A plant ecological evaluation of mechanical bush thinning in Marakele Park, Limpopo Province

By

FRANCINA CHRISTINA PIENAAR

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In the faculty of Natural & Agricultural Sciences
Department of Animal, Wildlife and Grassland Sciences
University of the Free State
Bloemfontein
South Africa

Supervisor: Prof. G.N. Smit
Department of Animal, Wildlife and Grassland Sciences, UVS, Bloemfontein

Co-supervisor: Dr. P.J. du Preez
Department of Plant Sciences, UVS, Bloemfontein

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CHAPTER 1

INTRODUCTION

In southern Africa the phenomenon of increasing woody plant density is commonly referred to as 'bush encroachment' and it involves the invasion of grasslands and the thickening of savanna (O'Connor & Crow, 1999). The grazing capacity of large areas of the South African savanna (bushveld) is reported to have declined due to bush encroachment (Donaldson, 1980; Gammon, 1984). On estimate some 20 million hectares of South Africa alone are currently affected by bush encroachment (Smit, 2003a). Removal of some or all of the woody plants will normally result in an increase of grass production and thus in grazing capacity. However, the results of woody plant removal may differ between veld types, with the outcome determined by both negative and positive responses to tree removal. This is because in savanna vegetation the physical determinants, biological interactions and individual species properties are unique to each spatial and temporal situation. In addition, past management practice has added to the complexity by bringing about different kinds and degrees of modification (Teague & Smit, 1992). The rapid establishment of woody seedlings after the removal of some or all of the mature woody plants may reduce the effective time span of bush control measures. In many cases the resultant re-establishment of new woody seedlings may in time develop into a state that is worse than the original (Smit *et al.*, 1999).

Bush control measures should comply with two important requirements before they can be considered successful. They should be ecologically responsible and economically justifiable. In southern Africa, judged on these two basic requirements, it is conceived that very few attempts at solving the bush encroachment problem can be considered successful. This is either because the cost is too high or the wrong approach has been followed, resulting in the loss of valuable woody plants and re-encroachment (Smit, 2003b).

According to Campbell (2000), a control programme for the management of encroaching vegetation must include three phases, namely:

- Initial control: drastic reduction of the existing population (e.g. cut trees, remove wood, control stumps, plant grass) plus hand or aerial application of herbicides with residual effect.
- Follow-up control: control of woody seedlings, root suckers and coppice regrowth (e.g. foliar and soil application of herbicides).

- Maintenance control: sustain low undesired plant numbers/density with low annual control costs (e.g. burn high fuel loads of grass). In this phase, encroaching plants are no longer considered a problem.

It is, nevertheless, important to monitor the situation two to three times a year (spring, mid summer and autumn) to avoid re-encroachment, spread and densification of undesired plants, and thereby increased control costs (Campbell, 2000). With bush encroachment, however, where the aim is not to eradicate all woody plants, but merely to manage them at more acceptable densities, effective control is often more complex.

Potential aids to the control of woody plants incorporate biological, chemical and mechanical procedures, each with their own potential uses and restrictions. So, for example, biological control is usually, but not always, restricted to the early prevention of bush encroachment or to the post-thinning management phase, while chemical and mechanical procedures are better suited to the initial thinning operations. Biological, chemical and/or mechanical procedures are not, therefore, necessarily mutually exclusive. Each needs to be applied in the appropriate circumstances (Smit *et al.*, 1999). An integrated control strategy uses a combination of the most suitable control methods for a species in a particular situation (De Beer & Jordaan, 2001). Such a strategy should incorporate methods to restore the bare soil after the removal of undesired plants especially on soils with a high clay content where capping is a major problem. Selection of suitable control methods should take the following factors into account:

- type of plant species,
- growth form (e.g. tree, shrub, seedling),
- density of the undesired plants,
- terrain,
- restoration requirements,
- available resources, and
- urgency/speed of control required for encroachment reduction, e.g. herbicides can achieve rapid thinning; biological control is slow but can be more permanent for some species (Campbell, 2000).

An important step to consider in vegetation restoration is the extent of transformation (from the original pristine state) of the specific area that needs to be restored. The greater the transformation, the greater the amount of post-thinning intervention required.

If, for example, a site has been ploughed or repeatedly burnt (to improve grazing) prior to encroachment, it is likely that indigenous soil-stored seed banks would have been entirely depleted and plant species will need to be re-introduced. However, if no disturbance other than encroachment has occurred at the site, there is potentially a seed bank of indigenous species in the soil that could be used in restoring the area after thinning (Holmes & Allsopp, 2000).

Biological control measures include procedures such as normal veld fires, stem burning and the use of browsers. Veld fires alone are less effective in killing woody components (Rutherford, 1981; Belsky, 1984; Sweet & Mphinyane, 1986; Trollope, 1999) but can be used to modify the structure of the woody layer (Harrington & Ross, 1974; Trollope, 1974; Trollope, 1980; Trollope, 1983; Trollope & Tainton, 1986, Sabiiti & Wein, 1988; Tainton *et al.*, 1991; Van Rooyen *et al.*, 2002).

Stem burning, in which a low intensity fire burns or smoulders for an extended period around the stem of the woody plant, can be used to selectively kill individual trees. This procedure is reasonably inexpensive as any available fuel may be used, but it is labour intensive and time consuming. It is not well suited for trees with small stems or for multi-stemmed woody species (Smit *et al.*, 1999).

Except for elephants (*Loxodonta africana*), the use of browsers for woody plant control largely excludes game (Anderson & Walker, 1974; Barnes, 1983; Pellew, 1983; Kalemera, 1989; Lewis, 1991). However, elephants are confined to large game reserves or game ranches and even here the number of elephants required for any significant impact on the woody vegetation would have to be so large that serious management problems could arise (Smit *et al.*, 1999).

The application of chemical control methods is normally expensive and should be considered only under specific circumstances. Chemical control is primarily suited for the initial thinning stage of bush control, although it can be used in follow-up operations. It may be necessary to resort to chemical control methods in the case of:

- the woody component being so dense that not enough fuel can be accumulated to support a fire intense enough to kill the top-growth of the target woody species,
- the majority of trees having grown beyond the reach of browsing animals,
- the tree density is so extensive that animal access is severely restricted,
- the woody component being largely unpalatable,
- where, for a variety of reasons, it is not practical to incorporate domestic browsers, and

- where herbicides are available, which will selectively affect the target woody species more severely than the palatable species (Trollope *et al.*, 1989).

When using herbicides it is important to adhere to the label recommendations and to avoid any contamination of non-target areas, especially erodable soil and water bodies. This method requires intensive management and close supervision. Restoration by planting suitable grass species can be seen as a control method because the establishment of a dense healthy grass cover can suppress undesired plant seedlings, stabilise the soil (i.e. combat soil erosion that would encourage re-encroachment) and the burning of high grass fuel loads can control undesired woody seedlings (Campbell, 2000).

Two broad types of herbicides are available for use. The first type is applied to the soil surface and is absorbed by plant roots and the second is sprayed onto the plant and absorbed directly by the aboveground parts of the plant. Soil applied formulations are marketed in the form of granules, wettable powders or liquid, with the active ingredient ranging in concentration from 10% to 70%. Granular products can be applied by hand, with some suited to aerial application. The latter procedure is, however, less often used because it is less selective than hand applications. With hand application, measured quantities of the granules are spread under the crown of the target plant, close to the stems. Wettable powders or liquid formulas need to be mixed with water and sprayed onto the soil surface adjacent to the stem of the tree.

Herbicides applied directly to the plant are either oil or water based and should be applied to either the stem or the leaves of the plant. They can be sprayed over the whole plant, onto only the stem of plants cut off close to the soil surface, or they can be applied to coppice growth (Smit *et al.*, 1999). When using foliar applications, the best time to spray is when the leaves of the plant are fully developed and maintain a high photosynthetic rate (Van Rooyen *et al.*, 2002).

Small trees with a stem diameter of less than 10 cm can be sprayed directly, while those with a stem diameter larger than 10 cm should be cut back before treatment. Here the tree should be cut off approximately 5 to 15 cm above the soil surface and be treated immediately after cutting. The cut surface and the remaining stump, as well as any exposed roots, should be thoroughly wetted (Smit *et al.*, 1999).

Soil applied herbicides, however, are not very selective since untreated woody plants often have roots that stretch far beyond their canopy diameter and can thus absorb these chemicals. It has been proved that non-target trees can absorb chemicals as far as 20 – 50 m from their trunks (Smit & Rethman, 1998b). Therefore it is generally not suited for use in conservation areas.

Herbicides sprayed onto plants are more selective since application is directly onto the target plant thus leaving other plants unaffected. However, chemicals are expensive and the application thereof is time consuming. Varying climatic and soil conditions may also affect the functioning of herbicides.

Mechanical thinning usually employs a heavy implement such as a bulldozer blade, which may also remove some of the roots of trees. However, this type of mechanical thinning almost always causes soil disturbance that can result in soil degradation and an increased establishment of pioneer seedlings such as *Dichrostachys cinerea* (sickle bush). The soil disturbance can initiate soil erosion, which removes the topsoil (the most fertile portion of the soil), leading to reduced permeability (less available water and minerals for plant utilisation) and ultimately to herbaceous vegetation with lower cover abundance and reduced feeding quality. These consequences are undesirable, as one of the most important objectives of veld management should be to encourage the development of a dense and stable herbaceous plant cover, so as to effectively control the rate of soil loss (Snyman, 1999). An alternative to a bulldozer is a mechanical cutter/mulcher such as the Barko Mulching Tractor, which cuts the tree stems to ground level and does not disturb the soil. It may, however, compact the soil due to its substantial weight.

The Barko Tractor was introduced to the South African savanna for the first time in March 2002 (Game & Hunt, 2003). The Barko tractor has been implemented on bush encroached areas in the Marakele Park (Pty.) Ltd. with the following objectives (Schroder, personal communication*****):

(i) To increase grass production and thus grazing capacity,

(ii) To improve biodiversity by increasing the species diversity, and

(iii) To increase the visibility of wildlife for the benefit of eco-tourism.

The concerns expressed not only regarding the success of this specific mechanical thinning procedure applied in Marakele Park (Pty.) Ltd., but also whether the set objectives were achieved, was the motivation for this study. This study was conducted with the following objectives:

(i) to identify, describe and interpret the plant communities of the specific study area in Marakele Park (Pty.) Ltd. ecologically, and thus determine the broad species diversity of the area,

*****Schroder, B., The Marakele Park (Pty.) Ltd., P.O. Box 2103, Thabazimbi, Limpopo Province, 0380, South Africa.

(ii) to establish the influence of the mechanical tree thinning treatments on different aspects of the woody layer, such as species composition, tree density, leaf biomass, browse production and browse capacity,

(iii) to determine the effect of the mechanical tree thinning treatments on coppice regrowth of the woody plants and the establishment of woody seedlings.

(iv) to evaluate the influence of the tree thinning treatments on the herbaceous species composition and veld condition,

(v) to assess the effect of this method of mechanical tree thinning on the herbaceous dry matter yield and associated grazing capacity, and

(vi) to describe the soil properties of the study area and to determine if the tree thinning treatments had any short term effects on the soil properties.

CHAPTER 2

STUDY AREA AND TRIAL LAYOUT

2.1 STUDY AREA

2.1.1 Geographical location

The Marakele National Park as well as the privately owned, contractual Marakele Park (Pty.) Ltd. and private game reserve, Welgevonden (hereafter referred to as the Greater Marakele National Park) is situated approximately 16 km north-east of Thabazimbi (Figure 2.1) in the south-western corner of the Waterberg Mountain Range and adjacent plains area in the Limpopo Province (formerly Northern Province), South Africa (Figure 2.2).

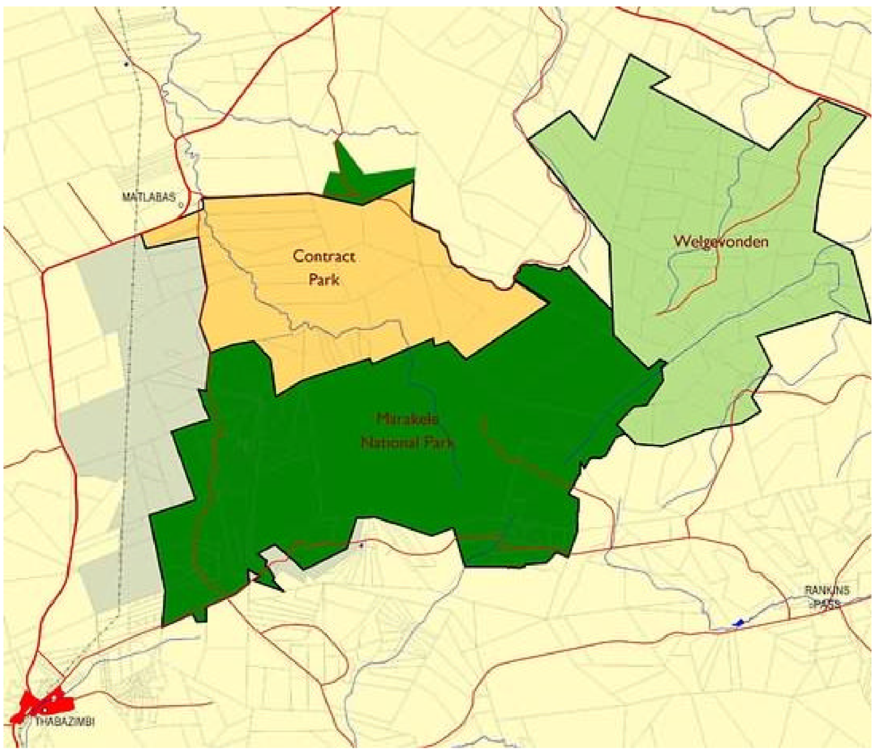


Figure 2.1: An illustration of the conservation areas that is included in the Greater Marakele National Park – namely Marakele National Park, Marakele Park (Pty.) Ltd. (contract park) and Welgevonden private nature reserve.

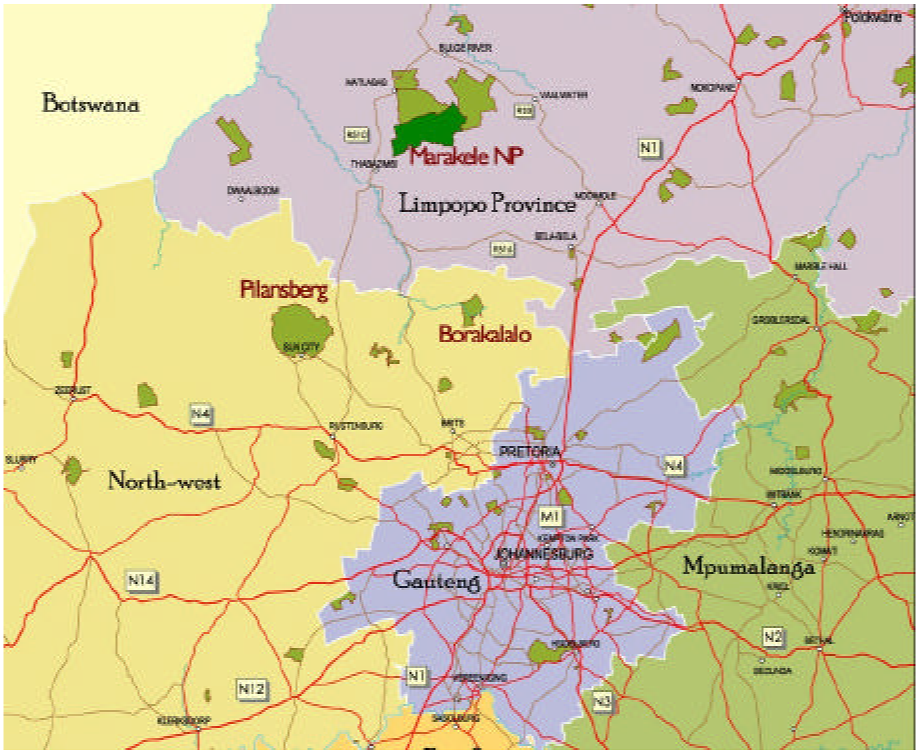


Figure 2.2: The geographical location of the Greater Marakele National Park in relation to the nearest towns and cities.

The Greater Marakele National Park currently extends from latitudes 24º15´ to 24º35´ south and longitudes 27º27´ to 27º47´ east. It is located in the transitional zone between the dry western and moister eastern regions of South Africa in a malaria-free area. The main water source of Marakele Park (Pty.) Ltd. (hereafter referred to as Marakele Park) is the Matlabas River. The catchment area of this river is situated in the Kransberg Mountains and flows down through the Matlabas Zijn Kloof into the lower lying areas. It primarily provides the park with water during the rainy season, but Marakele Park is provided with water all year round by three man made dams that are situated in the reserve.

2.1.2 History of the Greater Marakele National Park

The Marakele National Park, formerly known as the Kransberg National Park, was initiated in 1988 and formally proclaimed on 11 February 1994. The Minister of Environmental Affairs and Tourism proclaimed Marakele Park as a Schedule Two National Park in 2001. By way of a considerable investment from a Dutch businessman and philanthropist, Paul van Vlissingen, to assist South African National Parks (SANP) with the development of Marakele National Park, land is being bought and incorporated into the existing park on a contractual basis.

The Park is currently about 120 000 ha in extent (this includes contractual and scheduled property). There are no fences between Marakele National Park and Marakele Park, but fences are still present between Marakele National Park and the Welgevonden private nature reserve. However, the aim is to remove all fences to create a larger area with a higher biodiversity. The Greater Marakele National Park has an abundance of iron-age sites that will be made accessible to tourists in the future.

2.1.3 Geology and soil

Plant communities are directly related to geology and soil types that may occur in a specific area (Van Rooyen & Theron, 1996). As reported by Henning (2002), the geology of the Waterberg has already been described extensively by Jansen (1982) and Callaghan (1987) and can be divided into the Nylstroom, Matlabas and Kransberg Subgroups. The major geological formations of The Greater Marakele National Park are Post-Waterberg Rocks, Skilpadkop, Aasvoëlkop and Sandriviersberg (Henning, 2002). The park also consists of many different land types and soil forms that are described in Table 2.1.

Table 2.1: A description of the different land types and soil forms that characterise each of the ecological terrains that can be found in the Greater Marakele National Park (Beech & Van Riet, 2002a).

ECOLOGICAL TERRAIN	LAND TYPE	SOIL FORM*
Crest	Fa	Rock Mispah
Drainage line	Bd	Longlands Avalon
Drainage lines	Ae	Hutton Avalon
Drainage lines	Ib	Rock Oackleaf
Footslope	Ad	Clovelly Hutton
Lowland	Ah	Clovelly Oakleaf
Midslope	Ad	Clovelly Rock Mispah
Midslope	Fa	Rock Mispah Hutton

…Continues

Table 2.1 continued…

ECOLOGICAL TERRAIN	LAND TYPE	SOIL FORM*
Midslope	Ib	Rock Mispah Glenrosa
Plain	Ah	Clovelly Hutton
Scarp	Ib	Rock
Upper lowland	Bd	Avalon Longlands Clovelly
Valley floor	Fa	Hutton Clovelly
Wetland	Fa	Avalon Westleigh Katspruit

*Soil forms as described by MacVicar *et al.* (1977) and the Soil Classification Working Group (1991).

The location of the different land types and soil forms within the Greater Marakele National Park is illustrated in Figure 2.3.

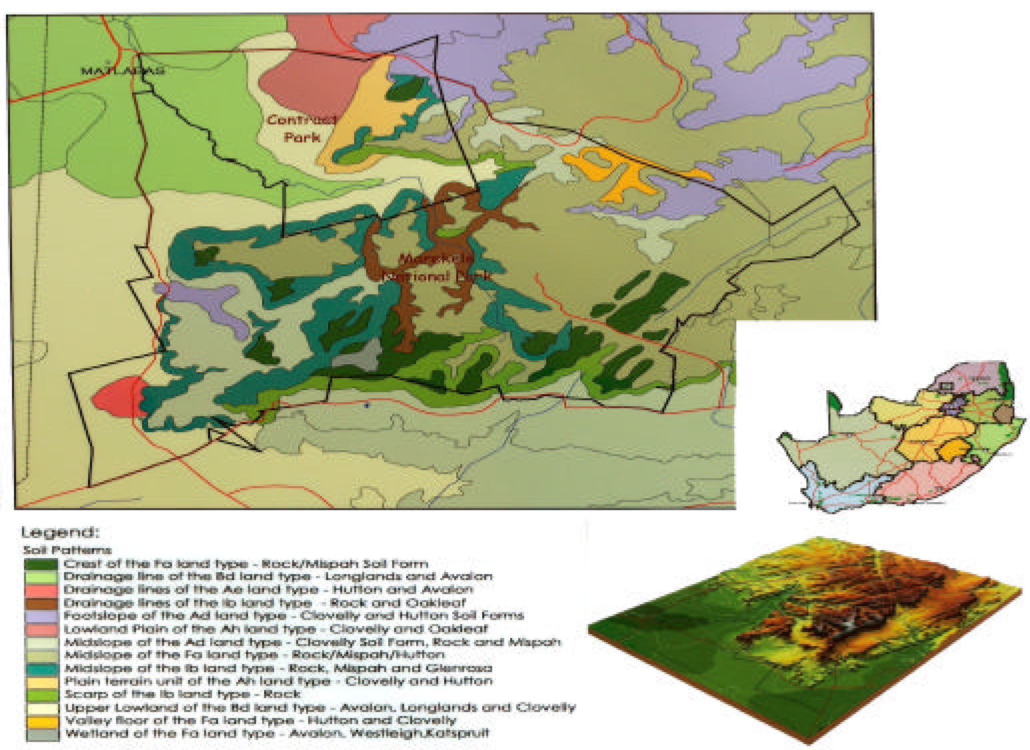


Figure 2.3: The distribution of the different land types and soil forms that can be found in the Greater Marakele National Park (Beech & Van Riet, 2002a).

Acocks (1988) also gives a description of the soil of the different vegetation types found in the Greater Marakele National Park (see section 2.1.5). He describes the soil of the Arid Sweet Bushveld as deep, fine grey-brown sand overlying granite, quartzite, sandstone or shale. The Mixed and Sourish Mixed Bushveld have shallow soil with impeded drainage. The underlying rocks are granite, sandstone, quartzite or shale covered by a shallow layer of gritty yellow-grey sandy loam on ouklip. The underlying rocks of the Sour Bushveld are described as quartzite, sandstone or shale covered by a soil of a sandy, gravelly nature that is very poor and sour. The description of the soils as given by the classification of the vegetation types of Low & Rebelo (1996) also corresponds with those of Acocks (1988).

2.1.4 Climate

Climate is a major determinant of the geographical distribution of species and vegetation types. Within any particular region, however, it is the microclimate, greatly influenced by local topography, which is of the greatest importance. Within any area of general climatic uniformity, local conditions of temperature, light, humidity and moisture vary greatly, and these factors play an important role in the production and survival of plants (Tainton & Hardy, 1999). The climatic data presented in the following sections were obtained from the Thabazimbi Weather Station.

2.1.4.1 *Temperature*

As with most environmental factors, it is not the mean, but the temperature range, which is most important for the survival of plants (Tainton & Hardy, 1999). In general, extreme weather conditions prevail within the Greater Marakele National Park, with dry hot summers and cold winter spells with frost in the lower lying areas. Temperatures within the Waterberg Moist Mountain Bushveld range from -6ºC to 39ºC, with an average of 18ºC. The temperature of the Sweet Bushveld varies between -5ºC and 40ºC, with an average of 21ºC, whereas the temperature of the Mixed Bushveld ranges between -8ºC and 40ºC, with an average of 21ºC (Low & Rebelo, 1996). The average monthly minimum and maximum temperatures obtained from the Thabazimbi Weather Station is presented in Tables 2.2 and 2.3, respectively.

Table 2.2: Average monthly minimum temperatures (ºC) for the years 1983-2005 (Thabazimbi Weather Station – 0587725CX).

Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MEAN
1983	-	-	-	-	-	-	2.7	4.2	10.7	15.8	18.4	18.7	11.8
1984	19.3	19.1	17.0	10.6	4.9	2.1	4.0	6.3	12.5	16.9	16.4	18.0	12.3
1985	19.1	18.1	16.4	9.3	4.5	1.8	1.2	7.2	12.5	17.2	18.5	18.7	12.0

…Continues

Table 2.2 continued…

Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MEAN
1986	19.2	17.5	16.9	13.8	7.4	2.3	2.5	6.5	12.4	15.0	16.2	18.7	12.4
1987	18.9	20.0	17.1	13.5	6.1	1.0	1.0	5.7	12.4	14.9	16.5	18.6	12.1
1988	18.8	18.3	-	-	4.5	0.7	-	4.3	10.2	14.6	15.6	16.8	11.5
1989	17.6	16.9	14.6	10.7	5.8	4.1	0.5	7.0	10.1	14.0	14.8	16.2	11.0
1990	17.8	15.4	15.4	11.7	4.9	1.2	4.4	5.7	12.1	16.8	19.9	19.6	12.0
1991	19.7	18.2	17.9	9.2	5.5	3.3	0.5	5.4	14.1	16.0	17.0	17.6	12.0
1992	19.5	19.5	16.6	13.3	4.7	2.4	2.0	5.0	-	-	-	-	10.4
1993	-	-	16.5*	12.9	10.3*	-	-	-	13.5	18.1	17.8	20.0	16.5
1994	19.4	19.5	17.1	12.8	5.8	3.1	-0.1	7.1	12.2	16.2	19.3	19.3*	12.0
1995	20.8	20.4	18.4	13.1	9.8	2.7	3.3	8.9	14.4	18.3	19.1	17.9	13.9
1996	19.9	18.8	15.7	12.5	8.0	2.7	2.3	9.0	12.8	18.5	17.8	19.0	13.1
1997	19.5	19.2	17.4	10.3	5.5	1.4	2.7	5.5	13.5	15.7	17.0	-	11.6
1998	-	19.0*	19.6	12.6	6.2	1.4	3.4	5.9	14.0	17.2	18.2	-	10.9
1999	-	20.5	19.4	16.6	13.3	5.7	4.4	6.5	12.4	-	-	-	12.4
2000	18.2	20.8	19.7	13.5	5.7	7.2	3.9	1.9	15.4	18.6*	19.2*	21.0	12.7
2001	22.9	19.6	18.6	16.1	4.9*	2.4	2.4	7.4	12.5	17.2	17.6*	18.7	13.8
2002	19.6	19.6	16.7	12.9	6.7	4.3	1.7	9.4	12.1	16.5	18.3	19.5	13.1
2003	19.9	20.2	16.9	15.8	7.0	5.9	1.3	5.6	12.6	18.0	19.3	20.6	13.6
2004	19.5	18.6	17.6	13.6	6.8	3.0	1.3	6.9	10.3	16.1	19.0	18.9*	12.1
2005	20.2	18.8	16.7	13.2	7.5	4.6	-	-	-	-	-	-	13.5
MEAN	19.5	19.0	17.3	12.8	6.5	3.0	2.3	6.3	12.5	16.5	17.7	18.7	

***** Indicates that the average is unreliable due to missing daily values.
- Indicates that data is missing or not yet available.

Table 2.3: Average monthly maximum temperatures (ºC) for the years 1983-2005 (Thabazimbi Weather Station – 0587725CX).

Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MEAN
1983	-	-	-	-	-	-	23.0	23.6	30.3	29.8	32.5	30.4	28.3
1984	33.2	33.1	29.7	27.3	25.6	21.1	21.5	25.2	29.7	30.8	29.0	31.1	28.1
1985	31.4	30.7	30.2	27.4	24.5	22.5	22.1	25.6	27.2	30.6	31.6	29.9	27.8
1986	31.6	30.4	30.0	26.0	25.8	22.2	22.7	26.0	27.3	28.1	28.1	30.4	27.4
1987	32.0	32.9	30.7	30.4	27.3	21.9	21.7	24.1	26.3	29.4	30.9	30.5	28.2
1988	32.7	30.1	-	-	24.7	21.8	-	26.1	28.4	28.8	30.5	28.1	27.9
1989	30.4	28.0	29.6	25.2	25.1	22.4	22.6	27.1	28.9	29.6	29.4	31.1	27.5
1990	30.9	29.6	29.9	27.6	24.1	23.1	24.3	25.2	28.7	31.0	33.2	32.2	28.3
1991	30.8	30.2	27.6	26.9	25.4	22.2	22.7	25.7	29.2	31.6	30.5	30.5	27.8
1992	33.7	34.9	31.1	29.7	26.4	23.9	23.7	23.8	-	-	-	-	28.4
1993	-	-	28.0*	27.1	26.9*	-	-	-	31.3	30.4	29.6	31.3	29.9
1994	29.7	29.5	31.7	29.7	26.6	22.1	21.6	25.4	30.9	30.2	32.4	32.9*	28.2
1995	33.4	33.9	29.7	28.1	23.8	22.3	23.6	26.4	30.9	32.9	32.1	30.0	28.9
1996	30.2	28.9	28.7	26.1	24.1	22.9	21.3	25.1	30.2	33.0	30.7	31.7	27.7
1997	31.2	32.0	27.9	26.4	23.7	23.0	22.7	27.0	28.5	30.4	31.6	-	27.7
1998	-	32.8*	34.5	31.6	27.3	26.1	24.7	26.2	30.7	30.9	31.4	-	29.3
1999	-	33.1	34.0	32.3	30.0	25.9	23.0	26.5	28.1	-	-	-	29.1
2000	28.1	29.9	29.7	26.5	23.9	23.1	23.2	25.2*	30.5	34.6*	32.0*	34.6	27.7
2001	37.6	30.5	30.6	29.1	25.8*	23.2	22.3	27.4	28.5	31.2.	27.8*	30.9	28.9
2002	33.5	32.9	32.1	30.3	26.5	22.0	23.8	26.9	29.3	32.3	33.9	33.2	29.7
2003	34.9	34.5	34.1	32.1	26.6	22.7	23.5	25.2	31.0	33.2	31.6	35.0	30.4
2004	32.0	29.9	27.9	27.0	25.2	21.8	22.0	27.6	28.8	32.4	34.3	30.6*	28.1
2005	32.5	33.7	31.0	27.7	27.6	26.1	-	-	-	-	-	-	29.8
MEAN	32.1	31.4	30.5	28.3	25.7	23.0	22.8	25.8	29.3	30.9	31.3	31.3	

***** Indicates that the average is unreliable due to missing daily values.
- Indicates that data is missing or not yet available.

2.1.4.2 *Rainfall*

Rainfall is the factor which most clearly determines the distribution of plant communities in South Africa, as well as the potential productivity of these communities (Tainton & Hardy, 1999). The Greater Marakele National Park is situated in the summer rainfall region and according to Van Staden (2002a), on average, 93.7% of the rainfall occurs from October to April in the form of heavy thunderstorms or soft rain. Furthermore, the period September to November is generally associated with 'dry' thunderstorms, which occur predominantly on high lying areas. The 'dry' thunderstorms are normally characterised by cloudy skies with intense lightning and no rain. Natural veld fires, caused by the lightning, usually occur during such 'dry' thunderstorms. In the Waterberg Moist Mountain Bushveld, annual rainfall varies between 650 mm to 900 mm, whereas the rainfall in the Sweet and Mixed Bushveld is much lower and varies between 350 mm to 650 mm (Low & Rebelo, 1996). The average monthly rainfall obtained from the Thabazimbi Weather Station is presented in Table 2.4.

Table 2.4: Average monthly rainfall (mm) for the years 1983-2005 (Thabazimbi Weather Station – 0587725CX).

Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MEAN
1983	65.4	16.0	90.0	44.0	2.0	9.0	0.0	20.0	15.0	270.5	130.0	135.2	66.4
1984	14.5	24.0	126.0	0.0	0.0	41.0	29.0	0.0	10.0	96.0	96.0	172.9	50.8
1985	133.1	63.0	53.0	0.0	2.0	0.0	0.0	10.0	6.0	58.5	26.5	152.1	42.0
1986	68.5	72.5	80.5	56.0	1.0	0.0	0.0	4.0	29.5	88.0	130.0	102.5	52.7
1987	68.5	87.5	104.5	14.0	0.0	0.0	0.0	18.0	8.5	34.0	144.0	98.5	48.1
1988	103.0	163.5	140.5	54.5	0.0	1.0	0.0	8.0	37.0	92.5	32.0	144.0	64.7
1989	54.5	240.5	43.5	42.5	0.0	7.8	0.0	6.5	0.0	37.9	103.7	135.6	56.0
1990	78.6	111.2	94.0	57.0	0.0	0.0	0.0	0.0	10.3	22.1	18.0	69.2	38.4
1991	268.3	141.3	206.9	0.0	0.0	6.5	-	0.0	4.0	34.0	115.0	148.0	84.0
1992	34.5	46.7	82.6	34.6	0.0	2.5	0.0	0.0	0.0	38.0	131.7	80.5	37.6
1993	53.9	143.2	159.7	43.4	0.0	0.0	0.5	0.0	18.0	74.4	76.3	136.7	58.8
1994	115.9	107.5	12.7	3.8	0.0	0.0	0.0	0.0	0.8	50.3	30.1	119.1	36.7
1995	76.8	46.8	110.5	19.1	19.0	0.0	0.0	5.5	1.0	52.0	123.4	144.6	49.9
1996	127.8	324.4	52.5	42.0	7.3	0.0	1.9	0.0	0.4	47.8	77.4	148.7	69.1
1997	261.1	20.6	133.4	11.0	49.3	1.0	1.1	0.3	42.7	22.0	76.6	96.8	59.7
1998	115.1	55.2	17.7	0.0	0.0	0.0	0.0	2.0	2.9	29.7	78.9	251.2	46.1
1999	95.1	18.9	24.7	26.8	71.5	0.5	0.0	0.0	2.7	42.4	24.0	265.3	47.7
2000	308.0	237.8	119.9	27.0	23.0	15.9	1.3	0.0	0.0	74.4	90.1	64.5	80.2
2001	11.1	148.7	36.3	48.0	35.8	2.3	0.0	0.0	19.1	129.3	176.1	66.0	56.1
2002	26.1	35.8	35.6	36.4	1.0	44.3	0.0	2.0	11.0	60.7	0.7	207.8	38.5
2003	72.8	63.2	8.8	6.6	0.0	14.0	0.0	0.0	0.2	41.4	21.4	3.4	19.3
2004	0.4	46.4	166.2	52.4	0.0	1.6	21.6	0.0	0.0	0.6	0.4	0.6*	26.3
2005	26.2	0.4	0.2	0.0	0.0	0.0	-	-	-	-	-	-	4.5
MEAN	94.7	96.3	82.6	26.9	9.2	6.4	2.6	3.5	10.0	63.5	77.4	130.6	

***** Indicates that the average is unreliable due to missing daily values.

- Indicates that data is missing or not yet available.

2.1.5 Vegetation

2.1.5.1 *The Greater Marakele National Park*

The vegetation of the Greater Marakele National Park falls within the Savanna biome as described by Rutherford & Westfall (1986) and Low & Rebelo (1996). This biome is the largest biome in southern Africa, occupying 46% of its area, and over one third of South Africa. A herbaceous ground layer dominated by grasses and an upper layer of woody plants characterise the savanna biome. Where the upper layer is near the ground, the vegetation may be referred to as Shrubveld. Where it is dense, it is referred to as Woodland and the intermediate stages are locally known as Bushveld (Low & Rebelo, 1996). According to the classification of Low & Rebelo (1996), the Greater Marakele National Park consists of three vegetation types, namely Waterberg Moist Mountain Bushveld (Type 12), Sweet Bushveld (Type 17) and Mixed Bushveld (Type 18). According to Acocks (1988) it consists of five vegetation types, namely North-eastern Mountain Sourveld (A8), Arid Sweet Bushveld (A14), Mixed Bushveld (A18), Sourish-Mixed Bushveld (A19) and Sour Bushveld (A20). The distribution of the five vegetation types of Acocks is illustrated in Figure 2.4.

