm long. The presence of these two types of thorns distinguishes *A. tortilis* from other African acacias. Leaves are smooth to densely pubescent, 1-7 cm long, with 2-14 pinnae each with 6-22 pairs of leaflets. Flowers are white or pale yellowish-white, fragrant, in round heads, solitary or in fascicles (Joker, 2000).

2.4.3 Uses

Acacia tortilis is a good erosion control plant. Due to its drought hardiness and fast growth, the species is considered more useful for this purpose than many indigenous species growing in arid zones. In the savanna biome, *A. tortilis* is an important browse species for goats and game. It is also an important source of fodder for domestic livestock. Foliage and fruits form an integral part of the browse. The leaves are fed green as well as dry (Joker, 2000).

2.5 BUSH ENCROACHMENT

The Conservation of Agricultural Resource Act, Act No. 43 of 1983, (CARA) revised regulation 15 and 16 promulgated by the Minister for Agriculture and Land Affairs on 15 March 2001, and the National Environmental Management: Biodiversity Act, Act of 2004 (No. 10 of 2004) (NEMBA), is a framework for the regulation of alien invasive alien and indigenous species. Bush encroachment is a term used for stands of plants where individual plants are closer to each other than three times the mean crown diameter. *Acacia tortilis* is categorized as a possible invasive species, and a species that indicate bush encroachment (Nel *et al*., 2004). The occurrence of this species in large numbers thus gives a valid reason to embark on a bush control strategy (Trollope *et al*., 1989).

In southern Africa the phenomenon of increasing woody plant density is commonly referred to as ‘bush encroachment’ (Mucina and Rutherford, 2006). The grazing capacity of large areas of the South African savanna is reported to have declined as a result of being encroached by bush, often to such an extent that many previously economically usable livestock properties are now no longer usable. Thus, removal in these areas of some or all of the woody plants will result in an increase of grass production and grazing capacity (Tainton, 1999).

2.5.1 Causes of bush encroachment

Factors causing bush encroachments are poorly understood (Ward, 2005). Walter’s two-layer hypothesis for tree-grass coexistence was an initial attempt at explaining the causes of bush encroachment. This model is based on the existence of two different life forms expressed in terms of root separation i.e. the assumption that water is the major limiting factor for both grassy and woody plants. He hypothesized that grasses use only topsoil moisture, while woody plants mostly use subsoil moisture. Under this assumption, removal of grasses, e.g. by heavy grazing, allows more water to penetrate into the sub-soil, where it is then available for woody plant growth (Ward, 2005).

According to Mampholo (2006), bush encroachment is caused when biological control mechanisms are disrupted. These biological control mechanisms are responsible for inhibiting the development of bush communities capable of being supported by the climatic and edaphic environments of the encroached veld types. These disruptions include: incorrect grazing practices, lack or misuse of fire, absence of browsing animals, lack of mechanical damage by large wild animals such as elephants and elevated concentration of CO_2 levels in the atmosphere. However, the reasons for an increase in the density of woody plants in any vegetation type are diverse and complex. Furthermore, (Trollope *et al*., 1989) stated that aggregation of bush is a result of the combination or the individualistic effect of these disruptions. They are briefly discussed below.

2.5.1.1 *Incorrect grazing practices*

Incorrect grazing practices may be in the form of under or over-utilization. Such practices reduce the vigour of the grass sward, thereby decreasing the competitive ability of grass against bush. Overgrazing diminishes water infiltration near the soil surface allowing less water to penetrate into the soil profile, thus enhancing the process of bush encroachment (Trollope *et al*., 1989).

2.5.1.2 *A lack or misuse of fire*

The natural fire frequency varies between annual and biennial in humid areas (mean annual rainfall > 650 mm). The frequency of fire is dependent on rainfall and the utilization of grass by animals. In the semi-arid areas natural fires are less frequent and dependent on the occurrence of exceptionally wet seasons. The misuse of fire through, for example, burning to stimulate out-of-season growth, and late burning, when grasses have already commenced spring growth, has been shown to seriously retard grass development, thus providing the woody component with a tremendous competitive advantage (Trollope *et al*., 1989). The misuse of fire has led to the implementation of fire laws in South Africa, which prohibits the use of fire in veld management practices during the time of the year when natural fires used to be one of the major factors that controlled bush encroachment. The absence of fire removed the important role fire plays in retarding the development of woody communities, and has led to bush encroachment in large parts of South Africa (Jordaan, 2004).

2.5.1.3 *Absence of browsing animals*

A large variety of natural browsers play an important role in controlling bush encroachment. For example, Du Toit (1967) reported a mortality of *A. karroo* by stocking goats continuously on coppicing individuals. Replacement of wild and domestic browsers by predominantly cattle and sheep in most farming systems allowed bush encroachment to take place virtually unhindered (Trollope *et al*., 1989).

2.5.1.4 *Lack of mechanical damage by large wild animals*

It is difficult to measure the extent to which large animals such as the elephant aided to control encroachment. Numerous thorn bushes that had been uprooted by elephant were observed by Moodie (1835) in the Eastern Cape Province. Apart from tree seedlings, the use of browsers to exercise control on woody plants largely excludes wild game, except elephants (Tainton, 1999).

2.5.2 Consequences of bush encroachment

Woody plant encroachment into savannas is a globally prevalent phenomenon and impacts ecosystem characteristics such as biodiversity, carbon storage, nutrient cycling, grazing and hydrology (Gray and Bond, 2013). Bush encroachment causes a significant reduction in the grazing capacity of veld (Mampholo, 2006). For example, De Klerk (2004) reported that bush encroachment of approximately 26 million ha of savannas in Namibia resulted in a loss of land productivity, and the carrying capacity declined from 1 Large Stock Unit (LSU) occupying 10 ha to 1 LSU occupying 20 or 30 ha. Furthermore, Du Toit (1967) and Trollope (1983) found that the annual production of grass material was reduced to approximately 40-50% in veld encroached by bush.

Ward (2005) stated that the aggregation of bush affects the agricultural productivity and biodiversity of 10 – 20 million ha of South Africa. Bush encroachment has adverse effects on the economy and livelihoods of farmers. De Klerk (2004) found that economic losses of more than R 7 651 million per annum had directly impacted on the livelihoods of 65 000 households in communal areas and on 6 283 commercial farmers and their employees.

2.5.3 Management approaches

In the control of the encroachment of undesirable plants, the most important factor that influences the adoption and implementation of a veld rehabilitation programme is economics (Jordaan, 2004). This concept is based on the fact that the majority of livestock producers have limited financial capital. Therefore, unless the control of these undesirable plants is of a non-capital intensive type, the rancher may have to be financially assisted with the veld rehabilitation programme. Trollope (1984) proposed two alternative approaches to the control of bush encroachment. One approach is to adapt the livestock system to the existing vegetation (viz. by using browsers such as goats as a part of the farming enterprise). The second approach is to modify the vegetation to suit a specific livestock system, particularly a system based on grazing animals, especially where the vegetation has been greatly modified by past management practice (using fire to reduce thickets).

2.5.3.1 *Mechanical bush control*

Mechanical bush control refers to the physical removal of problem species or physical damage to the plants, which eventually result in their death (Tainton, 1999). Mechanical control procedures range from simple procedures such as chopping or slashing, ring barking and uprooting, through the use of machines, including long weighted chains or cables pulled between bulldozers. Mechanical bush control procedures are more often the less successful means of bush control. Mechanical clearing of bush results in soil disturbances, generally severely affects the grass layer, and grasses must often re-establish themselves after such a treatment. Furthermore, severe soil disturbance may encourage the establishment of large numbers of seedlings of some woody plants (Smit, 2004). This may, in time, result in a woody community that is denser than the original community. Mechanical bush control is therefore usually avoided and only used to complement chemical or biological control methods (Trollope *et al*., 1989).

2.5.3.2 *Chemical bush control*

Chemical control methods are usually expensive to apply and should therefore be considered under specific circumstances. The control of bushes and trees through chemical methods can be carried out on a large scale and with quick results especially if chemicals are applied by air. According to Hoffman and O'Connor (1999), the question of when to use chemical bush control depends largely on cost effectiveness, compared with that of other control measures. Trollope *et al*. (1989) indicated that it may be resorted to when:

i. The woody component is so dense that not enough fuel accumulates to support a fire sufficiently intense to kill the top-growth of the target woody species;

ii. The majority of the trees have grown out beyond the reach of browsing animals;

iii. The tree density is such that animal access is severely restricted;

iv. The woody component is largely unpalatable;

v. For a variety of reasons, it is not practical to incorporate browsers in the livestock system; and

vi. Where herbicides are available which will selectively affect the target woody species more severely than the palatable species.

2.5.3.3 *Biological bush control*

Biological control measures refer to initiating, promoting or maintaining natural processes or phenomena which counter bush encroachment (Trollope *et al*., 1989).

i. Insects and plant diseases

Although periodic epidemics of locusts or army worms' or outbreaks of certain plant diseases can temporarily check bush encroachment. Their occurrence, however, is sporadic and uncontrollable, thereby excluding them as biological control methods (Hoffmann and O'Connor, 1999).

ii. Stocking rate

Although incorrect stocking rates of grazers are often mentioned as a cause of encroachment, it must be emphasized that stocking rate is in itself an important biological control measure. Under commercial pastoralism, the stocking rate is controlled by the manager and can therefore be manipulated with the objective of controlling bush. This can either be through stocking with grazers to develop and/or maintain a vigorous grass sward, or through stocking with browsers to utilize and control bush (Trollope *et al*., 1989).

iii. Seedling suppression

Seedling suppression is not a new concept in biological bush control, but is as yet untested. Seedling suppression is based on the principle that, in a plant community, certain factors inhibit the development of specific seedlings. For example, the frequency of seedlings of *Acacia nilotica* and *A. tortilis* were greatly reduced and usually absent under *Acacia* canopies (Smith and Goodman, 1986). In contrast, seedlings of other species tended to be restricted to areas below *Acacia* canopies. This phenomenon was largely ascribed to a response of reduced light intensity. A conclusion in terms of bush control is that, where the development of seedlings of the encroaching species is discouraged by lowered light intensities, a certain measure of bush control can be achieved by allowing selected trees to develop into large shade trees. It also creates a micro-climate for other species (Friedel and Blackmore, 1988; Jordaan, 2010).

iv. Fire

Veld burning *per se* is potentially effective only in the sour bushveld types because it is in these areas that rainfall is reliable and sufficient to produce enough grass fuel to support regular intense fires. The frequency of burning required to control bush encroachment depends on the rate at which re-encroachment occurs in the form of recovering coppice growth and seedling development. Generally, a hot fire (2000 – 3000 $kJs^{-1}m^{-1}$) applied once every three to four years effectively controls encroachment of bush from either seedlings or coppice growth (Trollope *et al*., 1989). In more arid areas fire alone is not effective in controlling bush, but it can reduce the height of the bush canopy to bring it within reach of domestic browsers, i.e. goats.

The use of fire is an inexpensive way of lowering and maintaining bush at an available height for browsing animals (Trollope, 1983). If the objective is to eradicate the bush, goats should be introduced soon after the fire. However, where the productivity of the trees is important, browsing should be delayed until coppice shoots have grown out to at least 10 – 15 cm (Tainton, 1999). Since burning effectively wastes browse above the browse line, lowering of bush to below the browse line can also be effected by effectively chopping the taller trees, thereby making additional browse available to the animals and stimulating coppice growth (Trollope *et al*., 1989).

v. Incorporating browsers

Where this method of biological control is used, the bush must be acceptable and at an available height to the browsing animal, which in turn must be adapted to the climatic environment of the area. This latter requirement reduces the attractiveness of using goats to control bush encroachment in the sour bushveld areas because existing commercial goat breeds do not generally thrive in a humid environment. It is therefore a method best suited to the sweet bushveld areas, where both the climate and browsing environment are favourable for goat ranching (Trollope *et al*., 1989).

2.6 GROWTH RINGS

Growth rings are the concentric circles visible in tree-trunk cross sections. They provide record of ecosystem events like fire, insect outbreaks, and logging. A growth ring is formed inside the bark by division of cambial cells, which produce large, thin-walled wood or xylem cells (early wood) at the beginning of the growing season and small, thick-walled wood cells (latewood) toward the end of the growing season (Schweingruber, 1996). Dendrochronology is a developing science dealing with annual and seasonal variations in growth-ring structures that have been precisely dated and arranged in annual time series (Fritts *et al*., 1991). It is a study undertaken in order to understand how ecological processes have worked in the past and how they might work in the future.

2.6.1 Relationship between growth rings and other tree dimensions

Irrespective of the formation of clearly distinguishable ring boundaries, many tropical tree species show pronounced growth variations triggered by fluctuations in temperature, water availability and phenology. An understanding of the linkage between growth dynamics and seasonal climatology is fundamental to derive climate reconstructions from tree-ring analysis. Stem diameters can vary on diurnal (day-night cycle), short-term (water shortage), and long-term (stem growth by cambial activity) time scales (Elferts *et al*., 2008). Long-term variations are the result of radial growth, whereas short-term stem diameter variations reflect changes of the internal water status (Brauning *et al*., 2008).

Tree growth is frequently affected by variations in climates, and the yearly sequence of favourable and unfavourable climate (wet and dry or warm and cold years), particularly shown by the sequence of wide and narrow rings (Fritts, 2012). Gindl *et al*. (2000) found that the growth of trees at the alpine treeline is primarily limited by temperature and the length of the growing season. A cool short growing season produces a narrow, low-density growth ring, whereas more favourable warmer conditions will lead to wider rings with higher latewood densities. According to Fritts (2012), dendrochronology is greatly dependent on the principle of limiting factors, which states that a biological process, such as growth, cannot proceed faster than is allowed by the most limiting factor. Therefore, the narrower rings provide more precise information on limiting climatic conditions than do the wider rings.

A study along the vertical transect in the sub-continental Swiss Rhone Valley revealed a strong relationship between precipitation and radial growth of several tree species in the lower montane region (Oberhuber *et al*., 1998). Furthermore, Ferrio *et al*. (2003) stated that limited water availability reduces cambial activity. When water is sufficiently available to the plant, there may be sufficient food for production of wide rings. But in dry sites or during years of low moisture, food completion within the tree is likely to be greater and the cambium at the base of the stem is likely to receive a limited food supply and may produce narrow rings (Fritts, 1966).

2.6.2 Effect of rainfall on growth rings

Tree growth depends on environmental factors, including location, surrounding foliage, water and temperature. The size of the growth rings has a direct relation to the intensity, frequency and availability of precipitation. For example, wider rings are an indication of favourable growth conditions. While the narrower rings show that there was less growth due to unfavourable growth conditions such as drought or cold cycles (Schweingruber and Poschlod, 2005). The amount of rainfall differs from year to year. Therefore, scientists use tree ring patterns to reconstruct regional patterns of drought and climate change (Fritts, 1966).

Seasonal patterns of wood growth are related to water availability. Many differences in the ring-width growth within a tree may be attributed to changing supplies of food, hormones and the intensity of rainfall. For example, in moist sites or during periods of favourable climate, there may be sufficient resources for the production of wide rings throughout the tree (Schweingruber and Poschlod, 2005). In dry sites or during years of low moisture availability and high temperatures, food competition within the tree is likely to be greater. Thus, the cambium at the base of the stem is likely to receive a limited food supply and may produce narrow rings (Fritts, 1966). Novak *et al*. (2013) stated that other anatomical characteristics, such as the occurrence of intra-annual density fluctuations and the presence of resin canals, have also proven to be highly dependent on climatic variability.

Brauning *et al*. (2008) found that in the tropics, trees do not grow continuously. Many tropical tree species show pronounced growth variations triggered by fluctuations in temperature and water availability. Furthermore, cambial activity reacts sensitively to moisture supply. When rainfall frequency is low, stem increment rates are also low, since transpiration rates probably exceed water uptake. Absolute growth rate, the change in a dimension per sampling interval throughout the growth of a plant is strongly influenced by the local soil conditions and probably also by crown competition and social tree status.

2.6.3 Effect of soil form on growth rings

The quality or health of a soil refers to its overall fitness, or effectiveness for supporting plant growth, managing water, and responding to environmental stresses (Doran and Zeiss, 2000). In some plants there is evidence of a close coupling between leaf water potential and plant resistance, but there is also a clear physical relationship between soil moisture content and soil hydraulic resistance (Kramer and Boyer, 1995). Different soil types have different characteristics and also, different plant species have different requirements. Some plants prefer soils with high acidity and poor drainage, whereas, some plants will not be able to thrive in such conditions. Therefore, the type of soil in which a plant grows has a critical impact on its growth and furthermore, the development of growth.

The characteristics of soil play a big part in the plant's ability to extract water and nutrients. If plants are to grow to their potential, the soil must provide a satisfactory environment for plant growth. The availability of plant nutrients is considerably affected by soil pH. Calcium, potassium, magnesium and sodium are alkaline elements, which are lost with increasing acidity, whereas phosphorous is more available under acidic soil conditions (Magdoff and Weil, 2004). Acidity can also induce deficiencies of micronutrients such as molybdenum, copper and boron, although a deficiency in the latter is more commonly seen in alkaline soils where over-liming has occurred. Other minor elements that may be deficient due to low solubility in high pH includes manganese and iron (Alloway, 2008).

2.6.4 Relationship between growth rings and tree age

In order to determine the age of a tree it must be cut down or felled. It is then relatively easy to determine its age by counting the growth or annual rings that can be seen on the sawn-off stump. Under the bark of a tree is the cambium, which forms new cells so that the tree can grow. Differences in the rate at which cells are produced by this tissue give rise to annual or growth rings (Hanton, 2006). Environmental climatic conditions have a substantial effect on the formation of growth rings. Fritts (1966) found that if conditions are good for growth (warm temperature and regular rainfall), the ring that is formed will be wider than those created in a colder year or one with extensive water shortages. Growth rings have proven to be an invaluable resource for age determination in woody plants. The technique requires the presence of growth rings with a clear demarcation between spring wood and summer wood (Bowman *et al*., 2013).

Growth ring analysis is a potential tool for obtaining information on the cambial activity, precise dating and sensitivity of the plant to climatic variables (Verheyden *et al*., 2004). In addition, it may provide information about the relationship between growth and environmental variables (including climate) and allows the detection of past changes in environmental conditions, which may aid in understanding forest dynamics. Counting growth rings can give a fairly accurate account of the tree's age. Therefore, when rings are conspicuous, they may be counted in order to obtain a reasonable approximation of the age of the tree. However, use of plant growth rings for age determination requires distinct rings and verification that these are produced annually (Fritts and Swetnam, 1986).

Due to the seasonal growth conditions imposed by climate, the assumption of annual ring deposition seems justifiable. Verification, however, is *sine qua non* for accurate age determination by ring counts because two growth anomalies are possible. For example, in years of extremely low rainfall, cambial growth may be limited to the extent that a growth ring will not be laid down. Failure to recognize such "missing rings" will underestimate the age of a stem. In some years, renewed growing conditions near the end of the growing season can result in additional spurt of growth and laying down of an additional "false ring". Failure to recognize false rings will overestimate the age of a stem (Fritts and Swetnam, 1986).

2.7 POPULATION DYNAMICS

Tree growth can be defined as the increase in dimensions of an individual tree through time (Bowman *et al*., 2013). The most commonly measured dimensions are height and diameter, because these are expedient measures that have high correlation with wood volume and biomass. The basal area of a stem (the cross-sectional area of stems) can be calculated and interpreted because it is an important dimension, useful in ecological and physiological studies. The rate of change of a dimension per unit time, or 'growth increment' can be expressed in either absolute or relative terms. Bowman *et al*. (2013) further explained that relative growth rate, the change in a dimension per sampling interval relative to initial size, is commonly used in studies of short-lived plants. It is less useful for tree growth; because there is an initial very rapid decline in relative growth rate with increasing tree size due to accumulation of non-photosynthetic material, such as stems, branches and roots.

The idea of counting plants never had a widespread appeal. Crawley and Ross (1990) found that there are two main reasons for this. Firstly, the longevity of plants is such that one individual may survive for a long period of time. Secondly, the phenotypic plasticity of plants is such that the fecundity of the same individual genotype may vary by four orders of magnitude, depending upon the circumstances of its cultivation. Furthermore, their study revealed that there is a general problem about what precisely to count. In animal ecology it is taken as axiomatic that counting refers to individual, free-living individuals. Plants, however, are modular in construction, and for practical purposes it makes more sense to estimate the plant biomass rather than to count the number individual genotypes (Harper, 1977). Again, it is unclear whether a count of the numbers of shoots per individual, or of the number of modules per shoot is the most appropriate currency for assessing plant abundance (Crawley and Ross, 1990).

2.7.1 Effect of growth form on plant communities

Tree growth form may have a positive or negative effect on the growth of grass, which in turn, will affect tree establishment and growth. Due to the higher organic carbon content the soil, bulk density is often lower in soil under tree canopies (Smith and Goodman, 1986). Furthermore, Smit (2004) demonstrated a consistent pattern of grass production around isolated *Acacia karroo* trees in the False Thornveld of the Eastern Cape, South Africa. High yields were recorded under and immediately to the south of the tree canopy, and low yields to the immediate north of the canopy. They attributed the former to the favourable influence of the trees on the micro-environment and the latter to the reduced water input associated with the physical redistribution of rainfall by the trees. There is a significant increase in both stem diameter and shoot extension of *Acacia nilotica* trees whose neighbours had been removed within a radius of 5 m (Smit, 2004).

There are differences in seedling morphology that may affect establishment in different types of ground cover. Seedlings of small-seeded species have small, elliptical cotyledons and form broad, flat, rosettes with a horizontal habit. In contrast, seedlings of the larger-seeded species have long, narrow cotyledons and form an erect to semi-erect basal rosette. Potentially, seedlings with an upright or vertical growth form can emerge through deep litter or vegetation better than those with a horizontal growth form (Gross, 1984).

In some cases, seedling establishment is unaffected by tree canopies while in others, establishment is limited to between canopy environments (Iponga *et al*., 2009). In the Eastern Cape Province, shading increased the density of *Acacia karroo* seedlings (Mucina and Rutherford, 2006), while at Nylsvley in the Limpopo Province, shading decreased the density of *Acacia tortilis* seedlings (Smit, 2004)

2.7.2 Competition within and between species

Inter- and intra- competition between plant species has long been regarded as a major determinant of the structure and function of woody plant communities in the African savannas (Shackleton, 2002). According to Bond *et al*. (2005), plant competition starts when resources, such as water, soil nutrients or sunlight, become available in insufficient amounts for individuals and the most successful competitors become the common members of the community. In savanna vegetation plants often compete with other plants, i.e. tree-tree, grass-grass or the more common tree-grass competition. Bucini (2010) found that an important determinant of woody seedling establishment is competition from other plants, either from other woody plants or herbaceous plants.

Tree-on-tree competition appears to be species specific or related to the shade tolerance of the seedlings (Loth *et al*., 2005). Furthermore, Smit (2004) demonstrated that tree species of communities dominated by *Acacia senegal*–*Acacia tortilis* and *Euclea divinorum*–*Acacia nilotica* have characteristic dispersal strategies. These were manifested through intra- and inter-specific competition among the dominant tree species. *Acacia senegal* became dominant in areas previously dominated by *Acacia tortilis*, while *Euclea divinorum* was replaced previous dominance by *Acacia nilotica*. It was, however, established by that *Euclea divinorum* does have the ability to establish under canopies, while seedlings of several *Acacia* species are distinctive as they fail to establish under the canopy of any established individual, regardless of species.

2.7.3 Relationship between plant size and plant density

The relationship between size and density may be a valuable tool to reveal the extent of competition and mechanisms for distribution patterns, structure and functioning of woody species in savanna vegetation types (Woodall and Westfall, 2009). The growth and subsequent size that a tree can achieve is largely dependent on the resources to which it has access. Although the available water and nutrients play a major role in the growth and size of the tree, the proximity and size of neighbouring individuals can ultimately determine the tree’s growth and final size (Ward, 2005). As observed by Smit (2004), the larger the tree, the larger the area (volume) of resource depletion around it, and the greater the competitive effect it may have on its neighbours.

The final size and structure of a plant has a significant effect on the establishment, growth and ultimate size of its neighbouring seedlings (Sankaran *et al*., 2004). Tainton (1999) stated that the distance between a tree and its nearest neighbour of the same species is not determined purely by chance, but that tree spacing is evenly distributed. The larger the individual, the greater is the distance between it and the nearest individual of the same species. There is thus a significant relationship between tree size and population density. It then comes as no surprise that as mean plant size per unit area increases, the number of individuals per unit area decreases.

2.8 LEGISLATION

The regulation of plants contributing to bush encroachment has lately been given an additional boost by the amendment of the Environmental Management Act, Act No 10 of 2004 in the form of alien invasive species (Government Gazette, 2014).

Chapter 2 of NEMBA Act gives directions to alien and invasive species management. Chapter 2 of the NEMBA Act is also responsible for species and organisms posing potential threats to biodiversity. The purpose of Chapter 2, is to prevent the unauthorized introduction and spread of invasive species to ecosystems and habitats where they do not occur naturally.

The other purpose of Chapter 2 of the NEMBA Act is to manage and control invasive species to prevent or minimize harm to the environment and to biodiversity in particular and to eradicate invasive species from ecosystem and habitats where these may harm such ecosystem or habitats. The first part of Chapter 5 of the NEMBA Act, deals with alien species specifically on restricted activities involving alien species and exemptions. Chapter 3 of NEMBA Act deals with restricted activities involving certain alien species totally prohibited, amendments of notices and duty of care relating to alien species.

The second part of Chapter 2 deals with invasive species, particularly with the list of invasive species, restricted activities involving listed invasive species, amendments of notices, duty of care relating to listed invasive species, request to competent authorities to issue directives, control and eradication of listed invasive species, invasive species control plans of organs of state and invasive species status reports (NEMBA). These undertakings by Government will, in a way, assist in management and minimization of bush encroaching species such as *Acacia tortilis*.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 STUDY AREA

The study was undertaken in the Limpopo Province of South Africa. The Limpopo Province (24.0000° S, 29.0000° E) is the northern-most province of South Africa, situated on a plateau 1 312 m above sea level. It is named after the Limpopo River that forms the northern border of South Africa. The climate of the province is classified as semi-arid, with the annual precipitation of between 300 and 1000 mm per annum. The Limpopo Province has warm to hot summers with moderate winters, average summer temperatures rise to 28.1°C and drop to 17°C and average winter temperatures range from 19.6°C to 4.7°C. The province is in the Savanna Biome, an area of mixed grassland and trees, generally known as Bushveld (Mucina and Rutherford, 2006).