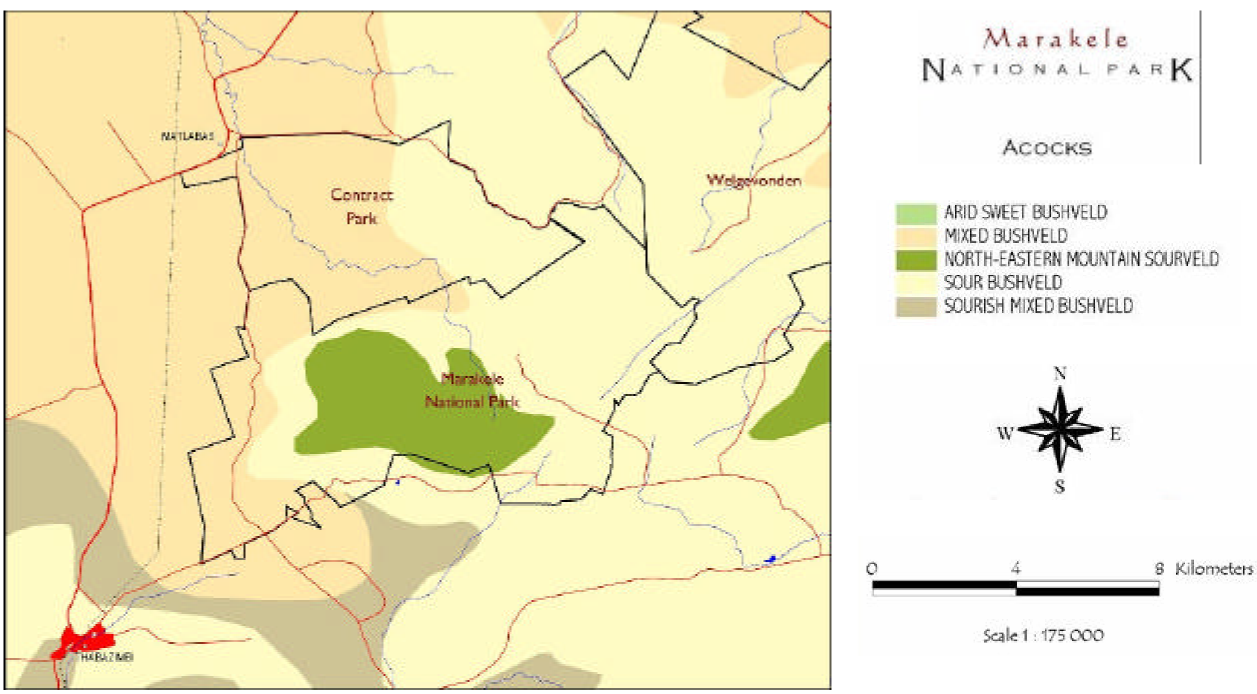


Figure 2.4: Distribution of the different vegetation types, according to Acocks (1988), which can be found in the Greater Marakele National Park.

Approximately 55% of the Greater Marakele National Park is characterised by the Waterberg Moist Mountain Bushveld vegetation type. This vegetation type occurs in the intermediate to high lying areas in the southern and south-eastern portions of the park. This area is characterised by relatively high rainfall (719 mm) and the resultant leaching of the soils results in a fairly low soil nutrient status. This limiting factor in turn results in a fairly low grazing capacity and only ubiquitous species such as kudu (*Tragelaphus strepsiceros*) and common reedbuck (*Redunca arundinum*) are common in these areas. This vegetation type is characterised by *Faurea saligna* (Willow beechwoods), *Protea caffra* (Common sugar bush) and *Englerophytum magalismontanum* (Stem-fruit). This vegetation type is not part of the specific study area (Marakele Park) in which the study was conducted.

Another major vegetation type is the Mixed Bushveld, which covers approximately 42% of the Greater Marakele National Park. This vegetation type is mainly found in the north-western and isolated south-western pockets of the park. It occurs predominantly on the undulating to flat plains and the soils are generally clayey, deeper and more nutrient-rich. Most of the charismatic game species such as black rhino (*Diceros bicornis*), elephant (*Loxodonta africana*) and wild dog (*Lycaon pictus*) are associated with this vegetation type. This vegetation type is characterised by species such as *Terminalia sericea* (Silver cluster-leaf), *Dichrostachys cinerea* (Sickle-bush), *Combretum apiculatum* (Red bushwillow), *Pterocarpus rotundifolius* (Round-leaved bloodwood) and various *Acacia* species. The greatest part of the specific study area (Marakele Park) is representative of the Mixed Bushveld.

Less than 3% of the Greater Marakele National Park is comprised of Sweet Bushveld. This veld type is mostly found along the banks of the Matlabas River and forms an important winter refuge area for game, particularly during limiting periods at the end of the dry season. The planned western expansion of the park, which excludes Marakele Park, will include more of this vegetation type which is crucial to sustain adequate numbers of prey species for large predators such as lion (*Panthera leo*) and scavengers such as spotted hyena (*Crocuta crocuta*). This vegetation type is present in the specific study area (Marakele Park) and comprises more than 3% of the contract park.

2.1.5.2 *Marakele Park*

The study was specifically conducted in Marakele Park. This study area can broadly be divided into six different vegetation units, each on different soil types. The vegetation units can be described as follows (Van Staden, 2002b):

1. *Terminalia sericea – Combretum zeyheri* low closed Woodland

This woodland is found on the Clovelly and Oakleaf soil types of the lowland plains of the Ah terrain unit. The characteristic woody species are *Acacia erubescens, Bauhinia petersiana, Boscia albitrunca*, *Burkea africana*, *Combretum apiculatum*, *C. zeyheri*, *F. saligna*, *Ochna pulchra*, *P. rotundifolius*, *Sclerocarya birrea*, *T. sericea* and *Ziziphus mucronata*. The dominant grass species are *Aristida congesta*, *Eragrostis curvula*, *E. lehmanniana*, *E. pallens*, *Heteropogon contortus*, *Panicum maximum*, *Pogonarthria squarrosa*, *Setaria sphacelata* and *Themeda triandra*. The dominant forbs are *Fadogia homblei*, *Hypoestes forskaolii*, *Ipomoea magnusiana*, *Sida dregei* and *S. cordiifolia*.

2. *Aloe marlothii – Acacia erubescens* low closed Shrubland

This shrubland is found on the Clovelly and Hutton soil types of the lowland plains of the Ah terrain unit. The characteristic woody species are *Acacia erubescens*, *Acacia nigrescens*, *Boscia albitrunca*, *Boscia foetida*, *C. apiculatum*, *D. cinerea* and *Sclerocarya birrea*. The dominant grass species are *Aristida congesta*, *Cynodon dactylon*, *E. lehmanniana*, *Eragrostis rigidior*, *Heteropogon contortus*, *Sporobolus fimbriatus* and *T. triandra*. The most prominent forbs are *Sanseviera pearsonii*, *Sida cordiifolia*, *Solanum incanum* and *Solanum panduriforme*.

3. *Protea caffra – Rhus dentata* low open Woodland

This Woodland is related to the mid-slopes of the Fa land type and is found on the Rock, Mispah, Glenrosa and Hutton soil types. The characteristic woody species are *Ancylobothrys capensis*, *Apodytes dimidiata*, *Burkea africana*, *Elephantorrhiza burkei*, *Lannea discolor*, *Maytenus undata*, *Mimusops zeyheri*, *Ozoroa paniculosa* and *Strychnos pungens*. The most prominent grass species are *Andropogon schirensis*, *Cymbopogon validus*, *Diheteropogon amplectens*, *Loudetia simplex*, *Melinis nerviglumis* and *Schizachyrium sanguineum*. The most prominent forb species are *Cheilanthus hirta*, *Commelina africana*, *Crassula swaziensis*, *Cyperus leptocladus*, *Leonotis microphylla*, *Fadogia homblei*, *Indigofera mollicoma*, *Silene burchelli*, *Tephrosia rhodesica* and *Xerophyta retinervis*.

4. *Dichrostachys cinerea – Acacia erubescens* low closed Woodland

This woodland is found on the Clovelly and Hutton soil types of the lowland plain terrain unit of the Bd land type. The following woody species are characteristic of this woodland:

Acacia erioloba, *A. erubescens*, *Acacia robusta*, *Boscia albitrunca*, *Combretum zeyheri*, *Dichrostachys cinerea*, *Grewia bicolor*, *Grewia flava*, *Grewia flavescens*, *Sclerocarya birrea*, *Spirostachys africana*, *Terminalia sericea* and *Ximenia caffra*. The dominant grass species are *Digitaria eriantha*, *Eragrostis lehmanniana*, *E. rigidior*, *H. contortus*, *Melinis repens*, *Panicum maximum*, *Perotis patens* and *Pogonarthria squarrosa*. The most prominent forbs are *Ipomoea obscura*, *Melhania* spp., *Pancratium* spp. and *Sida dregei*.

5. Sandy *Terminalia sericea – Burkea africana* low closed Woodland

This woodland is found on the Avalon, Longlands and Clovelly soil types of the lowland plain terrain unit of the Bd land type. The following woody species are characteristic of this woodland: *Burkea africana*, *C. zeyheri*, *Dichrostachys cinerea*, *Euclea crispa*, *Ochna pulchra*, *Terminalia brachystemma*, *T. sericea*, and *Ximenia americana*. The dominant grass species are *Aristida congesta*, *Digitaria eriantha*, *Eragrostis gummiflua*, *E. lehmanniana*, *E. pallens*, *E. rigidior*, *H. contortus*, *Panicum maximum*, *Perotis patens*, *Pogonarthria squarrosa* and *Stipagrostis uniplumis*. The prominent forbs are *Melhania* spp., *Pellaea calomelanos*, *Sida cordiifolia*, *S. dregei*, *Solanum panduriforme* and *Triumfetta sonderi*.

6. *Acacia mellifera – Grewia flava* low closed Woodland

This woodland is found on the Avalon and Longlands soil types of the lowland plain terrain unit of the Bd land type. The following woody species are characteristic of this woodland: *Acacia erioloba*, *A. erubescens*, *A. mellifera*, *A. robusta*, *Boscia albitrunca*, *B. foetida*, *Dichrostachys cinerea*, *G. flava* and *Spirostachys africana*. The following grass species are characteristic: *Aristida congesta*, *Bothriochloa radicans*, *Enneapogon cenchroides*, *Eragrostis lehmanniana* and *E. rigidior*. The dominant forbs are *Cleome maculata*, *Solanum incanum*, *S. panduriforme* and *Zinnia peruviana*.

It is important to note that the above-mentioned vegetation units represent a broad description of the study area and that the experimental plots were not present in all of these units. The different vegetation units that can be found in Marakele Park as well as in the rest of the Greater Marakele National Park are illustrated in Figure 2.5.

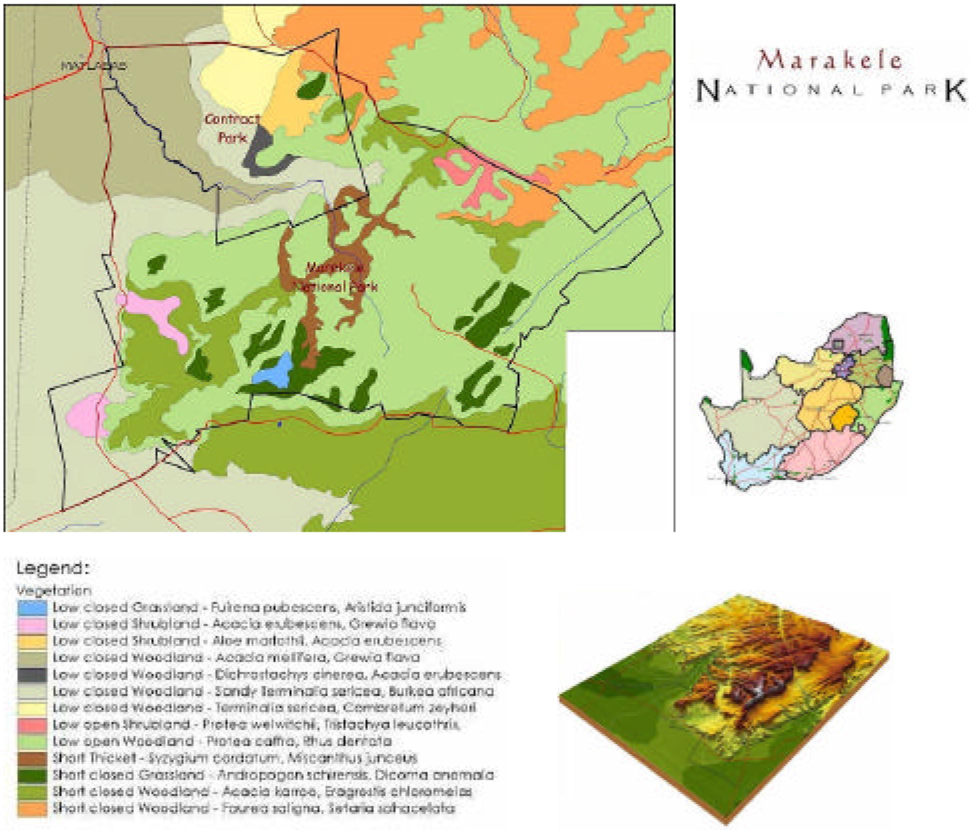


Figure 2.5: An illustration of the different vegetation units that can be found in the Greater Marakele National Park (Beech &Van Riet, 2002b).

2.1.6 Fauna

As its Tswana name suggests, the Greater Marakele National Park and Marakele Park has become a "place of sanctuary" for a large variety of wildlife, and is rich in game species. Some of the animal species in Marakele Park include large mammals such as the African elephant, black rhino, white rhino (*Ceratotherium simum*), buffalo (*Syncerus caffer*), leopard (*Panthera pardus*) and cheetah (*Acinonyx jubatus*). The relocation of wild dogs has already started in March 2003 and three male lions were introduced in October 2004. Spotted hyenas are also present in the Park.

Some of the resident antelopes occurring in the Park include kudu, eland (*Taurotragus oryx*), impala (*Aepyceros melampus*), waterbuck (*Kobus ellipsiprymnus*), tsessebe (*Damaliscus lunatus*) and many smaller species. Some of the more valuable antelope species such as roan (*Hippotragus equinus*) and sable (*Hippotragus niger*) can be found on Hoopdal (a privately owned property, integrated as part of Marakele Park to help with conservation) and Marakele National Park.

In addition to the mammals occurring in the Park, The Greater Marakele National Park also has the largest colony of Cape Vultures (*Gyps coprotheres*) in the world, with more than 800 breeding pairs. Other bird species include several eagle species, namely Black- (*Aquila verreauxii*), African hawk- (*Hieraaetus spilogaster*), Black-breasted snake- (*Circaetus pectoralis*) and Fish eagles (*Haliaeetus vocifer*) and a variety of smaller bird species like the Redeyed bulbul (*Pycnonotus nigricans*) and the Kalahari robin (*Erythropyga paena*).

2.2 TRIAL LAYOUT

2.2.1 Method of thinning woody plants

A mechanical bush clearing method was used in Marakele Park. A mechanical mulcher, namely The Barko Tractor (Figure 2.6a), was used in the South African savanna for the first time in March 2002 and was implemented to cut problem woody species to ground level to control bush encroachment. The Tractor was developed in the USA in 1963 and the cutter head has been manufactured in Italy since 1939. The Barko tractor with the cutter head (Figure 2.6b) is 3 m in height, 7.5 m in length, 2.5 m in width and weighs 16 tonnes. It has a cutting width of 2.5 m and a capability of cutting and mulching trees up to 40 cm in diameter. The Barko tractor is able to move at a speed of ± 4 km per hour through bush, which produces a cutting rate of 1 hectare per hour. In most circumstances, however, a rate of 1.5 – 2 hectares per hour is achieved (Game & Hunt, 2003).

(a) **(b)**

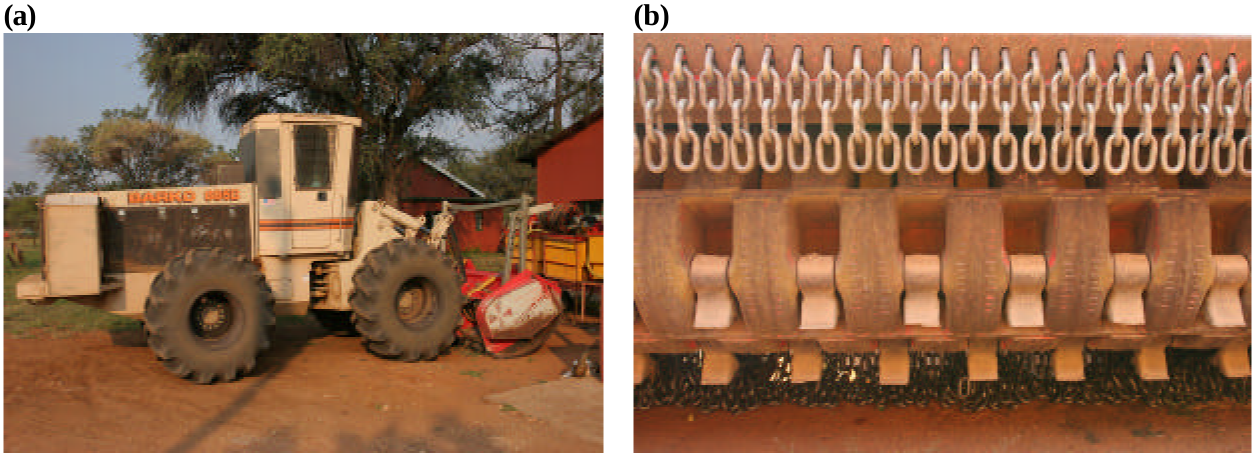


Figure 2.6: (a) The mechanical mulcher, Barko Tractor, used in Marakele Park for bush encroachment control. (b) The cutter head of the Barko Tractor (cutting width – 2.5 m).

The specific sites in the study area were first cut during 2002 and 2003. Since then no further treatments were used in these areas. A total of approximately 6 000 ha of encroached bush was removed before the onset of this study.

2.2.2 Selection of experimental plots

Experimental plots were selected on the basis of plant species and topographical differences in areas where the Barko Mulching Tractor was used to mechanically thin woody species. The thinning was not specifically done with a view to conduct a scientific study and the selection of experimental plots had to be done within the constraints and limitations of the existing thinned areas. For comparison purposes a thinned (treatment) and unthinned (control) plot was selected in the vegetation units where thinning was conducted. Based on the available tree thinned areas, three paired plots (six plots in total) were selected in three different vegetation units. The paired plots in each vegetation unit were located immediately adjacent to each other on the same geographical layout and soil type. Two additional thinned plots were included to compare the coppicing ability of woody species only. These plots represent vegetation units in which unthinned control plots could not be found. Each experimental plot was 100 m x 200 m (20 000 m^2) in size. The experimental plots were named according to the most dominant tree species (plants ha^{-1}) that was present in each plot. These names are presented in Table 2.5.

Table 2.5: The experimental plot names according to the most dominant tree species present in each of the plots, with a distinction between the treatment, control and coppice areas, as well as the abbreviations that they are referred to in further chapters.

Experimental plot name	Abbreviations used in text	Abbreviations used in graphs
Acacia mellifera – Grewia flava Treatment	Am-Gf Treatment	Am-Gf-T
Acacia mellifera – Grewia flava Control	Am-Gf Control	Am-Gf-C
Combretum apiculatum – Grewia flava Treatment	Ca-Gf Treatment	Ca-Gf-T
Combretum apiculatum – Grewia flava Control	Ca-Gf Control	Ca-Gf-C
Acacia erubescens – Dichrostachys cinerea Treatment	Ae-Dc Treatment	Ae-Dc-T
Acacia erubescens – Dichrostachys cinerea Control	Ae-Dc Control	Ae-Dc-C
Combretum apiculatum – Grewia flava Coppice	Ca-Gf Coppice	Ca-Gf-Cop
Acacia mellifera – Grewia flava Coppice	Am-Gf Coppice	Am-Gf-Cop

2.2.3 Vegetation description of the experimental plots

All the selected vegetation units were located in the Mixed Bushveld vegetation type (Acocks, 1988; Low & Rebelo, 1996). The chosen experimental plots were situated in three vegetation units dominated by different woody species (see Chapter 4). The first vegetation unit was characterised by the dominance of *Acacia mellifera* and *Grewia flava* (Figure 2.7). Other woody species found in relative quantities in this vegetation unit, include *Acacia erubescens*, *A. tortilis* and *Asparagus suaveolens*. The most dominant grass species of this vegetation unit were *Bothriochloa radicans*, *Eragrostis pilosa*, *E. rigidior*, *Panicum maximum* and *Urochloa mosambicensis*. The most dominant forb species in this vegetation unit were *Abutilon sonneratianum*, *Evolvulus alsinoides*, *Justicia flava*, *Justicia protracta*, *Solanum panduriforme* and *Tephrosia lupinifolia*.

(a1)

(a2)

(b1)

(b2)

Figure 2.7: Photos illustrating what the *Acacia mellifera – Grewia flava* vegetation unit looked like during the study period. (a) The *Acacia mellifera – Grewia flava* Treatment plot and (b) the *Acacia mellifera – Grewia flava* Control plot.

The second vegetation unit was dominated by *Combretum apiculatum* and *Grewia flava* (Figure 2.8). Other prevalent woody species included *Acacia erubescens*, *Dichrostachys cinerea*, *Combretum hereroense* and *Grewia monticola*. The most important grass species were *Aristida* species, *Digitaria eriantha*, *Melinis repens* and *Panicum maximum*. The most dominant forbs were *Agathisanthemum bojeri*, *Evolvulus alsinoides*, *Hermannia glanduligera*, *Justicia flava* and *Vahlia capensis*.

(a1)

(a2)

(b1)

(b2)

Figure 2.8: Photos illustrating what the *Combretum apiculatum – Grewia flava* vegetation unit looked like during the study period. (a) The *Combretum apiculatum – Grewia flava* Treatment plot and (b) the *Combretum apiculatum – Grewia flava* Control plot.

The third vegetation unit was dominated by *Acacia erubescens* and *Dichrostachys cinerea* (Figure 2.9). Other wide-spread woody species found in this vegetation unit were *Acacia karroo*, *Combretum apiculatum* and *Grewia flava*. The most dominant grass species included *Aristida* species, *Bothriocloa radicans*, *Eragrostis rigidior*, *Panicum maximum*, *Sporobolus panicoides* and *Urochloa mosambicensis*. The most dominant forb species were *Cyperus rupestris*, *Justicia flava* and *Hemizygia canescens*.

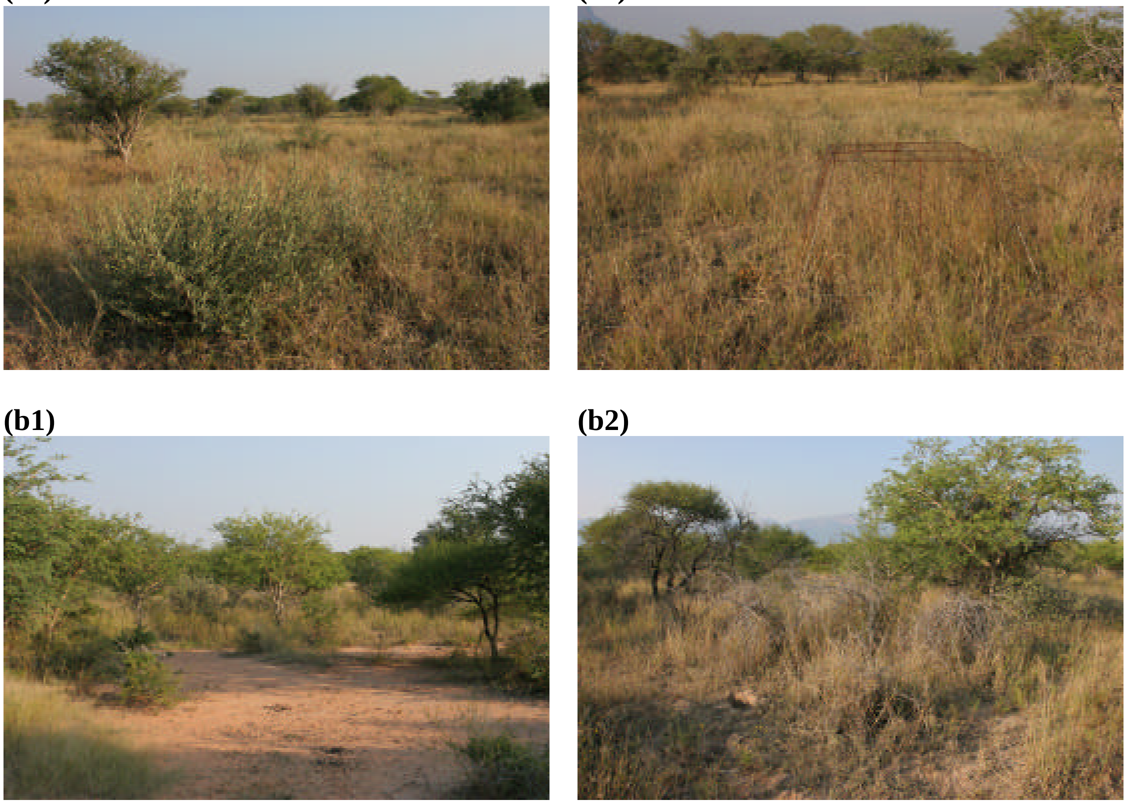


Figure 2.9: Photos illustrating what the *Acacia erubescens – Dichrostachys cinerea* vegetation unit looked like during the study period. (a) The *Acacia erubescens – Dichrostachys cinerea* Treatment plot and (b) the *Acacia erubescens – Dichrostachys cinerea* Control.

The two additional experimental plots, which were included to compare the coppicing ability of woody species, were situated in two different vegetation units. The first plot was characterised by the dominance of *Combretum apiculatum* and *Grewia flava* (Figure 2.10). Other prevailing woody species included *Acacia erubescens*, *Combretum hereroense*, *Combretum molle* and *Pterocarpus rotundifolius*. The dominant grass species of this vegetation unit included *Aristida* species, *Chloris virgata*, *Melinis repens*, *Panicum maximum* and *Sporobolus ioclados*. The most dominant forbs were *Abutilon sonneratianum*, *Agathisanthemum bojeri*, *Linum thunbergii*, *Monsonia burkeana* and *Tephrosia lupinifolia*. The second plot was dominated by *Acacia mellifera* and *Grewia flava* (Figure 2.11). Woody species that were also wide-spread in this vegetation unit were *Combretum apiculatum*, *Combretum molle*, *Gymnosporia senegalensis* and *Peltophorum africanum*. The most dominant grass species were *Aristida* species, *Bothriocloa radicans*, *Chloris virgata*, *Melinis repens*, *Panicum maximum* and *Urochloa mosambicensis*. The most dominant forbs included *Evolvulus alsinoides*, *Linum thunbergii*, *Tephrosia lupinifolia* and *Zornia milneana*.

Figure 2.10: Photos illustrating what the *Combretum apiculatum – Grewia flava* Coppice plot looked like during the study period.

Figure 2.11: Photos illustrating what the *Acacia mellifera – Grewia flava* Coppice plot looked like during the study period.

2.2.4 Geology and soil

The underlying geology is mainly sandstone with patches of conglomerate, siltstone and shale (Henning, 2002). A detailed description of the soil characteristics of each of the experimental plots is presented in Chapter 7.

2.2.5 Rainfall and temperature during the study period

Rainfall and temperature were the major climatic variables measured during the study period. Daily rainfall data were recorded as the mean of eight standard rain gauges, placed at different locations in Marakele Park. The monthly rainfall figures recorded from July 2003 to June 2005 (the duration of the study period), are presented in Figure 2.12.

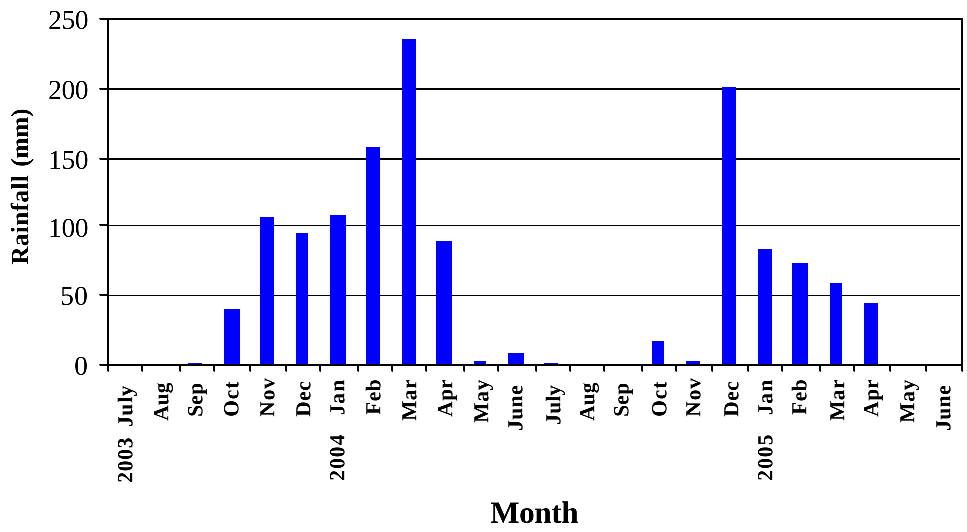


Figure 2.12: Monthly rainfall (mm) recorded in Marakele Park during the study period {July 2003 – June 2004 (first season) and July 2004 – June 2005(second season)}.

A comparison between the seasonal rainfall for the period 2000 to 2005 (Figure 2.13) clearly shows that the period during which the study was conducted, received well above average rainfall in comparison to the years when bush thinning was carried out (2002/2003).

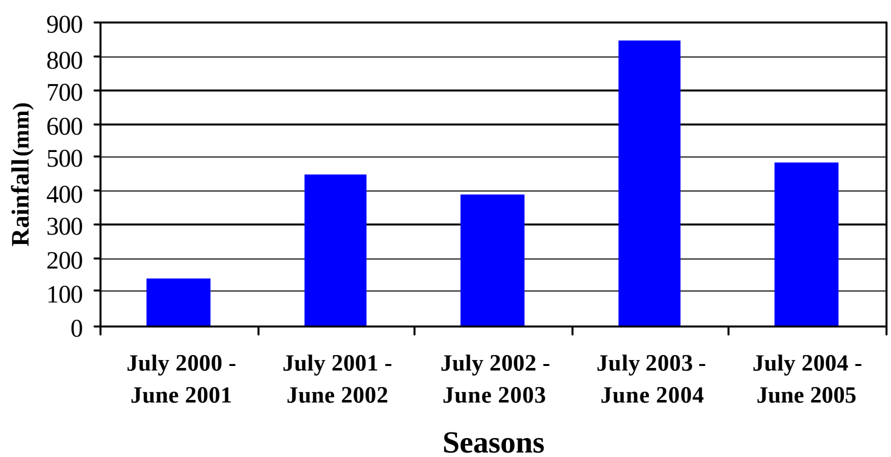


Figure 2.13: Seasonal rainfall (mm) for Marakele Park from July 2000 to June 2005.

Daily minimum and maximum temperature measurements were also taken during the study period and the monthly averages are illustrated in Figure 2.14.

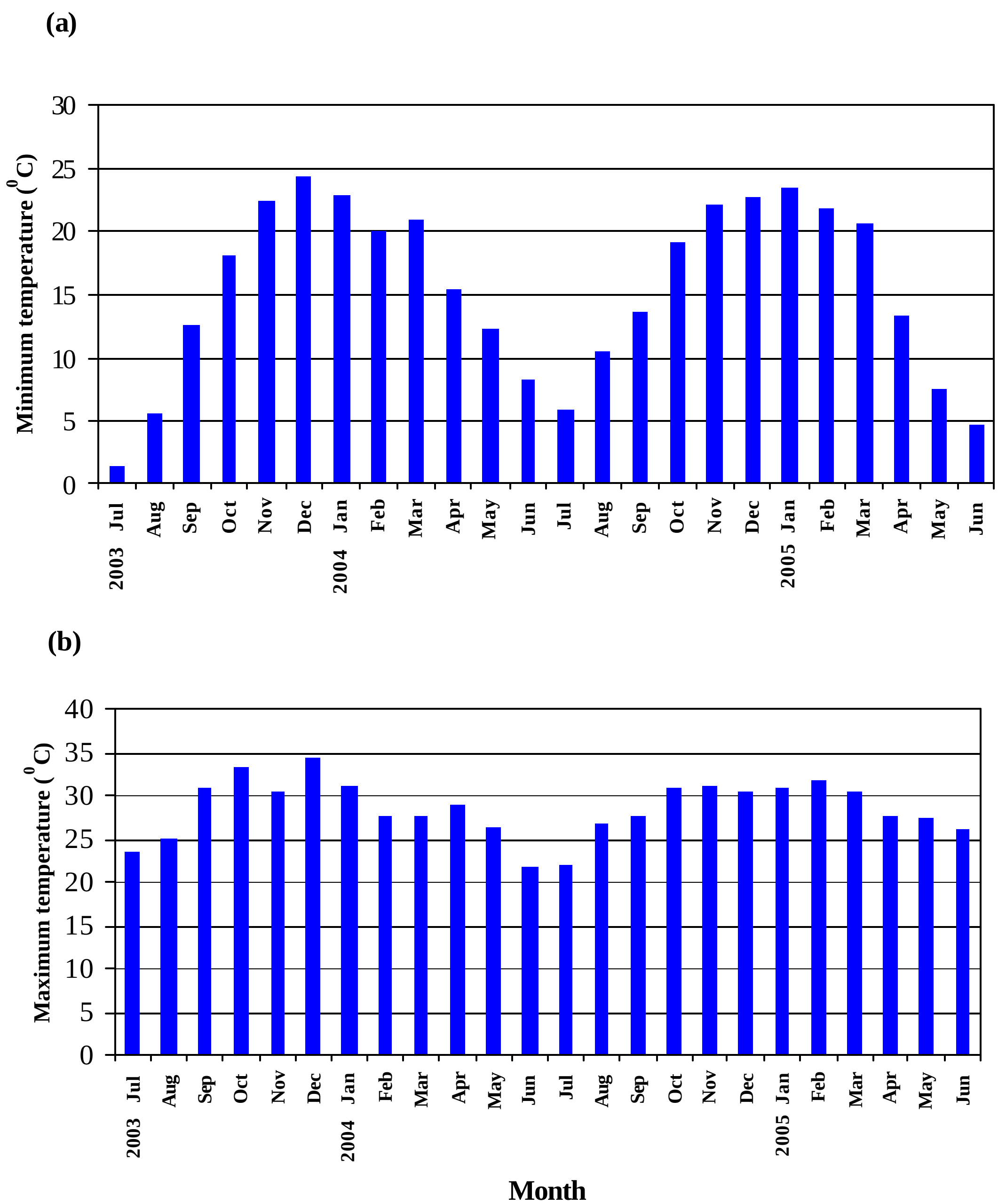


Figure 2.14: Monthly (a) minimum and (b) maximum temperature averages (ºC) recorded in Marakele Park during the study period (July 2003 to June 2005).