The research was conducted in the Capricorn and Waterberg districts of the Limpopo Province. The study was carried out at two study areas, namely the University of Limpopo's Syferkuil Experimental Farm and the Sondela Nature Reserve (Figure 3.1). Three sites were used for the study; two at Syferkuil and one at Sondela Nature Reserve or SNR. The two sites at Syferkuil were used to study growth ring formation and population dynamics of *Acacia tortilis* on different soil forms at the same mean annual rainfall. Two sites, one at Syferkuil and one at Sondela, were used to study growth ring formation and population dynamics of *A. tortilis* on a similar soil form (Hutton soil form), but at different mean annual rainfalls.

3.1.1 Syferkuil Experimental Farm

Syferkuil Experimental Farm (23°49’ S; 29°41’ E), is situated on the Pietersburg Plateau False Grassveld (Veld type 67) (Acocks, 1988). The mean temperature at Syferkuil ranges between 10°C and 25°C (Table 3.1) for winter and summer, respectively. The average long-term annual rainfall is 450 mm per annum. The dominant grasses are typical bushveld grasses such as *Aristida* species, *Heteropogon contortus* and *Themeda triandra*, while the woody component is dominated by *Acacia* species such as *Acacia hebeclada* and *Acacia rehmanniana*. The soil types in this area are of the Glenrosa and Hutton forms (Soil Classification Working Group, 1991).

3.1.1.1 *Soil forms*

The soils are hereby described according to the Soil classification, a taxonomic system for South Africa by Soil classification working group (1991).

i) Hutton soil form

Hutton is made up of Orthic A and red apedal B topsoil. However, the subsoil is unspecified. Orthic A horizon is a surface horizon that does not qualify as organic, humic, vertic or melanic topsoil although it may have been darkened by organic matter.

ii) Glenrosa soil form

Glenrosa is made up of Orthic A and lithocutanic B in the topsoil. However, the subsoil is unspecified. Orthic A horizon is a surface horizon that does not qualify as organic, humic, vertic or melanic topsoil although it may have been darkened by organic matter.

3.1.2 Sondela Nature Reserve

The site is situated at the Sondela Nature Reserve, on the southern part of the Springbok flats, approximately 10 km southeast of Bela Bela (Warmbaths) in the Limpopo Province (28°21’E, 24°25’S; 1 184 m above sea level). The long-term average annual rainfall of this site (60 year average) is 630 mm per annum. The long-term daily average maximum and minimum temperatures vary between 29.7°C and 16.5°C for December, and 20.8°C and 3.0°C for July, respectively. The vegetation type is classified as Sourish Mixed Bushveld, (Veld type 19) (Acocks, 1988) or, according to Low *et al*. (1996), Mixed Bushveld. The woody layer is dominated by *Acacia* species and *Dichrostachys cinerea,* and the grass layer by *Eragrostis* species (*Eragrostis barbinodis* and *Eragrostis rigidior*), *Heteropogon* *contortus, Panicum maximum* and *Themeda triandra.* The soil of the study area is of the Hutton form (Stella family) (Soil Classification Working Group, 1991).

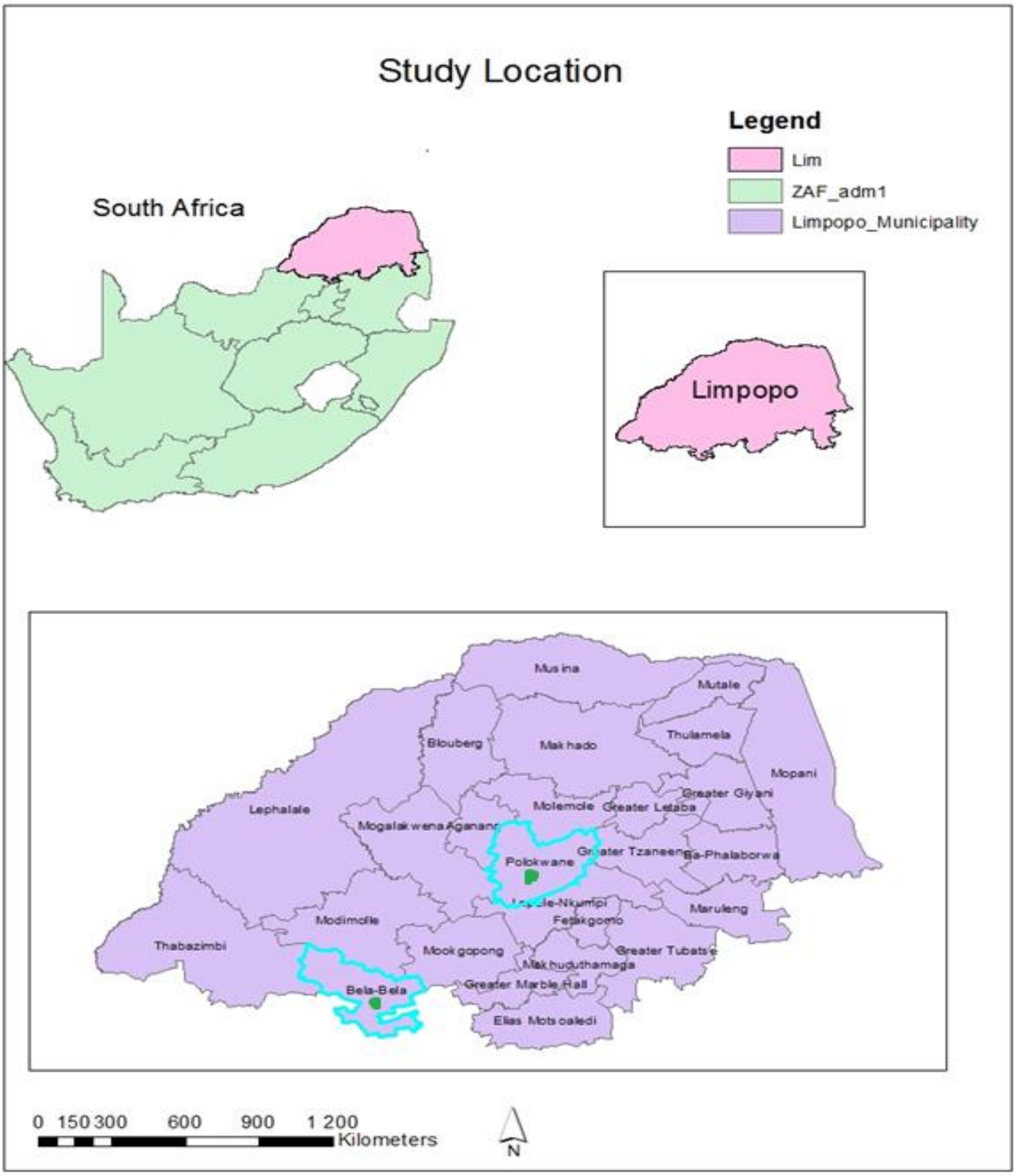

Figure 3.1 Study areas in the Limpopo Province where the research was conducted.

Table 3.1 The Long-Term Average (LTA) Meteorological data at the Syferkuil Experimental Farm (ISCW, 2014).

Month	Evap	FD	Rain	RHn	RHx	Suns	Tmin	Tma	Wind
Jan	201.4	0	72.6	36.8	89	7.8	16.1	27.6	139
Feb	188.2	0	66	35.1	88.9	7.8	15.8	27.5	138.8
Mar	170.1	0	58.6	35.6	90.2	7.4	14.4	26.8	114.7
Apr	137.4	0.8	30.8	31.2	90.1	7.8	10.5	25	104.7
May	124.9	5.7	11.3	25.8	88.7	8.5	5.7	22.9	90.8
Jun	112.6	8.8	7.5	24.3	85.1	8.5	2.5	20.7	98.5
Jul	116.8	3.5	7.5	25.3	85.3	8.6	2.4	20.3	105.9
Aug	156	0.1	4.1	25.3	81.9	8.9	4.6	22.4	126.7
Sep	191.1	0	8.6	27.8	78.5	8.8	9	25.4	155.5
Oct	223.2	0	41.7	32.3	80.4	8.3	12.4	26.2	181
Nov	195	0	88.4	36	83	7.6	14.2	26.4	163.1
Dec	199.2	0	71.2	36.7	85.8	7.4	15.5	27.1	141
Total	**2015.8**	**-**	**468.4**	**-**	**-**	**-**	**-**	**-**	**-**
Mean	**-**	**-**	**-**	**31**	**85.5**	**8.1**	**10.2**	**24.8**	**132.4**

KEY NOTES

Average first frost: 10 June
Average last frost: 22 August
Average frost season: 74 days
Average frost days year^{-1}: 20
Rain: Rainfall mm month^{-1}
FD days: Frost Days
Utot km day^{-1}: Wind run
Evap mm: A-Pan Evaporation
RHx %: Maximum Daily Relative Humidity
RHn %: Minimum Daily Relative Humidity
Suns hours: Sunshine hours
Tmax ^{o}C: Daily Maximum Temperature
Tmin ^{o}C: Daily Maximum Temperature

3.2 RESEARCH DESIGN

3.2.1 Sites that differ in soil form (Hutton vs Glenrosa)

The experimental layout was a 2 X 5 factorial (two soil form, five tree height classes 10 replications), incorporated in a Randomized Design.

3.2.2 Sites that differ in average annual rainfall (430 mm vs 630 mm)

The site at the Syferkuil Experimental Farm was compared to a site at The Sondela Nature Reserve. Both sites were on a Hutton soil form. The experimental layout was a 2 X 5 factorial (two long-term average annual rainfalls, five tree height classes 10 replications), incorporated in a Randomized Design.

3.3 DATA COLLECTION

3.3.1 Characterizing the woody component at the three sites

Vegetation surveys of the woody component were conducted in three 100 X 2 m line transects at each site. The line transects were set using a 100 m measuring tape. To determine which trees formed part of the transect, a 2 m metal rod was held at the centre over the measuring tape and each tree which was within the 2 m distance, formed part of the survey. All woody plants that occurred in the line transects were identified, the number of individuals counted and expressed as density (number of trees ha^{-1}).

Tree height and canopy width of each tree that occurred in each line transect was recorded. Using a tape measure, the height of the tree whose stem was within the 2 m parameter, was determined. The canopy width was determined, using the line intercept method, whereby the distance covered by a canopy that intercepts the tape measure, regardless of whether the stem of the tree is within the 2 m parameter, is recorded and computed. The number of trees in every height class ha^{-1} and the canopy cover were determined.

3.3.2 Characterizing the grass component at the sites

The grass was surveyed in three 100 x 2 m strip transects per site, using a 200 point nearest plant wheel point survey per transect (Du Toit, 1998). Each grass species, nearest to the point, was identified and recorded. The number of strikes, (the point striking an actively growing grass tuft), were also recorded. If no plants occurred within a radius of 30 cm from the point, it was regarded as a bare spot. Herbaceous (non-grass) plants were described as “Forbs”. Data was pooled and a total of 600 points were used to determine the percentage basal cover (number of strikes/number of points X 100), and the percentage grass species composition (number of individuals of species A/number of points X 100) of the site. The veld condition of the sites was determined, using the key species method (Trollope *et al*., 1989).

3.3.3 Determination of tree age

Fifty *Acacia tortilis* trees were selected at each site. These individuals were represented by five height classes; each class including 10 trees. The following height classes were used;

- <0.5 m (representing seedlings/young trees)
- >0.5 – 1.5 m (representing trees that fall within the browsing height of goats and other small browsers such as impala)
- >1.5 – 2.0 m (representing trees that fall within the browsing height of larger browsers such as kudu)
- >2.0 – 3.0 m (representing trees that fall within the browsing height of giraffe)
- >3.0 m (large trees)

The selected plants were felled, using a chainsaw, and a sample of the stem was used to determine the number of year rings. Stem samples of 500 mm long were cut at 0.75 m. Discs of 200 mm width (to prevent cracking) were sectioned from the samples and sanded at the University of the Limpopo's Technical Section, using a belt sander and a series of belts between 60 and 120 grain size.

Growth rings were counted by means of an Olympus SZ30 dissecting microscope with an eye piece graticule. Rings were counted in a Y pattern emanating from the centre of the stem (Figure 3.2). Every 10th year was marked with a pinprick, adapted from the method used by (Stokes and Smiley, 1996). At branch entry points the rings are scalloped. These areas were not used for counting the rings or measuring the stem diameter. The three lineage counts per stem were averaged and where necessary, adaptations were made to compensate for fungal infected areas. Where growth rings were not clearly visible or where holes occurred in the trunks, the number of rings that occurred in unaffected heartwood were divided by the length of the affected area and equalled the years approximated to that area (Mushove *et al*., 1995).

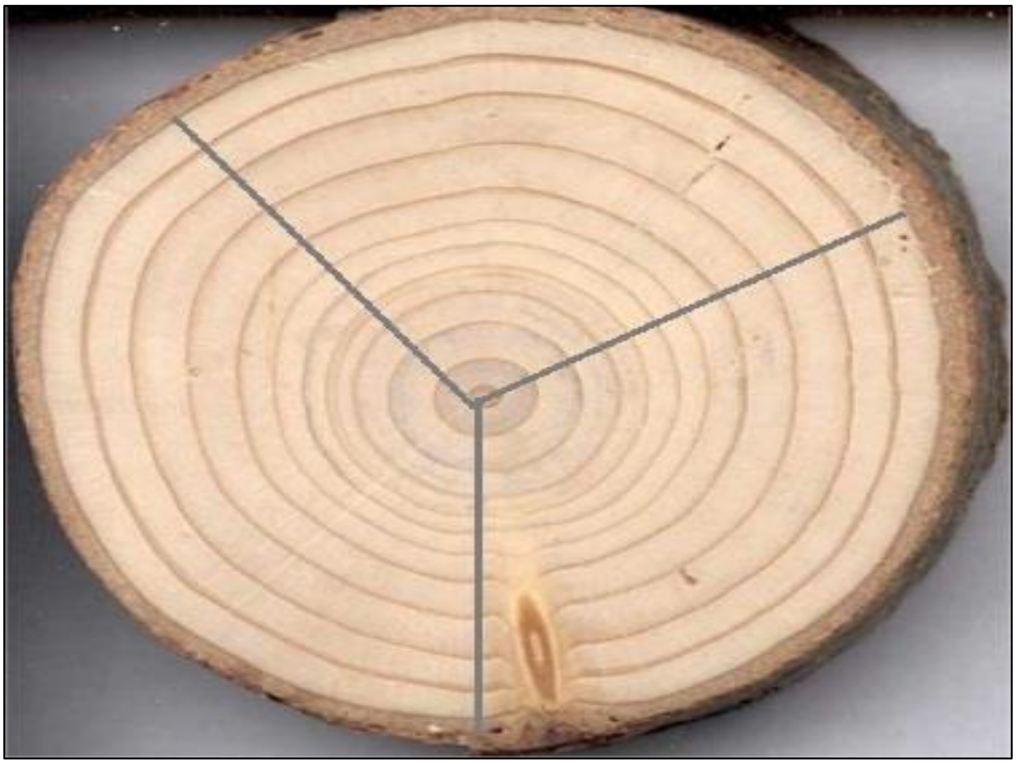

Figure 3.2 A felled stump with a Y pattern, for counting growth rings.

3.3.4 Stem circumference

Tree stems were cut at the height of 0.75 m, for accurate determination of growth rings. Guiot J. (1986) found that for accurate counting of growth rings, plants must be felled at 0.75 m. Circumference of the trunk was obtained with a measuring tape. The growth rate of *Acacia tortilis* was determined by dividing the average age of the trees, by the mean circumference of the trees (Nazim *et al*., 2013).

Distinctions were made between heartwood (inner, dark red-brown-coloured wood), middle-wood (shade lighter than heart wood) and sapwood (straw-coloured, outer wood) (Novak *et al*., 2013). Periderm, sapwood and heartwood widths were measured by means of callipers and added up to give the diameters of the periderm, sapwood and heartwood, respectively. For calculation purposes, heartwood included middle-wood. Sapwood excluded rhytidome, which is variable in thickness due to its roughness. The diameter of each section was halved (to obtain radius) and the formula πr^2 used to determine the surface area of each section.

3.3.5 Population dynamics and establishment sequences

To determine the tree population establishment, an additional tree density survey was conducted at each site. Using this data, the sample size for the determination of population dynamics was calculated. At each site, 10% of the *Acacia tortilis* population, as represented by the number of individuals in each height class, was used to determine the establishment/recruitment sequence of *A. tortilis*. The circumference of each tree was determined by measuring the stem circumference of sampled trees with a tape measure. Thereafter, using the correlation between stem circumference and tree age (as described under 3.4.2), the establishment and development dynamics of the plant population was determined.

3.4 DATA ANALYSIS

3.4.1 Correlation of the tree characteristics

To determine if differences in tree characteristics (tree heights, stem circumference, canopy diameter and number of growth rings) occurred between the three sites, data were subjected to a 2-tailed T-test for independent samples using the statistical programme GenStat (Payne *et al*., 2012).

3.4.2 Regression analysis of the tree characteristics and the two independent factors (rainfall and soil form)

To determine the relationships between tree heights, stem circumference, canopy diameter and number of growth rings, tree characteristic data were totalled and subjected to multiple regression analyses (Draper and Smith, 1981), using GenStat software (Payne *et al*., 2012).

3.4.3 Tree age and meteorological factors

Regressions that were obtained between tree growth parameters and meteorological factors, as well as the regressions between tree growth parameters and different soil forms were compared, using Pearson’s coefficient of correlation. The calculated correlation coefficients, also known as Pearson’s coefficient of correlation or the product moment correlation coefficient, is a measure of the linear relationship between two random variates ($-1 < r < 1$) (Draper and Smith, 1981).

To determine the relationship between growth rings and stem circumference, data obtained at each site were correlated with the long-term average rainfall of the sites (1905 to 2014), using GenStat software (Payne *et al*., 2012). Similar relationships between growth rings and stem circumference on different soil forms were also determined.

3.4.4 Population dynamics and establishment sequences

The age of different *Acacia tortilis* individuals encountered in the survey, described in 3.3.5, was determined, using the relationships obtained in 3.4.2. Distribution diagrams were then created, using Microsoft Excel 2010.

CHAPTER 4

CHARACTERISATION OF THE STUDY AREAS

This chapter represents the characterization of the different study sites based on empirical data interpretations only, involving several plant species. It serves as a baseline for Chapter 5, where the relationships between tree characteristics and establishment patterns of *Acacia tortilis* are described, based on representative samples from communities describe in this chapter.

4.1 HUTTON SOIL FORM, SYFERKUIL EXPERIMENTAL FARM (SITE 1)

4.1.1 Long-term average rainfall

Annual rainfall at the Syferkuil Experimental Farm, between 1905 and 2013, is illustrated in Figure 4.1. The long-term average rainfall was recorded as 458.02 mm. The lowest annual rainfall was 113.3 mm, recorded in 1918, and the highest rainfall was 950.4 mm, recorded in 1996.

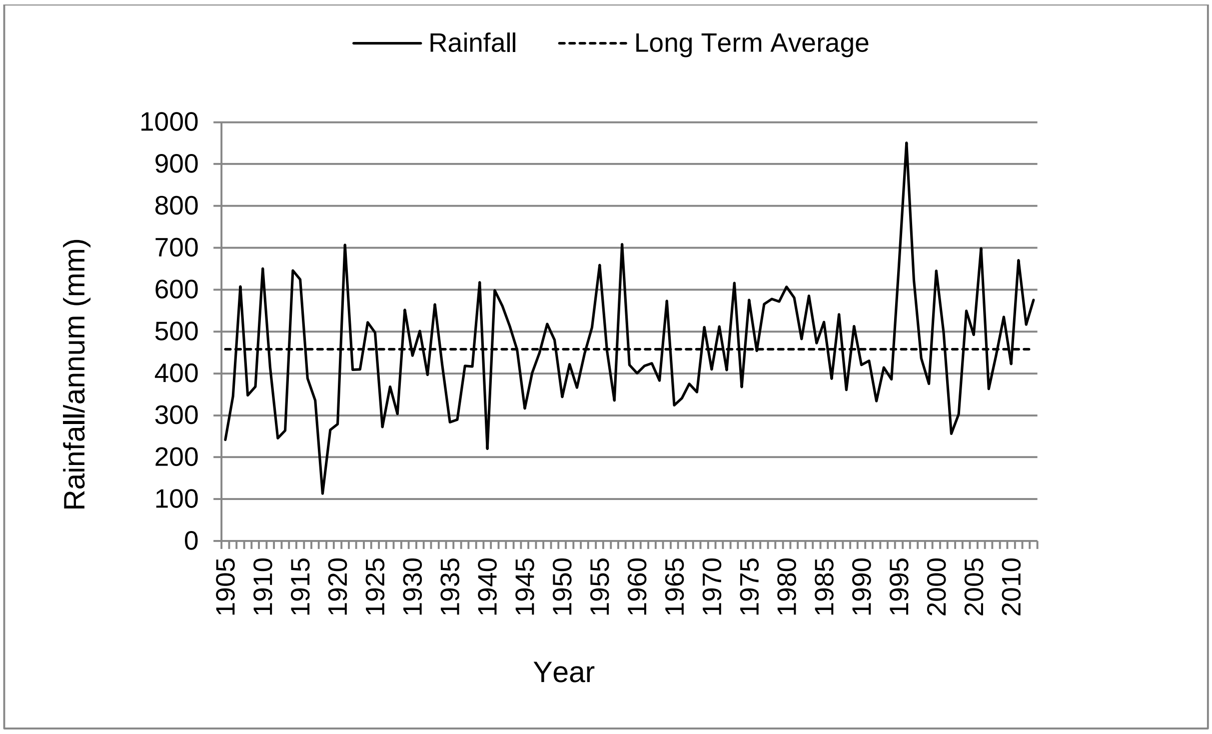

Figure 4.1 Long-term average rainfall at the Syferkuil Experimental Farm.

4.1.2 Vegetation

4.1.2.1 *Woody component*

Four different woody species occurred at this site, namely; *Acacia hebaclada, Acacia karroo, Acacia tortilis* and *Dichrostachys cinerea.*

i. Percentage composition

The species composition comprised of 40.3% *Acacia tortilis*, 29.85% *Acacia hebaclada*, 23.88% *Dichrostachys cinerea* and 5.97% *Acacia karroo* (Figure 4.2). The composition of the tree species indicates that *Acacia tortilis* is the dominant species in the area. *Acacia hebaclada* and *Dichrostachys cinerea* also occurred, however, at a lower rate. *Acacia karroo* was the least occurring species in the area.

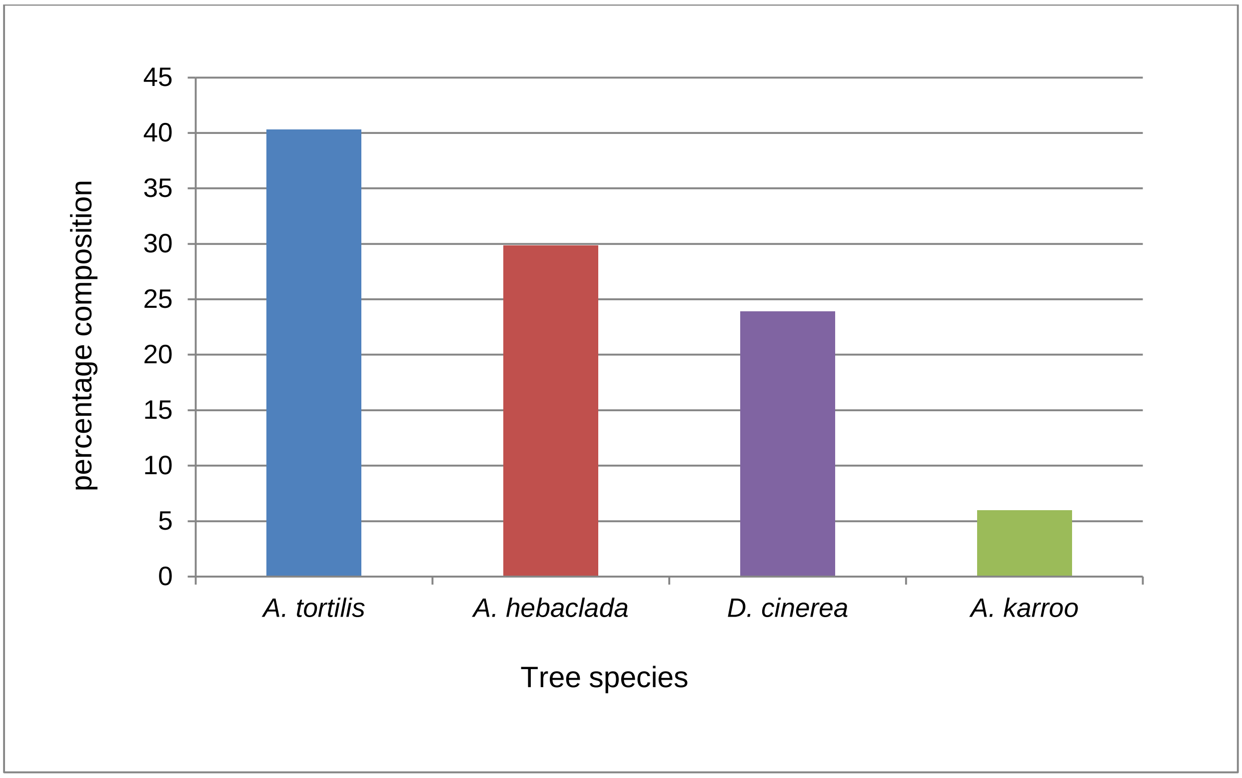

Figure 4.2 Percentage species composition of woody plants at the Syferkuil Experimental Farm, Site 1.

ii. Number of trees per height class

A total of 1118 trees ha^{-1} were found at the site (Figure 4.3). Where tree height was concerned, 317 trees ha^{-1}, which was the highest total of trees occurring in a height class, were found in the >2 – 3 m stratum. The second class with a high number of trees was the >0.5 – 1.5 m, stratum with a total of 284 trees ha^{-1}. The lowest number of trees in a height class was found in both the <0.5 m and higher than 3 m strata, where only 150 trees ha^{-1} were counted.