2.3 TERMINOLOGY

The terminology used in this thesis is in accordance with Trollope *et al*. (1990), unless referenced or described otherwise.

CHAPTER 3

PHYTOSOCIOLOGICAL STUDY

3.1 INTRODUCTION

We share the earth with at least 5 million – perhaps as many as 30 million – species of organisms. About 235 000 of these species are flowering plants and about 325 000 are non-flowering plants such as lichens, mosses and seaweeds. All living organisms depend on plants for food, shelter and fuel. Even when we use things obtained from animals, plants are used indirectly, because all animals ultimately depend on plants for their energy. It follows that the earth's ecosystems are also dependent on plants. Consequently, the well-being of the world of plants and the maintenance of biodiversity (a wide range of animals and plants), communities, ecosystems, biological processes and interactions, are of vital importance (Given, 1994).

Plants are a general feature of the natural landscape and grow in all but the most extreme environments. However, no species occurs everywhere in the world, each being distributed according to its own unique tolerance of the multitude of factors that comprise its environment. Species with similar ecological tolerances develop into recognisable plant formations with distinctive floristic and structural characteristics. At the broadest scale these represent the major biomes of the world (Archibold, 1995).

Vegetation can be described as an assemblage of plants growing together in a specific location. It can either be characterised by its constituent species or by the combination of functional and structural qualities that distinguish the physiognomy of vegetation. This is an important distinction that is exemplified by the variety of methods available for describing vegetation (Goldsmith *et al.*, 1986; Kent & Coker, 1992).

There are various reasons why it is important to incorporate vegetation ecology in any environmental study. The three most important reasons can be summarised as follows: (1) in most terrestrial parts of the world, the most distinct representation of an ecosystem is vegetation; (2) primary production (the process through which solar energy is transformed into green plant tissue during photosynthesis) generally results in vegetation; and (3) vegetation provides suitable environments within which organisms can exist, develop, reproduce and die (Kent & Coker, 1992).

Various ecologists regard vegetation as a component of ecosystems that displays the effects of environmental conditions on the ecology and therefore, adequate analysis of vegetation is a way of identifying valuable information about the different components of the ecosystem. It is emphasised that the study of plant communities as fundamental units of an ecosystem is essential for environmental planning and for the compilation of environmental management procedures (Bredenkamp & Brown, 2001). The description of vegetation units is also an important aspect of resource survey work, especially in the evaluation of land carrying capacity (Goldsmith *et al.*, 1986).

Individual plants are the basic elements constituting vegetation. Each plant species is classified according to a hierarchical system of identification and nomenclature by applying carefully selected criteria of physiognomy and growth structure. A species population consist of several individual plants of one species and plant communities are formed by groups of plant species populations assembled together within the local area. The presence or absence of particular species is of great importance. At this stage, the abundance of each species present becomes significant (Kent & Coker, 1992).

Species diversity is dependent on a variety of biotic (e.g. competition, symbiosis, predation) as well as abiotic factors, such as rainfall, temperature, fire, soil type, nutrients, and many more (Dye & Spear, 1982; Bredenkamp, 1985; Palmer *et al.*, 1988; Smit & Swart, 1994; Tainton & Hardy, 1999). Species diversity of most herbaceous plants normally increases when woody plants, which present competition for some of these biotic and abiotic factors, are removed from the area. However, if heavy grazing is maintained in an area, species composition will change and this change is usually associated with an increase of unpalatable, pioneer species (Dye & Spear, 1982; Du Toit & Aucamp, 1985).

The objectives of this study were to ecologically:

- identify,
- classify,
- describe, and
- interpret the plant communities of the specific experimental plots used during this study in Marakele Park.

3.2 PROCEDURE

The vegetation of the specific experimental plots in Marakele Park was ecologically classified by using the phytosociological method known as the Zürich-Montpellier, or Braun-Blanquet method (Braun-Blanquet, 1932). The Braun-Blanquet method is efficient in providing a framework for the classification of vegetation world-wide. This method is widely accepted and has been used within the different biomes of South Africa with great success by various researchers (Werger, 1973; Coetzee, 1974; Bredenkamp, 1975; Bredenkamp & Theron, 1976; Bredenkamp & Theron, 1978; Viljoen, 1979; Bredenkamp & Theron, 1980; Müller, 1986; Van Wyk & Bredenkamp, 1986; Behr & Bredenkamp, 1988; Bezuidenhout, 1988; Bredenkamp *et al.*, 1989; Bezuidenhout & Bredenkamp, 1990; Kooij *et al.*, 1990a,b,c; Bezuidenhout & Bredenkamp, 1991; Du Preez & Bredenkamp, 1991; Matthews, 1991; Du Preez & Venter, 1992; Fuls *et al.*, 1992; Schulze *et al.*, 1994; Smit *et al.*, 1995; Brown *et al.*, 1997; De Frey, 1999; Malan *et al.*, 1999; Henning, 2002; Janecke, 2002; Müller, 2002; Van Staden, 2002a; Botha, 2003).

The Braun-Blanquet method was initially described in detail by Braun-Blanquet (1932) and further descriptions of this method were made by Becking (1957), Kershaw (1973), Mueller-Dombois & Ellenberg (1974), Werger (1974), Westhoff & Van der Maarel (1978), Barbour *et al.* (1987) and Kent & Coker (1992). This method can be divided into two phases:

3.2.1 Botanical surveys (analytic phase)

This phase involved the acquisition of all relative vegetation data, represented in relevés, required for this study. (A list of the plant species encountered during the study is presented in Appendix A). During the survey, experimental plots were sampled in areas where the botanical composition was homogenous and representative of the specific area that needed to be surveyed.

Surveys were conducted during the period of March to May 2004. A total of 10 relevés were surveyed in each of the eight experimental plots (a total of 80 relevés for the study area). The cover-abundance scale (Table 3.1), for each species present in the experimental plots, was allocated according to the Braun-Blanquet scale. The plot sizes were fixed at 4 m x 4 m (16 m^2) for the grassland vegetation and 10 m x 10 m (100 m^2) for the shrub and tree vegetation (Bredenkamp & Theron, 1978). The environmental data, which includes factors such as altitude, aspect, slope, topography, texture, area percentage covered by rock as well as important biotic information, were obtained and documented for each relevé (Botha, 2003). The specific plot position was determined by a GPS (Global Positioning System).

Table 3.1: The Braun-Blanquet cover abundance values that were used in this study.

Cover Values	Description
r	One or few individuals, rare occurrence
+	Cover less than 1% of total plot area
1	Cover less than 5% of total plot area
2a*	Cover between 5 – 12.5% of total plot area
2b*	Cover between 12.5 – 25% of total plot area
3	Cover between 25 – 50% of total plot area
4	Cover between 50 – 75% of total plot area
5	Cover between 75 – 100% of total plot area

*****After Bredenkamp *et al.* (1993).

3.2.2 Data analyses (synthetic phase)

The survey data were captured in a database by means of the TURBOVEG programme (Hennekens, 1996a). The data were then exported to the visual editor programme namely MEGATAB (Hennekens, 1996b). An initial mathematical classification was obtained by using the Two-way Indicator Species Analysis (TWINSPAN) (Hill, 1979a). The table was then further arranged and refined by using Braun-Blanquet procedures {MEGATAB (Hennekens, 1996a)}.

The aim of this process was to identify and classify various units present in the vegetation of the study area. By identifying the possible differential plant species and associated species, the classified phytosociological table displayed the most important characteristics of the plant communities. Different vegetation units were identified and by using habitat specific species as a guideline, several physiognomic units were interpreted (Edwards, 1983; Kent & Coker, 1992; De Frey, 1999; Müller, 2002).

The arrangement of species and relevés in the phytosociological table leads to a sufficient classification system of syntaxa present in the vegetation of the study area. This can be used as the foundation for further ecological studies. Plant species acts as indicators for the habitat characteristics for the community and the Zürich-Montpellier approach determines if patterns in the botanical composition correspond with patterns in the environment (Werger, 1974). Insignificant species (defined as species with an occurrence of 4 or less), that were present in the phytosociological table, were omitted from the table.

The Detrended Correspondence Analysis (DECORANA) (Hill 1979b), an ordination algorithm was also applied to the dataset. This was done to determine floristic and environmental relationships between the various sample plots.

3.3 RESULTS AND DISCUSSION

From the classification of the dataset for the 80 relevés surveyed in Marakele Park, the following results were obtained: 3 Major communities, 7 Communities, 6 Sub-communities and 3 Variants. The results are presented in a phytosociological table (Appendix B).

3.3.1 Classification

The hierarchical classification of the 3 major communities is as follows:

1. *Justicia protracta – Zehneria marlothii* Major community
   - 1.1 *Diospyros lycioides – Grewia flava* Community
   - 1.2 *Abutilon pycnodon – Solanum panduriforme* Community

2. *Acacia erubescens – Combretum apiculatum* Major community
   - 2.1 *Rhus pyroides – Acacia erubescens* Community
     - 2.1.1 *Terminalia sericea – Cyperus rupestris* Sub-community
     - 2.1.2 *Oxalis depressa – Sporobolus panicoides* Sub-community
     - 2.1.3 *Combretum imberbe – Acacia mellifera* Sub-community
   - 2.2 *Grewia flavescens – Blumea mollis* Community
     - 2.2.1 *Peltophorum africanum – Triumfetta pilosa* Sub-community
       - 2.2.1.1 *Carissa bispinosa – Ziziphus mucronata* Variant
       - 2.2.1.2 *Peltophorum africanum – Aristida adscensionis* Variant
       - 2.2.1.3 *Combretum molle – Acacia erubescens* Variant
     - 2.2.2 *Tephrosia capensis – Grewia flava* Sub-community
     - 2.2.3 *Acacia erubescens – Grewia flava* Sub-community
   - 2.3 *Acacia erubescens – Triumfetta pilosa* Community

3. *Senna italica – Combretum apiculatum* Major community
   - 3.1 *Gossypium herbaceum – Pogonarthria squarrosa* Community
   - 3.2 *Vahlia capensis – Justicia protracta* Community

3.3.2 Description of the plant communities

1. *Justicia protracta – Zehneria marlothii* Major community

This major community is situated on the plains in the study area at altitudes ranging from 969 m – 991 m above sea level. Surface erosion in this area was mostly moderate and levels of trampling by game species ranged from moderate to high. The soils are sandy with a relatively low clay and silt content.

The *Justicia protracta – Zehneria marlothii* Major community is characterised by the diagnostic species of Species group C. This species group consists mainly of annual and perennial herbs with a low grazing value. This major community is represented by only a few woody species of which *Asparagus suaveolens* (Species group N), *Grewia flava* and *Acacia mellifera* (Species group T) are the most prominent. *Acacia mellifera* forms a number of impenetrable bush clumps in this community.

Other prominent species present in this major community include grasses such as *Bothriochloa insculpta*, *B. radicans*, *Chloris virgata*, *Eragrostis superba*, *Brachiaria nigropedata*, *B. deflexa* (Species group N), *Panicum maximum*, *Aristida congesta* subsp. *barbicollis*, and *Tragus racemosus* (Species group T), as well as forbs such as *Melolobium* spp., *Zehneria marlothii*, *Hibiscus engleri*, *Hermannia* spp., *Corchorus asplenifolius* (Species group C), *Evolvulus alsinoides*, *Abutilon sonneratianum*, *Justicia protracta*, *Tephrosia lupinifolia* and *Commelina africana* (Species group T).

This major community can be divided into the following communities, namely: the *Diospyros lycioides – Grewia flava* Community and the *Abutilon pycnodon – Solanum panduriforme* Community.

1.1 *Diospyros lycioides – Grewia flava Community*

This community is located at altitudes ranging between 969 m – 980 m above sea level. No surface rocks were noted in this community and surface erosion varied between none to moderate in some places. Crust formation of the soil was noted over most of the area and ranged from areas with only small patches with crust formations to large areas covered with hard crusts. The level of trampling by game species found in this community was moderate but there were a few areas where high levels of trampling occurred, especially on footpaths and latrines.

Most plant species in this community were exposed to full sun, however semi-shaded areas also occurred. This community is represented by 8 relevés with between 18 – 37 plant species per relevé.

The diagnostic species *Diospyros lycioides* (Species group A), is a shrub that could form thickets by coppicing from its root system (Coates Palgrave, 2002). *Grewia flava* (Species group T) is also a diagnostic species (it is absent in the *Abutilon pycnodon – Solanum panduriforme* Community). The high cover abundance values of *Melolobium* spp. (Species group C), *Bothriochloa insculpta* (Species group N), *Grewia flava*, *Evolvulus alsinoides* and *Panicum maximum* (Species group T) and the presence of *Sporobolus ioclados* (Species group S), *Linum thunbergii* and *Heteropogon contortus* (Species group T) also contributed to characterise this community.

1.2 *Abutilon pycnodon – Solanum panduriforme* Community

This community is located at an altitude ranging from 972 m to 991 m above sea level. Surface erosion varied from none to moderate in most areas and only slight crust formation occurred. No surface rock was found and the levels of trampling were mostly moderate, but high in some locations. This community is represented by 5 relevés with about 15 – 34 plant species per relevé.

This community's diagnostic species are *Abutilon pycnodon*, (Species group B), a bushy shrub (Coates Palgrave, 2002) or biennial herb (Germishuizen & Meyer, 2003), *Solanum panduriforme*, (Species group S), a perennial forb with a deep underground rootstock (Fabian & Germishuizen, 1997) and poisonous fruits (Bromilow, 2001). This community does not have dominant woody species but the woody species that are found include *Asparagus suaveolens*, *Acacia karroo* (Species group N) and *Acacia mellifera* (Species group T). An important characteristic of this community is the absence of the shrub *Grewia flava* (Species group T) that can be found in every other community of the study area. The dominant grasses are *Bothriochloa insculpta*, *B. radicans*, *Chloris virgata*, *Brachiaria nigropedata* (Species group N), *Panicum maximum* and *Tragus racemosus* (Species group T). Prominent forbs include *Melolobium* spp., *Corchorus asplenifolius* (Species group C), *Evolvulus alsinoides* and *Abutilon sonneratianum* (Species group T). This community is also characterised by the presence of *Polygala sphenoptera* (Species group P) and *Monsonia burkeana* (Species group S).

2. *Acacia erubescens – Combretum apiculatum* Major community

This major community is characterised by vegetation that covers disturbed areas, probably due to overgrazing, and where encroachment by *Acacia mellifera* is evident. According to Coates Palgrave (2002) *A. mellifera* could spread very rapidly, mostly by means of seed. Encroachment could take place to such an extent that *A. mellifera* can become troublesome to man and animal but also a threat to other plant communities by forming impenetrable, tangled thickets. These impenetrable thickets are a major problem in Marakele Park. Bush encroachment is usually encouraged by overgrazing and trampling by stock and game species (Van Vegten, 1983; Du Toit & Aucamp, 1985; Skarpe, 1990; Richter, 1991). The occurrence of high numbers of various game species is a cause of concern in Marakele Park.

This major community is the largest and most extensive of all the major communities. It is situated on the plains of Marakele Park and is mainly found in areas not far from the Matlabas River. The soil consists mostly of fine sand with a relatively low clay and silt content. The soil varies from relatively deep to fairly shallow in some areas where granite protrudes from the soil surface.

The characteristic species of this major community are those of Species group O. These species are *Acacia erubescens*, *Rhynchosia totta* and *Eragrostis biflora*. *Acacia erubescens* is a tree species which is well adapted to dry conditions and usually occurs along stream banks as well as on rocky outcrops (Coates Palgrave, 2002). *Rhynchosia totta* is a small climbing herb that arises from tuberous rootstocks (Fabian & Germishuizen, 1997) and *Eragrostis biflora* is a pioneer grass species with a low grazing value, which prefers shady and disturbed areas under trees and shrubs (Van Oudtshoorn, 1999). This major community consists of various tree and shrub species, which is dominated by *Acacia erubescens* (Species group O) and *Combretum apiculatum* (Species group S). Other dominant tree species include *Peltophorum africanum* (Species group J), *Acacia tortilis*, *Ziziphus mucronata*, *Combretum hereroense* (Species group M) and *Acacia mellifera* (Species group T). The shrub layer is dominated by *Grewia flavescens* (Species group L), *Dichrostachys cinerea*, *Grewia monticola* (Species group M), *Asparagus suaveolens* (Species group N), *Triumfetta pilosa* (Species group S) and *Grewia flava* (Species group T). The most prominent grass species include *Urochloa mosambicensis* (Species group M), *Bothriochloa insculpta*, *B. radicans*, *Chloris virgata* (Species group N), *Aristida adscensionis*, *Aristida congesta* subsp. *congesta*, *Melinis repens* (Species group S), *Panicum maximum*, *Aristida congesta* subsp. *barbicollis*, *Eragrostis pilosa* and *Tragus racemosus* (Species group T).

The most prevalent forbs are *Conyza podocephala* (Species group M), *Monsonia burkeana*, *Agathisanthemum bojeri* (Species group S), *Evolvulus alsinoides*, *Abutilon sonneratianum*, *Justicia protracta* and *Tephrosia lupinifolia* (Species group T).

This major community can be divided into 3 Communities, 6 Sub-communities and 3 Variants namely:

2.1 *Rhus pyroides – Acacia erubescens* Community
- 2.1.1 *Terminalia sericea – Cyperus rupestris* Sub-community
- 2.1.2 *Oxalis depressa – Sporobolus panicoides* Sub-community
- 2.1.3 *Combretum imberbe – Acacia mellifera* Sub-community

2.2 *Grewia flavescens – Blumea mollis* Community
- 2.2.1 *Peltophorum africanum – Triumfetta pilosa* Sub-community
  - 2.2.1.1 *Carissa bispinosa – Ziziphus mucronata* Variant
  - 2.2.1.2 *Peltophorum africanum – Aristida adscensionis* Variant
  - 2.2.1.3 *Combretum molle – Acacia erubescens* Variant
- 2.2.2 *Tephrosia capensis – Grewia flava* Sub-community
- 2.2.3 *Acacia erubescens – Grewia flava* Sub-community

2.3 *Acacia erubescens – Triumfetta pilosa* Community

2.1 *Rhus pyroides – Acacia erubescens* Community

This community is found adjacent to an open grass plain and is characterised by the occurrence of uncovered areas where water runoff is high during and after heavy rains. Surface erosion had a high prevalence and this could probably be attributed to the relatively high levels of trampling found in this community. Severe trampling by game species leads to soil compaction, which increases soil surface erosion, especially by water runoff (Bothma, 2002). The soil has a fine sandy texture and no rocks on the soil surface were noted.

The diagnostic species are represented by Species group H. These species are *Rhus pyroides*, *Cyperus rupestris*, *Hemizygia canescens* and *Gymnosporia senegalensis*. *Rhus pyroides* and *Gymnosporia senegalensis* are shrub species that are common in open woodland and bushveld. *Hemizygia canescens* is an annual herb which prefers disturbed areas and *Cyperus rupestris* usually occurs in shallow depressions and is especially notable after rains. The latter plant species was only found in areas where elephants left deep tracks in the soil after the heavy rains, causing water to accumulate.

The cover abundance of *Dichrostachys cinerea* (Species group M), *Bothriochloa radicans*, *Chloris virgata* (Species group N) and *Heteropogon contortus* (Species group T) is relatively higher in this community in comparison to the other two communities of the *Acacia erubescens – Combretum apiculatum* Major community.

Three sub-communities are present in this community, namely the *Terminalia sericea – Cyperus rupestris* Sub-community, the *Oxalis depressa – Sporobolus panicoides* Sub-community and the *Combretum imberbe – Acacia mellifera* Sub-community.

2.1.1 *Terminalia sericea – Cyperus rupestris* Sub-community

The locality of this sub-community ranges between 971 m – 992 m above sea level. Surface erosion was prominent in this area and varied from moderate to high. Crust formation of the soil was also extensive in this area and could be attributed to the high levels of trampling that occurred in this sub-community. Large numbers of hoofed animals like the plains zebra (*Equus quagga* – Synonym: *Equus burchelli*) and blue wildebeest (*Connochaetus taurinus*) was frequently sited in this sub-community and the presence of large elephant herds is also causing substantial soil damage, especially after heavy rains. Factors such as overgrazing and trampling are thus clearly key contributors to the extensive surface erosion and crust formation present in this area. Most of the forbs and grasses occurred in semi-shaded areas. This sub-community is represented by 7 relevés with 24 – 34 plant species per relevé.

Species group D contains the diagnostic species of this sub-community. They are *Terminalia sericea* (a common tree, closely associated with very sandy soils, found in open woodland and bushveld; Coates Palgrave, 2002), *Sansevieria pearsonii* (a xerophyte forming thick colonies from a creeping rhizome; Fabian & Germishuizen, 1997), *Cymbopogon pospischilli* (a perennial grass species with a low grazing value; Van Oudtshoorn, 1999), *Fuirena pubescens* (a tufted perennial occurring along river banks and in the vicinity of springs – this species was only found after the heavy rains in areas where water accumulated) and *Solanum rigescens* (a much-branched shrublet; Fabian & Germishuizen, 1997) as well as *Cyperus rupestris* (Species group H). All these species are associated with sandy soil. The dominant tree species of this sub-community are *Terminalia sericea* (Species group D), *Acacia erubescens* (Species group O) and *Combretum apiculatum* (Species group S), whereas *Dichrostachys cinerea* (Species group M), *Triumfetta pilosa* (Species group S) and *Grewia flava* (Species group T) are the most dominant shrubs.

The most prominent grass species are *Sporobolus panicoides* (Species group F), *Chloris virgata* (Species group N), *Aristida adscensionis*, *Melinis repens* (Species group S), *Eragrostis pilosa*, *Enneapogon cenchroides* and *Heteropogon contortus* (Species group T). *Eragrostis biflora* also has the highest cover abundance in this specific sub-community in comparison to all the other communities of the study area. Other important forbs found in this sub-community include *Conyza podocephala* (Species group M), *Justicia protracta* and *Schkuhria pinnata* (Species group T).

2.1.2 *Oxalis depressa – Sporobolus panicoides* Sub-community

This sub-community is represented by 4 relevés with 26 – 39 species per relevé. The altitude at which this area is located stays relatively constant at 994 m above sea level. No rock exposure was found and the surface erosion that occurred was mostly moderate. The levels of trampling were moderate to reasonably high in some areas and crust formation ranged from slight to severe in some parts of the sub-community.

Oxalis depressa (Species group E) is the only diagnostic species of this sub-community. This species is a herb arising from a small ovoid bulb and is associated with disturbed areas (Fabian & Germishuizen, 1997). Trees are not very widespread in this sub-community, but tree species that do occur are *Acacia tortilis* (Species group M) and *A. erubescens* (Species group O). The only dominant shrub is *Grewia flava* (Species group T). The most prevalent grass species include *Sporobolus panicoides* (Species group F), *Bothriochloa insculpta*, *B. radicans*, *Chloris virgata* (Species group N) and *Heteropogon contortus* (Species group T). The most dominant forb species are *Hemizygia canescens* (Species group H), *Chamaecrista mimosoides, Zornia milneana* (Species group S) and *Tephrosia lupinifolia* (Species group T).

2.1.3 *Combretum imberbe – Acacia mellifera* Sub-community

This sub-community is situated on the plains of the study area and is located at a constant altitude of 993 m above sea level. The surface erosion occurring in this area was mostly moderate and crust formation was present over most parts of this sub-community, but it was not severe. Trampling occurred at relatively high levels and animal trails were prominent in this sub-community. The *Combretum imberbe – Acacia mellifera* Sub-community is represented by 3 relevés with the number of plant species per relevé ranging from 26 to 33.

The diagnostic species of this sub-community include the plants of Species group G, namely *Combretum imberbe* and *Grewia bicolor*. These species are associated with riverine fringes and dry watercourses in woodland and bushveld and the leaves and/or fruits are browsed by various game species (Coates Palgrave, 2002). Other dominant tree species that can be found are *Rhus pyroides* (Species group H), *Acacia erubescens* (Species group O) and *A. mellifera* (Species group T). The most dominant grasses are *Chloris virgata* (Species group N), *Aristida congesta* subsp. *barbicollis* and *Tragus racemosus* (Species group T). The cover abundance of the forbs is lower in this sub-community. The most prevalent forbs include *Hemizygia canescens* (Species group H), *Rhynchosia totta* (Species group O), *Evolvulus alsinoides* and *Schkuhria pinnata* (Species group T).

2.2 *Grewia flavescens – Blumea mollis* Community

This community has the largest species diversity in comparison to all the other communities of the study area. This is due to the large area coverage of this community and the diversity of habitats present in this community. The soils of this community are also very sandy but some areas have a higher clay content than the other communities and the soil is more gravelly than the previously mentioned communities. In comparison to the other communities, this community is situated in close proximity to the Matlabas River.

Diagnostic species for this community are those present in Species group L. They are the shrub *Grewia flavescens* and the herbs *Blumea mollis*, *Indigofera filipes* and *Cyphostemma oleraceum*. This community is also characterised by the shrub *Carissa bispinosa* and the herb *Kohautia virgata* (Species group I) as well as the perennial weed *Achyranthus aspera* var. *sicula* (Species group J). The absence of species from Species group H is also characteristic of this community. The most dominant tree species are *Acacia erubescens* (Species group O) and *Combretum apiculatum* (Species group S), while *Grewia monticola* (Species group M), *Triumfetta pilosa* (Species group S) and especially *G. flava* (Species group T) are the most dominant shrubs. The most prevalent grass species are those from Species group N, namely *Bothriochloa insculpta*, *B. radicans* and *Chloris virgata*. Other prevailing grasses include *Aristida adscensionis* (Species group S), *Panicum maximum* and *Aristida congesta* subsp. *barbicollis* (Species group T). The most widespread forbs species are *Conyza podocephala* (Species group M), *Monsonia burkeana*, *Agathisanthemum bojeri* (Species group S) and *Tephrosia lupinifolia* (Species group T).

This community can be divided into 3 Sub-communities and 3 Variants, namely the *Peltophorum africanum – Triumfetta pilosa* Sub-community, including the *Carissa bispinosa – Ziziphus mucronata* Variant, the *Peltophorum africanum – Aristida adscensionis* Variant and the *Combretum molle – Acacia erubescens* Variant, the *Tephrosia capensis – Grewia flava* Sub-community and the *Acacia erubescens – Grewia flava* Sub-community.

2.2.1 *Peltophorum africanum – Triumfetta pilosa* Sub-community

This sub-community is another example of a typical area where *Acacia mellifera* encroachment is taking place. The location of this sub-community is at an altitude ranging from 975 m – 996 m and it is represented by a total of 16 relevés. The level of surface erosion that occurred in this sub-community was primarily moderate. Crust formation was minor in most areas but considerable crust formation was found in some parts, especially in the *Combretum molle – Acacia erubescens* Variant. The reason for this could be the relatively high trampling levels caused by animal species moving through this sub-community to reach the Matlabas River.

Diagnostic species of Species group J characterise this sub-community. These species are *Peltophorum africanum*, *Combretum molle* and *Achyranthus aspera* var. *sicula*. *Peltophorum africanum* and *Combretum molle* are trees with spreading crowns and their seeds germinate easily (Coates Palgrave, 2002). Both trees are browsed by game species (Van Wyk *et al.*, 2000). *Achyranthus aspera* var. *sicula* is a perennial herb which is often recognised as a weed. Other trees common in occurrence are *Acacia erubescens* (Species group O) and *Combretum apiculatum* (Species group S). *Grewia* species are the most dominant shrubs in this sub-community, especially *G. flava* (Species group T). *Bothriochloa insculpta*, *B. radicans*, *Chloris virgata* (Species group N), *Aristida adscensionis* (Species group S) and *A. congesta* subsp. *barbicollis* (Species group T) are the most dominant grass species, while *Blumea mollis* (Species group L), *Abutilon sonneratianum* and *Tephrosia lupinifolia* (Species group T) are the most dominant forbs.

Three Variants occur in this Sub-community.

2.2.1.1 *Carissa bispinosa – Ziziphus mucronata* Variant

This variant is represented by 7 relevés with 29 – 36 plant species per relevé. Rock exposure occurred to a maximum of approximately 30% gravel on the soil surface. The plant species of this variant had sun exposure ranging from full-sun to full-shade.

Diagnostic species of this variant are those found in Species group I, namely *Carissa bispinosa*, *Pupalia lappacea* and *Kohautia virgata*. The presence of *Sporobolus panicoides* (Species group F) and *Tephrosia capensis* (Species group K) are characteristic for this variant compared to the other two variants of this sub-community. Other important distinguishable traits of this variant are the absence of Species groups A, B, D, E, G, and H and the high cover abundance of *Ziziphus mucronata* (Species group M) and the perennial *Asparagus suaveolens* (Species group N).

2.2.1.2 *Peltophorum africanum – Aristida adscensionis* Variant

Rock exposure in this variant ranged from 0% to 60%, mainly in the form of gravel. This variant is represented by 4 relevés with a number of 19 – 28 plant species per relevé. The plants of this variant also had full sun exposure to plants which occurred only in the shade.

This variant does not have any diagnostic species, but is characterised by the absence of *Combretum molle* and *Achyranthus aspera* var. *sicula* (Species group J) which are diagnostic of the *Peltophorum africanum – Triumfetta pilosa* sub-community. The absence of *Acacia erubescens* (Species group O), which is diagnostic of the major community in which this variant occurs, is also an important distinguishing factor. The presence of *Cymbopogon pospischilli* (Species group D) and *Grewia bicolor* (Species group G) are also characteristic of this variant.

2.2.1.3 *Combretum molle – Acacia erubescens* Variant

This variant is located at altitudes ranging from 979 m to 996 m above sea level. The variant is represented by 5 relevés with 29 – 34 plant species per relevé. Rock exposure of the soil occurred mostly in the form of gravel and varied from 0% to 70% in some areas. The surface erosion was moderate and crust formation was prominent in some areas. Trampling levels ranged from moderate to high, most likely due to the occurrence of high populations of impala and eland that was sited regularly in this variant.

This variant does not have any diagnostic species. However, the high cover abundance of *Combretum molle* (Species group J) as well as *Acacia erubescens* (Species group O) is characteristic of this variant. Other characteristic traits of this variant are the presence of the shrub/herb *Abutilon pycnodon* (Species group B) and the perennial herb *Senna italica* subsp. *arachoides* (Species group R) and the absence of Species groups A, D, E, F, G, H and K.

2.2.2 *Tephrosia capensis – Grewia flava* Sub-community

The *Tephrosia capensis – Grewia flava* Sub-community occurs at an altitude of 978 m – 995 m above sea level and is also situated on the plains of Marakele Park. The surface erosion of the soil was only moderate in this sub-community and crust formation was not considerable. Trampling levels varied from moderate to high. This sub-community is represented by 4 relevés with 28 – 36 plant species per relevé. The soil consists mostly of sand of a medium to fine texture and rock exposure was minuscule in this area.

Only *Tephrosia capensis* (Species group K), a herb usually occurring on rocky slopes in grassland (Fabian & Germishuizen, 1997), is diagnostic of this sub-community. The presence of *Phyllanthus reticulatus* (Species group S), which only occurs in this sub-community of the *Acacia erubescens – Combretum apiculatum* Major community, and *Heteropogon contortus* (Species group T), which only occurs in this sub-community of the *Grewia flavescens – Blumea mollis* Community, is an important characteristic of this sub-community. *Phyllanthus reticulatus* is a much-branched shrub/tree normally occurring in riverine vegetation (Coates Palgrave, 2002), while *H. contortus* is a perennial grass that usually grows in gravelly soil. The absence of Species group I is also characteristic of this sub-community.

Various woody species occur in this sub-community. The most dominant tree species are *Acacia tortilis* (Species group M), *A. erubescens* (Species group O) and *Combretum apiculatum* (Species group S). The most dominant shrubs include *Dichrostachys cinerea* and *Grewia monticola* (Species group M). The most prevalent grass species are *Urochloa mosambicensis* (Species group M), *Bothriochloa insculpta*, *B. radicans* (Species group N) and *Aristida adscensionis* (Species group S). The most prevalent forbs are *Conyza podocephala* (Species group M) and *Abutilon sonneratianum* (Species group T).

2.2.3 *Acacia erubescens – Grewia flava* Sub-community

This sub-community is represented by 6 relevés with a number of plant species ranging from 10 – 32 species per relevé. The rock coverage in this area varied from 0% to 90% in some areas in the form of gravel, stones and rocks. The levels of trampling ranged from areas where no trampling occurred to areas where extensive trampling took place. Surface erosion was moderate to high in this sub-community and the crust formation of the soil was relatively widespread. The *Acacia erubescens – Grewia flava* Sub-community is located at altitudes between 975 m – 994 m above sea level.

The diagnostic species are not restricted to a specific Species group. The only exceptional characteristic trait of this sub-community is the high cover abundance of *Corchorus asplenifolius* (Species group C) that is not found elsewhere in the *Acacia erubescens* – *Combretum apiculatum* Major community. *Acacia erubescens* (Species group O) and *Combretum apiculatum* (Species group S) are the two most dominant tree species and *Triumfetta pilosa* (Species group S) and *Grewia flava* (Species group T) are the only dominant shrubs found in this sub-community. The most dominant grass species are *Panicum maximum* and *Aristida congesta* subsp. *barbicollis* (Species group T). Many forb species are found in this sub-community and the forbs found in Species group T have relatively high cover abundances. The most prominent forbs are *Abutilon sonneratianum*, *Justicia protracta*, *Tephrosia lupinifolia* and *Schkuhria pinnata* (Species group T).

2.3 *Acacia erubescens* – *Triumfetta pilosa* Community

Altitudes of the location of this community range between 970 m – 1 002 m above sea level and it is also situated on the plains of the study area. Surface erosion was reasonably moderate in this community and rock exposure of the soil varied between 0% and 80% in the form of gravel and stones. Crust formation was relatively common and the levels of trampling ranged from moderate to high. Eight relevés represent the *Acacia erubescens* – *Triumfetta pilosa* Community with the total plant species per relevé ranging between 21 and 35.

The diagnostic species of this community are not found in one specific species group. This community is characterised by the high cover abundance of the woody species *Acacia erubescens* (Species group O), *Combretum apiculatum* and *Triumfetta pilosa* (Species group S). The near absence of species present in Species group N of this community in comparison with the other communities of the *Acacia erubescens* – *Combretum apiculatum* Major community and the higher cover abundance of *Pogonarthria squarrosa* (Species group P), which is mostly absent in the other communities, are additional characteristic features. The forbs and grass species of Species group T, which mostly have an average to low grazing value and usually occur in disturbed areas, also have relatively high cover abundance in this community.

3. *Senna italica* – *Combretum apiculatum* Major community

This major community is situated on the plains of Marakele Park and is the community found closest to the Matlabas River. Plant species found in this community were exposed to full sunlight for most parts of the day.

The soils of the community are relatively shallow and consist of very fine sand with a low silt and clay content. The *Senna italica – Combretum apiculatum* Major community has the highest rock coverage in comparison to the other major communities. Elephants were regularly sited in this community, probably due to the close proximity of the river. Animal trails were prominent in this major community.