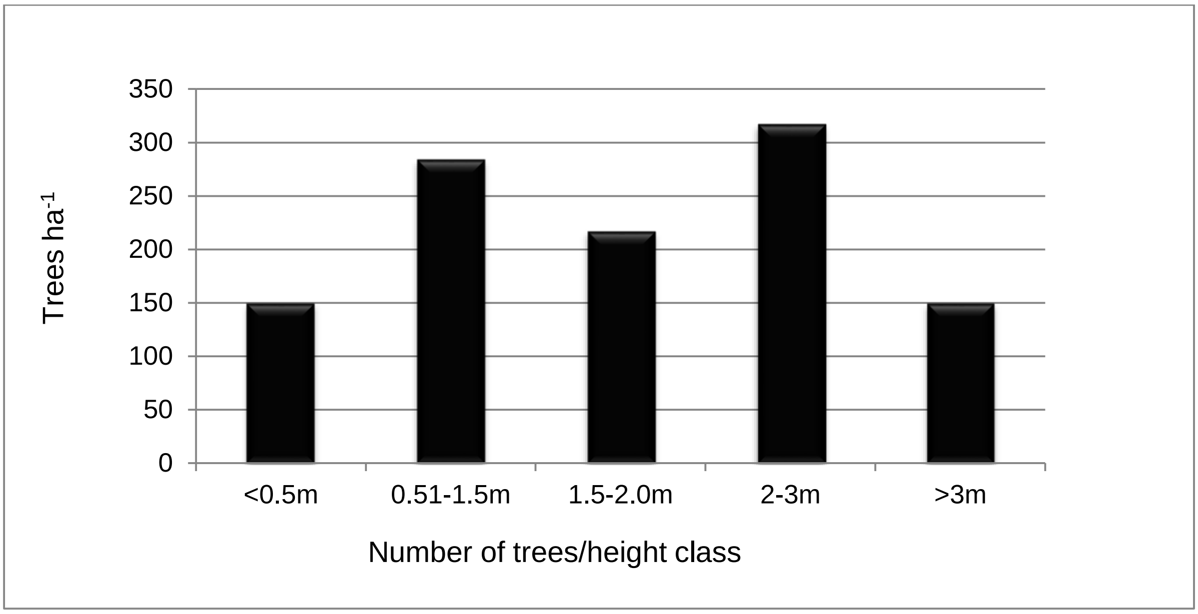

Figure 4.3 Total number of trees per height class at the Syferkuil Experimental Farm, Site 1.

iii. Distribution of woody species within the height classes

Only *Acacia tortilis* and *Dichrostachys cinerea* occurred in the lower strata (<0.5 m; seedling and small trees classes), with *Acacia karroo* only occurring as larger individuals. *Acacia hebaclada* and *Dichrostachys cinerea* followed the same tendency, but at a lower rate (Figure 4.4).

4.1.2.2 *Grass component*

Nine different grass species were identified (Table 4.1). Grasses comprised 84% of the species composition, with 13% of the area bare, and only 3% comprised of forbs. Of the grasses identified in the survey, *Pogonathria squarrosa* was the most dominant, comprising 43% of the species composition, while the least occurring species was *Hyparrhenia hirta*, which contributed only 1% to the grass composition. *Eragrostis lehmaniana* contributed 14% of the species composition, and was the second most dominant grass species.

The remaining grass species had relatively low occurrence rates in the survey; all contributing less than 10% of the grass composition. Approximately 90% of the species that occurred at the site were pioneer and sub-climax species. Veld at the Syferkuil Experimental Farm appeared to be in an average condition (veld condition score of 613). Increaser II and Increaser I species comprised 96.6% of the species composition, respectively, while the only Decreaser in the survey was *Panicum maximum,* and it contributed 3.4% to the species composition.

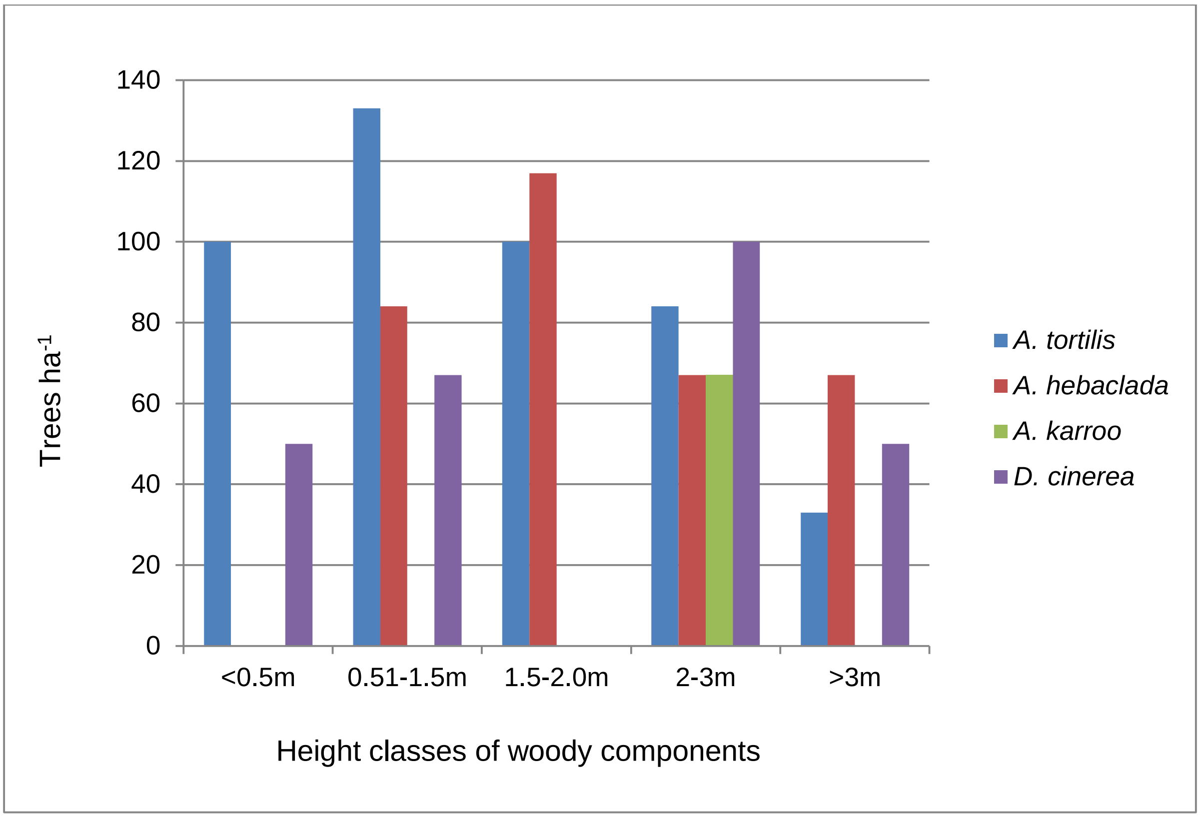

Figure 4.4 Height distribution of woody species at the Syferkuil Experimental Farm, Site 1.

Table 4.1 Grass species composition of the site at the Syferkuil Experimental Farm, Site 1

Grass species	No. points	Percentage Composition	Grazing value	Score
Aristida congesta	49	8.25	0	0
Eragrostis lehmaniana	86	14.25	3	258
Eragrostis rigidior	43	7.25	0	0
Eragrostis superba	14	2.25	4	56
Heteropogon contortus	25	4.25	2	50
Hyparrhenia hirta	7	1.00	5	35
Hypetherlia dissoluta	9	1.50	4	36
Panicum maximum	17	2.75	10	170
Pogonathria squarrosa	253	42.25	0	0
Bare spots	79	13.25	0	0
Forbs	18	3.00	0	0
Total	**600**	**100**	**28**	**613**

4.2 GLENROSA SOIL FORM, SYFERKUIL EXPERIMENTAL FARM (SITE 2)

4.2.1 Long-term average rainfall

Long-term average rainfall of Syferkuil Experimental Farm, between 1905 and 2013, is similar, for both Site 1 and Site 2 (Figure 4.1).

4.2.2 Vegetation

4.2.2.1 *Woody component*

Four different woody species were identified in the survey, namely; *Acacia hebaclada, Acacia karroo, Acacia tortilis* and *Dichrostachys cinerea.*

i. Percentage composition

The tree species comprised of 37.84% *Acacia tortilis*, 35.14% *Acacia hebaclada*, 8.1% *Acacia karroo,* and 18.92% *Dichrostachys cinerea* (Figure 4.5). The composition of the tree species indicates that *Acacia tortilis* is the most dominant woody of the site. *Acacia hebaclada* and *Dichrostachys cinerea* also occurred, however, at a lower rate. *Acacia karroo* was the least occurring species in the area.

ii. Number of trees per height class

A total of 1236 trees ha^{-1} occurred at the site (Figure 4.6). Where tree height is concerned, 307 trees ha^{-1}, which was the highest total of trees occurring in a height class, were found in the >0.5 – 1.5 m stratum. The class with the second highest number of trees was the >1.5 – 2 m stratum with 299 trees ha^{-1}. The lowest number of trees in a height class was found in the <0.5 m, which had 195 trees ha^{-1}. The >2 – 3 m and higher than 3 m strata had relatively high number of trees, 214 and 221 trees ha^{-1}, respectively.

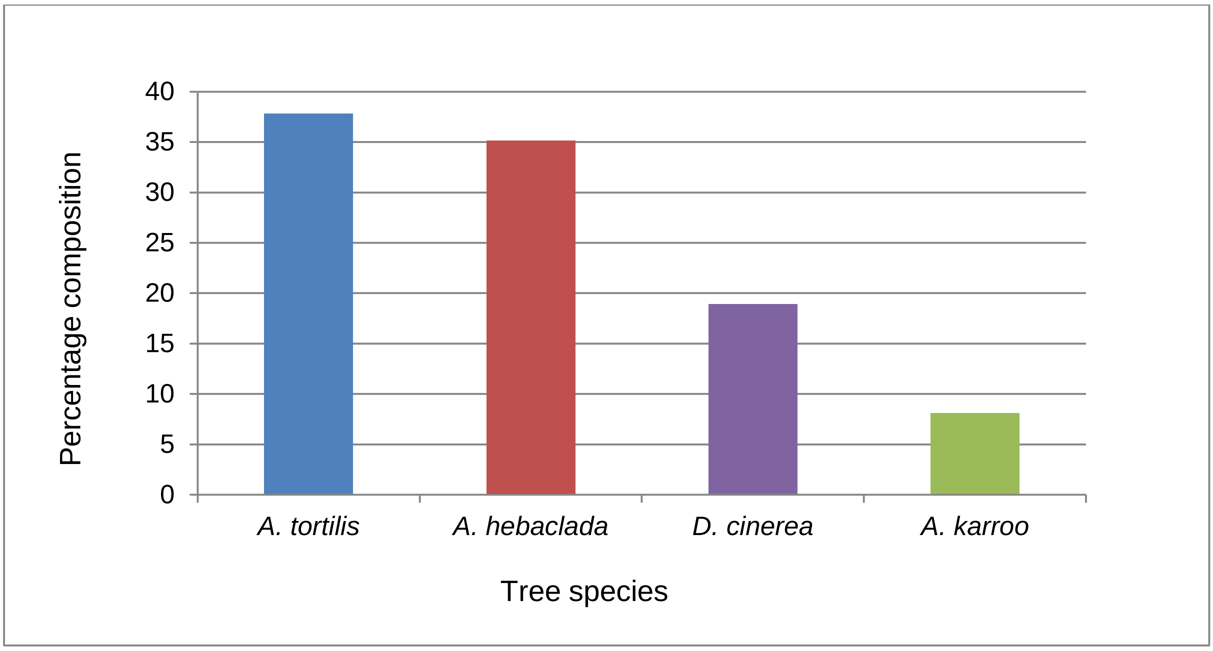

Figure 4.5 Percentage species composition of woody plants at the Syferkuil Experimental Farm, Glenrosa soil type (Site 2).

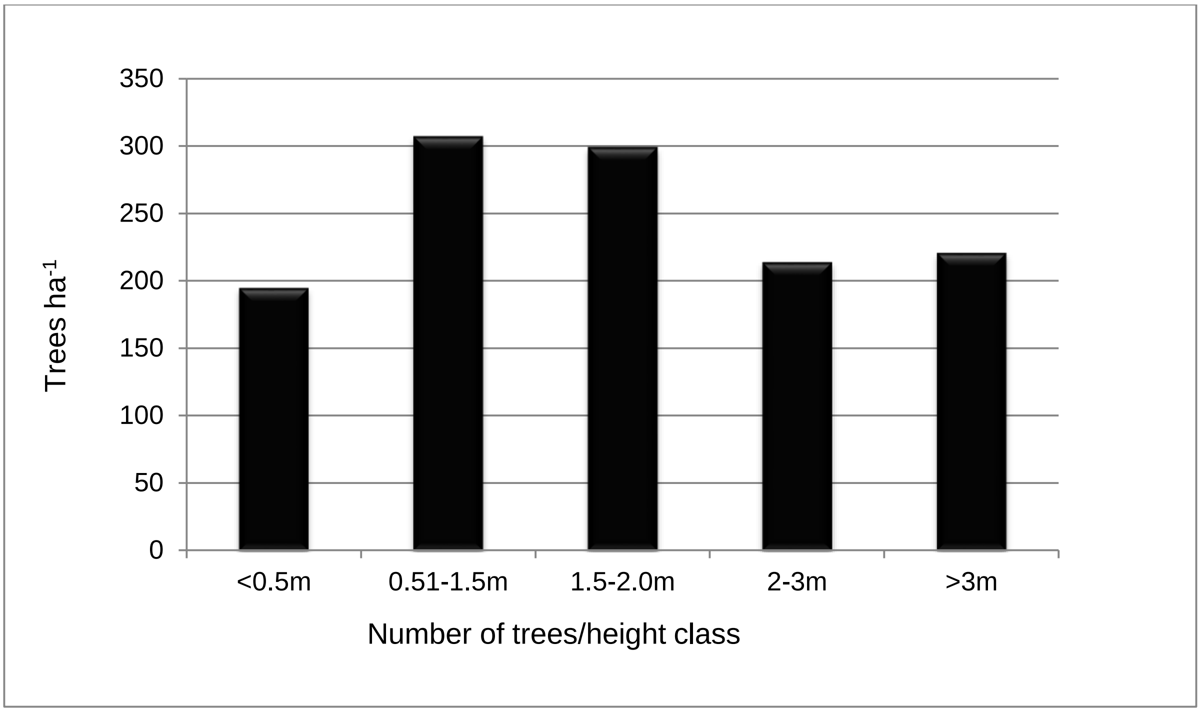

Figure 4.6 Total number of trees per height class at the Syferkuil Experimental Farm, Site 2.

iii. Distribution of woody species within the height classes

All tree species occurred in the lower strata (<0.5 m; seedling and small trees classes) and the >1.5 – 2 m strata (Figure 4.7). However, *Acacia karroo* did not occur in the >0.5 – 1.5 m and >3 m height classes. Furthermore, in height class >2 – 3 m *Dichrostachys cinerea* did not occur.

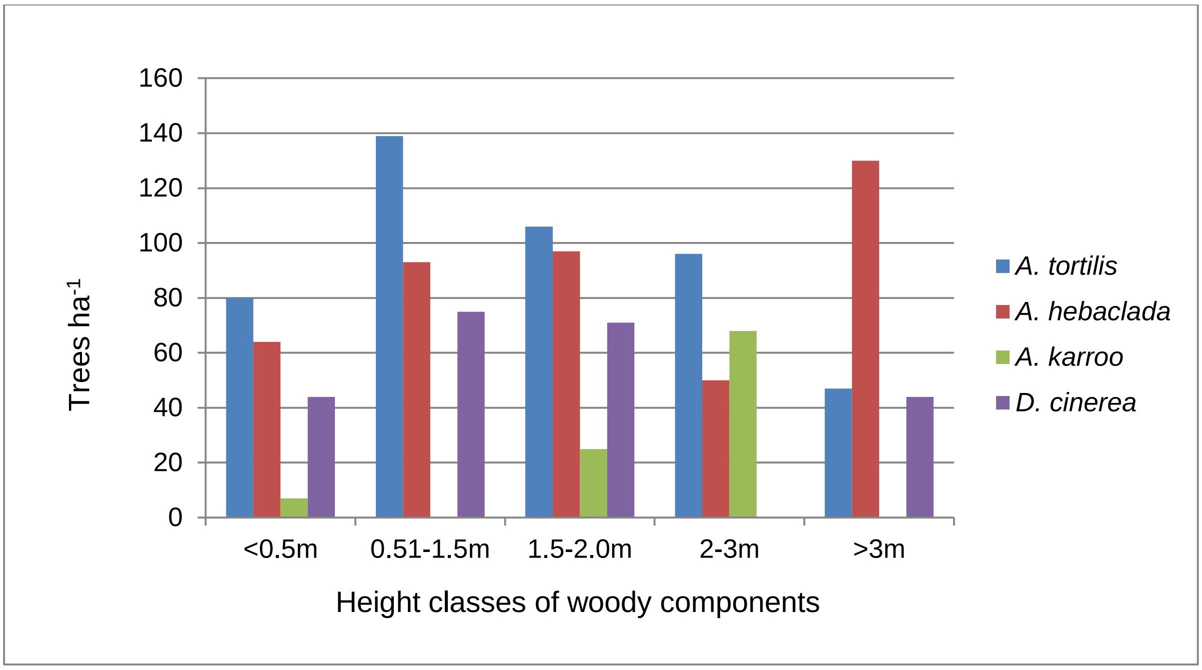

Figure 4.7 Height distribution of woody species at the Syferkuil Experimental Farm, Glenrosa soil type (Site 2).

4.2.2.2 *Grass component*

Seven different grass species were identified and a total of 480 grasses were counted at this site (Table 4.2). Grasses comprised 80% of the composition, while 16% of the area was bare. Forbs comprised 20% of the composition. Of the grasses identified in the survey, *Pogonathria squarrosa* was the most dominant grass, comprising 38.5% of the composition. The least occurring species was *Heteropogon contortus*, which contributed only 3%. *Aristida congesta* contributed 17% to the species composition, and was the second most dominant grass species. The remaining grass species had relatively low occurrence rates in the survey, all contributing less than 15% to the grass composition. Approximately 90% of the species that were identified in the survey were pioneer and sub-climax species. Veld at this site appeared to be in a below average condition (veld condition score of 386). Increaser II and Increaser I species comprised 96.6% of the percentage species composition, while the only decreaser in the survey, *Panicum maximum,* comprised only 2.33%.

Table 4.2 Grass species composition of the site at the Syferkuil Experimental Farm, Site 2

Grass species	No. of points	Percentage Composition	Grazing value	Score
Aristida congesta	102	17	0	0
Eragrostis rigidior	74	12.33	0	0
Eragrostis superba	25	4.17	4	100
Heteropogon contortus	18	3	2	36
Hyparrehnia hirta	16	2.67	5	80
Panicum maximum	14	2.33	10	170
Pogonathria squarrosa	231	38.5	0	0
Bare spots	96	16	0	0
Forbs	24	4	0	0
Total	**600**	**100**	**28**	**386**

4.3 HUTTON SOIL, SONDELA NATURE RESERVE (SITE 3)

4.3.1 Long-term average rainfall

The annual rainfall of the Sondela Nature Reserve, between 1938 and 2013, is illustrated in Figure 4.8. The long-term average annual rainfall is 629 mm. The lowest annual rainfall of 326 mm was recorded in 2006, and the highest rainfall of 1143 mm was recorded in 2009.

4.3.2 Vegetation

4.3.2.1 *Woody component*

Five different woody species were identified in the survey, namely; *Acacia gerrardii*, *Acacia karroo, Acacia nilotica, Acacia tortilis,* and *Dichrostachys cinerea.*

i. Percentage composition

The tree species comprised 35.48% *Acacia tortilis*, 12.9% *Acacia nilotica*, 12.9% *Acacia karroo*, 29.03% *Dichrostachys cinerea,* and 9.69% *Acacia gerrardii* (Figure 4.9). *Acacia tortilis* was the most dominant species in the area. *Dichrostachys cinerea* also dominated, however, at a lower rate. *Acacia gerrardii* was the least dominant species in the area.

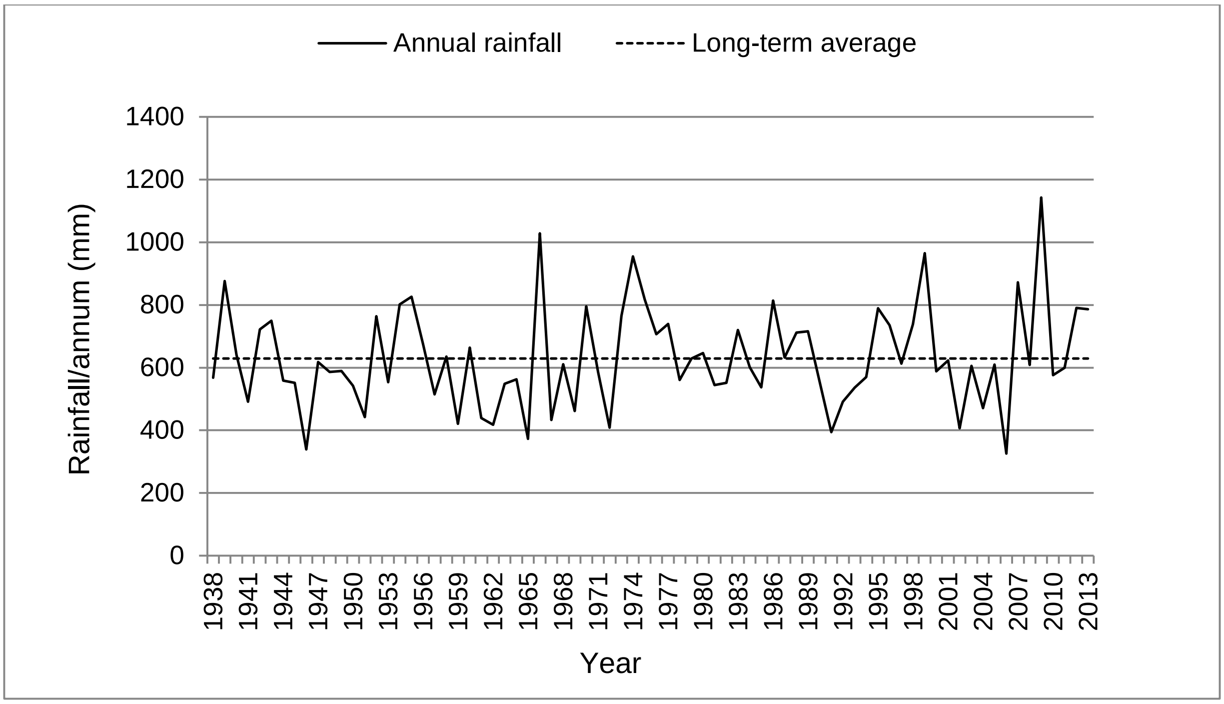

Figure 4.8 Long-term average rainfall at the Sondela Nature Reserve.

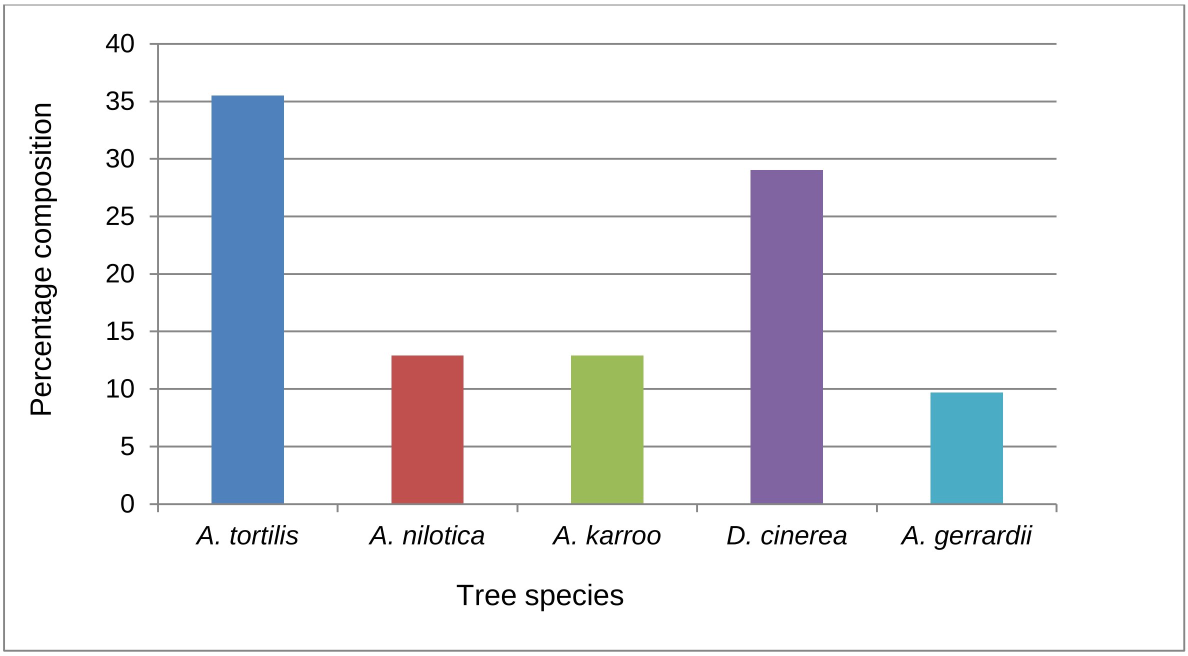

Figure 4.9 Percentage composition of woody species at the Sondela Nature Reserve, Hutton soil form (Site 3).

ii. Trees per height class

A total of 1550 trees ha^{-1} occurred at the site (Figure 4.10). Where tree height was concerned, 700 trees ha^{-1}, which was the highest total of trees occurring in a height class, were found in >3 m stratum. The class with the second highest number of trees was the >2 – 3 m stratum with a total of 250 trees ha$^{-1.}$ The lowest tree numbers was 200 trees ha^{-1}, found within <0.5 m, >0.5 – 1.5 m and >1.5 – 2 m strata.