The diagnostic species of this major community are those of Species group R, which only include *Senna italica* subsp. *arachoides*, a perennial herb found in disturbed areas, e.g. along roadsides in savanna areas (Fabian & Germishuizen, 1997). This major community is characterised by the absence of many Species groups (A, B, D – K) and the high cover abundance of the plant species from Species groups S and T. The only dominant tree species is *Combretum apiculatum* (Species group S) whereas *Triumfetta pilosa* (Species group S) and *Grewia flava* (Species group T) are the only dominant shrub species. The most dominant grass species are *Eragrostis rigidior*, *Digitaria eriantha*, *Melinis repens* (Species group S), *Panicum maximum*, *Eragrostis pilosa* and *Enneapogon cenchroides* (Species group T). The most prevalent forbs include *Chamaecrista mimosoides*, *Monsonia burkeana*, *Agathisanthemum bojeri* (Species group S), *Evolvulus alsinoides*, *Abutilon sonneratianum* and *Linum thunbergii* (Species group T). The relatively even distribution of *Phyllanthus reticulatus*, in comparison to the other 2 major communities is another characteristic of this major community. *Phyllanthus reticulatus* is a small shrub/tree which is browsed by game, although it is said that the fruits and roots are toxic (Coates Palgrave, 2002).

This major community can be divided into 2 Communities, namely the *Gossypium herbaceum – Pogonarthria squarrosa* Community and the *Vahlia capensis – Justicia protracta* Community.

3.1 *Gossypium herbaceum – Pogonarthria squarrosa* Community

The altitude at which this community is located ranges from 971 m to 990 m above sea level. This community is represented by 6 relevés with 20 – 35 plant species per relevé. Surface erosion varied from absent in some areas to moderate in other parts. Only slight crust formation occurred in most parts of this community, although a few areas were found where relatively large patches covered with crusts were present. Trampling by game species was mostly moderate. Areas with excessive trampling, however, were also found in this community. The soil of this community had rock coverage ranging from 40% to 80%, mostly in the form of gravel and stones.

Species group P contains the diagnostic species of this community. These species are *Polygala sphenoptera*, *Gossypium herbaceum* and *Pogonarthria squarrosa*. The grass species *Pogonarthria squarrosa* is a perennial with a low grazing value and it often colonises disturbed sandy soils (Van Oudtshoorn, 1999). The absence of *Justicia protracta* (Species group T) is an important characteristic of this community since it is present in all the other communities of the study area. The reason for its absence is not known. The most dominant grass species are *Eragrostis rigidior*, *Melinis repens* (Species group S), *Panicum maximum* and *Aristida congesta* subsp. *barbicollis* (Species group T). Forbs dominate this community. Forb species having the highest cover abundance include *Chamaecrista mimosoides*, *Monsonia burkeana*, *Agathisanthemum bojeri* (Species group S), *Evolvulus alsinoides* and *Linum thunbergii* (Species group T). The annual weed *Ceratotheca triloba* (Species group S) has the highest cover abundance in this community in comparison to the other communities of the study area.

3.2 *Vahlia capensis – Justicia protracta* Community

This community is situated at altitudes of 978 m to 1 012 m above sea level. Crust formation varied considerably in this community from areas with no crusts to areas where severe crust formation took place. Surface erosion was moderate throughout this community. Rock coverage varied between 50% and 95% and was mostly in the form of gravel and stones, but in places granite outcrops were noted. This community is represented by 7 relevés with 18 – 38 plant species per relevé.

Vahlia capensis (Species group Q) is the only diagnostic species of this community. This community is also dominated by the presence of various forb species. The most dominant forbs are *Chamaecrista mimosoides* (Species group S), *Evolvulus alsinoides*, *Justicia protracta* and *Linum thunbergii* (Species group T). The most dominant grasses are *Aristida adscensionis*, *Eragrostis rigidior*, *Melinis repens* (Species group S), *Eragrostis pilosa* and *Enneapogon cenchroides* (Species group T).

3.3.3 Ordination

The DECORANA ordination (Hill, 1979b) of the specific experimental plots in Marakele Park clearly indicates the differences in species composition of the various major communities and communities within the major communities (Figure 3.1) and also reflects the habitat affinities of the various vegetation units. Axis 1 and 2 represent the habitat factors that determine the ecological characteristics of each community.

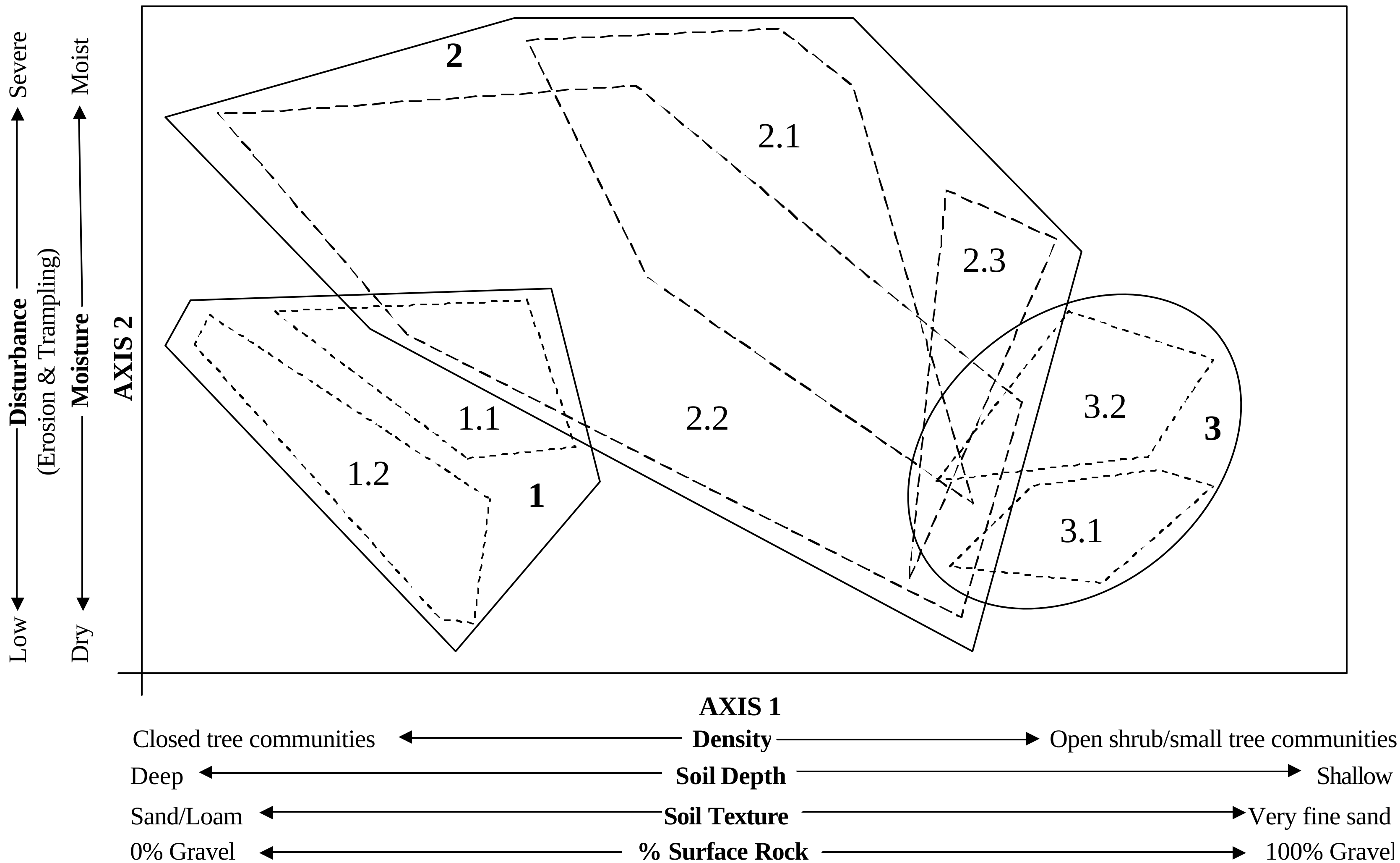


Figure 3.1: DECORANA ordination showing the distribution of the various major communities and communities in relation to environmental factors (Axis 1 & 2). (See section 3.3 for the names and descriptions of the major community and community numbers used in this figure).

The gradients represented by Axis 1 are plant density, soil depth, soil texture and % surface rock (mostly gravel and small stones). These gradients vary from areas with high tree densities, especially large *Acacia* trees, with relatively deep, sandy/loamy soil that has no occurrence of surface rocks (on the left) to areas with open shrub communities, with the occurrence of small trees, especially *Combretum* spp., on relatively shallow soil of a very fine sandy texture with a high occurrence of gravel (on the right). Axis 2 represents gradients of disturbance (mostly erosion and trampling by game species) that range from low levels of trampling and erosion at the bottom part to severe levels of trampling and erosion at the top part. This axis also indicates the levels of moisture found in the communities. At the bottom part are plant communities that are mostly adapted to dry areas whereas communities with plant species adapted to moist conditions, like *Cyperus* spp., are found at the top part.

3.4 CONCLUSIONS

The vegetation of the specific experimental plots in Marakele Park was identified, classified, described and ecologically interpreted. This study revealed that the vegetation of the specific experimental plots in Marakele Park could be divided into 3 major communities, 7 communities, 6 sub-communities and 3 variants, each with their own characteristic ecological traits. These ecological units serve as a basis for future management and effective utilisation for wildlife management.

The differences in the various communities, sub-communities and variants are reflections of different habitats formed by various abiotic and biotic factors. For example, it was found that *Acacia* species are associated with deeper, sandy soil, while *Combretum* species are associated with shallow, gravelly soil. It was also found that the most widespread herbaceous plant species were mostly forbs and grasses that are associated with disturbed areas. In order to understand and explain the differences in the various communities, a more comprehensive study on a syntaxonomical and synecological level is needed in order to reveal the true nature of these vegetation communities.

It is clear from the DECORANA diagram that the vegetation units (communities and sub-communities) overlap to some extent. The occurrence of the same plant species in various communities is not uncommon, but the overlapping results found during this study were most likely enhanced due to the small sample area surveyed.

These overlaps could be attributed to various environmental and biological conditions that have temporal and spatial impacts. Factors such as fire, long dry spells, inundation of depressions after thunderstorms and grazing could cause these overlaps with annual species occurring in several communities for relatively short time spans.

Thus, a more in depth survey (based on the Braun-Blanquet method) of Marakele Park as a whole is necessary to obtain a more accurate description of the various vegetation units present in the park. This will enable the compilation of a proper vegetation map for Marakele Park. A more detailed study would help to make accurate management decisions in order to manage the biotic component of Marakele Park more sufficiently.

CHAPTER 4

THE INFLUENCE OF THE TREE THINNING TREATMENTS ON THE DYNAMICS OF THE WOODY LAYER

4.1 INTRODUCTION

An increase of woody biomass is primarily a function of two processes. Firstly, by the increase in biomass of already established plants (vegetative growth) and, secondly, by increases in tree density, mainly from newly established seedlings (reproduction) (Smit, 2004). The excessive and undesirable increase in woody plant abundance is commonly referred to as bush encroachment. According to Brown & Archer (1999), species contributing to bush encroachment are indigenous trees or shrubs that are usually in equilibrium with their environment, but become unnaturally abundant as a reaction to the deterioration of the surrounding natural environment. Bush encroachment is one of the most prominent results of imbalances in savanna (bushveld) ecosystems and globally reduces the biodiversity of such areas (Kraaij, 2002). It has a profound effect on the productivity of the herbaceous layer, involving mainly available soil water as the primary determinant of production. It also accentuates the effects of drought and often gives rise to pseudo-droughts (fodder shortages during normal or dry years) (Richter, 1991; Meyer, 1997). It is thus essential to reduce the tree density in areas encroached by woody plants through various bush control measures in order to restore the production potential of the herbaceous layer.

Cutting of trees in South African savannas is consequently a common practice, either for direct use or during bush control measures, often without herbicides being applied (Smit, 2003). In both cases the coppicing regrowth of the woody plants has important consequences. The strong coppicing ability of woody plants in African savannas following damage by cutting (Milton, 1988; Mushove & Makoni, 1993), mega herbivores (Ben-Shahar, 1991; Lewis, 1991; Styles, 1993) or fire (Sweet & Mphinyane, 1986; Trollope & Tainton, 1986; Trollope, 1992) is a known fact. When one plant species is removed from the ecosystem, it is usually replaced by another plant species, which in most cases is less desirable. Bush encroachment therefore involves the replacement of the herbaceous cover by an undesirable woody component (Bester & Reed, 1997; Mouat *et al.*, 2003).

Regrowth of woody plants following mechanical bush control measures is a common occurrence (Dye & Spear, 1982; Gammon, 1984; Davidson, 1989; Teague & Smit, 1992; Smit & Rethman, 1998a; Richter *et al.*, 2001; Smit, 2003) and of great significance.

It has been suggested to treat cut stumps with a suitable herbicide, repeat the mechanical cutting over time and/or incorporate the use of fire (Kendall & Alchin, 1999; Trollope, 1999, Smit *et al.*, 1999; Campbell, 2000; Richter *et al.*, 2001; Smit, 2004). None of these follow-up treatments were employed on the treatment plots of the study area. Without follow-up treatments it is expected that the cutting may result in an encroached situation that is worse than the original state.

Both bush encroachment and the methods used to control it have consequences on the amount of potential browse available to herbivore game species (Barac, 2003). In reviewing techniques for determining available browse and browse utilisation, Rutherford (1979) stated that it is important to have a clear understanding of what is meant by browse and available browse. He described browse as the sum total of that material on woody plant species that is potentially edible to a specific set of animals. It is most commonly regarded as the current season's growth of both leaves and twigs. Available browse on the other hand is usually a more restricted quantity than browse and in most studies, available browse is simply determined on the basis of maximum height above ground to which a specified animal can utilise browse. The availability of browse below a specified browse height may be reduced by obstruction of browse material towards the centre of the plant by dense branch entanglements (Rutherford, 1979), while leaf senescence of winter deciduous species will lower available browse during certain periods (Styles, 1993).

However, being available does not necessarily mean that it will be eaten. This brings us to the concept of food preference. Grunow (1980) stated that browsers select between plant species as markedly as grazers do. Petrides (1975), cited by Barnes (1976), defined a 'preferred food species' as one which is proportionally more frequently in the diet of an animal than it is available in the environment, and 'food preference' as the extent to which food is consumed in relation to its availability. A 'principal food species' is being defined as one making a large contribution to the diet (Grunow, 1980).

Owen-Smith & Cooper (1987) distinguished between two basic categories of acceptability of woody plant species to browsing animals: (i) species favoured year round; and (ii) species generally rejected, except during certain periods. Barnes (1976) concluded that a proper understanding of animal-plant relationships in terms of intake will depend on knowledge of the diet of the animals, the number of plant species present and their distribution and availability. In addition, the actual intake of available browse may be influenced by chemical defences of woody plants (Rosenthal & Janzen, 1979; Van Hoven, 1984; Lindroth, 1989; Furstenburg, 1991;

Bryant *et al*., 1992; Van Wieren, 1992; Ksiksi *et al.*, 2005; Mosquera-Losada *et al.*, 2005), as well as nutritional characteristics of leaves in different phenological stages (Cooper, 1982; Heady, 1984; Owen-Smith & Cooper, 1987; Cooper *et al*., 1988; Lindroth, 1989; Palo & Lundberg, 1992; Styles, 1993; Ahmadi *et al.*, 2005; Pamo *et al*., 2005).

Tree thinning will invariably reduce the amount of available browse at peak biomass. However, the remaining browse may be better distributed, with leaves comparatively younger and remaining attached longer into the winter. This would shorten the leafless period of some species in early spring and may even eliminate it. High density stands may therefore not only be poorly suited to grazers because of reduced growth of herbaceous plants, but also to browsers because of their relatively poor browse supplying characteristics (Smit, 1994).

The objectives of this study were to analyse the effect of tree thinning treatments on the:

- canopy cover of the woody plants;
- density of the woody plants in terms of plants ha^{-1} (on a species basis);
- potential competitiveness of the woody layer in terms of Evapotranspiration Tree Equivalents (ETTE) ha^{-1} (on a species basis);
- regrowth (coppicing) and re-encroachment of the woody plants following the tree thinning treatments;
- potential browse production within specific height strata; and
- browsing capacity based on the browse production within the above height strata.

4.2 PROCEDURE

4.2.1 Canopy cover

The percentage canopy cover of each experimental plot was determined by randomly placing a measuring tape (100 m) in an absolutely straight line and then measuring the segments of the tape over-spanned by tree canopies. This procedure was repeated twice to measure the canopy cover over a total distance of 200 m in each experimental plot. The percentage canopy cover was calculated as the total length of these segments expressed as a percentage of the total tape measure length.

4.2.2 Quantification of the woody layer using the BECVOL-model

At the end of the 2003/2004 growing season (May/June), the spatial canopy of all rooted live woody plants encountered in two transects of 2.5 m x 100 m (250 m^2), randomly placed within each experimental plot, was measured. The woody plants encountered in each transect were also grouped into two categories in terms of the effect of the thinning treatments. The undamaged plants were categorised as normal (N) plants, while the woody plants that re-sprouted after cutting were categorised as coppice (C) plants (Appendix C). The total number of stems of each woody plant was also noted. The canopy measurements were repeated during the 2004/2005 growing season (May/June), but since the changes in the spatial canopy of undamaged (normal) woody plants would most likely be less than what can be detected accurately with the survey technique, only the fast growing coppice plants were measured. The measurements consisted of the following (Smit, 1989a; 1989b; 1994; 1996): (i) maximum tree height, (ii) height where the maximum canopy diameter occurs, (iii) height of first leaves or potential leaf bearing stems, (iv) maximum canopy diameter, and (v) base diameter of the foliage at the height of the first leaves (Appendix D). A measuring pole of 2.5 m was used for these measurements. Where difficulty arose with the direct measurements of tall woody plants, indirect methods, like the dimension meter (Smit, 1989c), were implemented.

Leaf volume and leaf dry mass estimates of each experimental plot were calculated from these measurements, using a modified version of the quantitative description technique of Smit (1989a; 1989b) as described by Smit (1994; 1996). For reasons explained above, the measurements of undamaged plants taken during the 2003/2004 season were used with the measurements of the coppice plants taken during the 2004/2005 season to calculate the leaf volume and leaf dry mass of the 2004/2005 season. This technique provides an estimate of the leaf volume and leaf dry mass at peak biomass, based on the relationship between the tree's spatial canopy volume and its leaf volume and leaf dry mass. This technique was compiled into the BECVOL-model (Biomass Estimates from Canopy VOLume) (Smit, 1994; 1996), which incorporates regression equations developed from harvested trees. It relates spatial canopy volume (independent variable) to leaf volume and leaf dry mass (dependant variable). The spatial tree canopy volume (x) is transformed to its normal logarithmic value, while y represents the estimated leaf dry mass.

The number of Evapotranspiration Tree Equivalents (ETTE) ha^{-1} was subsequently calculated from the leaf volume estimates (1 ETTE = mean leaf volume of a 1.5 m tall single-stemmed tree = 500 cm^3 leaf volume) (Smit, 1989a; 1989b). Since the ETTE-values are based on estimates of actual leaf biomass, it is considered a more accurate measure of potential competition of woody plants compared to simple density data (plants ha^{-1}).

In addition to total leaf dry matter (DM) ha^{-1}, stratified estimates of the leaf DM ha^{-1} below 1.5 m, 2.0 m and 5.0 m, respectively, were also calculated, using the BECVOL-model (Smit, 1994). The height of 1.5 m represents the mean browsing height of the goat (Aucamp, 1976) and impala (*Aepyceros melampus*) (Dayton, 1978), while 2.0 m and 5.0 m represent the mean browsing heights of the kudu (*Tragelaphus strepsiceros*) (Wentzel, 1990) and giraffe (*Giraffa camelopardalis*) (Skinner & Chimimba, 2005), respectively. These are mean and not maximum browsing heights, and were only used to draw comparisons. It is known that large individuals can reach higher, e.g. 2.5 m for kudu and 5.5 m for giraffe (Dayton, 1978), while breaking of branches may enable some browsers to utilise browse at even higher strata (Styles, 1993). The browsing capacity below the above-mentioned height strata was also determined for each month of the 2003/2004 season. The browsing capacity of the 2004/2005 season was not calculated because biomass changes of undamaged trees from the first to the second season were likely less than what can be detected accurately with the survey technique. The coppice plots were not included during the browsing capacity calculations due to a lack of comparable control plots.

Only leaf material – the main component of utilisable browse – was quantified, though young shoots may also be utilised. Available browse was assumed to be those amounts below the specified mean browsing heights.

4.2.3 Data analyses

The standard error of the mean number of stems was calculated by using Graphpad (1997). The following formula of Smit (2003b) was used to calculate the browsing capacity based on the leaf DM yield within the strata below the height of 1.5 m ($DM^{1.5}$), 2.0 m ($DM^{2.0}$) and 5.0 m ($DM^{5.0}$) for all the woody plants in the experimental plots:

$$y = d \div \frac{(DM \times f \times p)}{r}$$

Where: y = Browsing capacity (ha BU^{-1})
d = Number of days in a year (365)
DM = Total leaf DM yield (kg ha^{-1})
f = Utilisation factor
p = Phenology factor
r = Daily leaf DM required per BU {2.5% of body mass = 3.5 kg day^{-1} (Owen-Smith, 1999)}

A Browser Unit (BU) is defined as the metabolic equivalent of a kudu (*Tragelaphus strepsiceros*), a 100% browser, with a mean body mass of 140 kg (Dekker, 1997).

Specific phenology values was allocated to each woody species for the different months of the year, according to the percentage leaves which the woody species were carrying, to determine the maximum and minimum leave yield, respectively. The following phenology (p) values were used during this study:

- 0 = no leaves
- 1 = > 1 – 10% leaves;
- 2 = > 10 – 30% leaves;
- 3 = > 30 – 70% leaves; and
- 4 = > 70 – 100% leaves.

The mean phenology values of the different woody species for each month of the year were obtained from another study that was done in the same area (Bahlmann, in press), supplemented with data from Smit (1999) as well as personal observations. An utilisation factor (f) was also given to each of the woody species (Smit, personal communication*****). The values of f varied from 0.1 (plants that are poorly utilised) to 0.4 (plants that are regularly utilised) (Table 4.1). In addition, simple descriptive statistics were used.

4.3 RESULTS

4.3.1 Canopy cover

The percentage canopy cover for each experimental plot is presented in Table 4.2. From Table 4.2 it is clear that only the Ae-Dc Control and the Am-Gf Coppice plots had a higher percentage canopy cover than the area not covered by tree canopies. As expected the control plots had a higher canopy cover than the treatment plots.

4.3.2 Evapotranspiration Tree Equivalents and tree density

The Evapotranspiration Tree Equivalent values (ETTE) ha^{-1} at the end of the 2003/2004 and 2004/2005 seasons are presented in Table 4.3. From Table 4.3 it is clear that the *Acacia mellifera* dominated plots had the highest total ETTE ha^{-1}, with values exceeding 10 000 ETTE ha^{-1}. Also of note is the relatively small differences in ETTE ha^{-1} between some control plots and their corresponding treatment plots.

*****Smit, G.N., Department of Animal, Wildlife and Grassland Sciences, P.O. Box 339, University of the Free State, Bloemfontein, 9300.

Table 4.1: The utilisation factors (f) and the phenology (p) values allocated to all the recorded woody species for each month of the year that was used to calculate the browsing capacity.

Species	Utilisation factor (f)	Phenology value (p)											
		January	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**
Acacia caffra[a]	0.2	4	4	4	4	4	4	3	0	2	4	4	4
Acacia erubescens[b]	0.2	4	4	4	4	4	4	1	0	0	0	0	3.5
Acacia karroo[a]	0.2	4	4	4	4	4	4	3	0	1	3	4	4
Acacia luederitzii retinens[b]	0.2	4	4	4	4	4	4	1	0	0	0	3.5	4
Acacia mellifera[b]	0.2	4	4	4	4	4	4	1	0.5	1	1	3	3.5
Acacia robusta[b]	0.2	4	4	4	4	4	4	1	1	1	0.5	3	4
Acacia tortilis[a]	0.2	4	4	4	4	4	4	4	4	2	0	2	4
Asparagus suaveolens[c]	0.1	4	4	4	4	4	4	3	3	4	4	4	4
Carissa bispinosa[c]	0.1	4	4	4	4	4	4	4	4	4	4	4	4
Combretum apiculatum[b]	0.3	4	4	4	4	4	4	1	0	0	0.5	3	4
Combretum hereroense[c]	0.2	4	4	4	4	4	4	1	0	0	0.5	3	4
Combretum imberbe[c]	0.2	4	4	4	4	4	4	1	0	0	0.5	3	4
Combretum molle[c]	0.2	4	4	4	4	4	4	1	0	0	0.5	3	4

...Table continues

Table 4.1 continued…

Species	Utilisation factor (f)	Phenology value (p)											
		January	February	March	April	May	June	July	August	September	October	November	December
Dichrostachys cinerea[b]	0.2	4	4	4	4	4	4	1	0	0	0	2	3.5
Euclea undulata[c]	0	4	4	4	4	4	4	4	4	4	4	4	4
Grewia bicolor[c]	0.3	4	4	4	4	4	4	1	0.5	0	0	2.5	3
Grewia flava[b]	0.3	4	4	4	4	4	4	1	0.5	0	0	2.5	3
Grewia flavescens[c]	0.2	4	4	4	4	4	4	1	0.5	0	0	2.5	3
Grewia monticola[c]	0.3	4	4	4	4	4	4	1	0.5	0	0	2.5	3
Gymnosporia senegalensis[b]	0.1	4	4	4	4	4	4	1	2	2	1.5	3	4
Peltophorum africanum[c]	0.1	4	4	4	4	4	4	3	1	0	0	3	4
Pterocarpus rotundifolius[c]	0.1	4	4	4	4	4	4	3	1	0	0	3	4
Rhus pyroides[c]	0.1	4	4	4	4	4	4	4	3	3	3	4	4
Spirostachys africana[b]	0.1	4	4	4	4	4	4	2	1	0.5	0	4	4
Terminalia sericea[b]	0.1	4	4	4	4	4	4	2	1	1	1	2.5	4
Ziziphus mucronata[b]	0.2	4	4	4	4	4	4	4	3	2.5	0.5	2.5	4

[a]Smit (1999) [c]Personal observations
[b]Bahlmann (in press)

Table 4.2: The percentage canopy cover of woody plants and the area percentage not covered by tree canopies in each experimental plot.

Experimental plot	Canopy cover (%) (under trees)	No canopy cover (%) (between trees)
Acacia mellifera – Grewia flava Treatment	23.0	77.0
Acacia mellifera – Grewia flava Control	30.2	69.8
Combretum apiculatum – Grewia flava Treatment	17.1	82.9
Combretum apiculatum – Grewia flava Control	38.4	61.6
Acacia erubescens – Dichrostachys cinerea Treatment	22.1	77.9
Acacia erubescens – Dichrostachys cinerea Control	50.4	49.6
Combretum apiculatum – Grewia flava Coppice	38.3	61.7
Acacia mellifera – Grewia flava Coppice	51.5	48.5

Table 4.3: The Evapotranspiration Tree Equivalent values, (ETTE) ha^{-1}, of each experimental plot during the 2003/2004 and 2004/2005 seasons.

Experimental plot	ETTE ha^{-1}					
	2003/2004			2004/2005		
	Normal	Coppice	Total	Normal*	Coppice[a]	Total[o]
Acacia mellifera – Grewia flava Treatment	8 243	206	8 449	-	448	8 691
Acacia mellifera – Grewia flava Control	10 331	-	10 331	-	-	10 331
Combretum apiculatum – Grewia flava Treatment	3 403	350	3 753	-	1 148	4 551
Combretum apiculatum – Grewia flava Control	7 799	-	7 799	-	-	7 799
Acacia erubescens – Dichrostachys cinerea Treatment	3 381	747	4 128	-	947	4 328
Acacia erubescens – Dichrostachys cinerea Control	8 676	-	8 676	-	-	8 676
Combretum apiculatum – Grewia flava Coppice	4 348	892	5 240	-	2 660	7 008
Acacia mellifera – Grewia flava Coppice	9 676	1 240	10 916	-	3 974	13 650

*Undamaged (normal) plants were not measured during the 2004/2005 season.
[a]Only coppice plants were measured during the 2004/2005 season.
[o]The total of the treatment and coppice plots were calculated as the total of the normal plants measured during the 2003/2004 season plus the coppice plants measured during the 2004/2005 season, while the total of the 2003/2004 season for the control plots were also used for the 2004/2005 season.

The density (plants ha^{-1}) of each woody species recorded during the BECVOL-surveys in the Am-Gf Treatment plot during the 2003/2004 season is presented in Figure 4.1a, while the ETTE ha^{-1} of each woody species recorded in this plot is presented in Figure 4.1b. The density and ETTE ha^{-1} of each woody species recorded in the Am-Gf Control plot is presented in Figure 4.2a and Figure 4.2b, respectively. From Figure 4.1 it is noteworthy that in terms of tree density, *Grewia flava* is the dominant woody species, but in terms of leaf volume (ETTE ha^{-1}) *A. mellifera* is the dominant woody species in the Am-Gf Treatment plot. From Figure 4.2 it is clear that *G. flava* also had the highest density and *A. mellifera* also had the highest ETTE ha^{-1} in the Am-Gf Control plot.

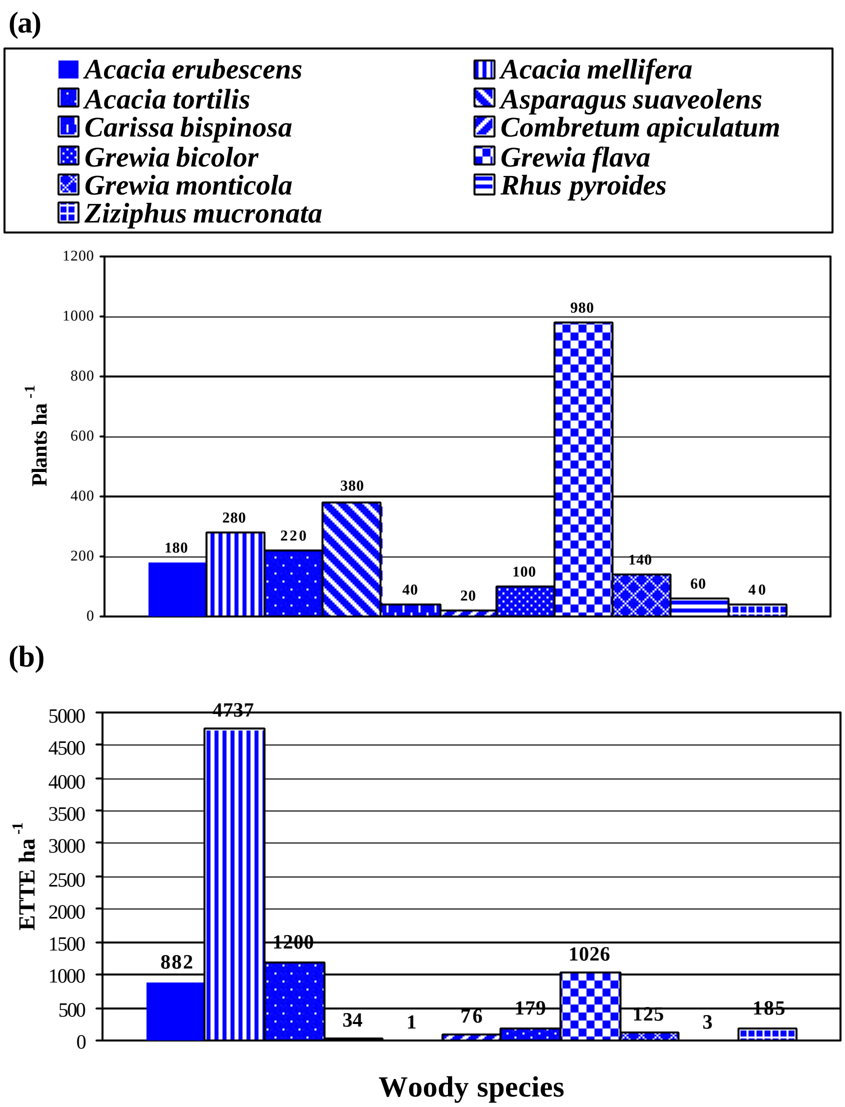


Figure 4.1: The contribution of individual woody species to (a) tree density (plants ha^{-1}), and (b) leaf volume (ETTE ha^{-1}), of the *Acacia mellifera – Grewia flava* Treatment plot during the 2003/2004 season.

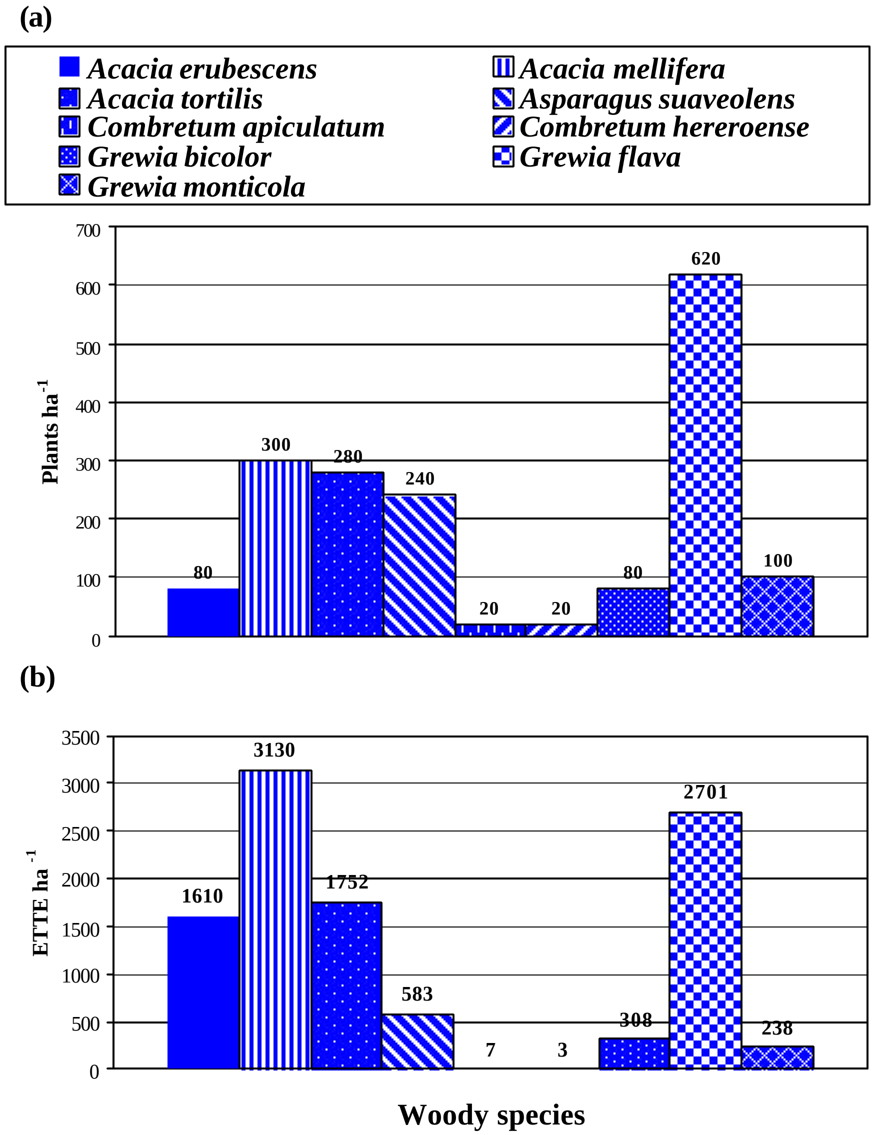
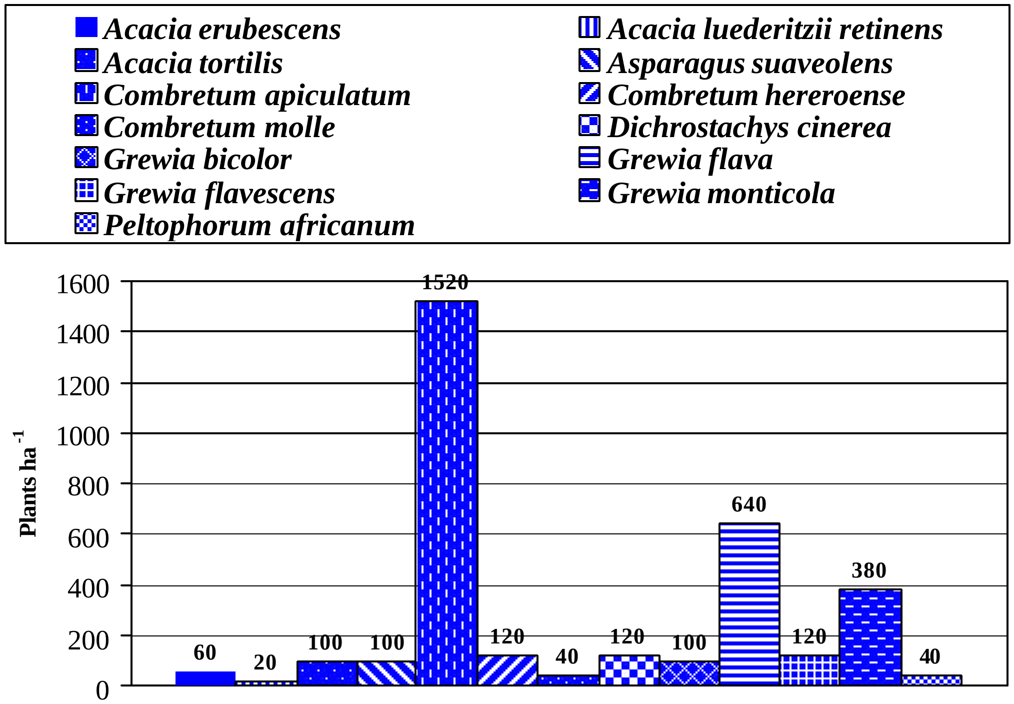


Figure 4.2: The contribution of individual woody species to (a) tree density (plants ha^{-1}), and (b) leaf volume (ETTE ha^{-1}), of the *Acacia mellifera* – *Grewia flava* Control plot during the 2003/2004 season.