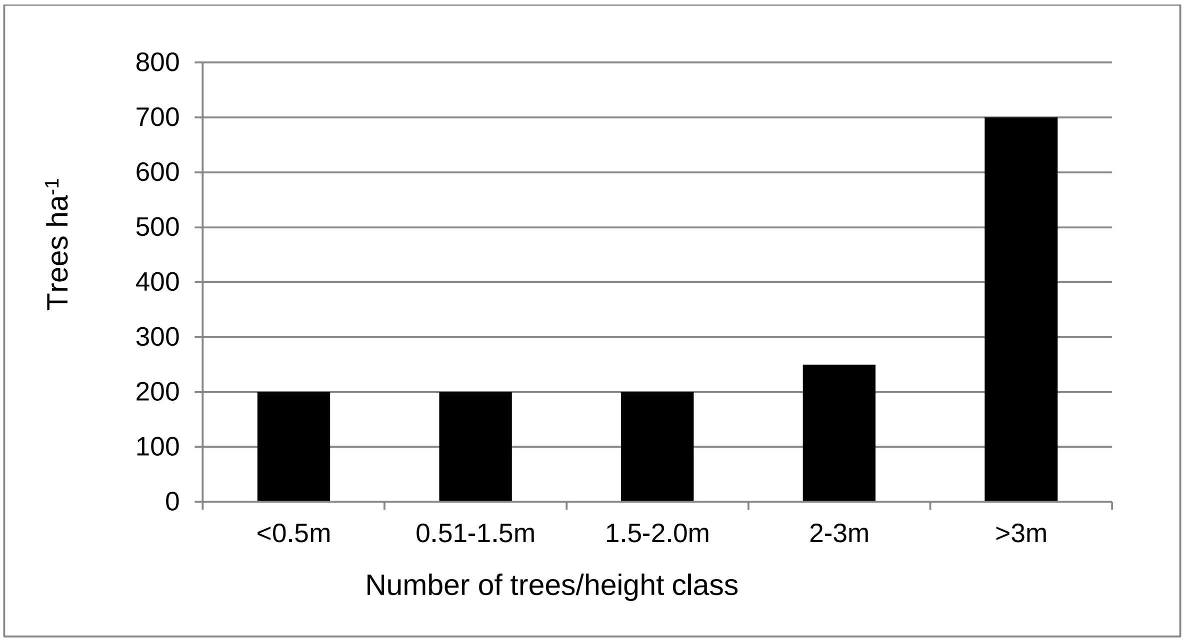

Figure 4.10 Total number of trees per height class at the Sondela Nature Reserve, Hutton soil form (Site 3).

iii. Distribution of woody species within the height classes

Acacia tortilis was the dominant species in the <0.5 m and >3 m strata, while *Dichrostachys cinerea* was the most dominant woody species in the <0.5 – 1.5 m and >2 – 3 m strata (Figure 4.11).

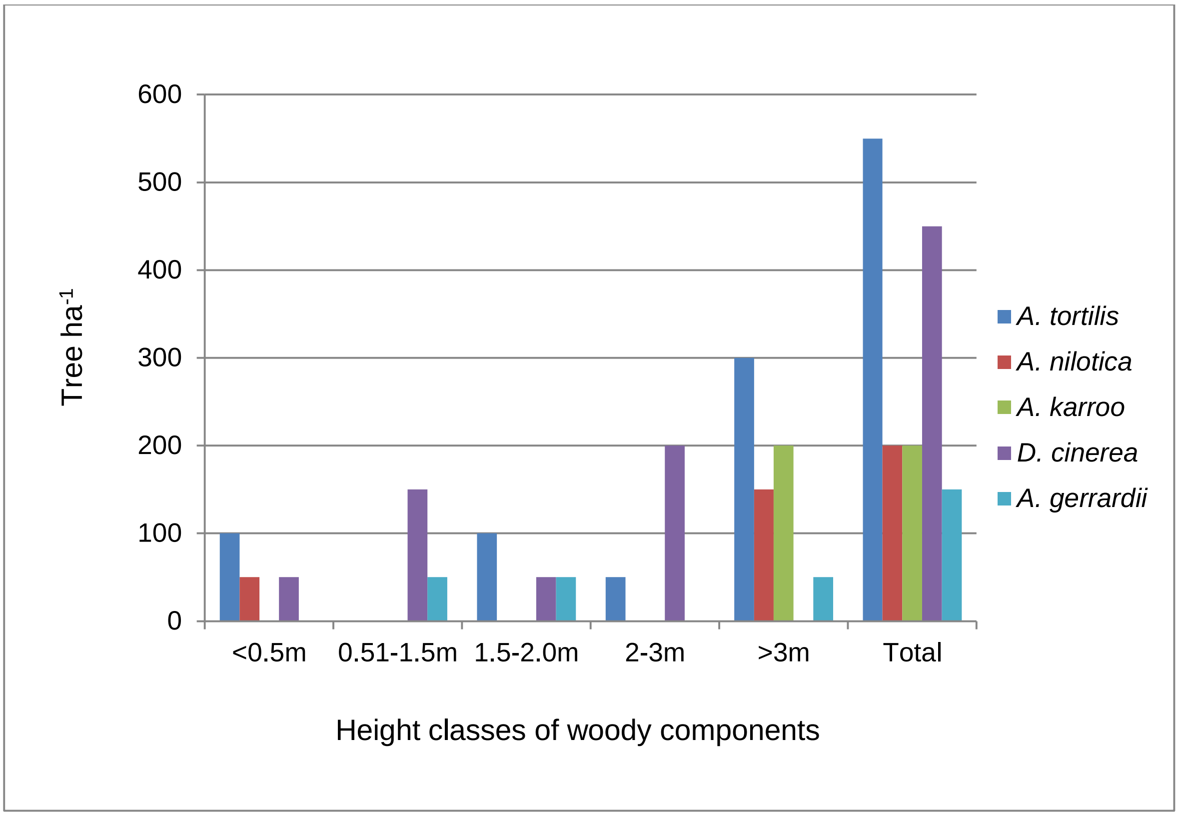

Figure 4.11 Woody species composition and distribution within the different height classes at Sondela Nature Reserve, Site 3.

4.3.2.2 *Grass component*

Fourteen different grass species were identified during the survey. Grass species comprised 73% (Table 4.3). Forbs comprised 10% of the composition and 16% of the area was bare. Of the identified grass species, *Heteropogon contortus* contributed approximately 44% to the total species composition and was the most common grass species in the area. *Themeda triandra* and *Tragus berteronianus* were the most uncommon grass species in the area, both comprising 1% of the composition. Bare spots and forbs comprised 16% and 10%, respectively. Veld at the Sondela Nature Reserve appeared to be in a good condition (veld condition score = 940). Two decreaser species occurred, namely *Themeda triandra* and *Cenchrus ciliaris* occurred, with the rest of the grasses classified as increasers. However, *Themeda triandra* and *Cenchrus ciliaris* comprised only 1.5%, while increaser species comprised 88.5% of the species composition.

Table 4.3 Grass species composition of the site at the Sondela Nature Reserve, Site 3

Grass species	**No. points**	**Percentage composition**	**Grazing value**	**Score**
Aristida congesta	26	4.33	0	0
A. congesta subsp. barbicolis	18	3.00	0	0
Tragus berteronianus	3	0.50	0	0
Bothriochloa insculpta	33	5.50	3	99
Bothriochloa radicans	3	0.50	2	6
Cenchrus ciliaris	6	1.00	6	36
Eragrostis lehmaniana	7	1.17	3	21
Eragrostis rigidior	14	2.33	0	0
Heteropogon contortus	262	43.67	2	542
Hyperthelia dissoluta	38	6.33	4	152
Melenis repens	10	1.67	1	10
Sporobolus africanus	9	1.50	3	27
Themeda triandra	3	0.50	5	15
Urochloa mosambicensis	8	1.33	4	32
Bare spots	98	16.33	0	0
Forbs	62	10.33	0	0
Total	**600**	**100**	**33**	**940**

4.4 DISCUSSION

4.4.1 Effect of soil form on vegetation (Site 1 vs Site 2)

Site 1 (Hutton Soil form) and Site 2 (Glenrosa Soil form) are study sites at the Syferkuil Experimental Farm, where the average long-term annual rainfall is 458.02 mm per annum. These two sites are exposed to the same annual and long-term average annual rainfall. However, it is important to note that they occur on different soil forms.

4.4.1.1 *Woody component*

i. Percentage composition

Four woody species occurred at the Syferkuil Experimental Farm, namely; *Acacia hebaclada, Acacia tortilis, Acacia karroo* and *Dichrostachys cinerea.* The occurrence of the same woody species at both sites would suggest that soil form did not significantly influence the diversity of the species. At Site 1

(Hutton soil form), the species composition comprised of 40.3% *Acacia tortilis,* 29.85% *Acacia hebaclada*, 23.88% *Dichrostachys cinerea* and 5.97% *Acacia karroo.* At Site 2 (Glenrosa soil form), the tree species comprised of 37.84% *Acacia tortilis,* 35.14% *Acacia hebaclada*, 18.92% *Dichrostachys cinerea* and 8.1% *Acacia karroo.* It appears that at both sites, *A. tortilis* is the most dominant woody species and *Acacia karroo* is the least occurring species. Although the plant species at the two sites appear to be following the same pattern relating to percentage species composition, there was only a slight difference in the composition of the species between sites. It is, however, important to note that species occupy similar positions in terms of dominance.

The results from Syferkuil Experimental Farm suggest that soil form did not significantly influence woody species diversity. On the contrary, Van der Heijden *et al.* (2008) found that soil microbes, including microbial pathogens, which are dependent on the type of soil, are important regulators of plant community dynamics and plant diversity, determining plant abundance and, in some cases, facilitating invasion by exotic plants. However, this study concluded that, based on a limited number of plant species, future work is needed to make systematic comparisons for a wide range of plants of different successional status to derive at general conclusions of how plant-soil feedback drives community dynamics.

ii. Number of trees per height class

A total of 1118 trees ha^{-1} were found at Syferkuil, Hutton soil form (Site 1), whereas on Glenrosa soil form (Site 2) 1236 trees ha^{-1} occurred*.* The Glenrosa soil form had a higher number of trees ha^{-1} than the Hutton soil. At Site 1 (Hutton soil form), the highest number of trees, 317 trees ha^{-1}, occurred in the >2 – 3 m stratum (Height class 4) and the lowest number of trees in both the <0.5 m (Height class 1) and higher than 3 m (Height class 5) strata, where only 150 trees ha^{-1} were counted. At Site 2 (Glenrosa soil form), the highest number of trees, 307 trees ha^{-1}, occurred in the >0.5 – 1.5 m stratum (Height class 2) and the lowest number of trees was in the <0.5 m stratum, which had 195 trees ha^{-1} (Height class 1). It appears that at both sites, the least number of trees occurred in the seedling height class. Also, it is important to note that in the >3 m height class only a few trees occurred, at both sites. It appears that soil type had an effect on the number of trees per height class. Site 1 (Hutton soil form) is dominated by larger trees (Height class 4), whereas Site 2 (Glenrosa soil form), is dominated by smaller trees (Height class 2). Similarly, Letey (1958) revealed that the important parameter which links soil water to plant growth is not soil water content but soil water potential. Furthermore, this study submitted that different types of soil contain different water amounts at a given potential and that soils with greater water potential will favour higher plant growth.

iii. Distribution of woody species within height classes

At Site 1 (Hutton soil form), only *Acacia tortilis* and *Dichrostachys cinerea* occurred in the lower strata (< 0.5 m; seedling and small trees classes), whereas, at Site 2 (Glenrosa soil form), all tree species occurred in the lower strata < 0.5 m and the >1.5 – 2 m strata. *Acacia karroo* had a low occurrence within these height classes, for both sites. *Acacia karroo* did not occur in the >0.5 – 1.5 m and >3 m height classes on the Glenrosa soil form and only occurred as larger individuals on the Hutton soil form. At Site 1 (Hutton soil form), there was a low level of establishment, with only two species occurring in the seedling height class. Conversely, Site 2 (Glenrosa soil form) had different species occurring in the seedling height class. Likewise, Pan and Bassuk (1985) found that the overall growth rate of *Ailanthus* seedlings was slowed in response to soil form as well as differences in compaction. Conclusively, soil form appeared to affect the distribution of woody species in different height classes, as well as establishment.

4.4.1.2 *Grass component*

At Site 1 (Hutton soil form), nine different grass species were identified, and the veld composition was as follows; 84% of the species composition consisted of grass, 13% of the area was bare and 3% of the species composition comprised of forbs. At Site 2 (Glenrosa soil form), seven different grass species were identified and the veld composition was as follows; 80% of the species composition comprised of grass, 16% of the area was bare, and 20% of the species composition comprised of forbs. A simple comparison of the veld composition between Site 1 (Hutton soil) and Site 2 (Glenrosa soil form) indicates that on the Hutton soil, veld was in a better condition as compared to veld on the Glenrosa soil form. A higher diversity of species occurred at Site 1 and also, only 3% of the area was bare, while 16% of the area was bare at Site 2 (Glenrosa soil form). Furthermore, the veld condition score was recorded as 613 for Site 1 (Hutton soil form) and 386 for Site 2 (Glenrosa soil form). Categorically, the difference in soil type appears to have an influence on both the diversity of the grass species occurring in the area and also on the veld condition. Although evidence has been submitted that soil properties can influence species composition (Van der Heijden *et al*., 2008), existing soil classification systems do not provide enough information on any particular soil to help establish relations between its chemical properties and plant distribution (Sollins, 1998).

4.4.2 Effect of rainfall on vegetation (Site 1 vs Site 3)

Site 1 (458.02 mm annum^{-1}, Hutton soil form) and Site 3 (629 mm annum^{-1}, Hutton soil form) are study areas at the Syferkuil Experimental Farm and Sondela Nature Reserve, respectively.

4.4.2.1 *Woody component*

i. Percentage composition

At Site 1, four woody species occurred namely; *Acacia hebaclada, Acacia tortilis, Acacia karroo* and *Dichrostachys cinerea.* The species composition comprised of 40.3% *Acacia tortilis,* 29.85% *Acacia hebaclada*, 23.88% *Dichrostachys cinerea* and 5.97% *Acacia karroo.* At Site 3, five different woody species were identified in the survey, namely; *Acacia gerrardii*, *Acacia karroo, Acacia nilotica, Acacia tortilis,* and *Acacia cinerea.* The tree species comprised 35.48% *Acacia tortilis*, 29.03% *Dichrostachys cinerea,* 12.9% *Acacia nilotica*, 12.9% *Acacia karroo* and 9.69% *Acacia gerrardii.* It appears that at both sites, *Acacia tortilis* was the most dominant woody species. Site 3 had a slightly higher woody species diversity, which could possibly be attributed to the frequency and intensity of the rainfall of the area. However, regarding percentage composition, there appeared to be a small difference between woody species found at Site1 and those found at Site 3. Convincingly, it appeared as if rainfall did not have a great influence on the percentage composition of the woody species between the two sites. This is in line with results obtained by Baez *et al.* (2013), who did a similar study on Chihuahuan desert grassland and shrubland plant communities.

ii. Number of trees per height class

A total of 1 118 trees ha^{-1} were found at Site 1, whereas at Site 3, 1 550 trees ha^{-1} occurred. Site 3 had a higher number of trees ha^{-1} than Site 1. At Site 1, the highest number of trees, 317 trees ha^{-1}, occurred in the 2 – 3 m stratum (Height class 4) and the lowest number of trees in both the <0.5 m (Height class 1) and >3 m (Height class 5) strata, where only 150 trees ha^{-1} were counted. At Site 3, 700 trees ha^{-1}, which was the highest total of trees occurring in a height class, were found in >3 m stratum (Height class 5) and the lowest number of trees was found in the <0.5 m, >0.5 – 1.5 m and >1.5 – 2 m strata, which had 200 trees ha^{-1} (Height class 1, 2 and 3). It is important to note that in >3 m height class, at Site 1, only a few trees occurred, while at Site 3, this is the highest total of trees occurring in a height class. It appears as if rainfall had an effect on the number of trees per height class. Site 1 was dominated by large trees (Height class 4). In contrast, Site 3 was dominated by larger trees (Height class 5). Moreover, not only did rainfall affect the total number of trees occurring at the sites, it also produced taller trees, where rainfall was higher. Studies using long-term observations and rainfall manipulations indicate that chronic changes in rainfall regimes often lead to non-linear and unexpected responses in plant community and functional diversity (Harpole *et al.,* 2007; Suttle *et al.,* 2007).

iii. Distribution of woody species within height classes

At Site 1, only *Acacia tortilis* and *Dichrostachys cinerea* occurred in the lower strata (<0.5m; seedling and small trees classes). Whereas, at Site 3, *Acacia tortilis* was the dominant species in the <0.5 m and >3 m strata, while *Dichrostachys cinerea* was the most dominant woody species in the >0.5 – 1.5 m and >2 – 3 m strata. *Acacia karroo* was the least occurring woody species at

Site 1 and *Acacia gerrardii* was the least occurring woody species at Site 3. *Acacia karroo* did not occur in the >0.5 – 1.5 m and >3 m height classes; it only occurred as larger individuals at Site 1. There was a low level of establishment, with only two species occurring in the seedling height class at Site 1. Similarly, Site 3 had relatively low establishment diversity, with three species occurring in the seedling height class. Rainfall did not appear to cause a significant difference in the distribution of woody species. However, Baez *et al.* (2013) found that changes in rainfall regimes had significant effect on the distribution and establishment of woody species. Consequently, the lack of difference in establishment between Site 1 (Hutton soil form) and Site 3 (Hutton soil form) is attributed to the minimal difference in the rainfall of the two study areas.

4.4.2.2 *Grass component*

At Site 1, nine different grass species were identified and the veld composition was as follows; 84% of the species composition comprised of grass, 13% of the area was bare and 3% of the species composition comprised of forbs. At Site 3, 14 different grass species were identified and the veld composition was as follows; 73% of the species composition comprised of grass, 16% of the area was bare and 10% of the species composition comprised of forbs. The grass species diversity of Site 3 was much higher than that of Site1, with a difference of six grass species between the two sites. High rainfall appeared to result in a diversified species composition. Only 3% of the area was bare at Site 1; However, Site 3 had a diverse composition of grass species, but a large percentage (16%) of the area was bare. Additionally, the veld condition score was recorded as 613, for Site 1 and 940, for Site 3. The difference in rainfall thus appears to have an influence on both the diversity of the grass species occurring in the area and the veld condition. These results are in line with results found by Baez *et al.* (2013), who found that drought consistently and strongly decreased cover of *Boutelaoua eriopoda*, a C4 grass, whereas higher rainfall slightly increased cover and diversity.

4.5 CONCLUSION

Site 1, where the soil form is Hutton and long-term average rainfall is 458.02 mm annum^{-1}, had a veld condition score of 613. Site 2, where the soil form is Glenrosa and long-term average rainfall is 458.02 mm annum^{-1}, had a veld condition score of 386. Site 3, with the long-term average rainfall of 629 mm annum^{-1} and Hutton soil form, had the veld condition score of 940. Convincingly, Site 2 had the poorest veld condition in relation to the two other sites and Site 3 had the best veld condition.

It appears that at the Syferkuil Experimental Farm, Hutton soil favours the growth of both woody components and grass components better than Glenrosa soil. Where rainfall is concerned, higher rainfall appears to create a more favourable veld than low rainfall. Scholes and Archer (1997) found that herbaceous production increases with lower soil temperatures, higher water holding capacity and greater organic matter. Therefore, the difference, in veld condition, between the three sites can be attributed to the difference in rainfall, between Sondela Nature Reserve and Syferkuil Experimental Farm, and also the difference in chemical properties of the soils.

CHAPTER 5

EFFECT OF SOIL TYPE AND RAINFALL ON PLANT GROWTH

5.1 INTRODUCTION

The aim of the study was to determine the limitations that rainfall and soil form may have on the physical development of *Acacia tortilis*, and to further determine whether these limitations can influence, either positively or negatively, the population size of *Acacia tortilis*. These limitations were expected to be reflected by the tree height, stem circumference, growth rings, and canopy.

The objectives of this study were thus to; firstly, determine the differences in tree height, stem circumference, growth rings, and canopy, between two soil forms and also at different annual rainfall within the same soil form (Hutton soil type). The second objective was to determine the relationships between all morphological traits, and analyse which of these relationships is the most closely correlated.

The study thus enquired whether the relative formation of tree height, stem circumference, growth rings, and canopy could or could not reflect the effect of rainfall or soil form on their development. This was to question whether the limitations that rainfall or soil form introduced during the development of a plant, could be physically manifested or even measured and analysed. Furthermore, this research aimed at determining if there was a relationship between tree morphological traits such as height, stem circumference, growth rings and canopy size. The third objective was to use the relationship with the highest correlation for the determination of tree population establishment patterns of *A. tortilis*.

5.2 METHODOLOGY

The methodology of the study was described elaborately in Chapter 3 of this document; page 34 through 38.

5.3 RESULTS

5.3.1 Effect of soil form on tree growth parameters

5.3.1.1 *Effect of soil form on stem circumference*

i. Height class 1 (<0.5 m)

The stem circumference of *Acacia tortilis* did not differ significantly between the Hutton and Glenrosa soil form ($p > 0.05$, Table 5.1, Table 1.1 B; Appendix B). The average stem circumference on the Hutton and Glenrosa soil forms were 4.2 cm and 5.2 cm, respectively (Figure 5.1). This resulted in an insignificant difference of the mean stem circumference (1 cm difference) between the two soil forms.

ii. Height class 2 (>0.5 – 1.5 m)

Stem circumference in height class 2 differed significantly between the Hutton and Glenrosa soil type ($p < 0.05$, Table 5.1, Table 1.2 B; Appendix B). The average stem circumference at the Hutton and Glenrosa soil forms were 22 cm and 11.2 cm, respectively (Figure 5.1). These differences in stem circumference lead to a significant difference in the mean stem circumference (10.8 cm difference) between the two soil forms.

iii. Height class 3 (>1.5 – 2.0 m)

In height class 3 the stem circumferences differed significantly between the Hutton and Glenrosa soil form ($p < 0.05$, Table 5.1, Table 1.3 B; Appendix B). The average stem circumference at the Hutton and Glenrosa soil forms were 28.9 cm and 24.2 cm, respectively (Figure 5.1). These differences in stem circumference lead to a significant difference in the mean stem circumference (4.7 cm difference) between the two soil forms.

iv. Height class 4 (>2.0 – 3.0 m)

Stem circumference in height class 4 did not differ significantly between the Hutton and Glenrosa soil form (P > 0.05, Table 5.1, Table 1.4 B; Appendix B). The average stem circumference at the Hutton and Glenrosa soil forms were 36.1 cm and 31.5 cm, respectively (Figure 5.1). These differences in stem circumference lead to an insignificant difference in the mean stem circumference (4.6 cm difference) between the two soil forms.

v. Height class 5 (> 3 m)

Stem circumference in height class 5 differed significantly between the Hutton and Glenrosa soil form (p < 0.05, Table 5.1, Table 1.5 B; Appendix B). The average stem circumference at the Hutton and Glenrosa soil forms were 52.7 cm and 37.7 cm, respectively (Figure 5.1). These differences in stem circumference lead to a significant difference in the mean stem circumference (15 cm difference) between the two soil forms.

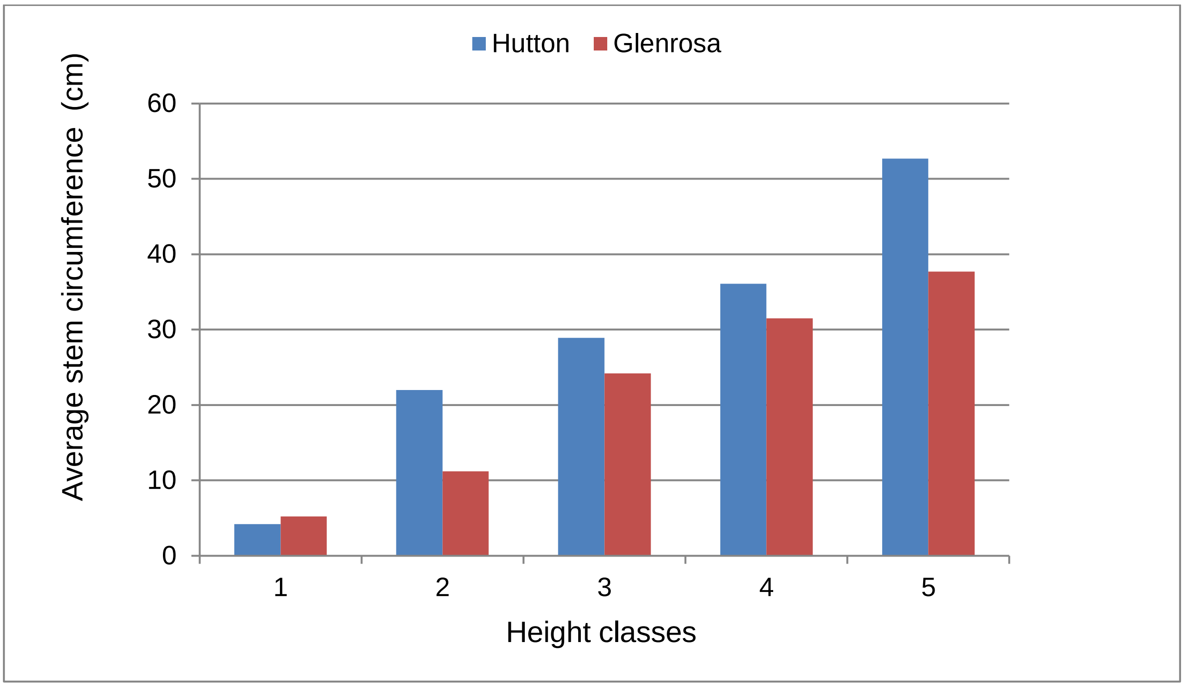

Figure 5.1 Mean stem circumference at the Syferkuil Experimental Farm, Site 1 and Site 2, on two different soil forms.