The density of each woody species recorded during the BECVOL-surveys in the Ca-Gf Treatment plot during the 2003/2004 season is presented in Figure 4.3a, while the ETTE ha^{-1} of each woody species recorded in this plot is presented in Figure 4.3b. Figure 4.4a presents the density of the Ca-Gf Control plot, while Figure 4.4b presents the ETTE ha^{-1} of the control plot. From Figure 4.3 it is evident that *Combretum apiculatum* had the highest density as well as the highest ETTE ha^{-1}. Compared to the treatment plot, *C. apiculatum* also had the highest density and ETTE ha^{-1} in the Am-Gf Control plot.

(a)



(b)

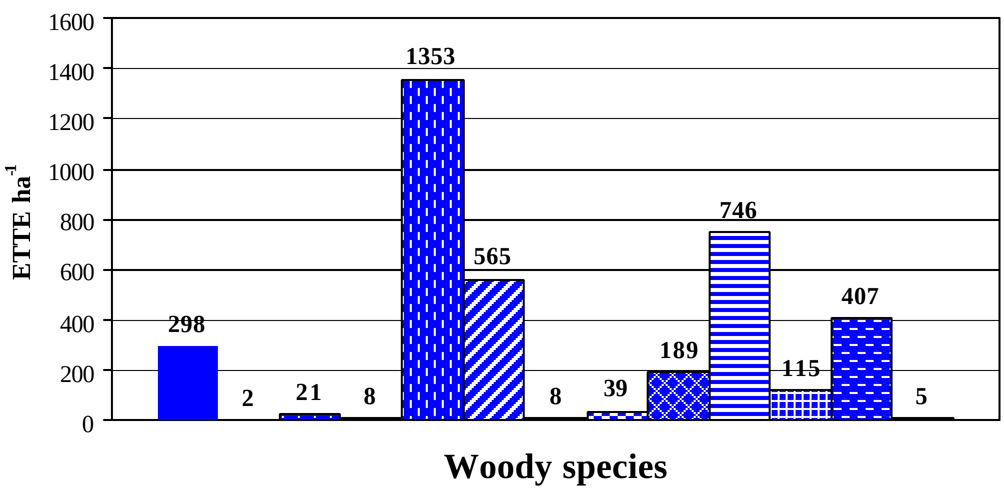


Figure 4.3: The contribution of individual woody species to (a) tree density (plants ha^{-1}), and (b) leaf volume (ETTE ha^{-1}), of the *Combretum apiculatum – Grewia flava* Treatment plot during the 2003/2004 season.

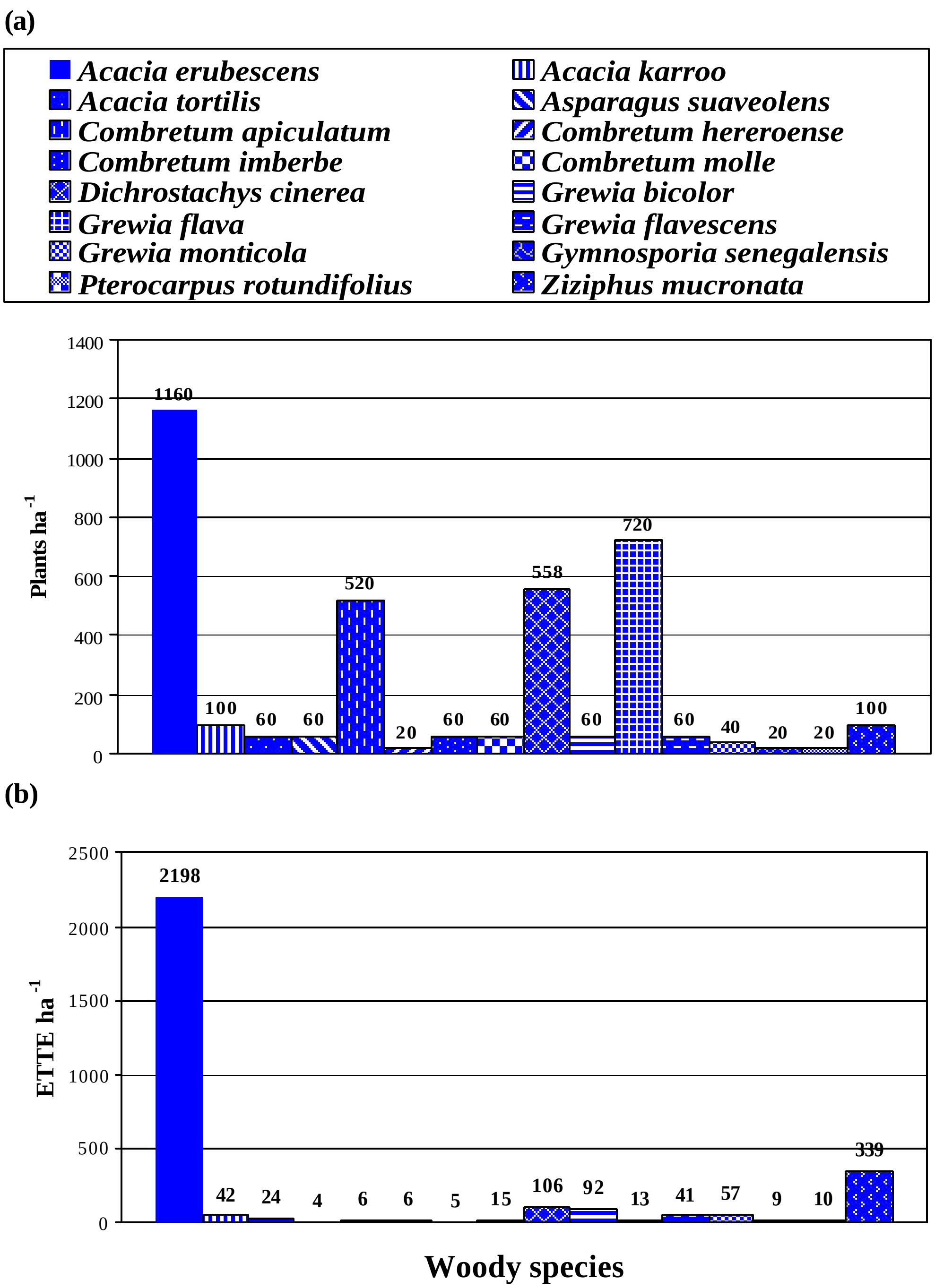


Figure 4.4: The contribution of individual woody species to (a) tree density (plants ha^{-1}), and (b) leaf volume (ETTE ha^{-1}), of the *Combretum apiculatum* – *Grewia flava* Control plot during the 2003/2004 season.

The density and ETTE ha^{-1} of each woody species recorded during the BECVOL-surveys in the Ae-Dc Treatment plot during the 2003/2004 season is presented in Figure 4.5a and Figure 4.5b, respectively. The density and ETTE ha^{-1} of each woody species recorded in the Ae-Dc Control plot is presented in Figure 4.6a and 4.6b, respectively. From Figure 4.5 it is evident that *Acacia erubescens* had the highest density as well as the highest ETTE ha^{-1} in the Ae-Dc Treatment plot. The same result was found for the Ae-Dc Control plot (Figure 4.6).

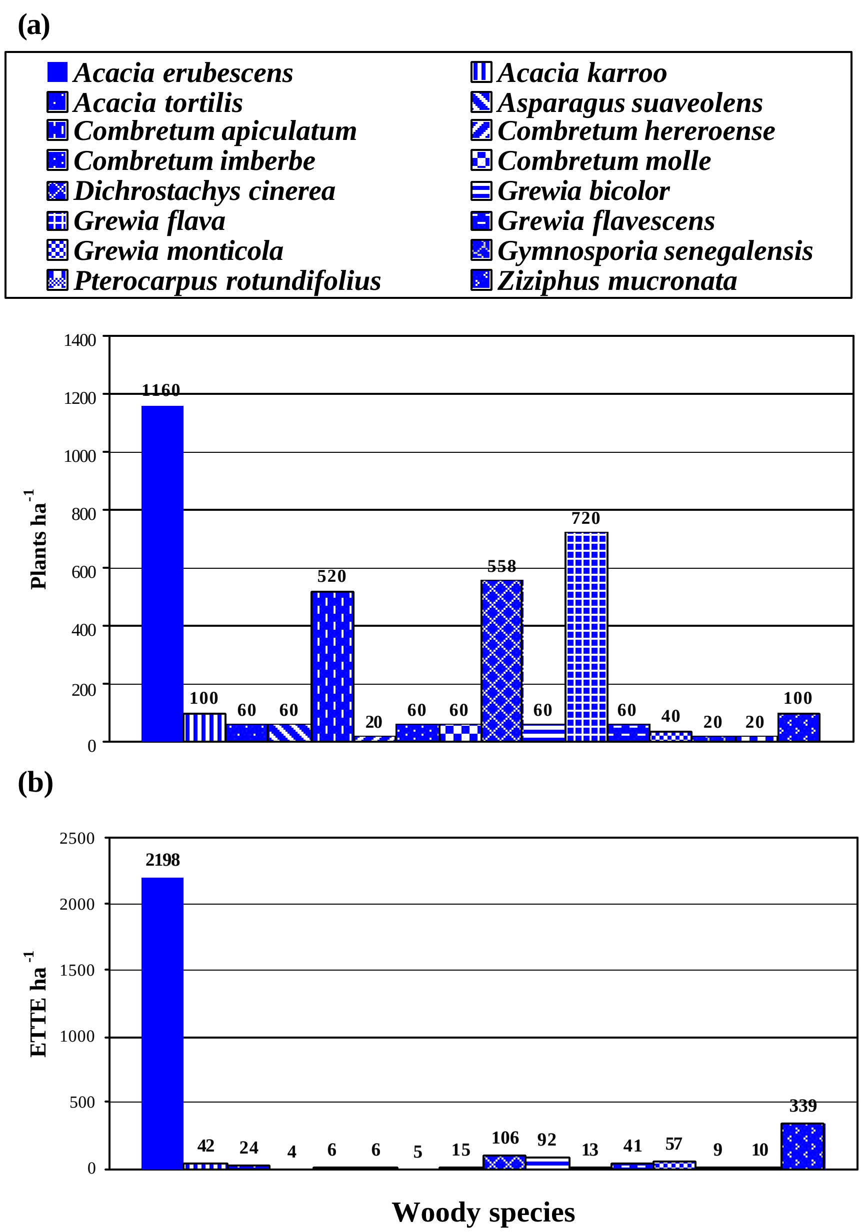


Figure 4.5: The contribution of individual woody species to (a) tree density (plants ha^{-1}), and (b) leaf volume (ETTE ha^{-1}), of the *Acacia erubescens – Dichrostachys cinerea* Treatment plot during the 2003/2004 season.

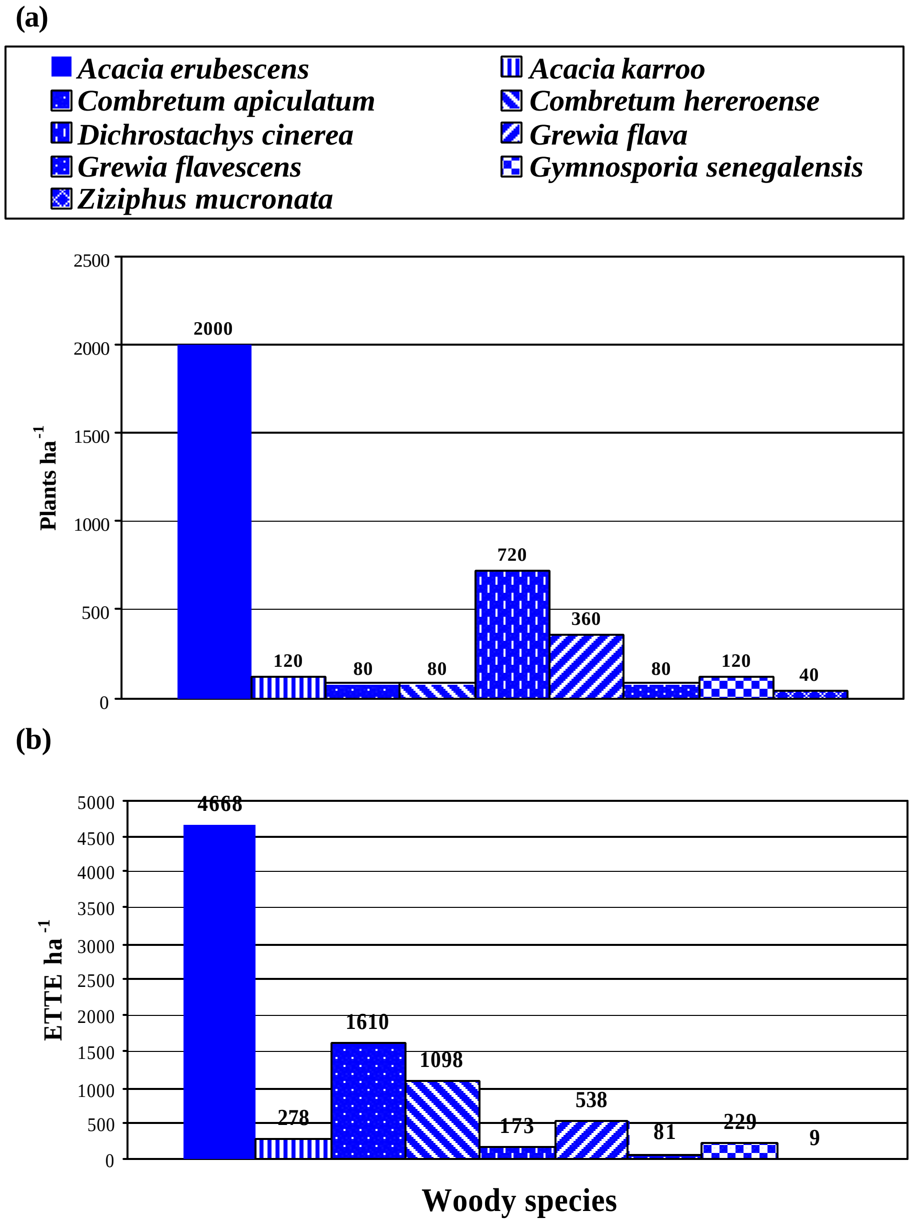


Figure 4.6: The contribution of individual woody species to (a) tree density (plants ha^{-1}), and (b) leaf volume (ETTE ha^{-1}), of the *Acacia erubescens – Dichrostachys cinerea* Control plot during the 2003/2004 season.

The density and ETTE ha^{-1} of each woody species recorded during the BECVOL-surveys in the Ca-Gf Coppice and Am-Gf Coppice plots during the 2003/2004 season is presented in Figure 4.7 and Figure 4.8, respectively. From Figure 4.7a and 4.7b it is evident that *C. apiculatum* had the highest density and ETTE ha^{-1} in the Ca-Gf Coppice plot, while Figure 4.8a and 4.8b shows that *A. mellifera* had the highest density and ETTE ha^{-1} in the Am-Gf Coppice plot.

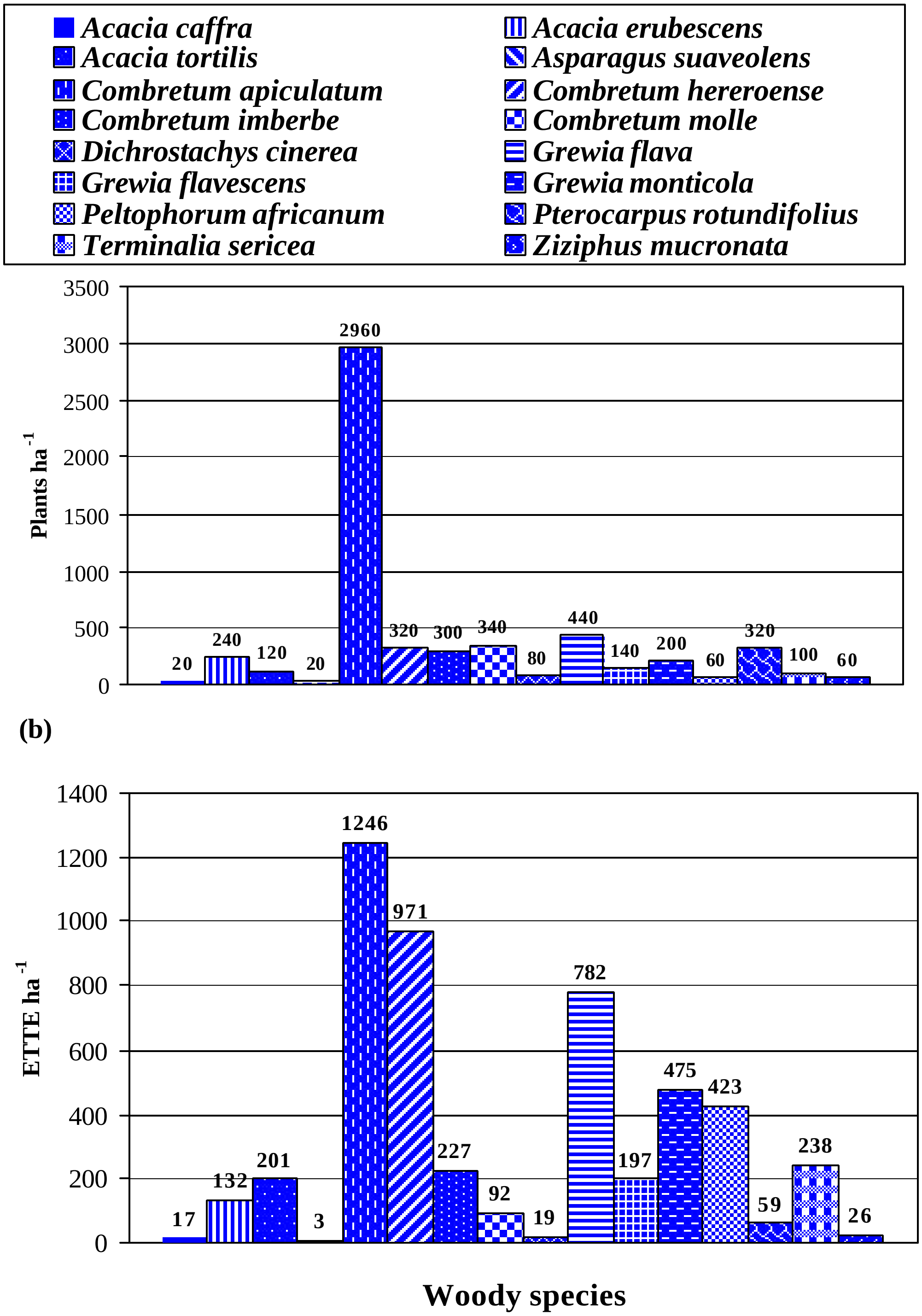


Figure 4.7: The contribution of individual woody species to (a) tree density (plants ha^{-1}), and (b) leaf volume (ETTE ha^{-1}), of the *Combretum apiculatum* – *Grewia flava* Coppice plot during the 2003/2004 season.

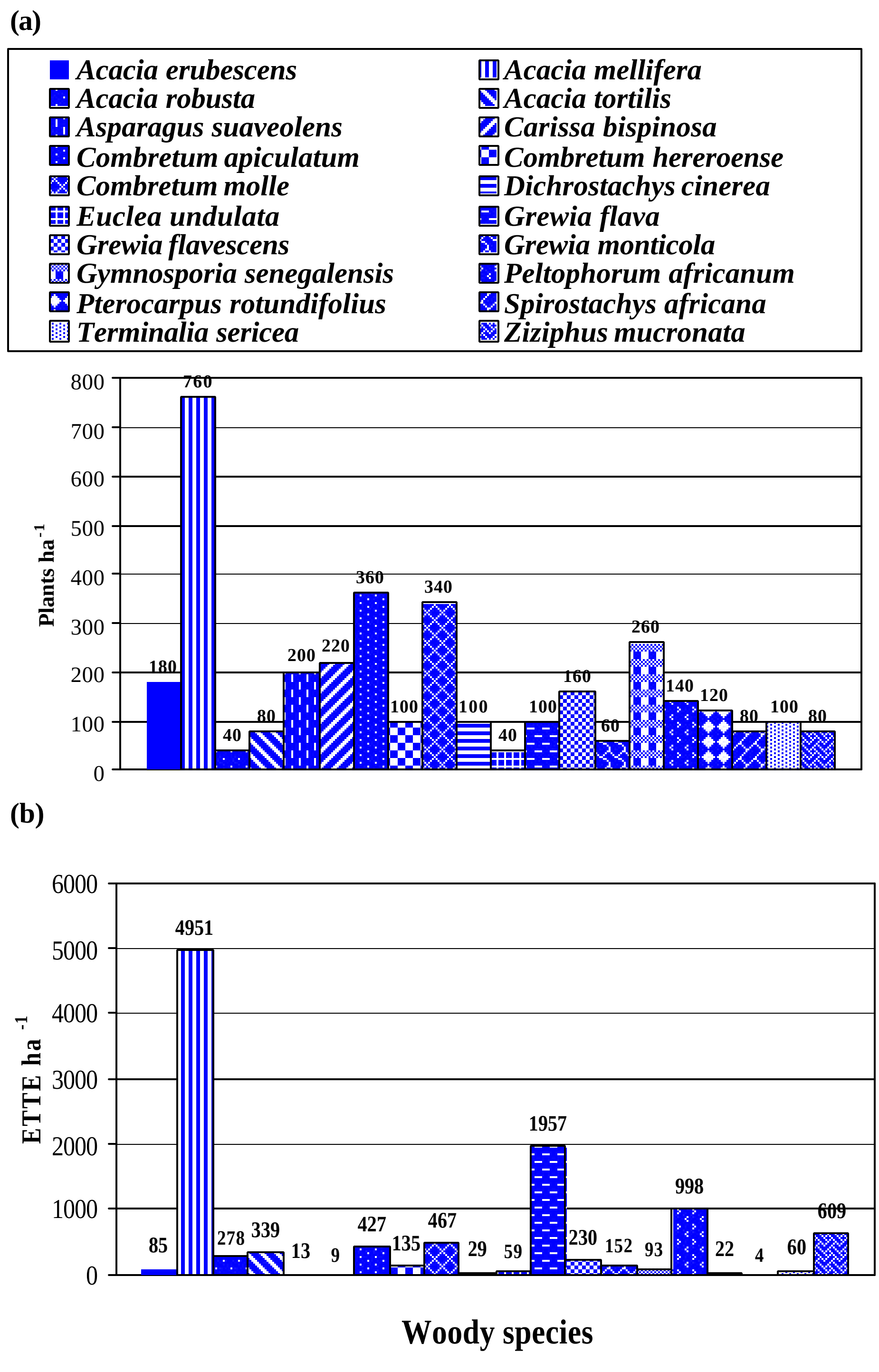


Figure 4.8: The contribution of individual woody species to (a) tree density (plants ha^{-1}), and (b) leaf volume (ETTE ha^{-1}), of the *Acacia mellifera – Grewia flava* Coppice plot during the 2003/2004 season.

4.3.3 Number of stems

The mean number of stems of the woody species recorded in each experimental plot for the 2003/2004 and 2004/2005 season, combined, is presented in Tables 4.4 to 4.11. It is clear that the coppice plants in the treatment plots had a higher number of stems in comparison to the undamaged (normal) woody plants. Naturally no coppice plants were present in the control plots. A large number of woody species was also recorded in the treatment plots compared to their corresponding control plots.

Table 4.4: The mean number of stems of the woody plant species recorded in the *Acacia mellifera – Grewia flava* Treatment plot. A distinction was made between undamaged (normal) and coppice plants. Numbers in parenthesis indicate the standard error of the means.

Experimental plot	Species	Mean number of stems (Standard error)	
		Normal	**Coppice**
***Acacia mellifera – Grewia flava* Treatment**	*Acacia erubescens*	1 (± 0.32)	2 (± 0.67)
	Acacia mellifera	2 (± 0.36)	8 (± 1.44)
	Acacia tortilis	1 (± 0.41)	4 (± 0.41)
	Asparagus suaveolens	5 (± 1.35)	7 (± 0.78)
	Carissa bispinosa	1 (± 0.00)	4 (± 0.00)
	Combretum apiculatum	5 (± 0.00)	5 (± 0.00)
	Dichrostachys cinerea	-	3 (± 0.67)
	Grewia bicolor	3 (± 0.41)	7 (± 1.05)
	Grewia flava	4 (± 0.50)	7 (± 0.44)
	Grewia monticola	3 (± 0.76)	11 (± 0.00)
	Gymnosporia senegalensis	-	11 (± 8.50)
	Rhus pyroides	2 (± 1.00)	9 (± 0.00)
	Ziziphus mucronata	4 (± 2.50)	6 (± 0.00)

-The species was not recorded.

Table 4.5: The mean number of stems of the woody plant species recorded in the *Acacia mellifera – Grewia flava* Control plot. Numbers in parenthesis indicate the standard error of the means.

Experimental plot	Species	Mean number of stems (Standard error)	
		Normal	**Coppice**
***Acacia mellifera – Grewia flava* Control**	*Acacia erubescens*	2 (± 0.85)	-
	Acacia mellifera	2 (± 0.43)	-
	Acacia tortilis	2 (± 0.33)	-
	Asparagus suaveolens	11 (± 2.06)	-
	Combretum apiculatum	1 (± 0.00)	-
	Combretum hereroense	2 (± 0.00)	-
	Grewia bicolor	7 (± 0.25)	-
	Grewia flava	10 (± 0.58)	-
	Grewia monticola	9 (± 1.17)	-

-No coppice plants were recorded.

Table 4.6: The mean number of stems of the woody plant species recorded in the *Combretum apiculatum – Grewia flava* Treatment plot. A distinction was made between undamaged (normal) and coppice plants. Numbers in parenthesis indicate the standard error of the means.

Experimental plot	Species	Mean number of stems (Standard error)	
		Normal	Coppice
***Combretum apiculatum – Grewia flava* Treatment**	*Acacia erubescens*	1 (± 0.00)	6 (± 0.88)
	Acacia tortilis	2 (± 0.63)	4 (± 0.37)
	Acacia luederitzii retinens	2 (± 0.00)	-
	Asparagus suaveolens	7 (± 1.26)	9 (± 0.00)
	Combretum apiculatum	2 (± 0.24)	4 (± 0.20)
	Combretum hereroense	2 (± 0.48)	5 (± 0.71)
	Combretum molle	3 (± 0.00)	-
	Dichrostachys cinerea	1 (± 0.17)	-
	Grewia bicolor	7 (± 1.44)	4 (± 1.50)
	Grewia flava	7 (± 0.55)	8 (± 0.61)
	Grewia flavescens	5 (± 0.75)	7 (± 1.50)
	Grewia monticola	3 (± 0.59)	6 (± 1.34)
	Peltophorum africanum	1 (± 0.00)	3 (± 0.00)
	Pterocarpus rotundifolius	-	1 (± 0.50)
	Ziziphus mucronata	-	4 (± 0.00)

-The species was not recorded.

Table 4.7: The mean number of stems of the woody plant species recorded in the *Combretum apiculatum – Grewia flava* Control plot. Numbers in parenthesis indicate the standard error of the means.

Experimental plot	Species	Mean number of stems (Standard error)	
		Normal	Coppice
***Combretum apiculatum – Grewia flava* Control**	*Acacia erubescens*	2 (± 0.28)	-
	Acacia mellifera	1 (± 0.00)	-
	Acacia tortilis	2 (± 0.58)	-
	Combretum apiculatum	3 (± 0.08)	-
	Combretum hereroense	1 (± 0.25)	-
	Combretum molle	1 (± 0.00)	-
	Dichrostachys cinerea	1 (± 0.46)	-
	Grewia bicolor	6 (± 1.00)	-
	Grewia flava	7 (± 0.39)	-
	Grewia flavescens	7 (± 0.55)	-
	Grewia monticola	6 (± 0.58)	-
	Peltophorum africanum	2 (± 0.00)	-
	Pterocarpus rotundifolius	1 (± 0.00)	-
	Terminalia sericea	2 (± 0.58)	-

-No coppice plants were recorded.

Table 4.8: The mean number of stems of the woody plant species recorded in the *Acacia erubescens – Dichrostachys cinerea* Treatment plot. A distinction was made between undamaged (normal) and coppice plants. Numbers in parenthesis indicate the standard error of the means.

Experimental plot	Species	Mean number of stems (Standard error)	
		Normal	Coppice
***Acacia erubescens – Dichrostachys cinerea* Treatment**	*Acacia erubescens*	2 (± 0.21)	3 (± 0.15)
	Acacia karroo	2 (± 0.92)	5 (± 0.50)
	Acacia mellifera	-	5 (± 0.00)
	Acacia tortilis	-	3 (± 0.44)
	Asparagus suaveolens	7 (± 1.00)	11 (± 0.00)
	Combretum apiculatum	2 (± 0.36)	4 (± 0.24)
	Combretum hereroense	1 (± 0.00)	-
	Combretum imberbe	1 (± 0.00)	4 (± 0.00)
	Combretum molle	-	3 (± 0.00)
	Dichrostachys cinerea	1 (± 0.00)	3 (± 0.17)
	Grewia bicolor	7 (± 1.00)	9 (± 0.00)
	Grewia flava	8 (± 0.58)	7 (± 0.43)
	Grewia flavescens	3 (± 0.00)	9 (± 0.00)
	Grewia monticola	5 (± 1.00)	-
	Gymnosporia senegalensis	2 (± 0.00)	-
	Pterocarpus rotundifolius	-	4 (± 0.00)
	Ziziphus mucronata	3 (± 0.00)	4 (± 0.65)

-The species was not recorded.

Table 4.9: The mean number of stems of the woody plant species recorded in the *Acacia erubescens – Dichrostachys cinerea* Control plot. Numbers in parenthesis indicate the standard error of the means.

Experimental plot	Species	Mean number of stems (Standard error)	
		Normal	Coppice
***Acacia erubescens – Dichrostachys cinerea* Control**	*Acacia erubescens*	2 (± 0.16)	-
	Acacia karroo	3 (± 0.88)	-
	Combretum apiculatum	2 (± 0.50)	-
	Combretum hereroense	3 (± 0.00)	-
	Dichrostachys cinerea	2 (± 0.22)	-
	Grewia flava	9 (± 1.57)	-
	Grewia flavescens	3 (± 0.50)	-
	Gymnosporia senegalensis	3 (± 0.58)	-
	Ziziphus mucronata	1 (± 0.00)	-

-No coppice plants were recorded.

Table 4.10: The mean number of stems of the woody plant species recorded in the *Combretum apiculatum – Grewia flava* Coppice plot. A distinction was made between undamaged (normal) and coppice plants. Numbers in parenthesis indicate the standard error of the means.

Experimental plot	Species	Mean number of stems (Standard error)	
		Normal	Coppice
***Combretum apiculatum – Grewia flava* Coppice**	*Acacia caffra*	-	5 (± 0.00)
	Acacia erubescens	1 (± 0.20)	3 (± 0.59)
	Acacia tortilis	1 (± 0.33)	3 (± 0.50)
	Asparagus suaveolens	9 (± 0.00)	-
	Combretum apiculatum	2 (± 0.19)	4 (± 0.12)
	Combretum hereroense	2 (± 0.31)	3 (± 0.95)
	Combretum imberbe	4 (± 0.33)	4 (± 0.38)
	Combretum molle	1 (± 0.26)	2 (± 0.34)
	Dichrostachys cinerea	1 (± 0.50)	3 (± 0.58)
	Grewia bicolor	-	7 (± 3.50)
	Grewia flava	8 (± 0.46)	7 (± 0.59)
	Grewia flavescens	7 (± 0.97)	-
	Grewia monticola	6 (± 0.33)	5 (± 0.00)
	Peltophorum africanum	2 (± 1.00)	7 (± 3.50)
	Pterocarpus rotundifolius	1 (± 0.21)	3 (± 0.64)
	Terminalia sericea	1 (± 0.24)	-
	Ziziphus mucronata	1 (± 0.00)	3 (± 1.20)

-The species was not recorded.

Table 4.11: The mean number of stems of the woody plant species recorded in the *Acacia mellifera – Grewia flava* Coppice plot. A distinction was made between undamaged (normal) and coppice plants. Numbers in parenthesis indicate the standard error of the means.

Experimental plot	Species	Mean number of stems (Standard error)	
		Normal	Coppice
***Acacia mellifera – Grewia flava* Coppice**	*Acacia erubescens*	25 (± 0.75)	3 (± 0.50)
	Acacia mellifera	15 (± 0.25)	3 (± 0.31)
	Acacia robusta	1 (± 0.00)	-
	Acacia tortilis	2 (± 1.33)	4 (± 0.00)
	Asparagus suaveolens	5 (± 1.08)	8 (± 1.21)
	Carissa bispinosa	1 (± 0.25)	3 (± 0.52)
	Combretum apiculatum	2 (± 1.33)	5 (± 0.32)
	Combretum hereroense	2 (± 1.50)	4 (± 0.76)
	Combretum molle	1 (± 0.22)	3 (± 0.37)
	Dichrostachys cinerea	1 (± 0.33)	2 (± 0.00)
	Euclea undulata	-	4 (± 0.50)
	Grewia bicolor	-	9 (± 4.67)
	Grewia flava	8 (± 0.55)	10 (± 0.74)
	Grewia flavescens	7 (± 1.41)	9 (± 1.36)
	Grewia monticola	9 (± 4.50)	8 (± 0.00)
	Gymnosporia senegalensis	1 (± 0.00)	5 (± 0.82)
	Peltophorum africanum	2 (± 0.48)	3 (± 0.00)
	Pterocarpus rotundifolius	1 (± 0.00)	5 (± 0.65)
	Spirostachys africana	1 (± 0.00)	2 (± 0.00)
	Terminalia sericea	1 (± 0.33)	2 (± 0.50)
	Ziziphus mucronata	3 (± 0.25)	-

-The species was not recorded.