Table 5.1 Summarised statistics of the growth parameter results between the three sites.

		Stem circumference (cm)			Tree height (m)			Tree rings			Crown diameter (m)		
Site	Height Class	Mean	Standard deviation	P value	Mean	Standard deviation	P value	Mean	Standard deviation	P value	Mean	Standard deviation	P value
Site 1 (Hutton soil form)	1	4.2	1.476	0.201	0.4350	0.0595	0.611	9.700	2.312	0.099	0.8120	0.3278	0.006
	2	22	3.399	0.01	1.191	0.2450	0.707	27.80	5.653	0.001	1.926	0.5322	0.002
	3	28.9	4.99	0.029	1.822	0.1043	0.606	46.20	17.03	0.093	2.270	0.7215	0.001
	4	36.1	6.402	0.239	2.541	0.2944	0.221	64.10	13.03	0.430	3.417	0.5869	0.630
	5	52.7	9.250	0.01	3.858	0.5152	0.333	101.50	20.27	0.001	5.101	0.4955	0.010
Vs.													
Site 2 (Glenrosa soil form)	1	5.2	1.874	0.201	0.4210	0.0615	0.611	8.000	2.055	0.099	0.4470	0.0833	0.006
	2	11.2	1.619	0.01	1.235	0.2694	0.707	14.90	2.079	0.01	0.605	0.9687	0.002
	3	24.2	3.765	0.029	1.789	0.1689	0.606	35.50	7.35	0.093	0.201	0.0264	0.001
	4	31.5	10.091	0.239	2.379	0.2764	0.221	56.80	25.43	0.430	3.589	0.9428	0.630
	5	37.7	6.993	0.01	3.635	0.4859	0.333	70.30	14.83	0.001	4.369	0.6376	0.010

Table 5.1 continued

		Stem circumference (cm)			**Tree height (m)**			**Tree rings**			**Crown diameter (m)**		
Site	**Height Class**	**Mean**	**Standard deviation**	**P value**	**Mean**	**Standard deviation**	**P value**	**Mean**	**Standard deviation**	**P value**	**Mean**	**Standard deviation**	**P value**
Site 1 (Hutton soil form)	1	4.200	1.467	0.556	0.4350	0.05949	0.727	9.700	2.312	0.167	0.10746	0.10366	0.132
	2	22.00	3.399	0.001	1.191	0.06001	0.006	27.80	5.653	0.001	1.926	0.5322	0.870
	3	28.90	4.999	0.001	1.822	0.1043	0.024	46.20	17.03	0.004	2.270	0.7215	0.467
	4	36.10	6.402	0.484	2.541	0.2944	0.987	64.10	13.03	0.146	3.417	0.587	0.008
	5	52.70	9.25	0.843	3.858	0.5152	0.019	101.5	20.27	0.059	5.101	0.495	0.005
Vs.													
Site 3 (Hutton soil form)	1	4.600	1.506	0.556	0.4260	0.05400	0.727	8.200	2.348	0.167	0.6290	0.1644	0.132
	2	10.90	2.846	0.001	1.465	0.0360	0.006	16.70	3.529	0.001	1.965	0.5163	0.870
	3	16.10	6.523	0.001	1.702	0.1134	0.024	25.20	10.90	0.004	2.010	0.8376	0.467
	4	33.30	10.605	0.484	2.543	0.2315	0.987	53.80	17.00	0.146	1.825	1.483	0.008
	5	51.50	16.50	0.843	4.850	1.0565	0.019	81.40	24.09	0.059	2.422	2.293	0.005

5.3.1.2 *Effect of soil form on tree height*

i. Height class 1 (<0.5 m)

Tree height did not differ significantly between the Hutton and Glenrosa soil form (P > 0.05, Table 5.1, Table 2.1 B; Appendix B). The average tree height at the Hutton and Glenrosa soil forms were 44 cm and 42 cm, respectively (Figure 5.2). These differences in tree height lead to an insignificant difference in the mean tree height (2 cm difference) between the two soil forms.

ii. Height class 2 (>0.5 – 1.5 m)

In height class 2, tree height did not differ significantly between the Hutton and Glenrosa soil form (P > 0.05, Table 5.1, Table 2.2 B; Appendix B). The average tree height at the Hutton and Glenrosa soil forms were 119 cm and 124 cm, respectively (Figure 5.2). These differences in tree height lead to an insignificant difference in the mean tree height (5 cm difference), between the two soil forms.

iii. Height class 3 (>1.5 – 2.0 m)

Tree height did not differ significantly between the Hutton and Glenrosa soil form (P > 0.05, Table 5.1, Table 2.4 B; Appendix B). The average tree height at the Hutton and Glenrosa soil form were 254 cm and 238 cm, respectively (Figure 5.2). These differences in tree height lead to an insignificant difference in the mean tree height (16 cm difference), between the two soil forms.

iv. Height class 4 (>2.0 – 3.0 m)

Tree height did not differ significantly between the Hutton and Glenrosa soil form (P > 0.05, Table 5.1, Table 2.4 B; Appendix B). The average tree height at the Hutton and Glenrosa soil forms were 254 cm and 238 cm, respectively (Figure 5.2). These differences in tree height lead to an insignificant difference in the mean tree height (16 cm difference), between the two soil forms.

v. Height class 5 (>3 m)

In height class 5, tree height did not differ significantly between the Hutton and Glenrosa soil form ($P > 0.05$, Table 5.1, Table 2.5 B; Appendix B). The average tree height at the Hutton and Glenrosa soil forms were 386 cm and 364 cm, respectively (Figure 5.2). These differences in tree height lead to an insignificant difference in the mean tree height (22 cm difference) between the two soil forms.

Figure 5.2 Average tree height at the Syferkuil Experimental Farm, Site 1 and Site 2, on two different soil forms.

5.3.1.3 *Effect of soil form on the number of growth rings*

i. Height class 1(<0.5 m)

Growth rings did not differ significantly between the Hutton and Glenrosa soil form ($p > 0.05$, Table 5.1, Table 3.1 B; Appendix B). The average number of rings at the Hutton and Glenrosa soil forms were 10 and 8, respectively

(Figure 5.3). This resulted in an insignificant difference of the mean growth rings (2 rings difference) between the two soil forms.

ii. Height class 2 (>0.5 – 1.5 m)

Growth rings differed significantly between the Hutton and Glenrosa soil form ($p > 0.05$, Table 5.1, Table 3.2 B; Appendix B). The average number of rings at the Hutton and Glenrosa soil forms were 28 and 14, respectively (Figure 5.3). This resulted in a significant difference of the mean growth rings (14 rings difference) between the two soil forms.

iii. Height class 3 (>1.5 -2.0 m)

Growth rings did not differ significantly between the Hutton and Glenrosa soil form ($p > 0.05$, Table 5.1, Table 3.3 B; Appendix B). The average number of rings at the Hutton and Glenrosa soil forms were 46 and 36, respectively (Figure 5.3). This resulted in an insignificant difference of the mean growth rings (10 rings difference) between the two soil forms.

iv. Height class 4 (>2.0 – 3.0 m)

Growth rings did not differ significantly between the Hutton and Glenrosa soil form ($p > 0.05$, Table 5.1, Table 3.4 B; Appendix B). The average number of rings at the Hutton and Glenrosa soil forms were 64 and 57, respectively (Figure 5.3). This resulted in an insignificant difference of the mean growth rings (7 rings difference) between the two soil forms.

v. Height class 5 (large trees)

Growth rings differed significantly between the Hutton and Glenrosa soil form ($p < 0.05$, Table 5.1, Table 3.5 B; Appendix B). The average number of rings at the Hutton and Glenrosa soil forms were 102 and 70, respectively (Figure 5.3). This resulted in a significant difference of the mean growth rings (32 rings difference) between the two soil forms.

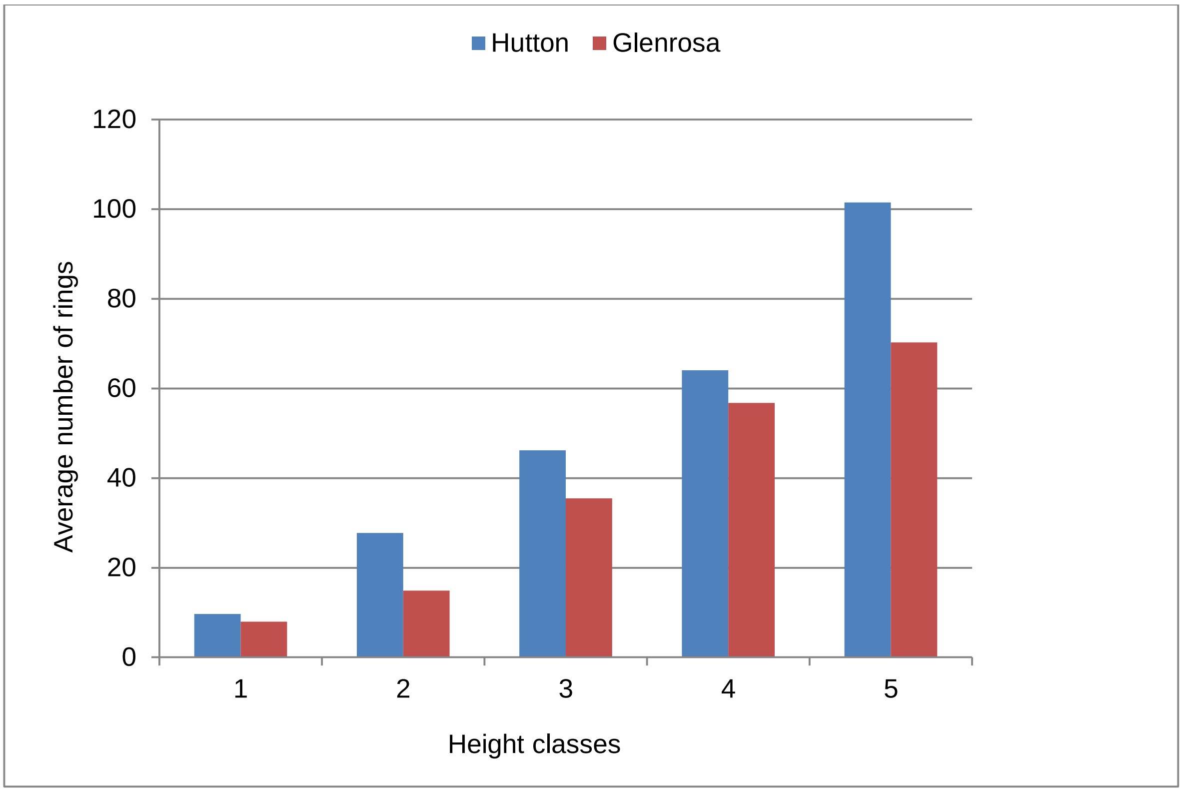

Figure 5.3 Average number of growth rings at the Syferkuil Experimental Farm, Site 1 and Site 2, on two different soil forms.

5.3.1.4 *Effect soil form on crown diameter*

i. Height class 1(<0.5 m)

Crown diameter in height class 1 differed significantly between the Hutton and Glenrosa soil form ($p < 0.05$, Table 5.1, Table 4.1 B; Appendix B). The average crown diameter at the Hutton and Glenrosa soil forms were 81.2 cm and 44.7 cm, respectively (Figure 5.4). These differences in crown diameter lead to a significant difference in the mean crown diameter (36.5 cm difference) between the two soil forms.

ii. Height class 2 (>0.5 – 1.5 m)

Crown diameter in height class 2 differed significantly between the Hutton and Glenrosa soil form ($p < 0.05$, Table 5.1, Table 4.2 B; Appendix B). The average crown diameter at the Hutton and Glenrosa soil forms were 192.6 cm and 60.5 cm, respectively (Figure 5.4). These differences in crown diameter lead to a significant difference in the mean crown diameter (132.1 cm difference) between the two soil forms.

iii. Height class 3 (>1.5 – 2.0 m)

Crown diameter in height class 5 differed significantly between the Hutton and Glenrosa soil form ($p < 0.05$, Table 5.1, Table 4.3 B; Appendix B). The average crown diameter at the Hutton and Glenrosa soil forms were 227 cm and 20.1 cm, respectively (Figure 5.4). These differences in crown diameter lead to a significant difference in the mean crown diameter (206.9 cm difference) between the two soil forms.

iv. Height class 4 (>2.0 – 3.0 m)

Crown diameter in height class 4 did not differ significantly between the Hutton and Glenrosa soil form ($p > 0.05$, Table 5.1, Table 4.4 B; Appendix B). The average crown diameter at the Hutton and Glenrosa soil forms were 321.7 cm and 358.9 cm, respectively (Figure 5.4). These differences in crown diameter lead to a significant difference in the mean crown diameter (37.2 cm difference) between the two soil forms.

v. Height class 5 (>3.0 m)

Crown diameter in height class 5 differed significantly between the Hutton and Glenrosa soil form ($p < 0.05$, Table 5.1, Table 4.5 B; Appendix B). The average crown diameter at the Hutton and Glenrosa soil form were 510.1 cm and 436.9 cm, respectively (Figure 5.4). These differences in crown diameter lead to a significant difference in the mean crown diameter (73.2 cm difference) between the two soil forms.

Figure 5.4 Mean crown diameter at the Syferkuil Experimental Farm, Site 1 and Site 2, on two different soil forms.

5.3.2 The effect of rainfall on tree growth parameters

5.3.2.1 *Effect of rainfall on the stem circumference*

i. Height class 1(<0.5 m)

Stem circumference of *Acacia tortilis* did not differ significantly between Hutton (Syferkuil) and Hutton (Sondela) ($p > 0.05$, Table 5.1, Table 5.1 B; Appendix B). The average stem circumference at the Syferkuil Experimental Farm and Sondela Nature Reserve soil form were 4.2 cm and 4.6 cm, respectively (Figure 5.5). This resulted in an insignificant difference of the mean stem circumference (0.4 cm difference) between the two sites.

ii. Height class 2 (>0.5 – 1.5 m)

Stem circumference of *Acacia tortilis* differed significantly between Hutton (Syferkuil) and Hutton (Sondela) ($p < 0.05$, Table 5.1, Table 5.2 B; Appendix

B). The average stem circumference at the Syferkuil Experimental Farm and Sondela Nature Reserve soil form were 22 cm and 10.9 cm, respectively (Figure 5.5). This resulted in a significant difference of the mean stem circumference (11.1 cm difference) between the two sites.

iii. Height class 3 (>1.5 – 2.0 m)

In height class 3, stem circumference differed significantly between Hutton (Syferkuil) and Hutton (Sondela) ($p < 0.05$, Table 5.1, Table 5.3 B; Appendix B). The average stem circumference at the Syferkuil Experimental Farm and Sondela Nature Reserve soil forms were 28.9 cm and 16.1 cm, respectively (Figure 5.5). This resulted in a significant difference of the mean stem circumference (12.8 cm difference) between the two sites.

iv. Height class 4 (>2.0 – 3.0 m)

Stem circumference did not differ significantly between Hutton (Syferkuil) and Hutton (Sondela) ($p > 0.05$, Table 5.1, Table 5.4 B; Appendix B). The average stem circumference at the Syferkuil Experimental Farm and Sondela Nature Reserve soil forms were 36.1 cm and 33.3 cm, respectively (Figure 5.5). This resulted in an insignificant difference of the mean stem circumference (2.8 cm difference) between the two sites.

v. Height class 5 (>3 m)

Stem circumference did not differ significantly between Hutton (Syferkuil) and Hutton (Sondela) ($p > 0.05$, Table 5.1, Table 5.5 B; Appendix B). The average stem circumference at the Syferkuil Experimental Farm and Sondela Nature Reserve soil forms were 52.7 cm and 51.1 cm, respectively (Figure 5.5). This resulted in an insignificant difference of the mean stem circumference (0.4 cm difference) between the two sites.

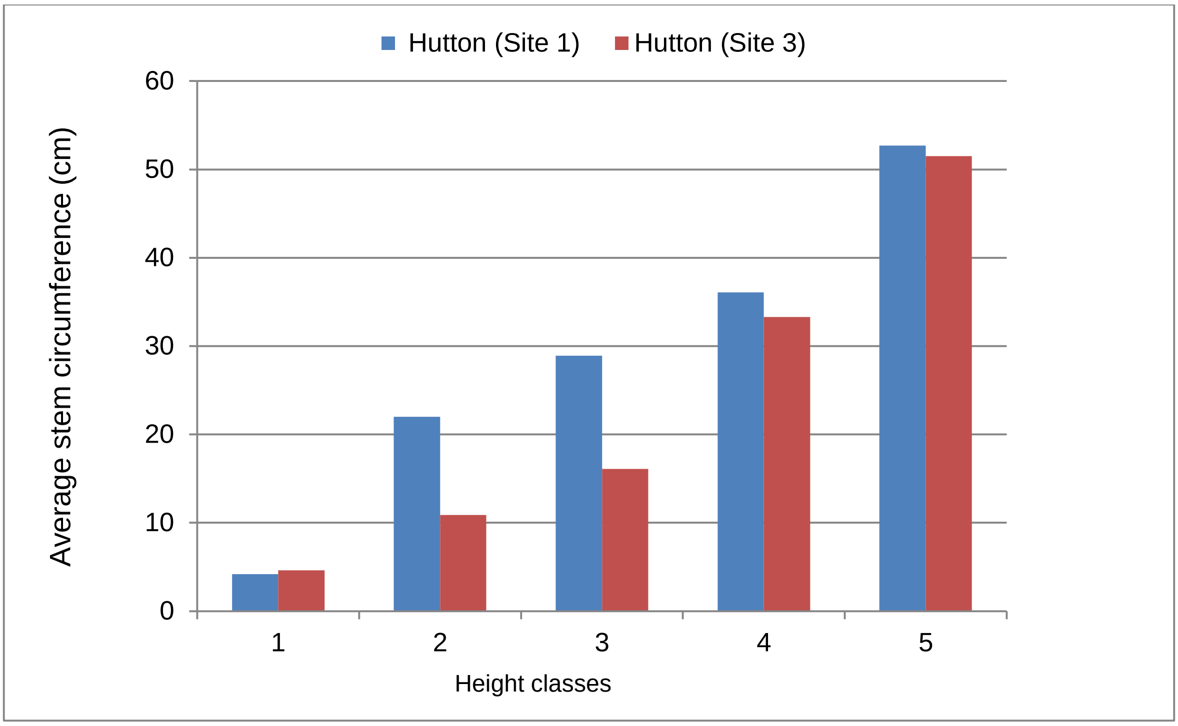

Figure 5.5 Mean stem circumference at Syferkuil Experimental Farm and Sondela Nature Reserve.

5.3.2.2 *Effect of rainfall on tree height*

i. Height class 1(<0.5 m)

Tree height did not differ significantly between Hutton (Syferkuil) and Hutton (Sondela) ($p > 0.05$, Table 5.1, Table 6.1 B; Appendix B). The average tree height at the Syferkuil Experimental Farm and Sondela Nature Reserve soil forms were 43.5 cm and 42.6 cm, respectively (Figure 5.6). This resulted in an insignificant difference of the mean tree height (0.9 cm difference) between the two sites.

ii. Height class 2 (>0.5 – 1.5 m)

Tree height differed significantly between Hutton (Syferkuil) and Hutton (Sondela) ($p < 0.05$, Table 5.1, Table 6.2 B; Appendix B). The average tree height at the Syferkuil Experimental Farm and Sondela Nature Reserve soil forms were 119.1 cm and 146.5 cm, respectively (Figure 5.6). This resulted in a significant difference of the mean tree height (27.4 cm difference) between the two sites.

iii. Height class 3 (>1.5 – 2.0 m)

Tree height differed significantly between Hutton (Syferkuil) and Hutton (Sondela) ($p < 0.05$, Table 5.1, Table 6.3 B; Appendix B). The average tree height at the Syferkuil Experimental Farm and Sondela Nature Reserve soil forms were 182.2 cm and 170.2 cm, respectively (Figure 5.6). This resulted in a significant difference of the mean tree height (12 cm difference) between the two sites.

iv. Height class 4 (>2.0 – 3.0 m)

Tree height did not differ significantly between Hutton (Syferkuil) and Hutton (Sondela) ($p > 0.05$, Table 5.1, Table 6.4 B; Appendix B). The average tree height at the Syferkuil Experimental Farm and Sondela Nature Reserve soil forms were 254.1 cm and 254.3 cm, respectively (Figure 5.6). This resulted in an insignificant difference of the mean tree height (0.2 cm difference) between the two sites.

v. Height class 5 (>3 m)

Tree height differed significantly between Hutton (Syferkuil) and Hutton (Sondela) ($p < 0.05$, Table 5.1, Table 6.5 B; Appendix B). The average tree height at the Syferkuil Experimental Farm and Sondela Nature Reserve soil forms were 385.8 cm and 485 cm, respectively (Figure 5.6). This resulted in a significant difference of the mean tree height (99.2 cm difference) between the two sites.

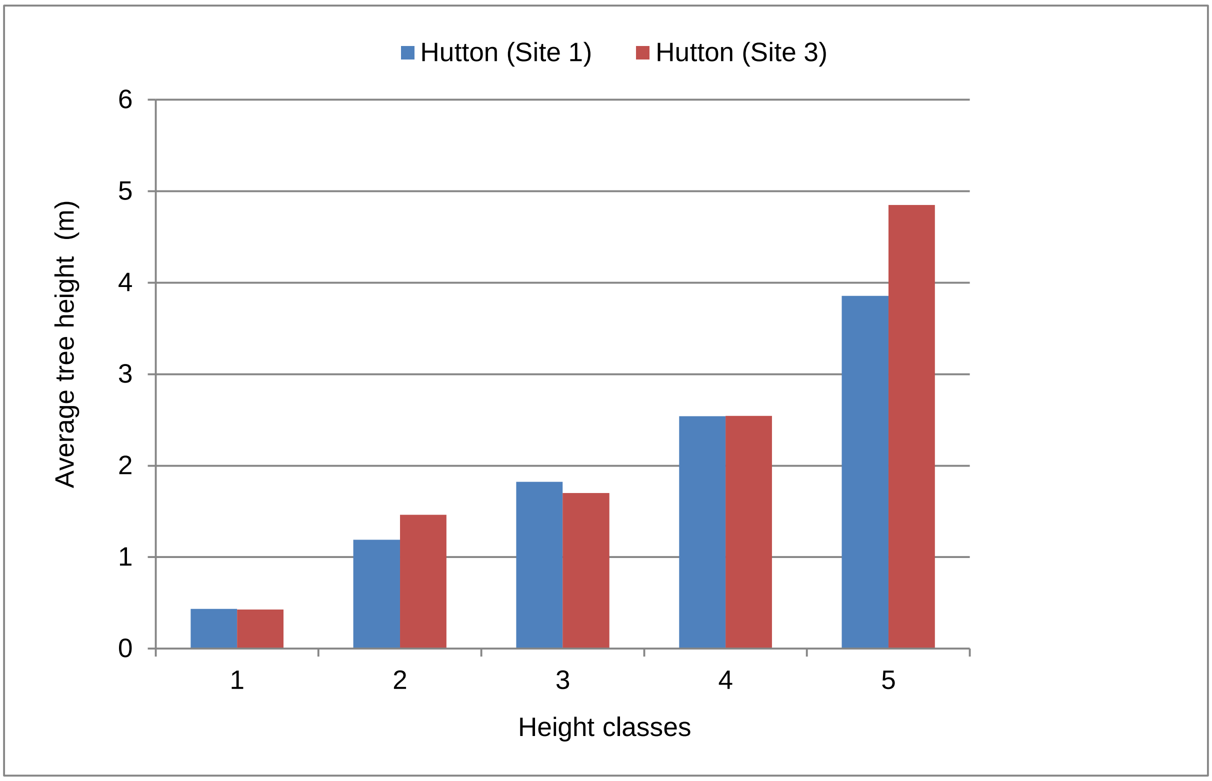

Figure 5.6 Mean tree height at Syferkuil Experimental Farm and Sondela Nature Reserve.

5.3.2.3 *Effect of rainfall on the number of growth rings*

i. Height class 1 (<0.5 m)

Growth rings did not differ significantly between Hutton (Syferkuil) and Hutton (Sondela) ($p > 0.05$, Table 5.1, Table 7.1 B; Appendix B). The average number of tree rings at the Syferkuil Experimental Farm and Sondela Nature Reserve soil forms were 10 and 8, respectively (Figure 5.7). This resulted in an insignificant difference of the mean growth rings (2 rings difference) between the two sites.

ii. Height class 2 (>0.5 – 1.5 m)

Growth rings differed significantly between Hutton (Syferkuil) and Hutton (Sondela) ($p < 0.05$, Table 5.1, Table 7.2 B; Appendix B). The average number of growth rings at the Syferkuil Experimental Farm and Sondela Nature Reserve soil forms were 28 and 17, respectively (Figure 5.7). This resulted in a significant difference of the mean growth rings (11 rings difference) between the two sites.

iii. Height class 3 (>1.5 – 2.0 m)

Growth rings differed significantly between Hutton (Syferkuil) and Hutton (Sondela) ($p < 0.05$, Table 5.1, Table 7.3 B; Appendix B). The average number of growth rings at the Syferkuil Experimental Farm and Sondela Nature Reserve soil forms were 46 and 25, respectively (Figure 5.7). This resulted in a significant difference of the mean growth rings (21 rings difference) between the two sites.

iv. Height class 4 (>2.0 – 3.0 m)

Growth rings did not differ significantly between Hutton (Syferkuil) and Hutton (Sondela) ($p > 0.05$, Table 5.1, Table 7.4 B; Appendix B). The average number of growth rings at the Syferkuil Experimental Farm and Sondela Nature Reserve soil forms were 64 and 54, respectively (Figure 5.7). This resulted in an insignificant difference of the mean growth rings (10 rings difference) between the two sites.

v. Height class 5 (>3 m)

Growth rings did not differ significantly between Hutton (Syferkuil) and Hutton (Sondela) ($p > 0.05$, Table 5.1, Table 7.5 B; Appendix B). The average number of growth rings at the Syferkuil Experimental Farm and Sondela Nature Reserve soil forms were 101 and 81, respectively (Figure 5.7). This resulted in an insignificant difference of the mean growth rings (20 rings) between the two sites.