4.3.4 Leaf dry matter yield

The total DM yield, as well as the DM yield within the various tree height classes, of the undamaged (normal) and coppice woody plants in each experimental plot, is presented in Figures 4.9 and 4.10 for the 2003/2004 and 2004/2005 season, respectively. From Figure 4.9a and 4.9b it is clear that the DM yield was the highest in the 2.0 m – 5.0 m height class of the undamaged (normal) plants in most of the treatment and coppice plots, while the DM yields of the coppice plants were restricted to the 0 m – 1.5 m height class. The Ca-Gf Treatment and Coppice plots were the only plots which did not have any leaf material above 5 m. Except for the Ca-Gf Control plot, the woody plants of the control plots (Figure 4.9c) also had the highest DM yield in the 1.5 m – 2.0 m height class.

The same results were found during the 2004/2005 season (Figure 4.10), except that the Am-Gf Coppice plot had coppice plants which had leaf material in the 1.5 m – 2.0 m height class. The DM yield of coppice plants in the 0 – 1.5 m height class was considerably higher during the 2004/2005 than the 2003/2004 season.

4.3.6 Browsing capacity

The browsing capacity of each experimental plot of each month during the 2003/2004 season (July 2003 – June 2004) and the various height strata is presented in Figures 4.11 to 4.16. The browsing capacity of the Am-Gf Treatment plot (Figure 4.11) started to decrease (more ha required per BU) from July until it reached the lowest grazing capacity point in October, after which it increased (less ha required per BU) drastically following the flush of new leaves. The same results were found in the Am-Gf Control plot (Figure 4.12). Of note is that the control plot did not experience such a dramatic decrease in browsing capacity compared to the treatment plot. The Am-Gf Control plot had a higher browsing capacity than the treatment plot in each height stratum, but especially in the 0 – 1.5 m height stratum (Figure 4.12a). The Am-Gf Control plot did, however, have a lower browsing capacity than the Am-Gf Treatment plot during October in the 0 – 5.0 m height stratum.

The browsing capacity of the Ca-Gf Treatment plot (Figure 4.13) reached its lowest point in September and it’s highest from January to June. The same result was found for the Ca-Gf Control plot (Figure 4.14). This control plot also had a higher browsing capacity for each browsing height in comparison to the Ca-Gf Treatment plot. The difference between the Ca-Gf Treatment and Control plots, however, was not as large as between the Am-Gf Treatment and Control plots.

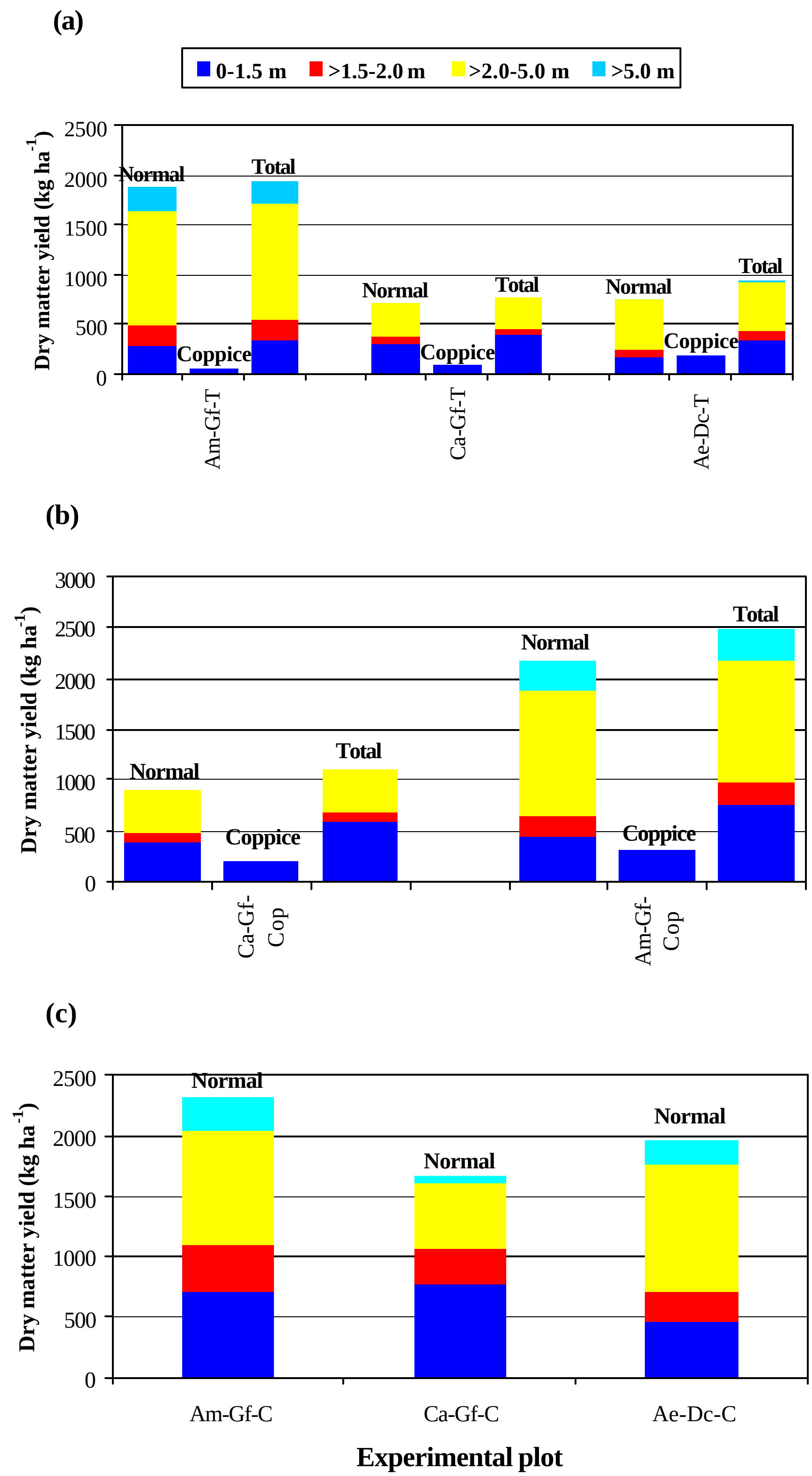


Figure 4.9: The total dry matter yield, as well as the dry matter yield within the various tree height classes, of the undamaged (normal) and coppice woody plants during the 2003/2004 season in (a) the treatment plots, (b) the coppice plots and (c) the control plots.

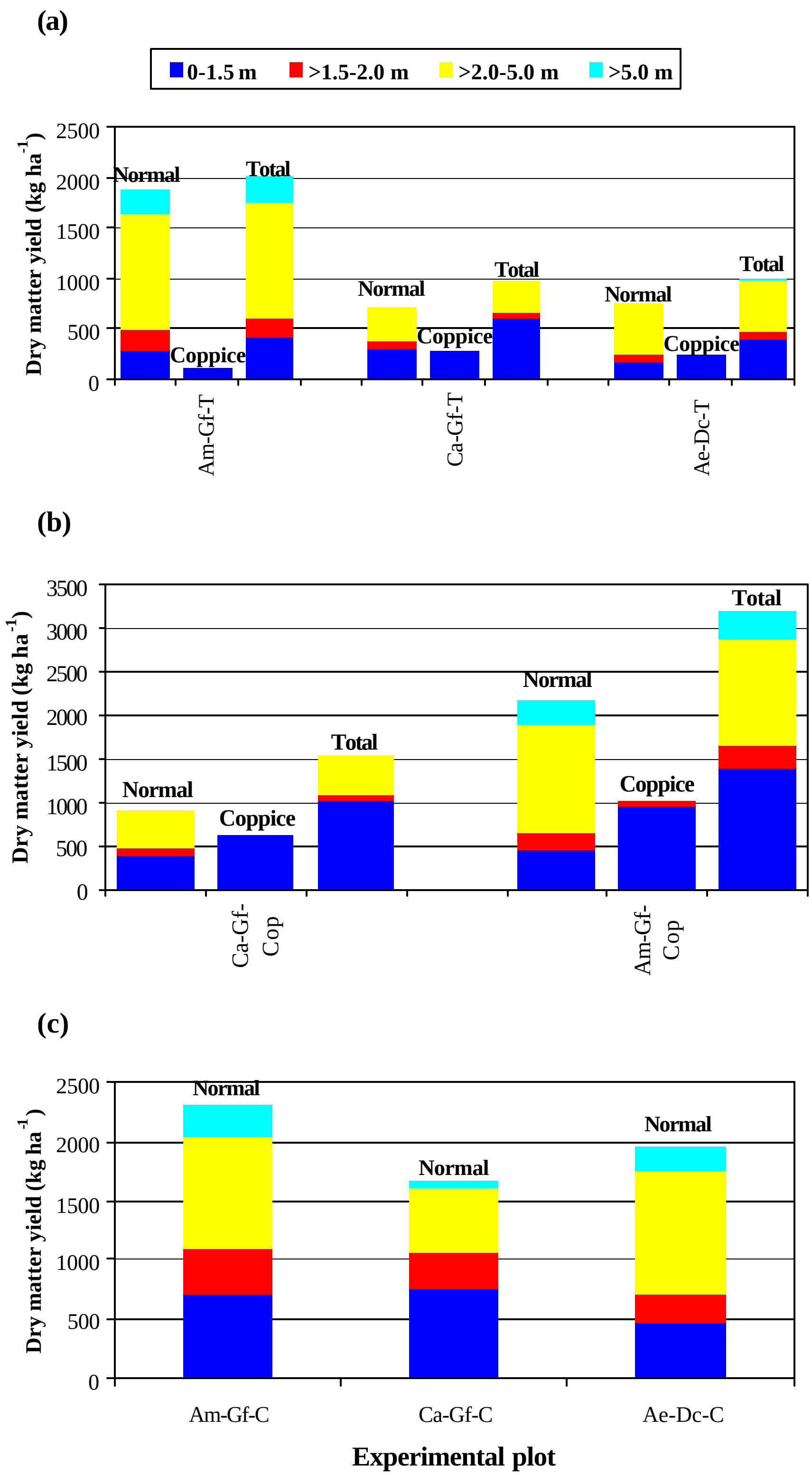
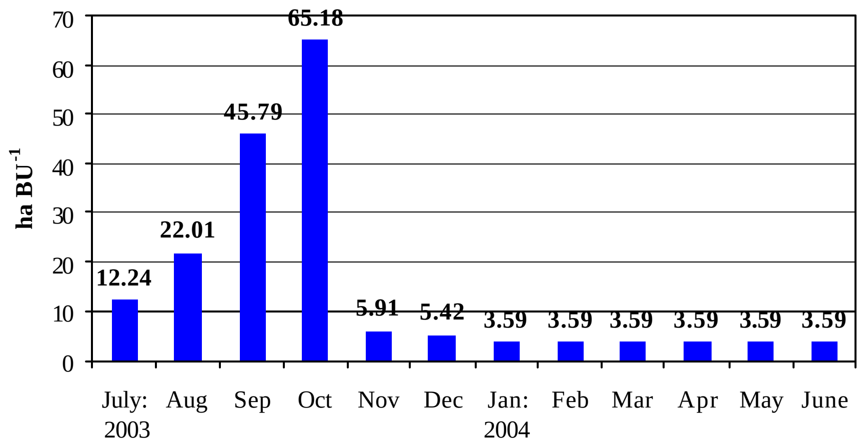
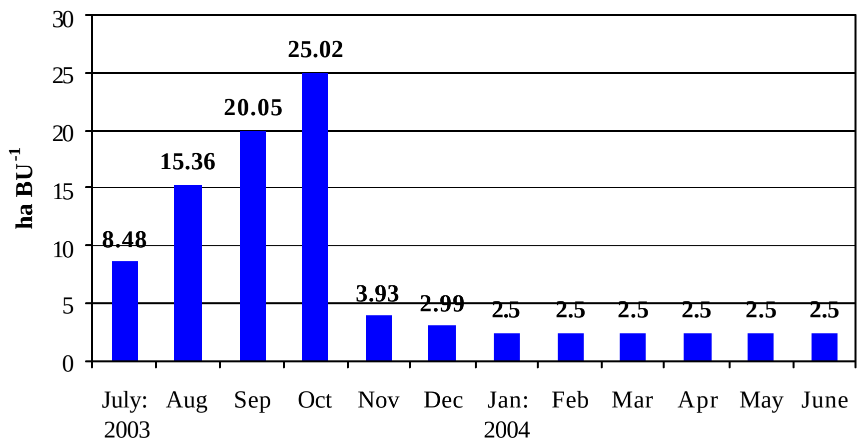


Figure 4.10: The total dry matter yield, as well as the dry matter yield within the various tree height classes, of the undamaged (normal) and coppice woody plants during the 2004/2005 season in (a) the treatment plots, (b) the coppice plots and (c) the control plots.

(a)



(b)



(c)

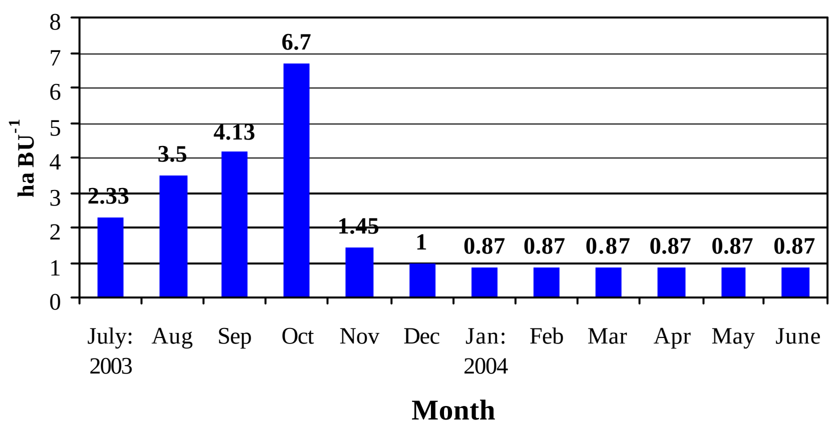


Figure 4.11: The browsing capacity (ha BU^{-1}) of the *Acacia mellifera – Grewia flava* Treatment plot of each month during the 2003/2004 season, based on the leaf dry matter yield of woody plants in the (a) 0 – 1.5 m, (b) 0 – 2.0 m, and (c) 0 – 5.0 m height stratums.

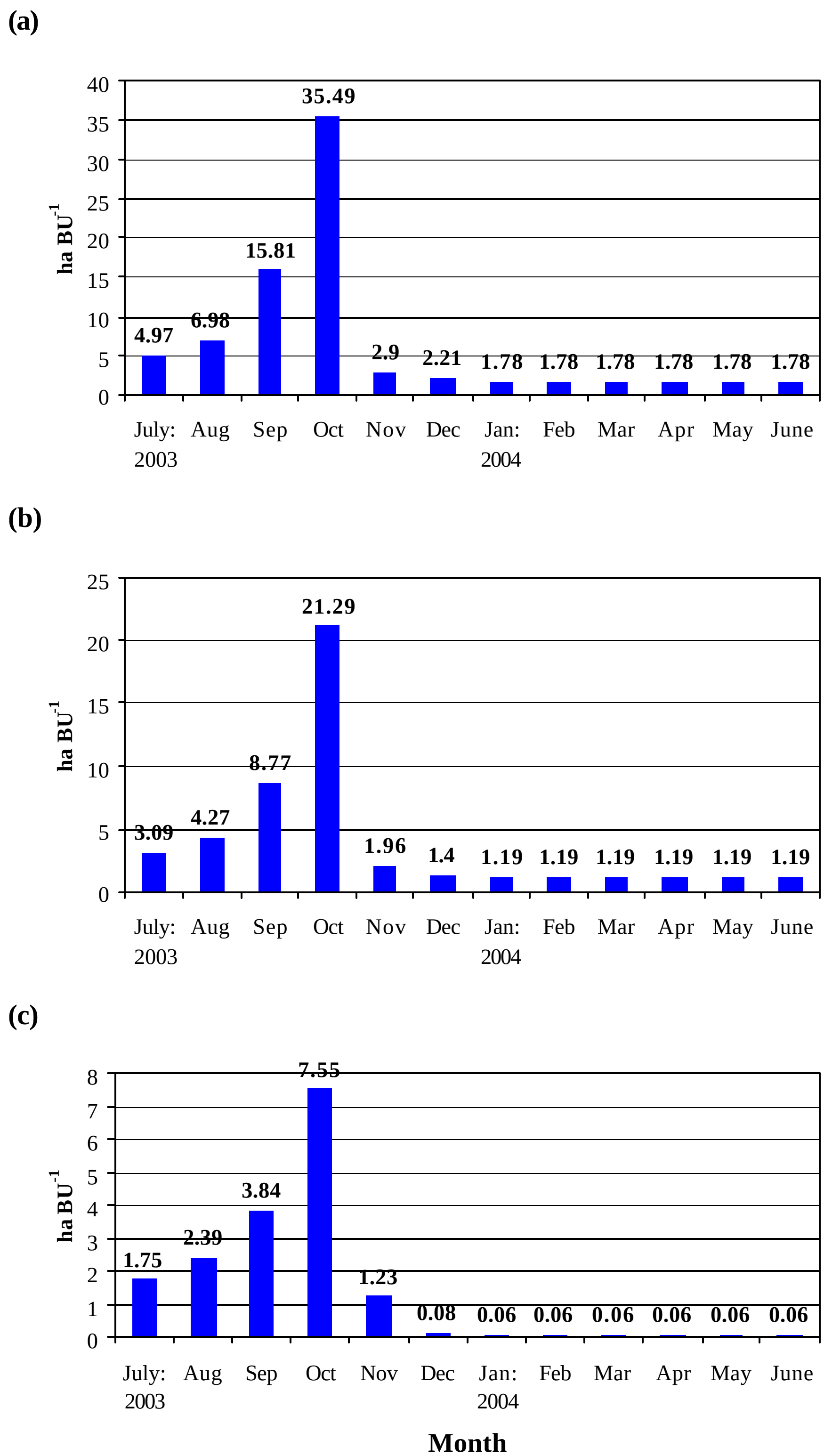


Figure 4.12: The browsing capacity (ha BU^{-1}) of the *Acacia mellifera – Grewia flava* Control plot of each month during the 2003/2004 season, based on the leaf dry matter yield of woody plants in the (a) 0 – 1.5 m, (b) 0 – 2.0 m, and (c) 0 – 5.0 m height stratums.

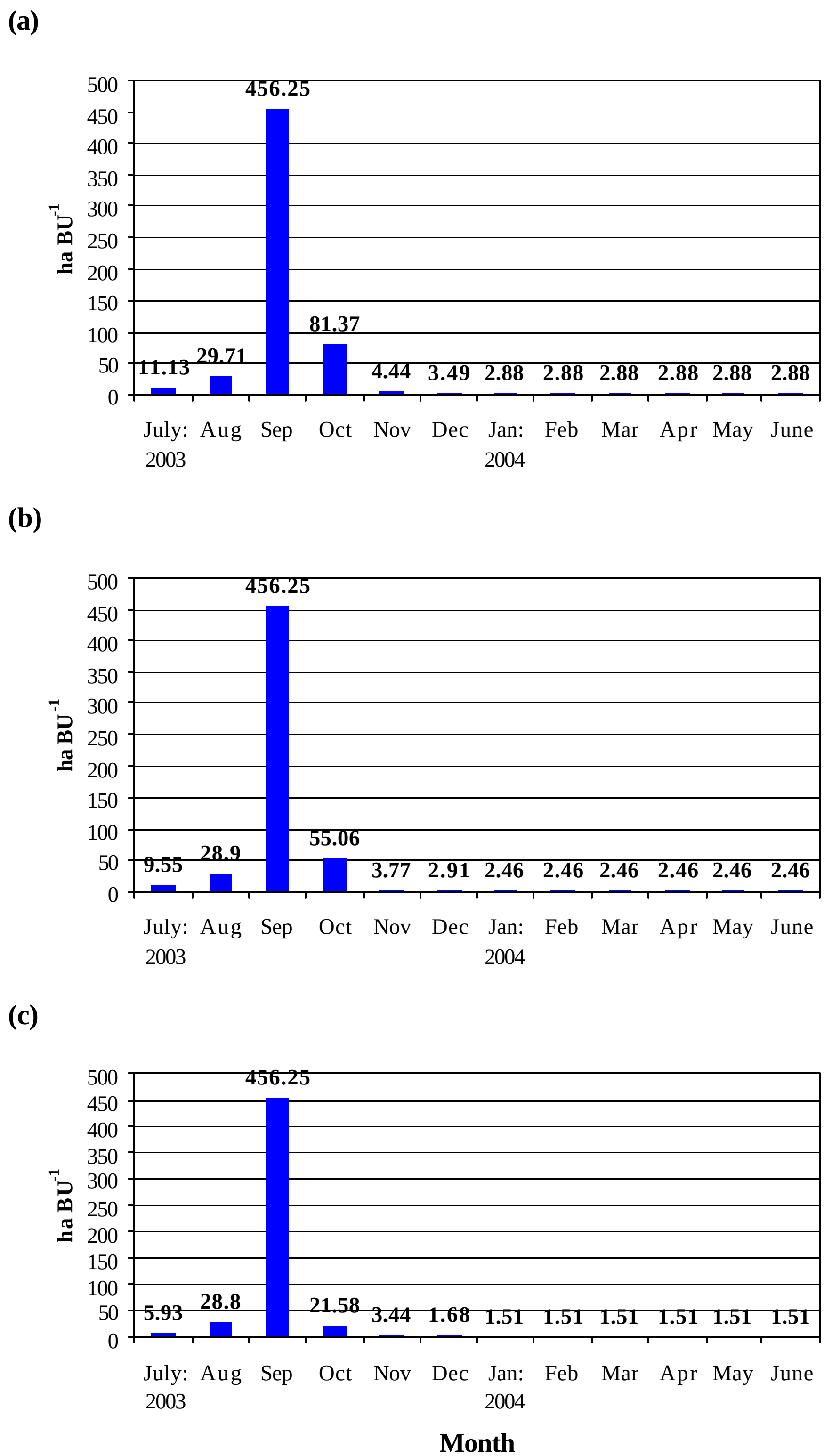


Figure 4.13: The browsing capacity (ha BU^{-1}) of the *Combretum apiculatum – Grewia flava* Treatment plot of each month during the 2003/2004 season, based on the leaf dry matter yield of woody plants in the (a) 0 – 1.5 m, (b) 0 – 2.0 m, and (c) 0 – 5.0 m height stratums.

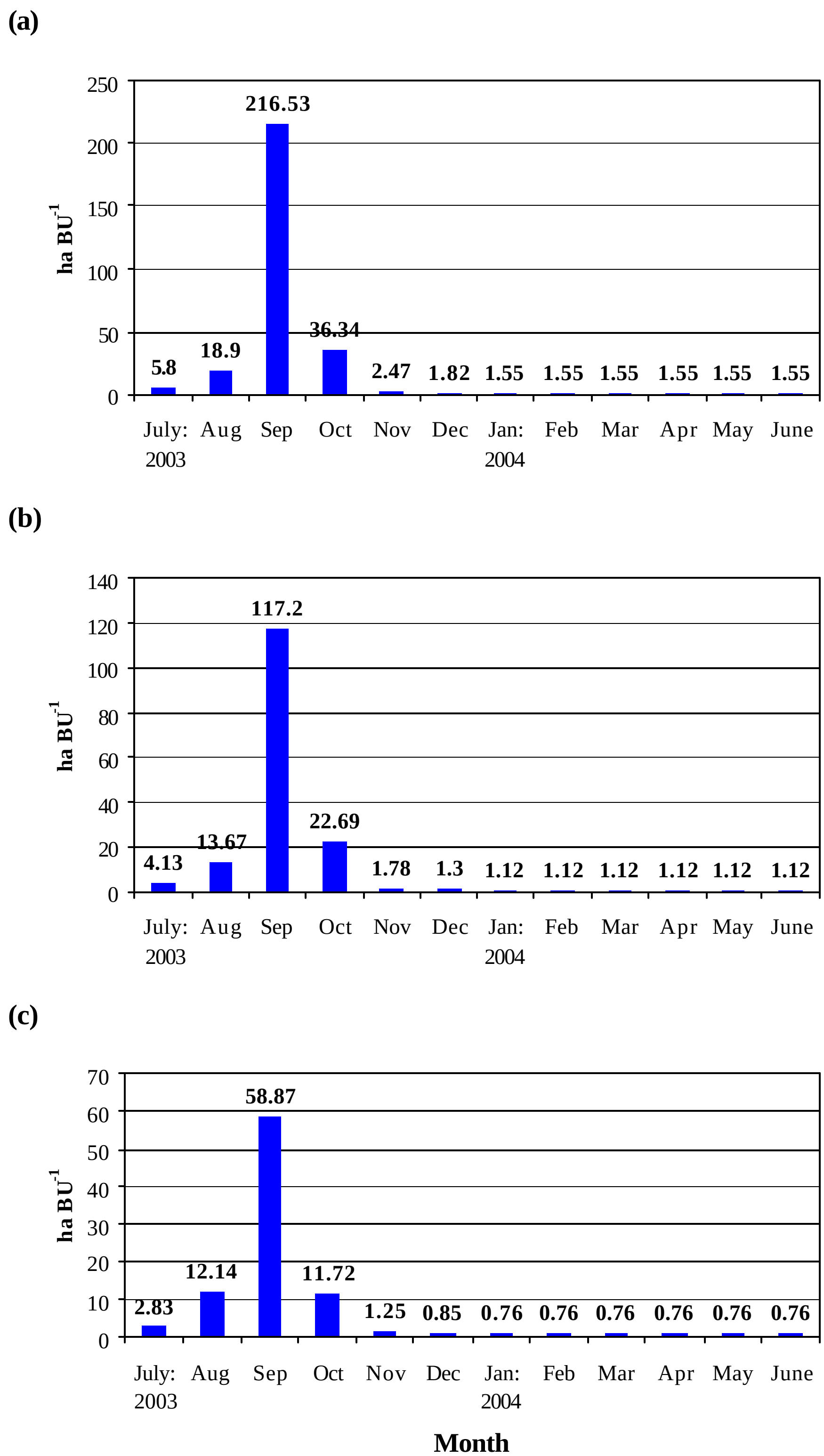
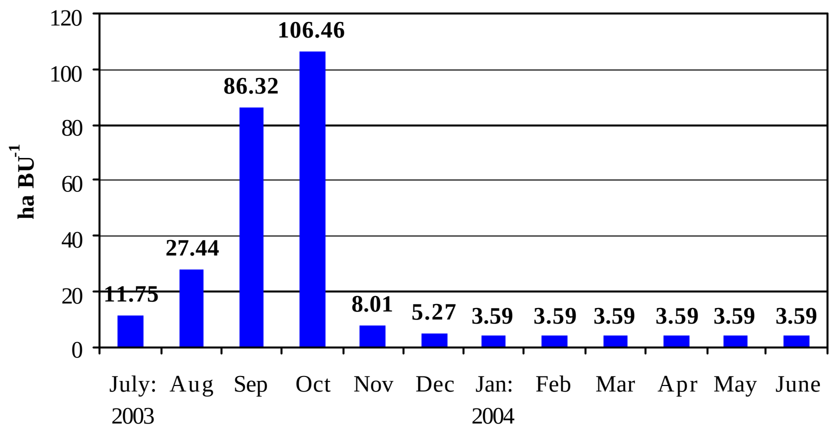
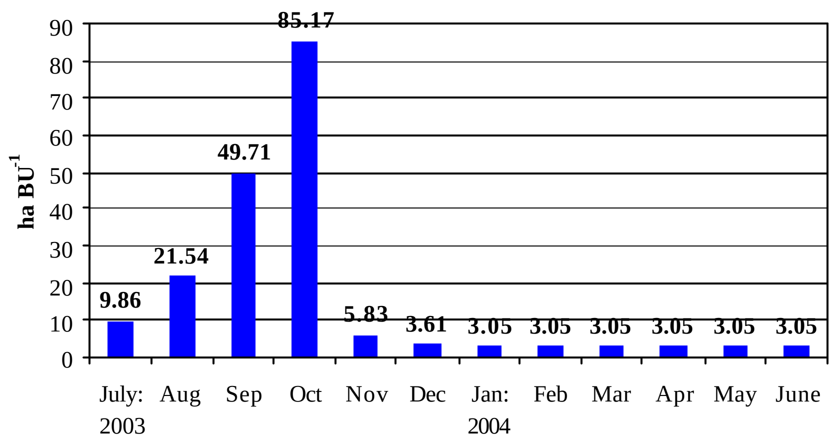


Figure 4.14: The browsing capacity (ha BU^{-1}) of the *Combretum apiculatum – Grewia flava* Control plot of each month during the 2003/2004 season, based on the leaf dry matter yield of woody plants in the (a) 0 – 1.5 m, (b) 0 – 2.0 m, and (c) 0 – 5.0 m height stratums.

(a)



(b)



(c)

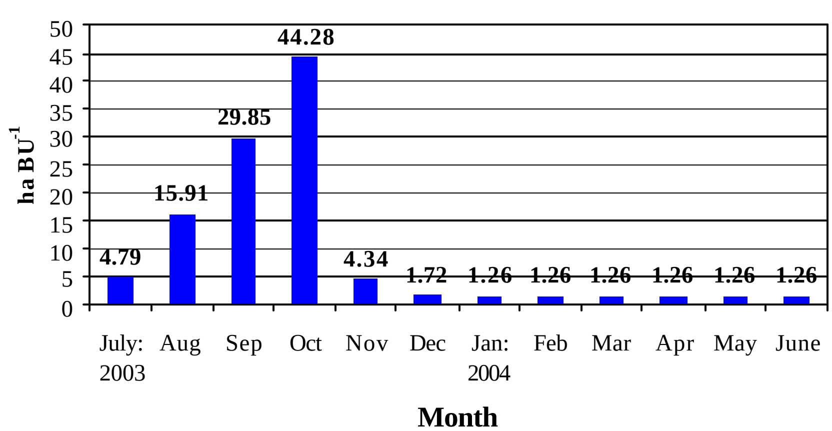


Figure 4.15: The browsing capacity (ha BU^{-1}) of the *Acacia erubescens – Dichrostachys cinerea* Treatment plot of each month during the 2003/2004 season, based on the leaf dry matter yield of woody plants in the (a) 0 – 1.5 m, (b) 0 – 2.0 m, and (c) 0 – 5.0 m height stratums.

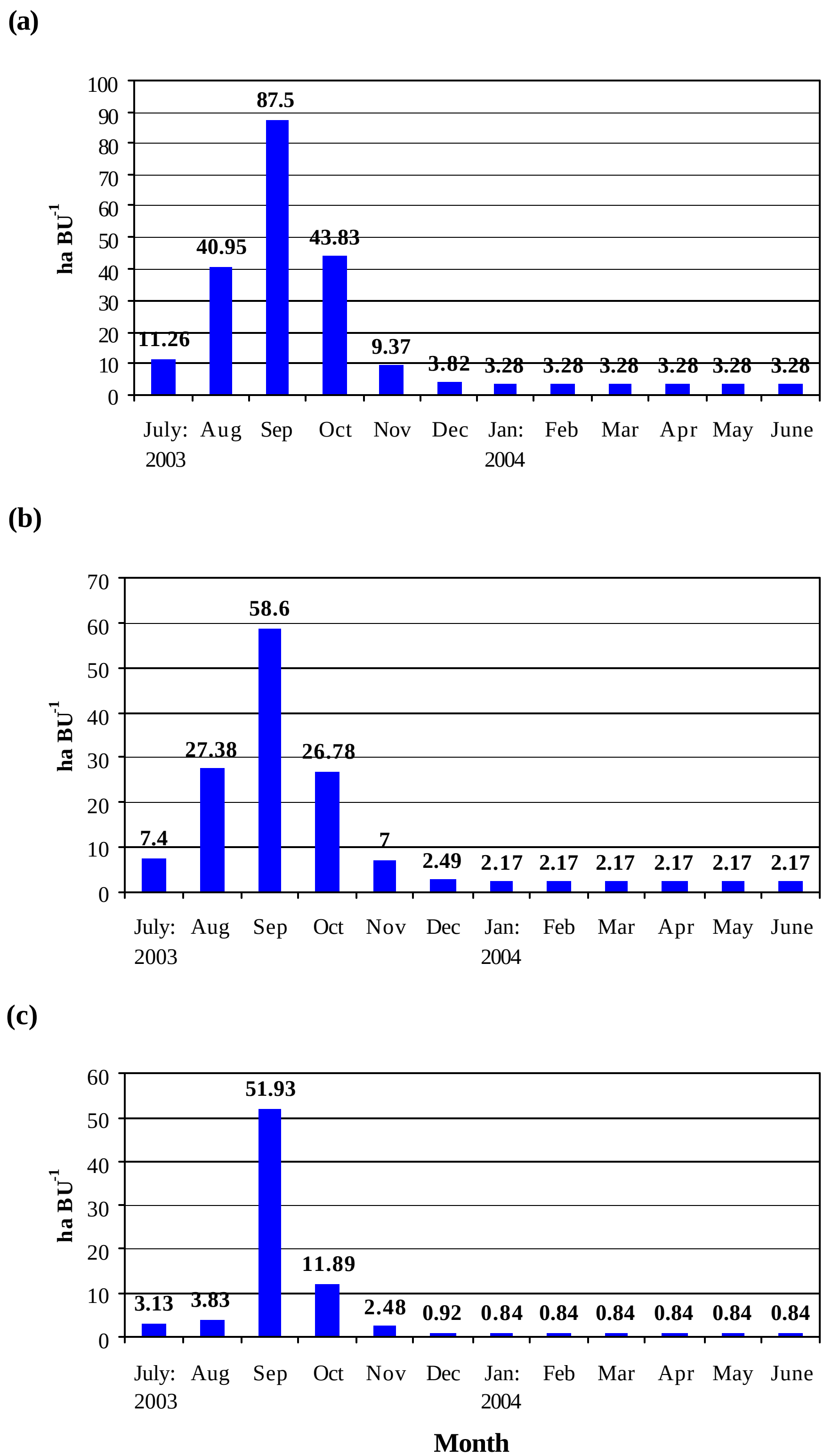


Figure 4.16: The browsing capacity (ha BU^{-1}) of the *Acacia erubescens – Dichrostachys cinerea* Control plot of each month during the 2003/2004 season, based on the leaf dry matter yield of woody plants in the (a) 0 – 1.5 m, (b) 0 – 2.0 m, and (c) 0 – 5.0 m height stratums.

The browsing capacity of the Ae-Dc Treatment plot (Figure 4.15) decreased from July and reached its lowest point in October after which it increased drastically. The Ae-Dc Control plot (Figure 416) reached its lowest grazing capacity in September and had the highest browsing capacity from January to June. The Ae-Dc Control plot had a consistently lower browsing capacity than the Ae-Dc Treatment plot during each month of the season. The Ae-Dc Treatment and Control plots were the only corresponding plots that did not have the lowest browsing capacity during the same month.

4.4 DISCUSSION

Tree thinning invariably results in drastic and immediate changes in the competition regime which had largely determined the growth and structure of the plant community involved. The growth and reproduction of the remaining trees are important for several reasons. Firstly, they have direct consequences on the re-establishment of woody plants. This is important in estimating the effective time span of tree thinning operations (Scholes, 1990). Secondly, trees are the main source of food to browsers and this food source is being altered. It is thus important not only to take the effect of tree thinning on the herbaceous layer into account, but also the effect on the dynamics of the woody layer.

An important determinant of woody seedling establishment is competition from other plants, either from other woody plants (Smith & Walker, 1983; Smith & Goodman, 1986; Schmidtt *et al.*, 1987; Smith & Shackleton, 1988; Ben-Shahar, 1991; Smit, 1994), or herbaceous plants (Van Vegten, 1983; Brown & Archer, 1989; Skarpe, 1990). Seedling establishment relative to canopy cover was examined in both *Acacia nilotica* and *A. tortilis* communities by Smith & Goodman (1986). Two species types were identified during their study, namely those whose establishment is associated with or unaffected by tree canopy cover and those whose establishment is limited to between-canopy or open areas. Of the latter type the *Acacia* seedlings is distinctive as they fail to establish under the canopy of any established individual, regardless of species. Knoop (1982) observed that on a site dominated by *Acacia* species, large numbers of seedlings germinated and survived in a plot cleared of herbaceous vegetation, while few were found in a control plot. Richter (1991) found similar results in *Acacia mellifera* dominated plots in the Molopo Thornveld. Similar results were also found in Marakele Park. In the experimental plots dominated by *Acacia* species, the control plots had no or a limited number of *Acacia* seedlings, but in the treatment and especially in the coppice plots, *Acacia* seedlings were prominent.

Another factor which could also affect the establishment of woody seedlings is soil disturbance. Mechanical bush control measures which involve heavy implements or machinery able to remove trees, including their roots, cause heavy disturbance of the soil. Severe degradation of the existing herbaceous layer and compaction of the soil surface to such an extent that regrowth of grass and ephemeral species are restricted, may result from such actions (De Klerk, 2004). Since the first species to occur after bush control are usually annual pioneer species with low grazing values (see Chapter 5), highly palatable, tufted, perennial grasses often need to be re-established – either by allowing a sufficient resting period without grazing to allow grass species to develop (succession) or by sowing grass seeds (restoration).

Disturbance of the soil surface may also lead to the germination of seed present in the soil seed bank or the stimulation of young emerging seedlings of problem woody species, resulting in an aggressive re-establishment of the problem woody species (e.g. *Dichrostachys cinerea*). This was evident in Marakele Park. In the Am-Gf Treatment plot, a number of 111 *A. mellifera* seedlings were counted in one of the transects (2.5 m x 100 m = 4 440 seedlings ha^{-1}), while a total of 576 seedlings (equal to 23 040 seedlings ha^{-1}) of this woody species were counted in the second transect during the 2004/2005 season. This is the result of only three seasons' growth after the initial tree thinning treatments. Similar results were found in studies done by Bester & Reed (1997) in Karstveld, Namibia, and Barac (2003) in the Thabazimbi region, Limpopo Province (in which Marakele Park is also situated). This may and most probably will lead to the occurrence of a much denser stand of problem woody species than was present before the initial tree thinning treatments were applied (Smit *et al.*, 1999).

An important factor that can also contribute to woody plant increase is herbivory. Van Vegten (1983) identified overgrazing of grasses as the main cause of woody plant increase in savanna areas of eastern Botswana. Skarpe (1990), who also did an investigation in Botswana, has showed that in areas with no and moderate grazing, shrub densities fluctuated but showed no consistent change, while density increased with heavy grazing. The increases in shrub abundance with heavy grazing were mainly accounted for by two species, *Acacia mellifera* and *Grewia flava*. They are both shallow rooted and according to Skarpe (1990), this suggests that they were favoured by an increase in water availability in the surface soil following overgrazing of the herbaceous layer. Similar results were found in this study.

It is clear that *A. erubescens*, *A. mellifera*, *C. apiculatum* and *G. flava* were the woody species which had the highest leaf biomass (ETTE ha^{-1}) and thus the greatest competition effect on the herbaceous layer in the various experimental plots. These species were the most dominant woody species which caused bush encroachment in Marakele Park. The same result was found by Barac (2003) in other locations in the Limpopo Province. All these species are usually found in arid areas where it is well adapted to dry conditions. *Acacia mellifera* in particular has a shallow, wide spreading root system (Smit, 1999), which enables it to use soil surface water much more effectively. Another woody species which proved to be a problem species was *Dichrostachys cinerea*. In the study that was done by Barac (2003) in Namibia, it was found that *D. cinerea* increased rather than decreased in density after the initial control method was applied. It was found that the density of this species increased when it was controlled biologically (fire) or mechanically and it was recommended that it should rather be controlled by chemical methods.

These species may form impenetrable thickets in overgrazed areas (Van Wyk *et al.*, 2000). Overgrazing is the most likely reason why these woody species, and especially *A. mellifera*, is such a problem in Marakele Park. Large herbivore populations are currently located in this park, especially selective short grass grazers like blue wildebeest and bulk feeders like elephant. The effect that herbivores can have on the herbaceous layer, which ultimately leads to the encroachment of woody species, is well documented (Anderson & Walker, 1974; Guy, 1981; Barnes, 1985; Lewis, 1987; Kalemera, 1989; Lewis, 1991; Styles, 1993). It is known that elephants can do considerable damage to vegetation and this is no exception in Marakele Park. Figure 4.17 illustrates the damage that these mega-herbivores can do to mature trees. The damage can lead to the establishment of new woody seedlings due to the lack of the suppressive effect that mature trees have on seedlings (Smith & Goodman, 1986; 1987) and it can also lead to vigorous coppicing of damaged woody species. This ultimately leads to higher woody plant densities which is detrimental to the herbaceous layer.

Since it is not known what the ETTE ha^{-1} and tree density and thus the potential competitiveness of the woody plants in each of the experimental plots were before the tree thinning treatments were applied, the only source of comparison was between the 2003/2004 and 2004/2005 season (the study period) after tree thinning treatments were implemented. The difference found in the ETTE ha^{-1} values of the treatment and their corresponding control plots, was not very high. This could mean that the number of woody plants removed during the initial thinning treatments was not enough or that rapid re-encroachment occurred since the thinning treatments. Based on the observed substantial regrowth (coppice) measured in the treatment plots after only one season, especially in the coppice plots, re-encroachment is a definite possibility.

Figure 4.17: The damage that elephants caused to woody plants during the study period in Marakele Park.

From the results of the ETTE ha^{-1} and the tree density of woody species in each experimental plot, it is clear that the woody species with the highest density in terms of plants ha^{-1} did not necessarily have the highest leaf volume (ETTE ha^{-1}) and thus the highest competitive effect on the herbaceous layer. It is therefore very important not only to take the absolute number of woody plants into account when making decisions on the thinning of woody plants in a specific area. The leaf volume (ETTE ha^{-1}) of woody plants gives a much more accurate account of the effect that the woody layer may have on the herbaceous layer.

From the 2003/2004 season to the 2004/2005 season the coppice plants increased substantially in terms of DM yield as well as competitiveness (ETTE ha^{-1}). The coppice plants were dominant in the 0 – 1.5 m height class. In the Am-Gf Coppice plot, coppice plants even contributed to the DM yield in the 1.5 m – 2.0 m height stratum, indicating the rapid growth of woody species within just one growing season. The coppice plants also had a higher number of stems in comparison to the undamaged (normal) plants, which indicates that the tree thinning treatments resulted in structural change of the woody plants. Barac (2003) also found that single-stemmed trees that were initially treated by means of mechanical bush control measures, tended to develop into multi-stemmed plants when regrowth (coppicing) of the plants occurred. If the coppicing of problem species is not prevented and controlled in time, the re-encroachment that usually occurs may be worse than the initial bush encroached state. Therefore, follow-up treatments (after-care) are an essential part of any bush control management programme (Richter, 1991; Smit *et al.*, 1999). Milton (1987) has found that repeated damage caused to the coppice shoots of most *Acacia* species tend to reduce regrowth of the plant in the following season.

The browse production was lower in the treatment plots compared to the control plots, which was as expected. The 2.0 m – 5.0 m height stratum contributed the most to the browse production in most of the experimental plots. When thinning treatments are applied, it is very important to keep in mind that the thinning must be of such a nature that it will benefit grazing as well as browsing animals. The type of browsing animals should also be taken into account to ensure that the correct number and size of woody plants are retained. For example, impala normally browse at a mean height of 1.5 m and if the woody species are thinned in such a way that the browse in this height stratum is reduced, it will be disadvantageous to these animals. The same is applicable for giraffes, which can browse up to a mean height of 5.0 m. If all the large trees are removed in an area where these animals are present, it would be to the detriment of these animals.

The browsing capacity differed between the various species dominated plots, which was as expected. Various factors can contribute to the variation in browsing capacity between different areas. One such determinant, which is especially important in dry deciduous savannas, is differences in phenology as reflected in differences in leaf emergence and leaf senescence. Milton (1987) as cited by Smit (1994) found that at Nylsvlei leaf fall begins in January in *A. mellifera* and in March in *Acacia burkei* and *A. caffra*. In the Kruger National Park, young *Acacia nigrescens* and *C. apiculatum* trees tended to retain some leaves over the dry season, whereas the mature trees generally lost most of their leaves (Novellie, 1989). The same phenomenon was recorded for *A. burkei* at Nylsvley (Milton, 1987), but some species differences occur. In this study the differences that were found between the leaf emergence and leaf senescence of the dominant woody species (see Table 4.1) in each experimental plot contributed to the variation in the browsing capacity of the various species dominated plots.

The most important ecological factor that contributed to the differences in browsing capacity between the various species dominated plots in the study area, was rainfall. In two separate studies Rutherford & Panagos (1982) and Moore (1989) found that rainfall affected leaf drop in general. Leaf fall as a result of water stress is used by some woody species as a drought avoidance strategy (Moore, 1989). Rainfall was not a limiting factor during the study period, especially during the second season. The ability of the woody species to use the available soil water would have been one of the important factors which determined the browsing capacity of each experimental plot. According to Donaldson (1967) *Acacia mellifera* seedlings do no establish during each growing season, but seedling establishment occurs in cycles during seasons characterised by above average rainfall. This might be the reason why the occurrence of seedlings of this specific woody species was so high in the study area, which had an above average rainfall during the study period. Another factor that would have played a role in influencing the available soil water is the soil characteristics of each experimental plot (see Chapter 7).

4.5 CONCLUSIONS

From the results of this study it is clear that the ecological effect of tree thinning is dependent on a range of determinants and more importantly, on the effect that these determinants have on each other. The determinants that had the largest influence on the regrowth of woody species after the initial thinning treatments in this study were competition (tree-tree and tree-grass competition), grazing pressure, rainfall, soil disturbance and the lack of follow-up treatments.

The unselective manner in which the Barko Tractor operated resulted in the loss of many mature trees. This was undesirable since it is suspected that it contributed to the emergence of a large number of woody seedlings. It is known that mature trees can prevent seedling establishment and suppress growth of neighbouring woody plants (Smith & Goodman, 1986; Smit *et al.*, 1999). The re-establishment of high numbers of woody plants will ultimately result in the return of a high competition interaction between the woody and herbaceous plants for soil water and nutrients, which implies that the objective to increase herbaceous DM yield will not be met.

The grazing regime of the current herbivore populations appears to have effectively neutralised the anticipated positive effect of a reduced number of woody plants. The effect of especially high density, selective short grass grazers, in particular, on the herbaceous layer caused a severe decrease in the ability of the herbaceous plants to compete with the woody layer. This most likely contributed to an increase of woody plants after the tree thinning treatments.

Rainfall also proves to be a very important determinant in the response of woody plants to, both competition from the herbaceous layer and grazing. The above-average rainfall received during the study period, benefited the woody plants by reducing or removing competition for soil water from the herbaceous layer. This enabled the woody species to re-grow and establish successfully, ultimately leading to the re-establishment of a high number of woody plants.

The soil disturbance caused by the Barko Tractor may have stimulated the germination of seed of problem woody species present in the soil seed bank. This resulted in an aggressive re-establishment of species such as *A. mellifera*. This substantiates the conclusion that the mechanical tree thinning treatments in Marakele Park was not very successful.

The lack of any form of follow-up treatments after the initial tree thinning, proved to be the most significant factor contributing to the rapid regrowth of woody plants in all the treated plots. The regrowth (coppicing) of virtually all the woody plants that were mechanically cut, emphasises the importance of follow-up treatments, either chemical, mechanical or a combination of both.

The thinning treatments also resulted in structural changes of the woody plants. Many woody plants changed from single-stemmed trees to multi-stemmed bushes and the dominant height stratum of the woody plants was reduced to 0 – 1.5 m. This may cause further problems in Marakele Park, mostly due to the obstruction of herbivore and browser movement and access to herbaceous plants by the thick bushes.

Another important characteristic of the woody layer that is influenced by the tree thinning treatments, is browsing capacity. The browsing capacity of the treatment plots were lower than those of the control plots, clearly indicating that the availability of browse will initially be restricted by the thinning treatments. It is important to take into account the species of browsers present in the study area, since different browsers have different browsing height preferences. The tree thinning treatments must thus be selective enough to provide for each browser species' requirements.

In order to improve the growth and production of perennial grass species after tree thinning, appropriate veld management practices need to be followed, of which conservative stocking rates are the most important. However, even if good management practices are in place, the coppicing and regrowth of problem woody species from stumps or roots may still occur. This makes follow-up treatments and constant monitoring of the thinned areas an important priority.

CHAPTER 5

THE INFLUENCE OF THE TREE THINNING TREATMENTS ON THE HERBACEOUS SPECIES COMPOSITION AND VELD CONDITION

5.1 INTRODUCTION

The potential for species change in the herbaceous layer following tree thinning is of considerable importance. The aim of tree thinning is usually to increase herbaceous production, but the species composition of herbaceous plants is also important as species may vary significantly in their acceptability to grazing herbivores (Smit & Rethman, 1999), not only due to differences in palatability but also due to phenological differences, e.g. rhizomatous, stoloniferous or tall tufted grasses (Smit, 1994). These habitat determinants are especially important in the case of multi-species ecosystems. Other considerations include long term stability as influenced by the state of plant succession (e.g. predominance of climax grasses, mainly perennials, or predominance of pioneer grasses, mainly annuals), ground cover for prevention of soil erosion and water runoff (Snyman *et al.*, 1985; Snyman & Van Rensburg, 1986, Snyman & Fouché, 1991, Snyman, 1993a; Snyman, 1999) and the maintenance of soil fertility (Bredenkamp, 1985; Hook *et al.*, 1991; Snyman & Du Preez, 2005).

Plant succession has been defined as a progressive development of vegetation in an area through a series of different plant communities, finally terminating in a climax community. Climax vegetation, in turn, has been defined as a final stable plant community in an ecological succession which is able to reproduce itself indefinitely under existing environmental conditions (Gabriel & Talbot, 1984). Succession is generally thought of as the orderly change of vegetation which lies at the heart of most methods commonly used to measure the condition of rangeland vegetation (Tueller & Platou, 1991). The establishment of herbaceous plants can be considered as secondary succession, which is defined as succession that occurs after the destruction of part or all of the original vegetation on a site. According to Tainton & Hardy (1999) secondary succession occurs wherever a plant community has been disturbed and is no longer in equilibrium with its environment, but where, at least, some residual effect of previous occupation of plants remains. The study area is an example of the latter state. The concept of stability and equilibrium of a plant community and the factors that influence this state is of great importance. From the literature it is apparent that plant communities can display both equilibrial and non-equilibrial trends.

Changes in grass species composition following thinning or clearing of woody plants in savanna and grasslands have been recorded worldwide. Similarly, grass species changes occurred where woody plants established for the first time. For example, in Arizona, Martin & Morton (1993) reported a greater perennial grass density where mesquite (*Prosopis velutina*) had been killed three years previously than on untreated areas. Oppositely, establishing mesquite in desert grassland has created patches of perennial grasses in otherwise homogeneous desert grassland vegetation (Yavitt & Smith, 1983). A reduction of the Andropogoneae grass tribe and an increase in Paniceae were found where *Eucalyptus* communities were cleared (Scanlan & Burrows, 1990). In the Nigerian Guinea mesic savanna (annual rainfall of > 1 000 mm), Sanford *et al*. (1982) reported that shading by open canopied trees provides a micro-environment where such favoured species as the Andropogons replace undesirable species such as *Schizachyrium sanguineum* and *Hyparrhenia* species.

The changes in herbaceous layer composition have an important effect on veld condition. Veld condition is defined as the 'state of health' of the veld in terms of its ecological status, resistance to soil erosion and its potential for producing forage for sustained optimum animal production (Trollope *et al.*, 1990; Barac, 2003; Botha, 2003). The understanding and application of veld management depend heavily on the principles of plant succession, indicator plants and ecosystem dynamics. It is generally assumed that grazing and burning treatments lead to changes in the productivity and stability of natural grazing. Veld condition assessment is an integral part of good veld management and should be implemented in any nature conservation area like Marakele Park. In addition, it is necessary that advisors and managers should be able to recognise vegetative and edaphic symptoms of a deteriorating veld condition so that the correct management can be applied to improve and maintain productivity of herbaceous vegetation (Roberts, 1970).

The objectives of this study were:

- to identify the dominant herbaceous species of the experimental plots,
- to determine if the tree thinning treatments had any short-term effect on the herbaceous species composition, and
- to determine if the tree thinning treatments had any effect on the veld condition of the specific experimental plots in Marakele Park.

5.2 PROCEDURE

5.2.1 Quantification of the woody layer

The same procedure of woody plant biomass estimates in terms of Evapotranspiration Tree Equivalents (ETTE) ha^{-1} as described in Chapter 4 in section 4.2 (procedure), is applicable in this chapter.

5.2.2 Species composition of the herbaceous layer

The species composition of the herbaceous layer, based on the frequency of occurrence, was determined within each experimental plot. The step-point method was used for this determination (Mentis, 1981). A total of 400 points per experimental plot, spaced at 2 m intervals, were recorded by using the nearest plant method. Point-observations were done in straight lines to ensure the proportional sampling of the uncanopied, canopied and previously canopied (where the trees were removed) sub-habitats as they occurred in the experimental plots. Following the approach described by Smit & Rethman (1999), two readings per point were recorded: (1) nearest herbaceous plant species (regardless of the type of plant, e.g. annual grasses, perennial grasses or forbs) (first point-observation reading) and (2) nearest perennial grass species (second point-observation reading). A 'bare patch' was noted where no herbaceous plants occurred in a radius of 30 cm around the survey point for both point-observation readings (Smit, 1994). Where possible, all the plants of the Poaceae family (grasses) as well as other herbaceous plants and weeds were identified on a species basis. The species composition determinations were done at the end of the growing season (April/May) of the 2003/2004 season and were repeated during the same period of the 2004/2005 season.

5.2.3 Veld condition assessment

A veld condition assessment was done according to the Ecological Index Method of Vorster (1982), as revised by Tainton *et al*. (undated) and described by Heard *et al*. (1986). This assessment was used as a means to compare the current condition of the veld between the various experimental plots and with the intention to serve as a reference with which subsequent assessments can be compared to determine trends in relation to specific environmental conditions and management interventions.

For the purpose of the veld condition assessment, the different herbaceous species (grasses and forbs) recorded in the experimental plots were divided into ecological groups, namely Decreasers, Increaser Ia, Increaser IIa, IIb and IIc (Dyksterhuis, 1949; Foran, 1976; Tainton *et al.*, 1980) (Appendix E). Grouping of the represented grasses and forbs into the various ecological groups was done by means of correlation analyses and the classification of Smit (1988). It involved the identification of well represented grass species that are typical of each ecological group. The occurrence of the other plant species (grasses and forbs) within the experimental plots was tested for correspondence with the occurrence of the typical species of each ecological group. The plant species were subsequently placed in the ecological group where the highest positive correlation with the typical species of that group occurred. In borderline cases or in the case of species with a low occurrence, personal judgement was also used.

Identification of the typical grass species, which represent each ecological group, was done according to the classification of Smit (1988). The following typical grass species were selected for each ecological group:

Decreaser: *Themeda triandra*
Increaser Ia: *Cymbopogon pospischilii*
Increaser IIa: *Heteropogon contortus*
Increaser IIb: *Eragrostis rigidior*
Increaser IIc: *Urochloa mosambicensis*

The percentage contribution of herbaceous species being classified in the same ecological group, was calculated and a relative index value was assigned to each group. A factor of 10 was used for Decreasers species, 7 for Ia and IIa species, 4 for Increaser IIb species and 1 for Increaser IIc species (Vorster, 1982). The veld condition score for a particular sample plot was subsequently calculated as the sum of the products of the proportion contributed by the different ecological groups, multiplied with the relative index values assigned to each group. The maximum score is 1 000, i.e. 100% Decreaser species and the minimum is 100, i.e. 100% Increaser IIc species (Tainton, 1982).

5.2.4 Data analyses

Statistical analyses comprised of correlation analyses using Pearson Correlation Coefficients (SAS, 1988) and linear regression analyses (GraphPad, 1997). In addition, simple descriptive statistics were used.

5.3 RESULTS

5.3.1 Quantification of the woody layer

The ETTE ha^{-1} results are presented in Chapter 4 in section 4.3.2. For the purpose of this chapter these figures served to describe the tree competition gradient against which the successional trends of the herbaceous plants were interpreted.

5.3.2 Herbaceous species composition

5.3.2.1 *Acacia mellifera – Grewia flava* plots

The herbaceous species composition based on the first point-observation reading of the Am-Gf Treatment and Control plots during both seasons is presented in Table 5.1 and Table 5.2, respectively. The most abundant herbaceous species found in the Am-Gf Treatment plot during the 2003/2004 season were *Justicia flava*, *Urochloa mosambicensis*, *Chloris virgata*, *Tephrosia lupinifolia*, *Brachiaria nigropedata*, *Solanum rigescens* and *Eragrostis pilosa*. In the Am-Gf Control plot, the most abundant species were *Evolvulus alsinoides*, *Justicia flava*, *Justicia protracta*, *Bothriochloa radicans*, *Melolobium* spp., *Pavonia burchellii* and *U. mosambicensis*. The most abundant species of the Am-Gf Treatment plot during the 2004/2005 season were *J. protracta*, *Aristida congesta* subsp. *congesta*, *Eragrostis rigidior*, *Senecio latifolius*, *A. congesta* subsp. *barbicollis* and *Evolvulus alsinoides*. The most abundant species of the Am-Gf Control plot in the second season were *U. mosambicensis, J. protracta*, *A. congesta* subsp. *congesta*, *B. radicans, J. flava*, *Melolobium* spp. and *Digitaria eriantha*.

The most abundant forb species recorded in the Am-Gf Treatment plot were mostly perennial herbs and weeds that occur on sandy soil in grassland and bushveld. The dominant forbs that were recorded in the Am-Gf Control plot were also mostly perennial herbs and species that are associated with shade, like *P. burchellii*. The most abundant grass species that were recorded in the treatment plot were mainly annual pioneers, e.g. *A. congesta*, and weak perennial subclimax species, e.g. *U. mosambicensis*. The dominant grasses that occurred in the control plot varied from pioneers, mostly *Aristida* species, to climax species, e.g. *D. eriantha*. The total percentage bare patches (based on the first point-observation reading) of the treatment plot, decreased with 4.3% from 13.3% in the 2003/2004 to 9% in the 2004/2005 season, while the percentage bare patches of the control plot decreased with 7% from 17.8% to 10.8%.

Table 5.1: The percentage species composition (first point-observation reading) based on the frequency of occurrence of herbaceous species in the *Acacia mellifera – Grewia flava* Treatment plot. The percentage bare patches present in this plot is also indicated. Numbers in parenthesis indicate the ranking order of the species during each season of the study period.

Experimental plot	Species	Percentage (%)	
		2003/2004	2004/2005
***Acacia mellifera – Grewia flava* Treatment plot**	*Justicia flava*	9.75 (1)	3.75 (6)
	Urochloa mosambicensis	5.50 (2)	3.25 (7)
	Chloris virgata	5.25 (3)	3.75 (6)
	Tephrosia lupinifolia	5.25 (3)	1.25 (12)
	Brachiaria nigropedata	4.25 (4)	-
	Solanum rigescens	4.25 (4)	0.75 (14)
	Eragrostis pilosa	4.25 (4)	-
	Abutilon sonneratianum	3.75 (5)	0.50 (15)
	Bothriochloa insculpta	3.75 (5)	0.75 (14)
	Bothriochloa radicans	3.00 (6)	1.75 (10)
	Heteropogon contortus	2.25 (7)	2.50 (8)
	Justicia protracta	2.25 (7)	10.00 (1)
	Kyphocarpa angustifolia	2.25 (7)	1.75 (10)
	Panicum maximum	2.25 (7)	1.25 (12)
	Solanum panduriforme	2.25 (7)	2.50 (8)
	Melolobium spp.	2.00 (8)	2.50 (8)
	Monsonia burkeana	2.00 (8)	-
	Schkuhria pinnata	2.00 (8)	0.50 (15)
	Ipomoea obscura subsp. *obscura*	1.75 (9)	0.75 (14)
	Pavonia burchellii	1.75 (9)	0.75 (14)
	Themeda triandra	1.75 (9)	2.25 (9)
	Albuca spp.	1.50 (10)	-
	Kohautia virgata	1.50 (10)	-
	Corchorus asplenifolius	1.25 (11)	0.50 (15)
	Zehneria marlothii	1.25 (11)	0.50 (15)
	Aristida congesta subsp. *barbicollis*	1.00 (12)	4.50 (4)
	Chenopodium carinatum	1.00 (12)	-
	Digitaria eriantha	0.75 (13)	2.25 (9)
	Eragrostis superba	0.75 (13)	1.00 (13)
	Melhania prostrata	0.75 (13)	0.75 (14)
	Tragus berteronianus	0.75 (13)	1.00 (13)
	Zornia milneana	0.75 (13)	0.25 (16)
	Aristida adscensionis	0.50 (14)	0.75 (14)
	Aristida congesta subsp. *congesta*	0.50 (14)	6.50 (2)
	Linum thunbergii	0.50 (14)	0.75 (14)
	Zinnia peruviana	0.50 (14)	-
	Abutilon pycnodon	0.25 (15)	1.50 (11)
	Brachiaria deflexa	0.25 (15)	0.50 (15)
	Enneapogon cenchroides	0.25 (15)	0.50 (15)
	Evolvulus alsinoides	0.25 (15)	4.00 (5)
	Hibiscus engleri	0.25 (15)	-
	Melinis repens	0.25 (15)	0.75 (14)
	Striga elegans	0.25 (15)	-
	Tragus racemosus	0.25 (15)	2.25 (9)
	Eragrostis rigidior	-	4.75 (3)
	Senecio latifolius	-	4.75 (3)
	Bidens pilosa	-	2.50 (8)

…Continues

Table 5.1 continued…

Experimental plot	Species	Percentage (%)	
		2003/2004	2003/2004
***Acacia mellifera* – *Grewia flava* Treatment plot**	*Rhynchosia caribaea*	-	1.50 (11)
	Eragrostis lehmanniana	-	1.25 (12)
	Geigeria burkei	-	1.25 (12)
	Sporobolus ioclados	-	1.00 (13)
	Commelina africana	-	0.75 (14)
	Helichrysum dregeanum	-	0.75 (14)
	Oxygonum sinuatum	-	0.75 (14)
	Vahlia capensis	-	0.50 (15)
	Blumea mollis	-	0.25 (16)
	Cenchrus ciliaris	-	0.25 (16)
	Ceratotheca triloba	-	0.25 (16)
	Cucumis zeyheri	-	0.25 (16)
	Cymbopogon pospischilii	-	0.25 (16)
	Dactyloctenium giganteum	-	0.25 (16)
	Enneapogon scoparius	-	0.25 (16)
	Nemesia albiflora	-	0.25 (16)
	Rhynchosia totta	-	0.25 (16)
	Tephrosia longipes	-	0.25 (16)
	Bare patches	**13.25**	**9.00**

- Indicates that the species was not recorded during the survey of that specific season.

Table 5.2: The percentage species composition (first point-observation reading) based on the frequency of occurrence of herbaceous species in the *Acacia mellifera* – *Grewia flava* Control plot. The percentage bare patches present in this plot is also indicated. Numbers in parenthesis indicate the ranking order of the species during each season of the study period.

Experimental plot	Species	Percentage (%)	
		2003/2004	2004/2005
***Acacia mellifera* – *Grewia flava* Control plot**	*Evolvulus alsinoides*	6.00 (1)	2.75 (9)
	Justicia flava	5.50 (2)	6.00 (4)
	Justicia protracta	5.25 (3)	6.75 (2)
	Bothriochloa radicans	4.25 (4)	6.50 (3)
	Melolobium spp.	3.75 (5)	5.00 (5)
	Pavonia burchellii	3.75 (5)	1.75 (12)
	Urochloa mosambicensis	3.75 (5)	13.25 (1)
	Bothriochloa insculpta	3.00 (6)	2.50 (10)
	Kyphocarpa angustifolia	3.00 (6)	1.50 (13)
	Corchorus asplenifolius	2.75 (7)	0.75 (16)
	Albuca spp.	2.50 (8)	-
	Eragrostis pilosa	2.50 (8)	-
	Hibiscus engleri	2.50 (8)	-
	Panicum maximum	2.50 (8)	2.75 (9)
	Solanum panduriforme	2.25 (9)	0.75 (16)
	Tragus racemosus	2.25 (9)	1.50 (13)
	Brachiaria nigropedata	2.00 (10)	-
	Polygala sphenoptera	2.00 (10)	-
	Abutilon sonneratianum	1.75 (11)	-
	Aristida adscensionis	1.75 (11)	0.50 (17)
	Aristida congesta subsp. *barbicollis*	1.75 (11)	2.00 (11)
	Chloris virgata	1.75 (11)	1.50 (13)

…Continues

Table 5.2 continued…

Experimental plot	Species	Percentage (%)	
		2003/2004	**2003/2004**
***Acacia mellifera* – *Grewia flava* Control plot**	*Digitaria eriantha*	1.75 (11)	4.75 (6)
	Eragrostis superba	1.75 (11)	0.50 (17)
	Heteropogon contortus	1.75 (11)	1.00 (15)
	Themeda triandra	1.75 (11)	-
	Tragus berteronianus	1.75 (11)	1.00 (15)
	Ipomoea obscura subsp. *obscura*	1.00 (12)	0.25 (18)
	Tephrosia lupinifolia	1.00 (12)	0.25 (18)
	Zornia milneana	1.00 (12)	-
	Aristida congesta subsp. *congesta*	0.75 (13)	6.50 (3)
	Cucumis zeyheri	0.75 (13)	-
	Monsonia burkeana	0.75 (13)	-
	Linum thunbergii	0.50 (14)	-
	Schkuhria pinnata	0.50 (14)	0.25 (18)
	Dicoma spp.	0.25 (15)	-
	Sporobolus ioclados	0.25 (15)	1.75 (12)
	Zehneria marlothii	0.25 (15)	0.50 (17)
	Senecio latifolius	-	3.75 (7)
	Eragrostis rigidior	-	3.00 (8)
	Hypoestes spp.	-	1.50 (13)
	Sporobolus nitens	-	1.25 (14)
	Abutilon pycnodon	-	1.00 (15)
	Enneapogon cenchroides	-	1.00 (15)
	Bidens pilosa	-	0.75 (16)
	Commelina africana	-	0.75 (16)
	Solanum rigescens	-	0.75 (16)
	Enneapogon scoparius	-	0.50 (17)
	Geigeria burkei	-	0.50 (17)
	Achyranthes aspera subsp. *sicula*	-	0.25 (18)
	Blepharis integrifolia	-	0.25 (18)
	Cenchrus ciliaris	-	0.25 (18)
	Ceratotheca triloba	-	0.25 (18)
	Hemizygia canescens	-	0.25 (18)
	Melhania prostrata	-	0.25 (18)
	Rhynchosia totta	-	0.25 (18)
	Striga elegans	-	0.25 (18)
	Bare patches	**17.75**	**10.75**

- Indicates that the species was not recorded during the survey of that specific season.

The number of herbaceous species recorded in the treatment plot increased from 44 species in the 2003/2004 season to 56 species in the 2004/2005 season (Table 5.1). Some of the most notable species that were present in the 2003/2004 season and which were not recorded in the 2004/2005 season were *Brachiaria nigropedata*, *E. pilosa* and a variety of forbs. The number of herbaceous species recorded in the control plot increased from 39 species in the 2003/2004 season to 45 species in the 2004/2005 season (Table 5.2). The additional species recorded during the 2004/2005 season were mostly weedy forbs, e.g. *Senecio latifolius*, and grasses with a low grazing value, e.g. *Sporobolus nitens*.

The most abundant perennial grass species based on the second point-observation readings in the Am-Gf Treatment plot in the 2003/2004 season were *U. mosambicensis*, *Panicum maximum*, *Bothriochloa insculpta* and *E. rigidior* (Table 5.3). *Urochloa mosambicensis* was included as a perennial grass according to the classification of Van Oudtshoorn (1999), but it was found by Smit (1988) that this grass species reacts mostly as an annual grass and is only regarded as a weak perennial species in favourable conditions (the same applies to *Enneapogon cenchroides*). The dominant species in the Am-Gf Control plot during this season were *P. maximum*, *B. radicans* and *U. mosambicensis* (Table 5.4). The dominant perennial grasses during the 2004/2005 season in the treatment and control plot were *D. eriantha*, *E. rigidior* and *B. radicans*.

Table 5.3: The percentage species composition (second point-observation reading) based on the frequency of occurrence of herbaceous species in the *Acacia mellifera – Grewia flava* Treatment plot. The percentage bare patches present in this plot is also indicated. Numbers in parenthesis indicate the ranking order of the species during each season of the study period.

Experimental plot	**Species**	**Percentage (%)**	
		2003/2004	**2004/2005**
Acacia mellifera – Grewia flava	*Urochloa mosambicensis*	19.75 (1)	3.25 (8)
Treatment plot	*Panicum maximum*	12.50 (2)	2.00 (10)
	Bothriochloa insculpta	10.00 (3)	5.75 (5)
	Eragrostis rigidior	10.00 (3)	11.25 (2)
	Heteropogon contortus	9.00 (4)	6.75 (4)
	Bothriochloa radicans	5.00 (5)	9.25 (3)
	Eragrostis superba	3.25 (6)	2.00 (10)
	Digitaria eriantha	2.50 (7)	13.75 (1)
	Sporobolus ioclados	2.50 (7)	1.75 (11)
	Themeda triandra	2.50 (7)	5.50 (6)
	Melinis repens	2.00 (8)	3.75 (7)
	Enneapogon cenchroides	0.50 (9)	1.25 (13)
	Eragrostis lehmanniana	-	2.25 (9)
	Cymbopogon pospischilii	-	1.50 (12)
	Panicum coloratum	-	1.00 (14)
	Pogonarthria squarrosa	-	1.00 (14)
	Schmidtia pappophoroides	-	1.00 (14)
	Cenchrus ciliaris	-	0.75 (15)
	Enneapogon scoparius	-	0.75 (15)
	Bare patches	**20.50**	**25.50**

- Indicates that the species was not recorded during the survey of that specific season.