Figure 5.7 Mean number of growth rings at Syferkuil Experimental Farm and Sondela Nature Reserve.

5.3.2.4 *Effect of rainfall on crown diameter*

i. Height class 1(<0.5 m)

Crown diameter did not differ significantly between Hutton (Syferkuil) and Hutton (Sondela) ($p > 0.05$, Table 5.1, Table 8.1 B; Appendix B). The average crown diameter at the Syferkuil Experimental Farm and Sondela Nature Reserve soil forms were 10.75 cm and 62.9 cm, respectively (Figure 5.8). This resulted in an insignificant difference of the mean crown diameter (52.2 cm difference) between the two sites.

ii. Height class 2 (>0.5 – 1.5 m)

Crown diameter did not differ significantly between Hutton (Syferkuil) and Hutton (Sondela) ($p > 0.05$, Table 5.1, Table 8.2 B; Appendix B). The average crown diameter at the Syferkuil Experimental Farm and Sondela Nature Reserve soil forms were 192.6 cm and 196.5 cm, respectively (Figure 5.8). This resulted in an insignificant difference of the mean crown diameter (3.9 cm difference) between the two sites.

iii. Height class 3 (>1.5 – 2.0 m)

Crown diameter did not differ significantly between Hutton (Syferkuil) and Hutton (Sondela) ($p > 0.05$, Table 5.1, Table 8.3 B; Appendix B). The average crown diameter at the Syferkuil Experimental Farm and Sondela Nature Reserve soil forms were 227 cm and 201 cm, respectively (Figure 5.8). This resulted in an insignificant difference of the mean crown diameter (26 cm difference) between the two sites.

iv. Height class 4 (>2.0 – 3.0 m)

Crown diameter differed significantly between Hutton (Syferkuil) and Hutton (Sondela) ($p < 0.05$, Table 5.1, Table 8.4 B; Appendix B). The average crown diameter at the Syferkuil Experimental Farm and Sondela Nature Reserve soil forms were 341.7 cm and 182.5 cm, respectively (Figure 5.8). This resulted in a significant difference of the mean crown diameter (159.2 cm difference) between the two sites.

v. Height class 5 (>3 m)

Crown diameter differed significantly between Hutton (Syferkuil) and Hutton (Sondela) ($p < 0.05$, Table 5.1, Table 8.5 B; Appendix B). The average crown diameter at the Syferkuil Experimental Farm and Sondela Nature Reserve soil forms were 510.1 cm and 242.2 cm, respectively (Figure 5.8). This resulted in a significant difference of the mean crown diameter (267.9 cm difference) between the two sites.

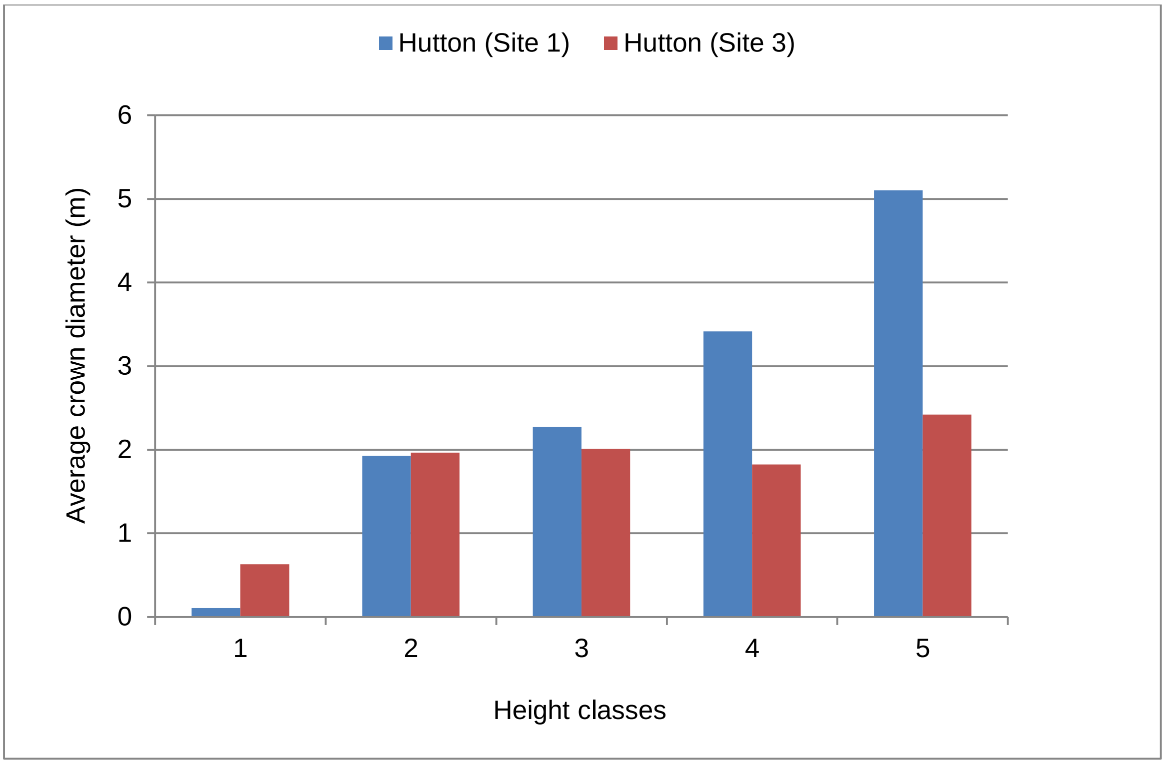

Figure 5.8 Mean crown diameter at Syferkuil Experimental Farm and Sondela Nature Reserve.

5.3.3 Correlation between plant growth parameters

5.3.3.1 *Stem circumference vs growth rings*

When the data was analysed, using linear regression modelling, the standard error of observations was estimated to be 4.19. The percentage variance accounted for was 94.1% (adjusted r^2 = 0.94.1; Table 9.2 B; Appendix B). A highly significant relationship between the stem circumference and number of growth rings thus occurred ($p < 0.001$). However, there was evidence of non-linearity, which then was added to the regression model to improve the predictions of number of rings per site, by using quadratic modelling. The non-linearity was introduced by residual 43 (Table 9.2 B; Appendix B), which was an extreme outlier. Thus, the 4.19 percentage of variance was added to the R-square value in order to get a more precise estimation of the tree age using the circumference of the stem. The end product was a highly significant ($p < 0.01$, Table 9.2 B) quadratic relationship ($r^2 = 0.9803$, Table 9.2 B; Appendix B), as illustrated in Figure 5.9.

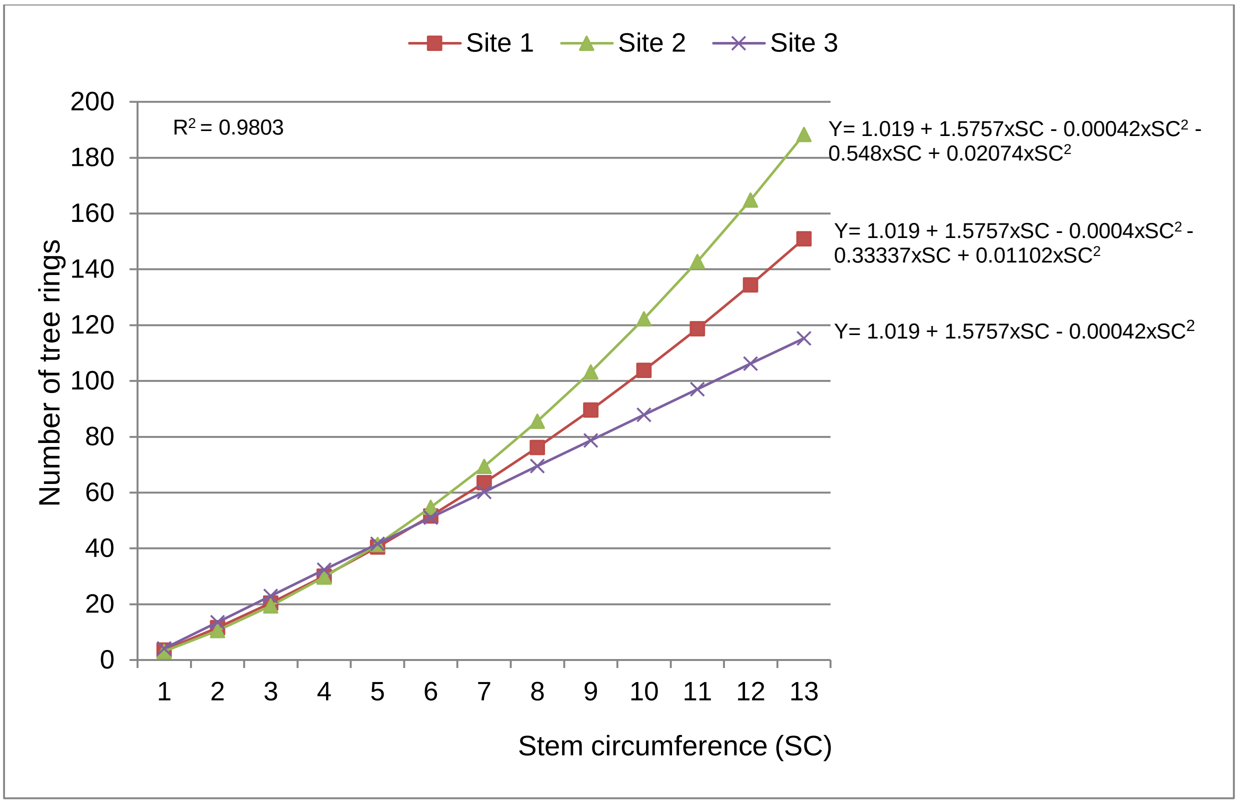

Figure 5.9 Predicted number of growth rings, based on the size of the stem, at the three sites.

According to the Pearson's coefficient of correlation (Table 9.2 B), there were significant differences between models from the three different sites. Subsequently, the equations to estimate the number of growth rings were indicated as follows:

It is important to note that Site 1 and Site 3 appear to have a linear relationship during young growth (up to 7 cm stem circumference), after which Site 1 appears to be quadratic. Site 3 appears to be totally linear, whereas Site 2 appears to be totally quadratic (Figure 5.9). However, it must also be noted that the standard errors (Table 9.1 B; Appendix B) are appropriate for interpretation of the predictions as summaries of the data, rather than as forecasts of new observations.

5.3.3.2 *Other tree characteristics*

There is a significant, high relationship between stem circumference and tree height ($p < 0.01$; $r = 0.8712$, Table 9.2 B; Appendix B). Similarly, although lower, there is a significant relationship between stem circumference and crown diameter ($p < 0.01$; $r = 0.6565$, Table 9.2 B; Appendix B). Plants from both Syferkuil Experimental Farm and Sondela Nature Reserve indicated a distinct correlation between *Acacia tortilis* stem circumference and height. Where the number of rings is concerned, there is a significant relationship between number of growth rings and tree height ($p < 0.01$; $r = 0.8485$, Table 9.2 B; Appendix B). There is also a significant, but lower, relationship between the number of growth rings and crown diameter ($p < 0.01$; $r = 0.6920$; Table B 9.2; Appendix B). Similarly, tree height and crown diameter are also significantly correlated ($p < 0.01$; $r = 0.6240$; Table 9.2 B; Appendix B). Furthermore, it is important to note that the relationship between tree height and number of growth rings can also be used as an alternative, if stem circumference is less convenient.

5.3.3.3 *Population establishment*

The prediction models were used to determine the establishment pattern of *A. tortilis* communities at the three sites. By sampling a percentage of plants' stem circumferences in an area and determining the tree age, using the obtained regressions, it was possible to determine, by counting backwards, how many plants were established in a particular year and further, correlate it to the rainfall of the area in that particular year. However, Figures 5.10, 5.11 and 5.12 clearly indicate that there is no correlation between establishment and rainfall ($r = 0.0525$, 0.2154, and 0.0582 for Site 1, 2 and 3, respectively). Therefore, the model cannot be used to determine future population establishment sequences based only on the annual rainfall of the area.

However, there appeared to be a subjective pattern between the amount of rainfall and the rate of establishment at Site 1 (Figure 5.10). While there is no direct correlation between the number of trees established and rainfall, it generally appears as if *Acacia tortilis* establishment occurred mainly during the drier periods; the highest establishment occurred in 1997, where the annual rainfall was 565.6 mm and the establishment of 70 trees ha^{-1} was recorded. The second highest establishment was 60 trees ha^{-1}, during the year of 2010, where the annual rainfall was recorded at 422.9 mm. However, in 1996, where the highest rainfall was recorded, only 20 seedlings ha^{-1} established. This may be due to an increase in the grass and forb population, which in turn supressed the establishment of many woody species.

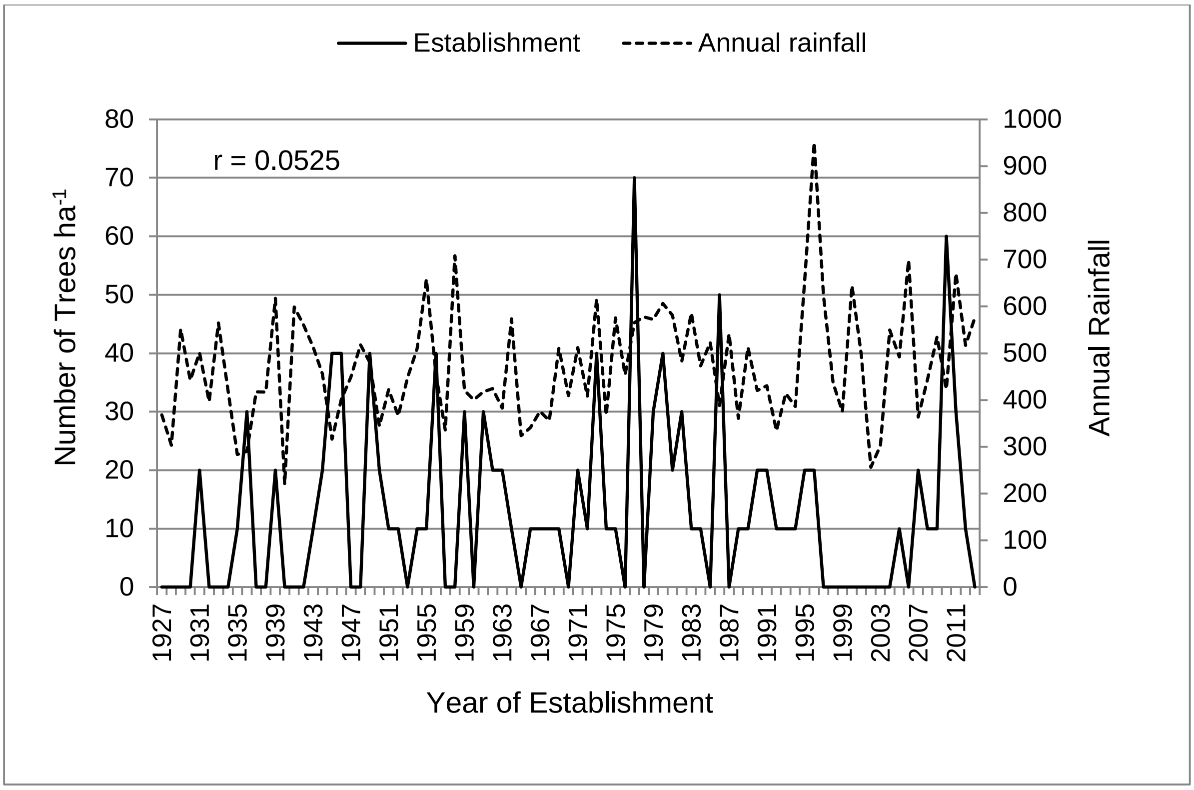

Figure 5.10 Establishment patterns and rainfall at Syferkuil Experimental Farm, Site 1.

Similarly, at Site 2 (Figure 5.11) appears as if establishment occurred mainly during dry periods, despite no direct correlation between the number of trees established and rainfall. The highest seedling establishment occurred in 1983, where the annual rainfall was 585.8 mm and the establishment of 70 trees ha^{-1} was recorded. The second highest establishment was 60 trees ha^{-1}, during the years 1969 and 1971, where the annual rainfall was recorded at 510.5 mm and 512.2 mm, respectively. It is, however, important to note that both 1969 and 1971 were preceded by a year of relatively lower rainfall. Although these may suggest that there is a correlation between rainfall and establishment, the pattern is not sustained throughout the years of establishment. Furthermore, in 1996, when the highest rainfall was recorded, only 40 seedlings ha^{-1} established.

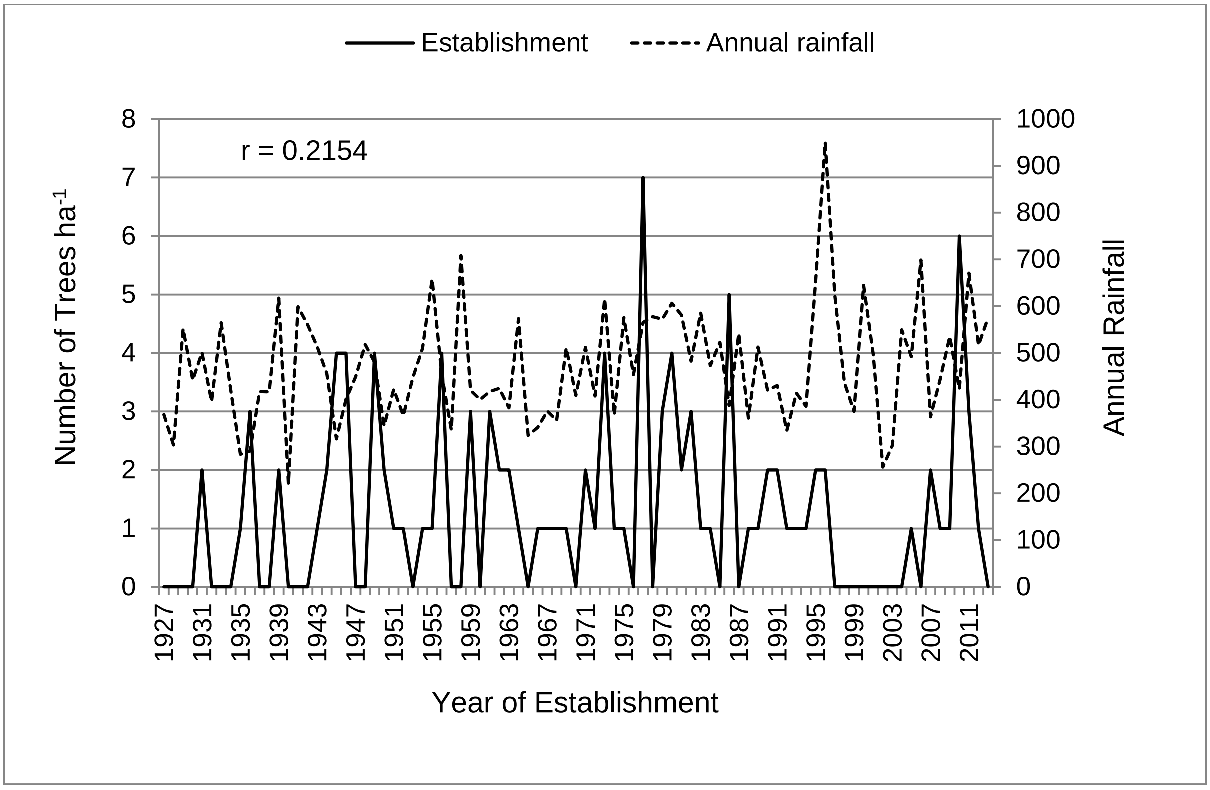

Figure 5.11 Establishment patterns and rainfall at Syferkuil Experimental Farm, Site 2.

Similar to the previous two sites, subjective observation of Figure 5.12 indicates the absence of a pattern between the amount of rainfall and the rate of establishment, with establishment appeared to be favoured by dry periods. However, there is no direct correlation between the number of trees established and rainfall. From 1939 to 1962, seedling establishment was restricted to erratic establishment at low numbers. The highest establishment occurred in the year 1989, the annual rainfall was 512 mm and the establishment of 60 trees ha^{-1} was recorded. The second highest establishment was 50 trees ha^{-1}, during 1987, 1993 and 1998, where the annual rainfalls were recorded at 814 mm, 491 mm, and 613 mm, respectively. However, in 2010, where the highest annual rainfall was recorded (1 143 mm), no seedlings were established.

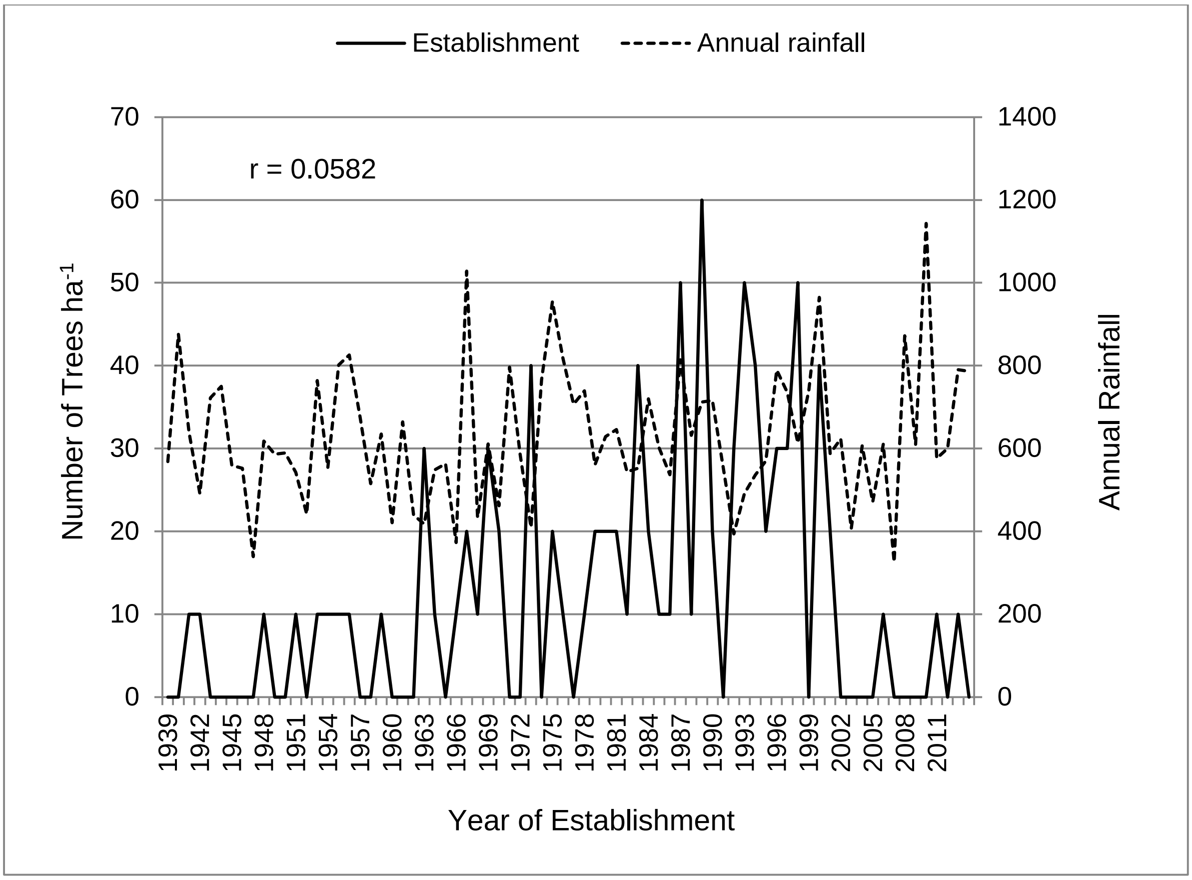

Figure 5.12 Establishment patterns and rainfall at Sondela Nature Reserve, Site 3.

At the three sites, initial establishment occurred within four years of each other. Site 2 (Syferkuil Experimental Farm) appears to be the oldest of the three sites, with its first establishment occurring in 1927, followed by Site 3 (Sondela Nature Reserve), where first seedling establishment was in 1929. Site 1 (Syferkuil Experimental Farm) appears to be the youngest site, the first establishment of seedlings occurred in 1931 (Figure 5.13). Site 1 is the dense of all sites; with a total of 1118 trees ha^{-1}. Site 2 and Site 3 were denser than Site 1, with totals of 1236 trees ha^{-1} and 1550 trees ha^{-1}, respectively. Furthermore, all three sites have growth curves similar to general sigmoidal growth curves. All sites are still ascending, with signs of flattening out.

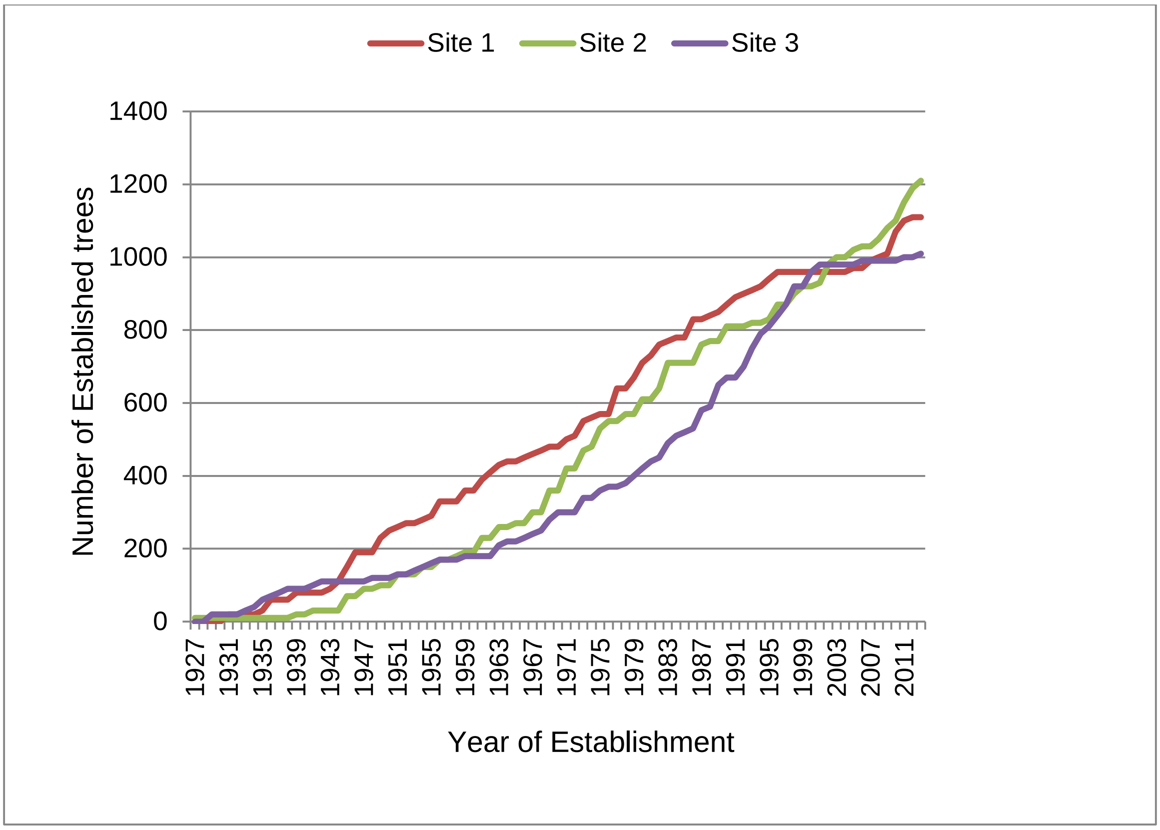

Figure 5.13 Cumulative establishments of *A. tortilis* at the three sites.

5.4 DISCUSSION

5.4.1 Stem circumference

The stem circumference of *A. tortilis* was significantly affected by the type of soil on which the tree grows. However, the difference in rainfall did not prove to have a significant effect the stem circumference. Understanding the relationships between weather and the rate and pattern of stem growth will facilitate the prediction of wood properties at a given site (Downes *et al*., 1999). Of the five height classes that were characterised to test the effect of soil, only two height classes (1 and 4) did not show any difference in stem circumference, while three differed, indicating that the type of soil on which the plant grows has an influence on the stem circumference. Conversely, only two height classes (2 and 3) were significantly affected by rainfall, indicating that rainfall had a smaller effect on the stem circumference of *A. tortilis*.

Inter-annual and seasonal variations in stem diameter increment are well-known phenomena of seasonally dry tropical forests (Grogan and Schulze, 2012). Furthermore, Sass-Klaassen *et al*. (2007) found that morphological traits (trees size, leaf parameters) and wood-anatomical variables (sapwood area, conduit size and density) differ significantly between wet and dry sites. However, tree growth has been described as an effect of control by limiting factors (Fritts, 1966).

Rocky soils such as Glenrosa are generally shallow and overlie an impending layer such as hard rock or weathering saprolite (Corbett *et al*., 2009). This type of a soil has low water-holding capacity due to the low organic matter content. Furthermore, Downes *et al*., (1999) found that soil water is a major determinant of cambial activity. In the study reported here, the difference in annual rainfall (500 mm vs 600 mm) was apparently not as significant as a dry site vs a wet site, and therefore not large enough to allow soil water to be a limiting factor between the two sites.

5.4.2 Tree height

Tree height was not significantly affected by the type of soil on which the plant grows. However, rainfall significantly influenced the final size and height of *Acacia tortilis*. From the five height classes that were characterised to test the effect of soil type, none indicated a difference in the growth pattern and size of the plant. On the contrary, height classes 2, 3 and 5 strongly indicated that the rainfall had a big influence on the growth of the plant. This study reports that Hutton and Glenrosa soil form did not prove to have different influences on the growth of *A. tortilis*.

Years during which trees grow faster than average have been shown to correspond with higher than average annual rainfall totals or wetter than average dry seasons (Grogan and Schulze, 2012). Furthermore, (Garg and Kumar, 2012) found that sandy soils supported maximum increase in plant height, fresh weight and percent dry weight. Red soils also supported increases in the aforementioned parameters but at a lower rate than sandy soil. Sass-Klaasen *et al*. (2007) illustrated that there is a positive high correlation between high rainfall and morphological traits such as plant height. This study indicates that when plants grow in separate areas, other limiting factors such as temperature are infinitesimal and rainfall will directly influence the size of the plant.

5.4.3 Growth rings

Growth rings of *Acacia tortilis* were affected by the type of soil on which the plant grows but the effect was insignificant between sites. Rainfall also did not prove to have a significant effect on the number of growth rings. Of the five height classes that were characterised to test the effect of soil, two height classes (2 and 5) showed a big difference in the number of growth rings. Height classes 2 and 3 also indicated that rainfall had a strong influence on the number of growth rings. Fritts (2012) established that tree growth is frequently affected by variations in climate (wet and dry or warm and cold years), and it is primarily recorded by the sequence of wide and narrow rings in large number of trees.

The impact of water availability on annual changes in conduit size and density is evidence by the strong positive correlation between the growth-ring width chronologies and the amount of rainfall (Sass-Klaassen *et al*., 2007). Since external factors such as rainfall can only be measured by the width of the rings formed, it is an indication that neither soil type nor the amount of rainfall can influence the absolute number of rings significantly. In this research study, only the total numbers of rings were measured and recorded, and no other measurements were studied on the growth rings. Therefore, the two affected height classes are not sufficient to prove that either soil or rainfall had an influence on their development and growth, and furthermore, these recorded minimal differences may be attributed to unknown factors, either than rainfall or soil type.

5.4.4 Crown diameter

The crown diameter of *A. tortilis* was significantly affected by the type of soil on which the tree grows. However, rainfall did not prove to have a significant effect on the size and growth of the crown. Of the five height classes that were characterised to test the effect of soil, only height classes 4 did not reflect any difference in the growth pattern and size of the crown. Height classes 1, 2 and 3 did not show any indication of a significant difference introduced by rainfall. Grogan and Schulze (2012) determined that crown diameter may be sensitive to rainfall totals and corresponding soil water availability, which is largely based on the soil's water holding capacity (Soil classification working group, 1991).

Sass-Klaasen *et al*. (2007) found that trees in wet areas had bigger crowns than trees in dry areas. However, in this study the difference in rainfall between the two areas did not introduce a significant difference in the development and the ultimate size of the crown. Conversely, soil type proved to have a great influence on the growth and size of the crown. This may be attributed to the great difference in the soil's water holding capacity, and also, the minimal difference in the total precipitation between the Sondela Nature Reserve and the Syferkuil Experimental Farm. Therefore, the crown diameter of *A. tortilis* is more influenced by the type of soil than the rainfall.

5.4.5 Predictions from regression model

Correlations between growth rings and stem circumference, tree height and crown diameter, proved to be significantly relationship. However, tree rings against stem circumference had the highest correlation (r = 98.1). Many studies have explored the relationship between growth rate and wood properties such as density. Commonly, these studies use diameter at a given tree age to indicate growth rate (Downes *et al*., 1999). This study indicates that there is a direct, positive relationship between stem circumference and the number of growth rings. Therefore, this high correlation makes it possible to create a prediction model. Using the prediction model, tree age can be determined, based solely on stem circumference. However, the absence of a correlation between rainfall and establishment makes it impossible to determine the pattern of bush encroachment based solely on the amount of rainfall. Conversely, tree age can be determined without cutting trees down, suggesting that the old destructive method of determining tree age can be eliminated, particularly for endangered plant species. It is however noteworthy that, this prediction model is effective only on *A. tortilis* at the three specified study sites, and that further studies should include other tree species in other meteorological areas.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

Bush encroachment leads to the suppression of desirable grasses and herbs by undesirable woody species, often in an area where it previously did not occur, or the aggregation of existing undesirable plants in an area. The density of woody components, particularly of *A. tortilis,* at the study sites were as follows; 1 118 trees ha^{-1} at site 1 (Hutton soil, Syferkuil Experimental Farm), 1 236 trees ha^{-1} at site 2 (Glenrosa soil form, Syferkuil Experimental Farm) and 1 550 trees ha^{-1} Site 3 (Hutton soil form, Sondela Nature Reserve). This concludes that the areas were encroached by *Acacia tortilis*.

Bush encroachment will continually be part of savannas and management measures will not be able to eliminate woody plants completely. In all the study sites where vegetation sampling was carried out, the total number of trees was above 1 000 trees ha^{-1}, which is high for the annual rainfall of the two areas. The long-term rainfall for Syferkuil Experimental Farm and Sondela Nature Reserve are 458.02 mm and 629 mm, respectively. All three sites appear to be encroached, if the view of Bowman *et al* (2013) is to be shared, which states that the woody component of any given area should not be more than double the amount of the rainfall of that area.

The wide range in the data observed for most of the morphological traits and the significant mean squares obtained have shown that these plant traits are more affected by the type of soil where they occur than the difference in rainfall. This indicates that soil can in fact act as a limiting factor, effecting the optimal growth of a plant. Rainfall, however, did not prove to have the same limiting effect on the plant. This observation may be attributed to the relatively small difference in rainfall, between the two areas. The difference in long-term annual rainfall between Syferkuil Experimental Farm and Sondela Nature Reserve was 170.98 mm. This difference might not have been sufficient to show significant limitations on plant growth.

There are high correlations between all morphological traits. Each trait can influence, either positively or negatively, all the other morphological traits. However, the strongest correlation was found between the number of growth rings and the stem circumference at 0.75 m height. This relationship is so closely related that it made it possible to approximate the number of growth rings, solely based on the size of the stem. Therefore, using this relationship between number of growth rings and the size of the stem, a prediction model was successfully designed and tree population establishment patterns of *Acacia tortilis* were determined. This also served as a non-destructive method to determine tree age. However, due to the absence of a correlation between rainfall and establishment, the prediction model in this study, cannot be used to forecast future establishment patterns or aggregation of bush in an area, where wet and dry years are concerned.

6.2 ANSWERS TO THE RESEARCH QUESTIONS

i. Can the relative formation of growth rings reflect the effect of rainfall on their development? – No, it does not reflect the effect of rainfall.

ii. Can the relative formation of growth rings reflect the effect of soil on *A. tortilis* development? Yes, there were differences between soil forms.

iii. Is there any relationship between growth rings and stem circumference of *A. tortilis*? Yes, there is a highly significant relationship (r^2=0.9803)

v. Will the relationships between growth rings and stem circumference contribute in determining the establishment dynamics of the tree population? Yes, the relationship can be used to describe tree population establishment.

6.3 RECOMMENDATIONS AND AREAS OF FUTURE RESEARCH

- Future research on bush control should include more than one encroaching species, because this will provide a broader perspective on the encroachment patterns and furthermore, provide a platform to identify the common denominator between all the species.

- The concentration should be on studying establishment patterns of encroachers and determining factors which cause increased aggregation of bush, by assessing the main growth limiting factors such as rainfall, temperature and soil type.

- The study, however, submits that natural developments responsible for establishment patterns and population dynamics of woody species are complex, and their effects are only visible after an extensive period. Therefore, to understand these influential processes, several seasons of observations and monitoring would be recommended.

- It is recommended that when determining the establishment of any encroaching species, a sample larger than 10% be taken, in order to create a more distinctive pattern of establishment, allowing the factor which influences establishment pattern the highest to be determined and extensively analyzed.

- Since the effect of rainfall and other external factors on growth rings can only be shown by the relative formation of the rings, it is therefore recommended that when conducting a dendrochronological study, the width of the rings should also be measured, as they may convey information which will otherwise remain undetected when using other means.

- The influence of growth limiting factors such as soil and climatic impacts, as well as area-specific environmental factors should be further researched.

It is important to note that woody components play a significant role in the ecosystem. Therefore, management should aim at stimulating a true savanna co-dominated by both woody and grass species, and sustaining balanced vegetation to the benefit of all components of the ecosystem.

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APPENDIX A

DATA

Table 1A Trees sampled at the Syferkuil Experimental Farm (Glenrosa soil form)

Tree number	Height classes	Tree height	Stem circumference	Crown diameter	Number of tree rings
1	1	0.5	6	0.63	12
2	1	0.48	6	1.6	13
3	1	0.39	4	0.81	9
4	1	0.44	5	0.77	11
5	1	0.47	5	0.62	12
6	1	0.36	5	0.67	10
7	1	0.45	3	0.55	7
8	1	0.32	2	0.48	6
9	1	0.45	4	0.93	9
10	1	0.49	2	1.06	8
11	2	0.87	17	1.25	18
12	2	1.34	28	2.47	36
13	2	1.18	23	2.34	30
14	2	1.27	20	2.3	26
15	2	1.5	25	2.61	31
16	2	0.99	19	1.44	21
17	2	1.46	21	1.97	26
18	2	1.38	25	2.18	34
19	2	0.79	23	1.51	31
20	2	1.13	19	1.19	25
21	3	1.94	36	3.04	71
22	3	1.65	29	2.12	55
23	3	1.84	28	3.32	37
24	3	1.86	25	2.28	33
25	3	1.95	34	1.32	62
26	3	1.78	37	2.86	72
27	3	1.69	24	1.62	34
28	3	1.92	25	1.6	31
29	3	1.85	24	1.62	29
30	3	1.74	27	2.92	38
31	4	2.41	35	3.31	64
32	4	2.79	41	3.5	73
33	4	2.45	30	4.67	49
34	4	2.3	35	2.87	66
35	4	2.13	32	3.2	52
36	4	2.94	36	3.75	70
37	4	2.31	33	3.39	59
38	4	2.37	27	2.42	45

39	4	2.56	31	2.88	47
40	4	2.74	46	3.66	86
41	5	3.3	35	4.9	69
42	5	4.59	59	5.34	108
43	5	4.82	43	4.52	130
44	5	3.41	57	5.92	103
45	5	4.1	60	5.45	113
46	5	3.77	65	4.64	129
47	5	3.48	55	4.86	94
48	5	3.59	45	4.44	75
49	5	4	50	5.5	90
50	5	3.52	58	5.44	104

Table 2A Trees sampled at the Syferkuil Experimental Farm (Hutton soil form)

Tree number	Height classes	Tree height	Stem circumference	Crown diameter	Number of tree rings
51	1	0.49	7	0.38	10
52	1	0.39	5	0.42	9
53	1	0.38	5	0.35	8
54	1	0.46	6	0.5	9
55	1	0.3	8	0.41	11
56	1	0.41	7	0.49	9
57	1	0.48	5	0.61	8
58	1	0.48	4	0.53	6
59	1	0.37	2	0.36	5
60	1	0.45	3	0.42	5
61	2	1.44	8	0.09	12
62	2	0.9	10	0.09	12
63	2	1.49	11	0.18	15
64	2	1.38	12	0.19	14
65	2	0.82	11	0.12	15
66	2	0.98	13	0.14	18
67	2	1.03	11	0.15	16
68	2	1.35	14	0.18	18
69	2	1.47	11	2.73	14
70	2	1.49	11	2.18	15
71	3	1.91	21	0.18	30
72	3	1.55	23	0.21	34
73	3	1.61	22	0.18	31
74	3	1.85	23	0.18	33
75	3	1.77	22	0.17	32
76	3	1.53	19	0.18	27
77	3	1.95	31	0.22	52
78	3	1.99	29	0.22	43

79	3	1.82	27	0.25	39
80	3	1.91	25	0.22	34
81	4	2.09	20	2.51	28
82	4	2.15	36	2.49	73
83	4	2.2	23	3.62	32
84	4	2.44	22	3.21	32
85	4	2.64	24	3.84	33
86	4	2.02	34	2.76	61
87	4	2.57	27	3.65	55
88	4	2.4	48	4.31	94
89	4	2.37	47	5.62	95
90	4	2.91	34	3.88	65
91	5	3.2	44	4.81	89
92	5	3.22	44	4.47	80
93	5	3.62	42	4.41	82
94	5	4.22	40	5.75	71
95	5	3.55	33	4.36	61
96	5	3.82	42	3.61	79
97	5	4.67	23	3.69	39
98	5	3.5	43	4.14	79
99	5	3.4	31	4.68	58
100	5	3.15	35	3.77	65

Table 1ATrees sampled at the Sondela Nature Reserve (Hutton soil form)

Tree number	Height classes	Tree height	Stem circumference	Crown diameter	Number of tree rings
101	1	0.4	2	1	5
102	1	0.43	6	0.8	10
103	1	0.5	3	0.7	5
104	1	0.39	6	0.6	11
105	1	0.42	5	0.53	9
106	1	0.4	4	0.55	7
107	1	0.44	3	0.61	6
108	1	0.46	5	0.49	8
109	1	0.5	6	0.55	10
110	1	0.32	6	0.46	11
111	2	1.48	9	1.8	15
112	2	1.42	8	1.8	12
113	2	1.49	13	2.2	19
114	2	1.5	16	3.2	24
115	2	1.44	8	1.8	14
116	2	1.45	13	2.2	18
117	2	1.47	9	1.4	16
118	2	1.5	8	2.13	13

119	2	1.5	12	1.62	17
120	2	1.4	13	1.5	19
121	3	1.6	11	1.7	16
122	3	1.8	17	0.42	26
123	3	1.7	21	2.2	34
124	3	1.67	32	1.84	52
125	3	1.65	13	1.7	20
126	3	1.68	10	2.6	16
127	3	1.8	15	2.4	23
128	3	1.58	11	1.6	17
129	3	1.94	14	1.94	23
130	3	1.6	17	3.7	25
131	4	2.8	40	3.7	66
132	4	2.8	49	1.12	73
133	4	2.7	37	4.2	65
134	4	2.5	28	0.83	48
135	4	2.53	27	0.65	46
136	4	2.5	22	2.6	34
137	4	2.2	19	3.4	27
138	4	2.8	46	0.78	72
139	4	2.2	41	0.57	68
140	4	2.4	24	0.4	39
141	5	4.8	49	3.9	74
142	5	3.8	63	1.23	95
143	5	4.6	53	4.7	80
144	5	5.3	67	7.7	100
145	5	5.4	27	1.38	45
146	5	5.5	70	1.15	111
147	5	4.2	40	1.04	68
148	5	3.9	34	0.72	59
149	5	3.8	38	0.9	63
150	5	7.2	74	1.5	119

APPENDIX B

DATA ANALYSIS

1B. Impact of soil type on the stem circumference of *Acacia tortilis:* SEF (Hutton) vs. SEF (Glenrosa)

Table 1.1 B Two-sample t-test comparing the effect of soil type on the stem circumference: height class 1 (0.0 – 0.5 m)

Variate: SC
Group factor: Site

Summary

Sample	Size	Mean	Variance	Standard deviation	Standard error of mean
1	10	4.200	2.178	1.476	0.4667
2	10	5.200	3.511	1.874	0.5925

Difference of means: -1.000
Standard error of difference: 0.754

95% confidence interval for difference in means: (-2.585, 0.5846)

Test of null hypothesis that mean of SC with Site = 1 is equal to mean with Site = 2

Test statistic t = -1.33 on 18 d.f.

Probability = 0.201

Table 1.2 B Two-sample t-test comparing the effect of soil type on the stem circumference: height class 2 (0.5 – 1.5 m)

Variate: SC
Group factor: Site

Summary

Sample	Size	Mean	Variance	Standard deviation	Standard error of mean
1	10	22.00	11.556	3.399	1.0750
2	10	11.20	2.622	1.619	0.5121

Difference of means: 10.800
Standard error of difference: 1.191

95% confidence interval for difference in means: (8.225, 13.37)

Test of null hypothesis that mean of SC with Site = 1 is equal to mean with Site = 2

Test statistic t = 9.07 on approximately 12.88 d.f.

Probability < 0.001

Table 1.3 B Two-sample t-test comparing the effect of soil type on the stem circumference: height class 3 (1.5 – 2.0 m)

```
Variate: SC
Group factor: Site

Summary

                                         Standard   Standard error
Sample   Size     Mean     Variance      deviation         of mean
1          10    28.90        24.99          4.999           1.581
2          10    24.20        14.18          3.765           1.191

Difference of means:              4.700
Standard error of difference:     1.979

95% confidence interval for difference in means: (0.5422, 8.858)

Test of null hypothesis that mean of SC with Site = 1 is equal to mean with Site = 2

Test statistic t = 2.37 on 18 d.f.

Probability = 0.029
```

Table 1.4 B Two-sample t-test comparing the effect of soil type on the stem circumference: height class 4 (2.0 – 3.0 m)

```
Variate: SC
Group factor: Site

Summary

                                         Standard   Standard error
Sample   Size     Mean     Variance      deviation         of mean
1          10    36.10        40.99          6.402           2.025
2          10    31.50       101.83         10.091           3.191

Difference of means:              4.600
Standard error of difference:     3.779

95% confidence interval for difference in means: (-3.340, 12.54)

Test of null hypothesis that mean of SC with Site = 1 is equal to mean with Site = 2

Test statistic t = 1.22 on 18 d.f.

Probability = 0.239
```

Table 1.5 B Two-sample t-test comparing the effect of soil type on the stem circumference: height class 5 (>3 m)

```
Variate: SC
Group factor: Site

Summary

                                          Standard   Standard error
Sample    Size       Mean    Variance    deviation          of mean
1           10      52.70       85.57        9.250            2.925
2           10      37.70       48.90        6.993            2.211

Difference of means:            15.000
Standard error of difference:    3.667

95% confidence interval for difference in means: (7.296, 22.70)

Test of null hypothesis that mean of SC with Site = 1 is equal to mean with Site = 2

Test statistic t = 4.09 on 18 d.f.

Probability < 0.001
```

2B. Impact of soil type on the height of *A. tortilis:* SEF (Hutton) vs. SEF (Glenrosa)

Table 2.1 B Two-sample t-test comparing the effect of soil type on tree height: height class 1 (0.0 – 0.5 m)

```
Variate: TH
Group factor: Site

Summary

                                             Standard   Standard error
Sample    Size      Mean     Variance   deviation          of mean
1           10    0.4350     0.003539     0.05949          0.01881
2           10    0.4210     0.003788     0.06154          0.01946

Difference of means:            0.0140
Standard error of difference:   0.0271

95% confidence interval for difference in means: (-0.04287, 0.07087)

Test of null hypothesis that mean of TH with Site = 1 is equal to mean with Site = 2

Test statistic t = 0.52 on 18 d.f.

Probability = 0.611
```

Table 2.2 B Two-sample t-test comparing the effect of soil type on tree height: height class 2 (0.5 – 1.5 m)

```
Variate: TH
Group factor: Site

Summary

                                             Standard   Standard error
Sample    Size      Mean     Variance   deviation          of mean
1           10     1.191      0.06001      0.2450          0.07747
2           10     1.235      0.07256      0.2694          0.08518

Difference of means:            -0.044
Standard error of difference:    0.115

95% confidence interval for difference in means: (-0.2859, 0.1979)

Test of null hypothesis that mean of TH with Site = 1 is equal to mean with Site = 2

Test statistic t = -0.38 on 18 d.f.

Probability = 0.707
```

Table 2.3 B Two-sample t-test comparing the effect of soil type on tree height: height class 3 (1.5 – 2.0 m)

```
Variate: TH
Group factor: Site

Summary

                                                   Standard    Standard error
Sample    Size        Mean     Variance    deviation            of mean
1            10       1.822      0.01088       0.1043            0.03299
2            10       1.789      0.02854       0.1689            0.05343

Difference of means:               0.0330
Standard error of difference:   0.0628

95% confidence interval for difference in means: (-0.09892, 0.1649)

Test of null hypothesis that mean of TH with Site = 1 is equal to mean with Site = 2

Test statistic t = 0.53 on 18 d.f.

Probability = 0.606
```

Table 2.4 B Two-sample t-test comparing the effect of soil type on tree height: height class 4 (2.0 – 3.0 m)

```
Variate: TH
Group factor: Site

Summary

                                                   Standard    Standard error
Sample    Size        Mean     Variance    deviation            of mean
1            10       2.541      0.08665       0.2944            0.09309
2            10       2.379      0.07641       0.2764            0.08741

Difference of means:               0.162
Standard error of difference:   0.128

95% confidence interval for difference in means: (-0.1063, 0.4303)

Test of null hypothesis that mean of TH with Site = 1 is equal to mean with Site = 2

Test statistic t = 1.27 on 18 d.f.

Probability = 0.221
```

Table 2.5 B Two-sample t-test comparing the effect of soil type on tree height: height class 5 (>3.0 m)

Variate: TH
Group factor: Site

Summary

Sample	Size	Mean	Variance	Standard deviation	Standard error of mean
1	10	3.858	0.2654	0.5152	0.1629
2	10	3.635	0.2361	0.4859	0.1537

Difference of means: 0.223
Standard error of difference: 0.224

95% confidence interval for difference in means: (-0.2475, 0.6935)

Test of null hypothesis that mean of TH with Site = 1 is equal to mean with Site = 2

Test statistic t = 1.00 on 18 d.f.

Probability = 0.333

3B. Impact of soil type on the number of tree rings of *A. tortilis:* SEF (Hutton) vs. SEF (Glenrosa)

Table 3.1 B Two-sample t-test comparing the effect of soil type on tree rings: height class 1 (0.0 – 0.5 m)

```
Variate: NR
Group factor: Site

Summary

                                        Standard  Standard error
Sample   Size      Mean    Variance    deviation         of mean
1          10     9.700       5.344        2.312          0.7311
2          10     8.000       4.222        2.055          0.6498

Difference of means:              1.700
Standard error of difference:     0.978

95% confidence interval for difference in means: (-0.3549, 3.755)

Test of null hypothesis that mean of NR with Site = 1 is equal to mean with Site = 2
Test statistic t = 1.74 on 18 d.f.

Probability = 0.099
```

Table 3.2 B Two-sample t-test comparing the effect of soil type on tree rings: height class 2 (0.5 – 1.5 m)

```
Variate: NR
Group factor: Site

Summary

                                        Standard  Standard error
Sample   Size      Mean    Variance    deviation         of mean
1          10     27.80       31.96        5.653           1.788
2          10     14.90        4.32        2.079           0.657

Difference of means:             12.900
Standard error of difference:     1.905

95% confidence interval for difference in means: (8.725, 17.07)

Test of null hypothesis that mean of NR with Site = 1 is equal to mean with Site = 2

Test statistic t = 6.77 on approximately 11.39 d.f.

Probability < 0.001
```

Table 3.3 B Two-sample t-test comparing the effect of soil type on tree rings: height class 3 (1.5 – 2.0 m)

```
Variate: NR
Group factor: Site

Summary

                                        Standard   Standard error
Sample    Size      Mean    Variance   deviation          of mean
1           10     46.20       290.0       17.03            5.385
2           10     35.50        54.1        7.35            2.325

Difference of means:            10.700
Standard error of difference:    5.865

95% confidence interval for difference in means: (-2.051, 23.45)

Test of null hypothesis that mean of NR with Site = 1 is equal to mean with Site = 2

Test statistic t = 1.82 on approximately 12.24 d.f.

Probability = 0.093
```

Table 3.4 B Two-sample t-test comparing the effect of soil type on tree rings: height class 4 (2.0 – 3.0 m)

```
Variate: NR
Group factor: Site

Summary

                                        Standard   Standard error
Sample    Size      Mean    Variance   deviation          of mean
1           10     64.10       169.9       13.03            4.122
2           10     56.80       646.6       25.43            8.041

Difference of means:             7.300
Standard error of difference:    9.036

95% confidence interval for difference in means: (-11.68, 26.28)

Test of null hypothesis that mean of NR with Site = 1 is equal to mean with Site = 2

Test statistic t = 0.81 on 18 d.f.

Probability = 0.430
```

Table 3.5 B Two-sample t-test comparing the effect of soil type on tree rings: height class 5 (>3 m)

```
Variate: NR
Group factor: Site

Summary

                                            Standard   Standard error
Sample    Size      Mean     Variance      deviation          of mean
1           10    101.50        410.9          20.27            6.410
2           10     70.30        219.8          14.83            4.688

Difference of means:              31.200
Standard error of difference:      7.942

95% confidence interval for difference in means: (14.51, 47.89)

Test of null hypothesis that mean of NR with Site = 1 is equal to mean with Site = 2

Test statistic t = 3.93 on 18 d.f.

Probability < 0.001
```

4B. Impact of soil type on the crown diameter of *A. tortilis:* SEF (Hutton) vs. SEF (Glenrosa)

Table 4.1 B Two-sample t-test comparing the effect of soil type on the crown diameter: height class 1 (0.0 – 0.5 m)

```
Variate: CD
Group factor: Site

Summary

                                          Standard   Standard error
Sample   Size     Mean     Variance      deviation          of mean
1          10   0.8120      0.10746         0.3278          0.10366
2          10   0.4470      0.00693         0.0833          0.02633

Difference of means:             0.365
Standard error of difference:    0.107

95% confidence interval for difference in means: (0.1272, 0.6028)

Test of null hypothesis that mean of CD with Site = 1 is equal to mean with Site = 2

Test statistic t = 3.41 on approximately 10.16 d.f.

Probability = 0.006
```

Table 4.2 B Two-sample t-test comparing the effect of soil type on the crown diameter: height class 2 (0.5 – 1.5 m)

```
Variate: CD
Group factor: Site

Summary

                                          Standard   Standard error
Sample   Size     Mean     Variance      deviation          of mean
1          10    1.926       0.2833         0.5322           0.1683
2          10    0.605       0.9687         0.9842           0.3112

Difference of means:             1.321
Standard error of difference:    0.354

95% confidence interval for difference in means: (0.5776, 2.064)

Test of null hypothesis that mean of CD with Site = 1 is equal to mean with Site = 2

Test statistic t = 3.73 on 18 d.f.

Probability = 0.002
```

Table 4.3 B Two-sample t-test comparing the effect of soil type on the crown diameter: height class 3 (1.5 – 2.0 m)

Variate: CD
Group factor: Site

Summary

Sample	Size	Mean	Variance	Standard deviation	Standard error of mean
1	10	2.270	0.5206	0.7215	0.2282
2	10	0.201	0.0007	0.0264	0.0084

Difference of means: 2.069
Standard error of difference: 0.228

95% confidence interval for difference in means: (1.553, 2.585)

Test of null hypothesis that mean of CD with Site = 1 is equal to mean with Site = 2

Test statistic t = 9.06 on approximately 9.02 d.f.

Probability < 0.001

Table 4.4 B Two-sample t-test comparing the effect of soil type on the crown diameter: height class 4 (2.0 – 3.0 m)

Variate: CD
Group factor: Site

Summary

Sample	Size	Mean	Variance	Standard deviation	Standard error of mean
1	10	3.417	0.3444	0.5869	0.1856
2	10	3.589	0.8889	0.9428	0.2981

Difference of means: -0.172
Standard error of difference: 0.351

95% confidence interval for difference in means: (-0.9098, 0.5658)

Test of null hypothesis that mean of CD with Site = 1 is equal to mean with Site = 2

Test statistic t = -0.49 on 18 d.f.

Probability = 0.630

Table 4.5 B Two-sample t-test comparing the effect of soil type on the crown diameter: height class 5 (>3 m)

Variate: CD
Group factor: Site

Summary

Sample	Size	Mean	Variance	Standard deviation	Standard error of mean
1	10	5.101	0.2455	0.4955	0.1567
2	10	4.369	0.4065	0.6376	0.2016

Difference of means: 0.732
Standard error of difference: 0.255

95% confidence interval for difference in means: (0.1955, 1.268)

Test of null hypothesis that mean of CD with Site = 1 is equal to mean with Site = 2

Test statistic t = 2.87 on 18 d.f.

Probability = 0.010

5B. Impact of rainfall on the stem circumference of *A. tortilis*: diameter: (SEF Hutton vs. SNR Hutton)

Table 5.1 B Two-sample t-test comparing the effect of rainfall on the stem circumference (SEF vs. SNR): height class 1 (0.0 – 0.5 m)

```
Variate: SC
Group factor: Site

Summary

                                              Standard   Standard error
Sample    Size       Mean    Variance    deviation          of mean
1            10      4.200       2.178         1.476           0.4667
3            10      4.600       2.267         1.506           0.4761

Difference of means:              -0.400
Standard error of difference:      0.667

95% confidence interval for difference in means: (-1.801, 1.001)

Test of null hypothesis that mean of SC with Site = 1 is equal to mean with Site = 3

Test statistic t = -0.60 on 18 d.f.

Probability = 0.556
```

Table 5.2 B Two-sample t-test comparing the effect of rainfall on the stem circumference (SEF vs. SNR): height class 2 (0.5 – 1.5 m)

```
Variate: SC
Group factor: Site

Summary

                                              Standard   Standard error
Sample    Size       Mean    Variance    deviation          of mean
1            10      22.00      11.556         3.399           1.0750
3            10      10.90       8.100         2.846           0.9000

Difference of means:              11.100
Standard error of difference:      1.402

95% confidence interval for difference in means: (8.155, 14.05)

Test of null hypothesis that mean of SC with Site = 1 is equal to mean with Site = 3

Test statistic t = 7.92 on 18 d.f.

Probability < 0.001
```

Table 5.3 B Two-sample t-test comparing the effect of rainfall on the stem circumference (SEF vs. SNR): height class 3 (1.5 – 2.0 m)

```
Variate: SC
Group factor: Site

Summary

                                        Standard   Standard error
Sample   Size     Mean   Variance   deviation          of mean
1          10    28.90      24.99       4.999            1.581
3          10    16.10      42.54       6.523            2.063

Difference of means:               12.800
Standard error of difference:       2.599

95% confidence interval for difference in means: (7.340, 18.26)

Test of null hypothesis that mean of SC with Site = 1 is equal to mean with Site = 3

Test statistic t = 4.93 on 18 d.f.

Probability < 0.001
```

Table 5.4 B Two-sample t-test comparing the effect of rainfall on the stem circumference (SEF vs. SNR): height class 4 (2.0 – 3.0 m)

```
Variate: SC
Group factor: Site

Summary

                                        Standard   Standard error
Sample   Size     Mean   Variance   deviation          of mean
1          10    36.10      40.99       6.402            2.025
3          10    33.30     112.46      10.605            3.353

Difference of means:               2.800
Standard error of difference:      3.917

95% confidence interval for difference in means: (-5.430, 11.03)

Test of null hypothesis that mean of SC with Site = 1 is equal to mean with Site = 3

Test statistic t = 0.71 on 18 d.f.

Probability = 0.484
```

Table 5.5 B Two-sample t-test comparing the effect of rainfall on the stem circumference (SEF vs. SNR): height class 5 (>3 m)

```
Variate: SC
Group factor: Site

Summary

                                       Standard   Standard error
Sample   Size     Mean    Variance    deviation          of mean
1          10    52.70        85.6         9.25            2.925
3          10    51.50       272.3        16.50            5.218

Difference of means:           1.200
Standard error of difference:  5.982

95% confidence interval for difference in means: (-11.37, 13.77)

Test of null hypothesis that mean of SC with Site = 1 is equal to mean with Site = 3

Test statistic t = 0.20 on 18 d.f.

Probability = 0.843
```

6B. Impact of rainfall on the height of *A. tortilis*: (SEF Hutton vs. SNR Hutton)

Table 6.1 B Two-sample t-test comparing the effect of rainfall on tree height (SEF vs. SNR): height class 1 (0.0 – 0.5 m)

```
Variate: TH
Group factor: Site

Summary

                                          Standard   Standard error
Sample    Size      Mean     Variance    deviation          of mean
1           10    0.4350     0.003539      0.05949          0.01881
3           10    0.4260     0.002916      0.05400          0.01707

Difference of means:           0.0090
Standard error of difference:  0.0254

95% confidence interval for difference in means: (-0.04438, 0.06238)

Test of null hypothesis that mean of TH with Site = 1 is equal to mean with Site = 3

Test statistic t = 0.35 on 18 d.f.

Probability = 0.727
```

Table 6.2 B Two-sample t-test comparing the effect of rainfall on tree height (SEF vs. SNR): height class 2 (0.5 – 1.5 m)

```
Variate: TH
Group factor: Site

Summary

                                          Standard   Standard error
Sample    Size      Mean     Variance    deviation          of mean
1           10     1.191      0.06001       0.2450          0.07747
3           10     1.465      0.00129       0.0360          0.01138

Difference of means:           -0.2740
Standard error of difference:   0.0783

95% confidence interval for difference in means: (-0.4500, -0.09799)

Test of null hypothesis that mean of TH with Site = 1 is equal to mean with Site = 3

Test statistic t = -3.50 on approximately 9.39 d.f.

Probability = 0.006
```

Table 6.3 B Two-sample t-test comparing the effect of rainfall on tree height (SEF vs. SNR): height class 3 (1.5 – 2.0 m)

Variate: TH
Group factor: Site

Summary

Sample	Size	Mean	Variance	Standard deviation	Standard error of mean
1	10	1.822	0.01088	0.1043	0.03299
3	10	1.702	0.01286	0.1134	0.03586

Difference of means: 0.1200
Standard error of difference: 0.0487

95% confidence interval for difference in means: (0.01762, 0.2224)

Test of null hypothesis that mean of TH with Site = 1 is equal to mean with Site = 3

Test statistic t = 2.46 on 18 d.f.

Probability = 0.024

Table 6.4 B Two-sample t-test comparing the effect of rainfall on tree height (SEF vs. SNR): height class 4 (2.0 – 3.0 m)

Variate: TH
Group factor: Site

Summary

Sample	Size	Mean	Variance	Standard deviation	Standard error of mean
1	10	2.541	0.08665	0.2944	0.09309
3	10	2.543	0.05360	0.2315	0.07321

Difference of means: -0.002
Standard error of difference: 0.118

95% confidence interval for difference in means: (-0.2508, 0.2468)

Test of null hypothesis that mean of TH with Site = 1 is equal to mean with Site = 3

Test statistic t = -0.02 on 18 d.f.

Probability = 0.987

Table 6.5 B Two-sample t-test comparing the effect of rainfall on tree height (SEF vs. SNR): height class 5 (>3 m)

Variate: TH
Group factor: Site

Summary

Sample	Size	Mean	Variance	Standard deviation	Standard error of mean
1	10	3.858	0.2654	0.5152	0.1629

```
3            10        4.850      1.1161      1.0565            0.3341

Difference of means:               -0.992
Standard error of difference:       0.372

95% confidence interval for difference in means: (-1.795, -0.1893)
```

Test of null hypothesis that mean of TH with Site = 1 is equal to mean with Site = 3

```
Test statistic t = -2.67 on approximately 13.05 d.f.

Probability = 0.019
```

7B. Impact of rainfall on the number of tree rings of *A. tortilis*: (SEF Hutton vs. SNR Hutton)

Table 7.1 B Two-sample t-test comparing the effect of rainfall on tree rings (SEF vs. SNR): height class 1 (0.0 – 0.5 m)

```
Variate: NR
Group factor: Site

Summary

                                        Standard   Standard error
Sample   Size     Mean    Variance     deviation          of mean
1          10    9.700       5.344         2.312           0.7311
3          10    8.200       5.511         2.348           0.7424

Difference of means:            1.500
Standard error of difference:   1.042

95% confidence interval for difference in means: (-0.6890, 3.689)

Test of null hypothesis that mean of NR with Site = 1 is equal to mean with Site = 3

Test statistic t = 1.44 on 18 d.f.

Probability = 0.167
```

Table 7.2 B Two-sample t-test comparing the effect of rainfall on tree rings (SEF vs. SNR): height class 2 (0.5 – 1.5 m)

```
Variate: NR
Group factor: Site

Summary

                                        Standard   Standard error
Sample   Size     Mean    Variance     deviation          of mean
1          10    27.80       31.96         5.653            1.788
3          10    16.70       12.46         3.529            1.116

Difference of means:            11.100
Standard error of difference:    2.107

95% confidence interval for difference in means: (6.673, 15.53)

Test of null hypothesis that mean of NR with Site = 1 is equal to mean with Site = 3

Test statistic t = 5.27 on 18 d.f.

Probability < 0.001
```

Table 7.3 B Two-sample t-test comparing the effect of rainfall on tree rings (SEF vs. SNR): height class 3 (1.5 – 2.0 m)

Variate: NR
Group factor: Site

Summary

Sample	Size	Mean	Variance	Standard deviation	Standard error of mean
1	10	46.20	290.0	17.03	5.385
3	10	25.20	118.8	10.90	3.447

Difference of means:	21.000
Standard error of difference:	6.394

95% confidence interval for difference in means: (7.567, 34.43)

Test of null hypothesis that mean of NR with Site = 1 is equal to mean with Site = 3

Test statistic t = 3.28 on 18 d.f.

Probability = 0.004

Table 7.4 B Two-sample t-test comparing the effect of rainfall on tree rings (SEF vs. SNR): height class 4 (2.0 – 3.0 m)

Variate: NR
Group factor: Site

Summary

Sample	Size	Mean	Variance	Standard deviation	Standard error of mean
1	10	64.10	169.9	13.03	4.122
3	10	53.80	288.8	17.00	5.374

Difference of means:	10.300
Standard error of difference:	6.773

95% confidence interval for difference in means: (-3.929, 24.53)

Test of null hypothesis that mean of NR with Site = 1 is equal to mean with Site = 3

Test statistic t = 1.52 on 18 d.f.

Probability = 0.146

Table 7.5 B Two-sample t-test comparing the effect of rainfall on tree rings (SEF vs. SNR): height class 5 (>3 m)

```
Variate: NR
Group factor: Site

Summary

                                           Standard   Standard error
Sample    Size      Mean    Variance     deviation          of mean
1           10    101.50       410.9         20.27            6.410
3           10     81.40       580.3         24.09            7.618

Difference of means:            20.100
Standard error of difference:    9.956

95% confidence interval for difference in means: (-0.8167, 41.02)

Test of null hypothesis that mean of NR with Site = 1 is equal to mean with Site = 3

Test statistic t = 2.02 on 18 d.f.

Probability = 0.059
```

8B. Impact of rainfall on the crown diameter of *A. tortilis*: (SEF Hutton vs. SNR Hutton)

Table 8.1 B Two-sample t-test comparing the effect of rainfall on crown diameter (SEF vs. SNR): height class 1 (0.0 – 0.5 m)

```
Variate: CD
Group factor: Site

Summary

                                              Standard    Standard error
Sample     Size       Mean      Variance     deviation          of mean
SEF       10 0.8120 0.10746       0.3278      0.10366
SNR          10     0.6290       0.02703       0.1644           0.05199

Difference of means:              0.183
Standard error of difference:     0.116

95% confidence interval for difference in means: (-0.06065, 0.4266)

Test of null hypothesis that mean of CD with Site = 1 is equal to mean with Site = 3

Test statistic t = 1.58 on 18 d.f.

Probability = 0.132
```

Table 8.2 B Two-sample t-test comparing the effect of rainfall on crown diameter (SEF vs. SNR): height class 2 (0.5 – 1.5 m)

```
Variate: CD
Group factor: Site

Summary

                                              Standard    Standard error
Sample     Size       Mean      Variance     deviation          of mean
1            10      1.926        0.2833       0.5322           0.1683
3            10      1.965        0.2666       0.5163           0.1633

Difference of means:             -0.039
Standard error of difference:     0.234

95% confidence interval for difference in means: (-0.5316, 0.4536)

Test of null hypothesis that mean of CD with Site = 1 is equal to mean with Site = 3

Test statistic t = -0.17 on 18 d.f.

Probability = 0.870
```

Table 8.3 B Two-sample t-test comparing the effect of rainfall on crown diameter (SEF vs. SNR): height class 3 (1.5 – 2.0 m)

Variate: CD
Group factor: Site

Summary

Sample	Size	Mean	Variance	Standard deviation	Standard error of mean
1	10	2.270	0.5206	0.7215	0.2282
3	10	2.010	0.7016	0.8376	0.2649

Difference of means: 0.260
Standard error of difference: 0.350

95% confidence interval for difference in means: (-0.4745, 0.9945)

Test of null hypothesis that mean of CD with Site = 1 is equal to mean with Site = 3

Test statistic t = 0.74 on 18 d.f.

Probability = 0.467

Table 8.4 B Two-sample t-test comparing the effect of rainfall on crown diameter (SEF vs. SNR): height class 4 (2.0 – 3.0 m)

Variate: CD
Group factor: Site

Summary

Sample	Size	Mean	Variance	Standard deviation	Standard error of mean
1	10	3.417	0.344	0.587	0.1856
3	10	1.825	2.200	1.483	0.4691

Difference of means: 1.592
Standard error of difference: 0.504

95% confidence interval for difference in means: (0.4903, 2.694)

Test of null hypothesis that mean of CD with Site = 1 is equal to mean with Site = 3

Test statistic t = 3.16 on approximately 11.75 d.f.

Probability = 0.008

Table 8.5 B Two-sample t-test comparing the effect of rainfall on crown diameter (SEF vs. SNR): height class 5 (>3 m)

Variate: CD
Group factor: Site

Summary

Sample	Size	Mean	Variance	Standard deviation	Standard error of mean
1	10	5.101	0.245	0.495	0.1567

```
3           10       2.422      5.259      2.293          0.7252

Difference of means:           2.679
Standard error of difference:  0.742

95% confidence interval for difference in means: (1.022, 4.336)

Test of null hypothesis that mean of CD with Site = 1 is equal to mean with Site = 3

Test statistic t = 3.61 on approximately 9.84 d.f.

Probability=0.005
```

9B. DETERMINATION OF TREE AGE

Table 9.1 B Linear modelling

Identifier	Minimum	Mean	Maximum	Values	Missing
SC	2.000	24.67	74.00	150	0
NR	5.000	41.34	130.0	150	0

Regression analysis

Response variate: SC
Fitted terms: Constant + NR

Summary of analysis

Source	d.f.	s.s.	m.s.	v.r.	F pr.
Regression	1	40425.	40425.30	2376.36	<.001
Residual	148	2518.	17.01		
Total	149	42943.	288.21		

Percentage variance accounted for 94.1
Standard error of observations is estimated to be 4.12.

The following units have large standardized residuals.

Unit	Response	Residual
43	43.00	-7.11

Estimates of parameters

Parameter	estimate	s.e.	t(148)	t pr.
Constant	2.885	0.560	5.15	<.001
NR	0.5271	0.0108	48.75	<.001

```
     -+---------+---------+---------+---------+---------+
75.0 I                                        3         I
     I                                     3            I
     I                                 3         1      I
     I                                3                 I
     I                                  111 1           I
     I                           3   1                  I
50.0 I                        33    12                  I
     I                        3112 12 2                 I
     I                      3:: :2               1      I
     I                     331:                         I
     I                 :  :::1                          I
     I            : 2 :212                              I
25.0 I          :: : :  2                               I
     I       11:::                                      I
     I      1 :3                                        I
     I     ::33                                         I
     I   :::                                            I
     I  :::                                             I
 0.0 I  :1                                              I
     -+---------+---------+---------+---------+----------
    0.0      30.0      60.0      90.0     120.0     150.0

                     SC  v. NR using factor Site
```

Table 9.2 B Quadratic modelling

Number of rings modelled against stem circumference.rtf

Identifier	Minimum	Mean	Maximum	Values	Missing
SC	2.000	24.55	74.00	150	1
NR	5.000	40.74	129.0	150	1

Correlations (-1 < r < 1)

NR	1	-			
SC	2	**0.9803**	-		
CD	3	0.6920	0.6565	-	
TH	4	0.8485	0.8712	0.6240	-
		1	2	3	4

Number of observations: 149

Two-sided test of correlations different from zero

NR	1	-			
SC	2	**<0.001**	-		
CD	3	<0.001	<0.001	-	
TH	4	<0.001	<0.001	<0.001	-
		1	2	3	4

Predictions from the regression model at the three sites

Site	1		2		3		
		Prediction	s.e.	Prediction	s.e.	Prediction	s.e.
	SC						
	2	3.55	0.817	3.16	0.777	4.17	0.802
	8	11.63	0.658	10.54	0.638	13.60	0.610
	14	20.48	0.666	19.39	0.742	23.00	0.638
	20	30.10	0.731	29.70	0.828	32.36	0.758
	26	40.47	0.775	41.48	0.824	41.70	0.867
	32	51.61	0.781	54.72	0.791	51.01	0.934
	38	63.52	0.771	69.42	0.918	60.29	0.961
	44	76.18	0.808	85.58	1.367	69.53	0.973
	50	89.61	0.976	103.21	2.112	78.75	1.019
	56	103.80	1.313	122.30	3.100	87.93	1.159

62	118.76	1.808	142.86	4.303	97.09	1.439
68	134.47	2.440	164.87	5.711	106.21	1.863
74	150.95	3.196	188.35	7.318	115.31	2.421

Estimates of parameters

Site	TreeNr	Height_Class	NR	SC	FITTED	RESIDUAL
1	1	1	12	6.00	9.21	-0.7831
1	2	1	13	6.00	9.74	-0.9115
1	3	1	9	4.00	7.63	-0.8858
1	4	1	11	5.00	8.68	-0.8987
1	5	1	12	5.00	9.21	-1.0271
1	6	1	10	5.00	8.16	-0.7702
1	7	1	7	3.00	6.57	-0.8730
1	8	1	6	2.00	6.05	-0.9888
1	9	1	9	4.00	7.63	-0.8858
1	10	1	8	2.00	7.10	-1.2457
1	11	2	18	17.00	12.37	1.1280
1	12	2	36	28.00	21.86	1.4941
1	13	2	30	23.00	18.70	1.0474
1	14	2	26	20.00	16.59	0.8306
1	15	2	31	25.00	19.22	1.4057
1	16	2	21	19.00	13.95	1.2295
1	17	2	26	21.00	16.59	1.0741
1	18	2	34	25.00	20.80	1.0208
1	19	2	31	23.00	19.22	0.9190
1	20	2	25	19.00	16.06	0.7156
1	21	3	71	36.00	40.31	-1.0507
1	22	3	55	29.00	31.87	-0.6993
1	23	3	37	28.00	22.39	1.3658
1	24	3	33	25.00	20.28	1.1491
1	25	3	62	34.00	35.56	-0.3806
1	26	3	72	37.00	40.83	-0.9355
1	27	3	34	24.00	20.80	0.7775
1	28	3	31	25.00	19.22	1.4057
1	29	3	29	24.00	18.17	1.4191
1	30	3	38	27.00	22.91	0.9943
1	31	4	64	35.00	36.62	-0.3939
1	32	4	73	41.00	41.36	-0.0879
1	33	4	49	30.00	28.71	0.3137
1	34	4	66	35.00	37.67	-0.6510
1	35	4	52	32.00	30.29	0.4157
1	36	4	70	36.00	39.78	-0.9219

1	37	4	59	33.00	33.98	-0.2390
1	38	4	45	27.00	26.60	0.0967
1	39	4	77	46.00	43.47	0.6186
1	40	4	86	46.00	48.21	-0.5418
1	41	5	69	35.00	39.25	-1.0371
1	42	5	108	59.00	59.81	-0.1994
1	43	5	130	43.00	71.40	-7.1052
1	44	5	103	57.00	57.17	-0.0424
1	45	5	113	60.00	62.44	-0.6050
1	46	5	129	65.00	70.88	-1.4689
1	47	5	94	55.00	52.43	0.6317
1	48	5	75	45.00	42.41	0.6315
1	49	5	90	50.00	50.32	-0.0785
1	50	5	104	58.00	57.70	0.0743