Over the two seasons, the percentage bare patches (based on the second point-observation readings) of the treatment plot increased from 20.5% to 25.5%, while it decreased from 26.3% to 25.3% in the control plot. The perennial grasses recorded in the treatment plot increased from 12 species in the 2003/2004 season to 19 species in the 2004/2005 season. The additional species recorded in the 2004/2005 season were mostly climax grasses with either a high grazing value, e.g. *Panicum coloratum*, or a low grazing value, e.g. *Cymbopogon pospischilii*.

Twelve species were recorded during the first season in the control plot, while 14 species were recorded during the second season. The species composition only changed to a small extent over the two seasons.

Table 5.4: The percentage species composition (second point-observation reading) based on the frequency of occurrence of herbaceous species in the *Acacia mellifera – Grewia flava* Control plot. The percentage bare patches present in this plot is also indicated. Numbers in parenthesis indicate the ranking order of the species during each season of the study period.

Experimental plot	Species	Percentage (%)	
		2003/2004	2004/2005
Acacia mellifera – Grewia flava	*Panicum maximum*	12.00 (1)	7.25 (5)
Control plot	*Bothriocloa radicans*	10.00 (2)	12.75 (2)
	Urochloa mosambicensis	10.00 (2)	2.00 (10)
	Heteropogon contortus	9.50 (3)	3.75 (7)
	Bothriochloa insculpta	8.75 (4)	9.00 (4)
	Eragrostis rigidior	6.00 (5)	13.00 (1)
	Digitaria eriantha	5.75 (6)	10.50 (3)
	Eragrostis superba	4.25 (7)	2.50 (8)
	Sporobolus ioclados	2.75 (8)	4.50 (6)
	Themeda triandra	2.50 (9)	-
	Enneapogon cenchroides	1.50 (10)	1.75 (11)
	Cymbopogon pospischilii	0.75 (11)	-
	Sporobolus nitens	-	3.75 (7)
	Enneapogon scoparius	-	2.25 (9)
	Eragrostis chloromelas	-	1.50 (12)
	Cenchrus ciliaris	-	0.25 (13)
	Bare patches	**26.25**	**25.25**

- Indicates that the species was not recorded during the survey of that specific season.

5.3.2.2 *Combretum apiculatum – Grewia flava* plots

The species composition of the Ca-Gf Treatment plot is presented in Table 5.5. The most abundant species of the 2003/2004 season were *Oxygonum sinuatum*, *Agathisanthemum bojeri*, *Aristida adscensionis*, *Hermannia glanduligera* and *A. congesta barbicollis*. The species composition of the Ca-Gf Control plot is presented in Table 5.6. The most abundant species during the 2003/2004 season were *Agathisanthemum bojeri*, *O. sinuatum*, *Vahlia capensis*, *Evolvulus alsinoides* and *Aristida congesta* subsp. *barbicollis*. During the 2004/2005 season the most dominant species of the treatment plot were *A. congesta congesta*, *Eragrostis rigidior*, *O. sinuatum*, *A. congesta barbicollis*, *Melinis repens* and *Evolvulus alsinoides* and for the control plot they were *Eragrostis rigidior*, *Justicia protracta*, *Melinis repens*, *A. congesta congesta* and *Agathisanthemum bojeri*.

Table 5.5: The percentage species composition (first point-observation reading) based on the frequency of occurrence of herbaceous species in the *Combretum apiculatum – Grewia flava* Treatment plot. The percentage bare patches present in this plot is also indicated. Numbers in parenthesis indicate the ranking order of the species during each season of the study period.

Experimental plot	Species	Percentage (%)	
		2003/2004	2004/2005
***Combretum apiculatum – Grewia flava* Treatment plot**	*Oxygonum sinuatum*	7.25 (1)	7.00 (2)
	Agathisanthemum bojeri	7.00 (2)	0.75 (16)
	Aristida adscensionis	5.50 (3)	2.25 (10)
	Hermannia glanduligera	5.50 (3)	-
	Aristida congesta subsp. *barbicollis*	4.75 (4)	6.25 (3)
	Justicia flava	4.50 (5)	0.25 (18)
	Melinis repens	3.75 (6)	5.75 (4)
	Aristida congesta subsp. *congesta*	3.50 (7)	7.25 (1)
	Evolvulus alsinoides	3.50 (7)	5.00 (5)
	Pogonarthria squarrosa	3.25 (8)	2.75 (9)
	Linum thunbergii	3.00 (9)	1.50 (13)
	Eragrostis pilosa	2.75 (10)	-
	Abutilon sonneratianum	2.50 (11)	3.50 (7)
	Schkuhria pinnata	2.00 (12)	0.75 (16)
	Senna italica subsp. *arachoides*	2.00 (12)	-
	Zornia milneana	2.00 (12)	1.50 (13)
	Digitaria eriantha	1.75 (13)	4.00 (6)
	Eragrostis rigidior	1.75 (13)	7.00 (2)
	Monsonia burkeana	1.75 (13)	-
	Sporobolus ioclados	1.75 (13)	-
	Tephrosia lupinifolia	1.75 (13)	0.75 (16)
	Tragus racemosus	1.75 (13)	1.50 (13)
	Corchorus asplenifolius	1.50 (14)	-
	Kyphocarpa angustifolia	1.50 (14)	0.50 (17)
	Solanum panduriforme	1.50 (14)	0.25 (18)
	Urochloa mosambicensis	1.25 (15)	2.00 (11)
	Eragrostis biflora	1.00 (16)	0.50 (17)
	Panicum maximum	1.00 (16)	0.25 (18)
	Themeda triandra	1.00 (16)	2.25 (10)
	Tragus berteronianus	1.00 (16)	0.75 (16)
	Albuca spp.	0.75 (17)	-
	Ceratotheca triloba	0.75 (17)	1.25 (14)
	Heteropogon contortus	0.75 (17)	1.75 (12)
	Justicia protracta	0.75 (17)	0.50 (17)
	Polygala sphenoptera	0.75 (17)	-
	Brachiaria nigropedata	0.50 (18)	0.75 (16)
	Chloris virgata	0.50 (18)	1.00 (15)
	Hibiscus engleri	0.50 (18)	-
	Cenchrus ciliaris	0.25 (19)	-
	Gossypium herbaceum	0.25 (19)	0.50 (17)
	Senecio latifolius	-	3.25 (8)
	Melhania prostrata	-	2.75 (9)
	Chamaecrista mimosoides	-	2.25 (10)
	Schmidtia pappophoroides	-	2.25 (10)
	Hemizygia canescens	-	2.25 (10)
	Rhynchosia totta	-	2.00 (11)
	Enneapogon cenchroides	-	1.75 (12)

…Continues

Table 5.5 continued…

Experimental plot	Species	Percentage (%)	
		2003/2004	2004/2005
***Combretum apiculatum* – *Grewia flava* Treatment plot**	*Setaria pumila*	-	1.50 (13)
	Trichoneura grandiglumis	-	1.50 (13)
	Pavonia burchellii	-	1.25 (14)
	Sporobolus nitens	-	1.25 (14)
	Abutilon pycnodon	-	0.50 (17)
	Enneapogon scoparius	-	0.50 (17)
	Helichrysum dregeanum	-	0.50 (17)
	Solanum rigescens	-	0.50 (17)
	Sporobolus panicoides	-	0.50 (17)
	Bidens pilosa	-	0.25 (18)
	Commelina africana	-	0.25 (18)
	Ipomoea obscura subsp. *obscura*	-	0.25 (18)
	Eragrostis lehmanniana	-	0.25 (18)
	Geigeria burkei	-	0.25 (18)
	Hermannia spp.	-	0.25 (18)
	Jatropha zeyheri	-	0.25 (18)
	Cyperus rupestris	-	0.25 (18)
	Tephrosia capensis	-	0.25 (18)
	Vahlia capensis	-	0.25 (18)
	Bare patches	**11.25**	**3.00**

- Indicates that the species was not recorded during the survey of that specific season.

Table 5.6: The percentage species composition (first point-observation reading) based on the frequency of occurrence of herbaceous species in the *Combretum apiculatum – Grewia flava* Control plot. The percentage bare patches present in this plot is also indicated. Numbers in parenthesis indicate the ranking order of the species during each season of the study period.

Experimental plot	Species	Percentage (%)	
		2003/2004	2004/2005
***Combretum apiculatum* – *Grewia flava* Control plot**	*Agathisanthemum bojeri*	12.00 (1)	4.75 (4)
	Oxygonum sinuatum	9.00 (2)	3.25 (5)
	Vahlia capensis	7.50 (3)	0.25 (15)
	Evolvulus alsinoides	6.50 (4)	1.75 (10)
	Aristida congesta subsp. *barbicollis*	6.00 (5)	3.00 (6)
	Justicia flava	4.75 (6)	0.50 (14)
	Linum thunbergii	4.75 (6)	0.75 (13)
	Monsonia burkeana	4.75 (6)	1.25 (11)
	Aristida adscensionis	4.50 (7)	2.50 (8)
	Hermannia glanduligera	4.25 (8)	-
	Aristida congesta subsp. *congesta*	3.50 (9)	4.75 (4)
	Melinis repens	3.00 (10)	5.25 (3)
	Schkuhria pinnata	2.75 (11)	-
	Eragrostis pilosa	2.25 (12)	-
	Abutilon sonneratianum	2.00 (13)	1.25 (11)
	Eragrostis rigidior	2.00 (13)	17.50 (1)
	Zornia milneana	2.00 (13)	0.25 (15)
	Chloris virgata	1.75 (14)	-
	Kyphocarpa angustifolia	1.75 (14)	0.25 (15)
	Tephrosia lupinifolia	1.75 (14)	0.50 (14)
	Albuca spp.	1.25 (15)	0.25 (15)

…Continues

Table 5.6 continued…

Experimental plot	Species	Percentage (%)	
		2003/2004	2004/2005
***Combretum apiculatum* – *Grewia flava* Control plot**	*Setaria pumila*	1.25 (15)	0.25 (15)
	Cucumis zeyheri	1.00 (16)	-
	Ipomoea obscura subsp. *obscura*	0.75 (17)	-
	Melhania prostrata	0.75 (17)	1.25 (11)
	Panicum maximum	0.75 (17)	1.25 (11)
	Themeda triandra	0.50 (18)	0.75 (13)
	Heteropogon contortus	0.25 (19)	0.75 (13)
	Justicia protracta	-	8.50 (2)
	Pogonarthria squarrosa	-	3.00 (6)
	Digitaria eriantha	-	2.75 (7)
	Trichoneura grandiglumis	-	2.50 (8)
	Helichrysum dregeanum	-	2.00 (9)
	Enneapogon cenchroides	-	1.75 (10)
	Schmidtia pappophoroides	-	1.75 (10)
	Ceratotheca triloba	-	1.25 (11)
	Enneapogon scoparius	-	1.25 (11)
	Geigeria burkei	-	1.00 (12)
	Hibiscus engleri	-	1.00 (12)
	Tragus racemosus	-	1.00 (12)
	Chamaecrista mimosoides	-	0.50 (14)
	Osteospermum muricatum	-	0.50 (14)
	Rhynchosia totta	-	0.50 (14)
	Senecio latifolius	-	0.50 (14)
	Solanum rigescens	-	0.50 (14)
	Sporobolus ioclados	-	0.50 (14)
	Urochloa mosambicensis	-	0.50 (14)
	Barleria galpinii	-	0.25 (15)
	Brachiaria deflexa	-	0.25 (15)
	Cenchrus ciliaris	-	0.25 (15)
	Commelina africana	-	0.25 (15)
	Corchorus asplenifolius	-	0.25 (15)
	Crabbea angustifolia	-	0.25 (15)
	Eragrostis superba	-	0.25 (15)
	Cyperus indecorus subsp. *decurvatus*	-	0.25 (15)
	Senna italica subsp. *arachoides*	-	0.25 (15)
	Sporobolus nitens	-	0.25 (15)
	Sporobolus panicoides	-	0.25 (15)
	Tragus berteronianus	-	0.25 (15)
	Zehneria marlothii	-	0.25 (15)
	Bare patches	**6.75**	**13.25**

- Indicates that the species was not recorded during the survey of that specific season.

The dominant forb species that occurred in the treatment and control plots varied from spreading annual to bushy perennial herb species. Forbs were the most abundant species in the control plot. The dominant grass species that were present in the treatment and control plots were mostly pioneer, e.g. *Aristida* species, and subclimax species, e.g. *M. repens* and *E. rigidior*. The percentage bare patches in the Ca-Gf Treatment plot decreased from 11.3% in the first season to 3% in the second season, while the percentage bare patches of the Ca-Gf Control plot increased from 6.8% to 13.3%.

Forty herbaceous plant species were recorded in the treatment plot during the survey of the 2003/2004 season, while 57 species were recorded during the 2004/2005 season. Some of the most notable changes were the increase of *D. eriantha* from 1.8% in the 2003/2004 season to 4% in the 2004/2005 season and *Senecio latifolius*, which were not recorded in the 2003/2004 season, to 3.3% in the 2004/2005 season. The number of herbaceous species recorded in the control plot increased from 28 species in the 2003/2004 season to 54 species in the 2004/2005 season. The additional species found in the latter season ranged from unpalatable grasses and forbs to highly desirable grasses like *D. eriantha* and *Schmidtia pappophoroides*.

The most abundant perennial grass species (based on the second point-observation readings) recorded during the 2003/2004 season in the Ca-Gf Treatment plot were *M. repens*, *D. eriantha* and *Pogonarthria squarrosa* (Table 5.7). The most abundant perennial grass species in the Ca-Gf Control plot were *M. repens*, *Panicum maximum* and *D. eriantha* (Table 5.8). The most abundant grass species during the 2004/2005 season in the treatment plot included *E. rigidior*, *M. repens* and *D. eriantha*. *Eragrostis rigidior* increased from 8% to 24% over the two seasons. Other notable changes found over the two seasons were the absence of *Sporobolus ioclados* in the second season and the presence of *Schmidtia pappophoroides*, a climax perennial with a high grazing value, in the second season, which was not recorded during the survey of the first season. The most abundant perennial grass species recorded during the 2004/2005 season in the control plot were *E. rigidior*, *M. repens* and *Pogonarthria squarrosa*. *Eragrostis rigidior* increased drastically from 4% to 35.5% over the two seasons. Other notable changes found in the Ca-Gf Control plot were the relatively high occurrence of *P. squarrosa*, which was not recorded during the 2003/2004 season and the large decrease of *Panicum maximum* from the first to the second season. The same result for the occurrence of *P. maximum* was found in the Ca-Gf Treatment plot.

The percentage bare patches (based on the second point-observation readings) in the treatment plot increased from 17.8% to 18.5%, while the percentage bare patches in the control plot increased from 14.8% to 20.8%. The number of perennial grasses recorded in the treatment plot increased from 13 species in the 2003/2004 season to 15 species in the 2004/2005 season and the species composition changed marginally over the two seasons. The number of perennial grasses recorded in the control plot increased from 13 species in the 2003/2004 season to 17 species in the 2004/2005 season.

Table 5.7: The percentage species composition (second point-observation reading) based on the frequency of occurrence of herbaceous species in the *Combretum apiculatum – Grewia flava* Treatment plot. The percentage bare patches present in this plot is also indicated. Numbers in parenthesis indicate the ranking order of the species during each season of the study period.

Experimental plot	Species	Percentage (%)	
		2003/2004	2004/2005
***Combretum apiculatum – Grewia flava* Treatment plot**	*Melinis repens*	13.50 (1)	12.50 (2)
	Digitaria eriantha	11.00 (2)	9.00 (3)
	Pogonarthria squarrosa	9.25 (3)	7.25 (4)
	Urochloa mosambicensis	9.25 (3)	5.25 (6)
	Panicum maximum	8.50 (4)	0.50 (14)
	Eragrostis rigidior	8.00 (5)	24.00 (1)
	Sporobolus ioclados	8.00 (5)	-
	Themeda triandra	3.00 (6)	4.25 (8)
	Brachiaria nigropedata	2.75 (7)	0.75 (13)
	Cenchrus ciliaris	2.50 (8)	-
	Heteropogon contortus	2.25 (9)	5.75 (5)
	Enneapogon cenchroides	2.25 (9)	2.00 (10)
	Eragrostis superba	1.75 (10)	-
	Schmidtia pappophoroides	-	4.50 (7)
	Trichoneura grandiglumis	-	2.25 (9)
	Enneapogon scoparius	-	1.25 (11)
	Sporobolus nitens	-	1.25 (11)
	Eragrostis lehmanniana	-	1.00 (12)
	Bare patches	**17.75**	**18.50**

- Indicates that the species was not recorded during the survey of that specific season.

Table 5.8: The percentage species composition (second point-observation reading) based on the frequency of occurrence of herbaceous species in the *Combretum apiculatum – Grewia flava* Control plot. The percentage bare patches present in this plot is also indicated. Numbers in parenthesis indicate the ranking order of the species during each season of the study period.

Experimental plot	Species	Percentage (%)	
		2003/2004	2004/2005
***Combretum apiculatum – Grewia flava* Control plot**	*Melinis repens*	15.25 (1)	11.75 (2)
	Panicum maximum	12.75 (2)	1.00 (11)
	Digitaria eriantha	8.50 (3)	6.00 (4)
	Enneapogon cenchroides	8.50 (3)	2.75 (7)
	Sporobolus ioclados	7.50 (4)	0.50 (13)
	Urochloa mosambicensis	7.50 (4)	0.50 (13)
	Schmidtia pappophoroides	6.00 (5)	3.50 (5)
	Eragrostis superba	4.00 (6)	0.25 (14)
	Heteropogon contortus	4.00 (6)	2.25 (8)
	Eragrostis rigidior	4.00 (6)	35.50 (1)
	Cenchrus ciliaris	3.00 (7)	0.25 (14)
	Brachiaria nigropedata	2.25 (8)	0.75 (12)
	Themeda triandra	2.00 (9)	2.00 (9)
	Pogonarthria squarrosa	-	6.50 (3)
	Trichoneura grandiglumis	-	3.25 (6)
	Enneapogon scoparius	-	1.50 (10)
	Sporobolus nitens	-	1.00 (11)
	Bare patches	**14.75**	**20.75**

- Indicates that the species was not recorded during the survey of that specific season.

5.3.2.3 *Acacia erubescens – Dichrostachys cinerea* plots

The most abundant plant species (based on the first point-observation readings) in the Ae-Dc Treatment plot during the 2003/2004 season were *Aristida congesta* subsp. *barbicollis*, *Justicia flava*, *Oxygonum sinuatum*, *A. congesta congesta* and *A. adscensionis* (Table 5.9). In the Ae-Dc Control plot they were *A. congesta barbicollis*, *Sporobolus panicoides*, *Justicia flava*, *A. congesta congesta*, *Eragrostis pilosa* and *Cyperus rupestris* (Table 5.10). The most abundant species during the 2004/2005 season in the treatment plot were *Senecio latifolius*, *A. congesta barbicollis*, *Eragrostis rigidior*, *A. congesta congesta* and *U. mosambicensis*. The most abundant species recorded in the control plot during the second season included *Senecio latifolius*, *E. rigidior*, *Chloris virgata*, *E. lehmanniana*, *Corchorus asplenifolius*, *Geigeria burkei* and *A. congesta congesta*.

The dominant forb species of the treatment plot were mostly annual weeds, while the dominant forbs of the control plot were mostly perennial herbs. The dominant grass species of the treatment plot varied from annual pioneers, e.g. *Aristida* species, to perennial subclimax species, e.g. *U. mosambicensis*. The dominant grasses that occurred in the control plot varied from annual pioneer species that usually grow in light shade in warm dry bushveld, e.g. *Sporobolus panicoides*, to perennial climax species, e.g. *E. lehmanniana*. The percentage bare patches (based on the first point-observation readings) recorded in the treatment plot decreased from 7% in the first season to 3.5% in the second season, while it decreased from 7% to 6% in the control plot.

The number of herbaceous species recorded in the Ae-Dc Treatment plot ranged from 54 species in the 2003/2004 season to 46 species in the 2004/2005 season. Herbaceous species that increased to a relative extent in the treatment plot from the first to the second season, included *Digitaria eriantha* (4.3% increase) and *Heteropogon contortus* (3% increase), but the most noticeable increases were those of *S. latifolius* (10.8% increase) and *E. rigidior* (8% increase). The number of herbaceous species recorded in the control plot varied from 40 species in the first season to 45 species in the second season and the species composition changed considerably over the two seasons. A number of grass species was recorded during the survey of the 2004/2005 season that was not recorded during the 2003/2004 season. These grasses ranged from palatable pioneer species, e.g. *Dactyloctenium giganteum*, to unpalatable climax species, e.g. *Cymbopogon pospischilii*.

Table 5.9: The percentage species composition (first point-observation reading) based on the frequency of occurrence of herbaceous species in the *Acacia erubescens* – *Dichrostachys cinerea* Treatment plot. The percentage bare patches present in this plot is also indicated. Numbers in parenthesis indicate the ranking order of the species during each season of the study period.

Experimental plot	Species	Percentage (%)	
		2003/2004	2004/2005
***Acacia erubescens* – *Dichrostachys cinerea* Treatment plot**	*Aristida congesta* subsp. *barbicollis*	5.00 (1)	9.75 (2)
	Justicia flava	4.50 (2)	4.00 (8)
	Oxygonum sinuatum	4.00 (3)	2.75 (9)
	Aristida congesta subsp. *congesta*	3.75 (4)	7.25 (4)
	Aristida adscensionis	3.50 (5)	1.00 (16)
	Eragrostis pilosa	3.25 (6)	-
	Conyza podocephala	2.75 (7)	-
	Hemizygia canescens	2.75 (7)	1.00 (16)
	Monsonia burkeana	2.75 (7)	-
	Tragus racemosus	2.75 (7)	1.00 (16)
	Cyperus rupestris	2.50 (8)	-
	Urochloa mosambicensis	2.50 (8)	6.25 (5)
	Brachiaria deflexa	2.25 (9)	-
	Commelina africana	2.25 (9)	1.25 (15)
	Justicia protracta	2.25 (9)	0.50 (18)
	Panicum maximum	2.25 (9)	2.50 (10)
	Tragus berteronianus	2.00 (10)	0.50 (18)
	Blumea mollis	1.75 (11)	-
	Bothriochloa insculpta	1.75 (11)	1.00 (16)
	Evolvulus alsinoides	1.75 (11)	2.75 (9)
	Polygala sphenoptera	1.75 (11)	-
	Schkuhria pinnata	1.75 (11)	1.75 (13)
	Abutilon sonneratianum	1.50 (12)	1.50 (14)
	Bidens pilosa	1.50 (12)	-
	Eragrostis biflora	1.50 (12)	-
	Heteropogon contortus	1.50 (12)	4.50 (7)
	Hermannia glanduligera	1.50 (12)	-
	Indigofera holubii	1.50 (12)	-
	Kyphocarpa angustifolia	1.50 (12)	-
	Oxalis depressa	1.50 (12)	-
	Tephrosia lupinifolia	1.50 (12)	0.50 (18)
	Digitaria eriantha	1.25 (13)	5.50 (6)
	Nemesia albiflora	1.25 (13)	-
	Rhynchosia totta	1.25 (13)	-
	Sporobolus panicoides	1.25 (13)	-
	Solanum rigescens	1.25 (13)	-
	Zornia milneana	1.25 (13)	0.25 (19)
	Bothriochloa radicans	1.00 (14)	1.25 (15)
	Chamaecrista mimosoides	1.00 (14)	-
	Ipomoea obscura subsp. *obscura*	1.00 (14)	0.75 (17)
	Eragrostis rigidior	1.00 (14)	9.00 (3)
	Eragrostis superba	1.00 (14)	0.75 (17)
	Hibiscus cannabinus	1.00 (14)	-
	Pavonia burchellii	1.00 (14)	-
	Hibiscus engleri	0.75 (15)	-
	Panicum coloratum	0.75 (15)	1.50 (14)
	Senna italica subsp. *arachoides*	0.75 (15)	-

…Continues

Table 5.9 continued…

Experimental plot	Species	Percentage (%)	
		2003/2004	2004/2005
***Acacia erubescens – Dichrostachys cinerea* Treatment plot**	*Sporobolus ioclados*	0.75 (15)	0.25 (19)
	Agathisanthemum bojeri	0.50 (16)	0.25 (19)
	Kalanchoe lanceolata	0.50 (16)	-
	Melinis repens	0.50 (16)	1.00 (16)
	Achyranthes aspera subsp. *sicula*	0.25 (17)	-
	Hermbstaedtia odorata	0.25 (17)	-
	Kalanchoe paniculata	0.25 (17)	-
	Senecio latifolius	-	10.75 (1)
	Eragrostis lehmanniana	-	2.75 (9)
	Linum thunbergii	-	2.25 (11)
	Geigeria burkei	-	2.00 (12)
	Melhania prostrata	-	1.50 (14)
	Chloris virgata	-	1.00 (16)
	Eragrostis chloromelas	-	1.00 (16)
	Pogonarthria squarrosa	-	1.00 (16)
	Ceratotheca triloba	-	0.75 (17)
	Dactyloctenium giganteum	-	0.75 (17)
	Kohautia virgata	-	0.75 (17)
	Brachiaria nigropedata	-	0.50 (18)
	Solanum panduriforme	-	0.50 (18)
	Corchorus asplenifolius	-	0.25 (19)
	Cymbopogon pospischilii	-	0.25 (19)
	Striga elegans	-	0.25 (19)
	Bare patches	**7.00**	**3.50**

- Indicates that the species was not recorded during the survey of that specific season.

Table 5.10: The percentage species composition (first point-observation reading) based on the frequency of occurrence of herbaceous species in the *Acacia erubescens – Dichrostachys cinerea* Control plot. The percentage bare patches present in this plot is also indicated. Numbers in parenthesis indicate the ranking order of the species during each season of the study period.

Experimental plot	Species	Percentage (%)	
		2003/2004	2004/2005
***Acacia erubescens – Dichrostachys cinerea* Control plot**	*Aristida congesta* subsp. *barbicollis*	5.25 (1)	3.25 (7)
	Sporobolus panicoides	5.25 (1)	0.25 (16)
	Justicia flava	4.50 (2)	-
	Aristida congesta subsp. *congesta*	4.25 (3)	4.25 (5)
	Eragrostis pilosa	4.25 (3)	-
	Cyperus rupestris	3.75 (4)	3.25 (7)
	Aristida adscensionis	3.25 (5)	1.75 (11)
	Chloris virgata	3.00 (6)	5.75 (3)
	Panicum maximum	3.00 (6)	0.50 (15)
	Bothriochloa radicans	2.75 (7)	-
	Eragrostis rigidior	2.75 (7)	7.25 (2)
	Evolvulus alsinoides	2.75 (7)	-
	Schkuhria pinnata	2.75 (7)	0.25 (16)
	Abutilon sonneratianum	2.25 (8)	0.25 (16)
	Agathisanthemum bojeri	2.25 (8)	-
	Bidens pilosa	2.25 (8)	-
	Fuirena pubescens	2.25 (8)	-

…Continues

Table 5.10 continued…

Experimental plot	Species	Percentage (%)	
		2003/2004	2003/2004
***Acacia erubescens – Dichrostachys cinerea* Control plot**	*Pavonia transvaalensis*	2.25 (8)	-
	Tephrosia lupinifolia	2.25 (8)	0.25 (16)
	Zornia milneana	2.25 (8)	0.25 (16)
	Bothriochloa insculpta	2.00 (9)	-
	Hemizygia canescens	2.00 (9)	0.75 (14)
	Oxygonum sinuatum	2.00 (9)	1.00 (13)
	Conyza podocephala	1.75 (10)	-
	Justicia protracta	1.75 (10)	0.50 (15)
	Monsonia burkeana	1.75 (10)	-
	Osteospermum muricatum	1.75 (10)	-
	Vernonia poskeana	1.75 (10)	-
	Oxalis depressa	1.50 (11)	-
	Rhynchosia totta	1.50 (11)	0.50 (15)
	Solanum rigescens	1.50 (11)	-
	Tragus berteronianus	1.50 (11)	2.00 (10)
	Tragus racemosus	1.50 (11)	3.00 (8)
	Commelina africana	1.25 (12)	0.50 (15)
	Corchorus asplenifolius	1.25 (12)	5.00 (4)
	Digitaria eriantha	1.25 (12)	2.00 (10)
	Kyphocarpa angustifolia	1.25 (12)	-
	Hermannia glanduligera	1.00 (13)	-
	Hermbstaedtia linearis	0.75 (14)	-
	Kalanchoe lanceolata	0.75 (14)	0.25 (16)
	Senecio latifolius	-	13.75 (1)
	Eragrostis lehmanniana	-	5.75 (3)
	Geigeria burkei	-	5.00 (4)
	Linum thunbergii	-	3.75 (6)
	Eragrostis gummiflua	-	3.00 (8)
	Cymbopogon pospischilii	-	2.75 (9)
	Portulaca quadrifida	-	2.75 (9)
	Urochloa mosambicensis	-	2.00 (10)
	Enneapogon cenchroides	-	1.75 (11)
	Brachiaria nigropedata	-	1.25 (12)
	Melhania prostrata	-	1.25 (12)
	Melinis repens	-	1.25 (12)
	Enneapogon scoparius	-	1.00 (13)
	Tephrosia capensis	-	1.00 (13)
	Vahlia capensis	-	1.00 (13)
	Heteropogon contortus	-	0.75 (14)
	Striga elegans	-	0.75 (14)
	Ceratotheca triloba	-	0.50 (15)
	Dactyloctenium giganteum	-	0.50 (15)
	Eragrostis superba	-	0.50 (15)
	Panicum coloratum	-	0.50 (15)
	Blepharis integrifolia	-	0.25 (16)
	Setaria pumila	-	0.25 (16)
	Bare patches	**7.00**	**6.00**

- Indicates that the species was not recorded during the survey of that specific season.

The most abundant perennial grass species (based on the second point-observation readings) of the Ae-Dc Treatment plot during the 2003/2004 season were *Panicum maximum*, *U. mosambicensis* and *Bothriochloa insculpta* (Table 5.11). The most abundant species of the Ae-Dc Control plot in the first season were *E. rigidior*, *P. maximum* and *E. lehmanniana* (Table 5.12). The most abundant grass species in the treatment plot during the 2004/2005 season were *Digitaria eriantha*, *E. rigidior* and *U. mosambicensis*, while *E. rigidior*, *E. lehmanniana* and *E. gummiflua* were the most abundant species in the control plot.

Noticeable changes in the treatment plot over the two seasons were the substantial decrease of *P. maximum* and *B. insculpta* from the first to the second season and the corresponding increase of *D. eriantha*, *E. rigidior* and *E. lehmanniana* from the first to the second season. Noticeable changes in the control plot were a similar decrease in *P. maximum* and a moderate increase of *E. rigidior*, *E. lehmanniana* and *C. pospischilii* from the first to the second season.

Table 5.11: The percentage species composition (second point-observation reading) based on the frequency of occurrence of herbaceous species in the *Acacia erubescens – Dichrostachys cinerea* Treatment plot. The percentage bare patches present in this plot is also indicated. Numbers in parenthesis indicate the ranking order of the species during each season of the study period.

Experimental plot	**Species**	**Percentage (%)**	
		2003/2004	**2004/2005**
***Acacia erubescens – Dichrostachys cinerea* Treatment plot**	*Panicum maximum*	16.75 (1)	1.50 (9)
	Urochloa mosambicensis	12.75 (2)	16.00 (3)
	Bothriochloa insculpta	10.00 (3)	1.00 (11)
	Digitaria eriantha	8.25 (4)	18.75 (1)
	Bothriochloa radicans	7.50 (5)	2.00 (7)
	Eragrostis rigidior	7.25 (6)	18.50 (2)
	Heteropogon contortus	5.50 (7)	9.75 (4)
	Sporobolus ioclados	5.00 (8)	0.25 (12)
	Eragrostis superba	4.25 (9)	1.75 (8)
	Melinis repens	3.75 (10)	2.25 (6)
	Enneapogon cenchroides	2.50 (11)	-
	Cymbopogon pospischilii	2.00 (12)	1.25 (10)
	Brachiaria nigropedata	0.75 (13)	1.00 (11)
	Pogonarthria squarrosa	0.75 (13)	1.75 (8)
	Eragrostis chloromelas	-	1.00 (11)
	Panicum coloratum	-	1.00 (11)
	Eragrostis lehmanniana	-	8.00 (5)
	Bare patches	**13.00**	**14.25**

- Indicates that the species was not recorded during the survey of that specific season.

Table 5.12: The percentage species composition (second point-observation reading) based on the frequency of occurrence of herbaceous species in the *Acacia erubescens – Dichrostachys cinerea* Control plot. The percentage bare patches present in this plot is also indicated. Numbers in parenthesis indicate the ranking order of the species during each season of the study period.

Experimental plot	Species	Percentage (%)	
		2003/2004	2004/2005
Acacia erubescens –	*Eragrostis rigidior*	15.25 (1)	22.00 (1)
Dichrostachys cinerea	*Panicum maximum*	12.50 (2)	2.25 (7)
Control plot	*Eragrostis lehmanniana*	10.25 (3)	17.00 (2)
	Eragrostis gummiflua	9.50 (4)	10.00 (3)
	Digitaria eriantha	6.75 (5)	8.00 (6)
	Eragrostis superba	5.75 (6)	0.50 (12)
	Urochloa mosambicensis	5.25 (7)	9.00 (4)
	Enneapogon cenchroides	4.50 (8)	0.50 (12)
	Heteropogon contortus	4.50 (8)	2.00 (8)
	Sporobolus ioclados	4.50 (8)	-
	Cymbopogon pospischilii	3.75 (9)	8.25 (5)
	Melinis repens	2.75 (10)	1.50 (10)
	Pogonarthria squarrosa	2.50 (11)	-
	Brachiaria nigropedata	1.50 (12)	1.75 (9)
	Panicum coloratum	-	1.00 (11)
	Eragrostis chloromelas	-	0.50 (12)
	Bare patches	**10.75**	**15.75**

- Indicates that the species was not recorded during the survey of that specific season.

The percentage bare patches (second point-observation readings) in the treatment plot increased marginally from 13% in the first season to 14.3% in the second season, while the percentage bare patches in the control plot increased from 10.8% to 15.8%. The number of perennial grasses recorded in the treatment plot increased from 14 species in the first season to 16 species in the second season and the species composition has changed to a small extent. The number of species that occurred in the control plot remained the same over the two seasons, but the species composition of this plot has also changed slightly. A substantial decrease of *P. maximum* was also evident in this control plot. Other changes recorded were the moderate increase of *E. lehmanniana* and the absence of *Sporobolus ioclados* in the 2004/2005 season.

5.3.3 Relations between tree leaf biomass and herbaceous species composition

Relations between the percentage herbaceous species composition and tree leaf biomass, expressed as ETTE ha^{-1}, were established for all the experimental plots combined (Table 5.13). This was done independently during both seasons for each of the two point-observation readings. It was determined that the relations between bare patches and ETTE ha^{-1} of the first point-observation readings were positively correlated during both seasons. However, the relations between the ETTE ha^{-1} and percentage bare patches were non-significant ($P > 0.05$).

The relations between all the herbaceous species composition percentage and ETTE ha^{-1} were negative during both seasons and these relations were also non-significant ($P > 0.05$). The percentage species composition of the annual grasses during both seasons and of the forbs during the 2003/2004 season was negatively correlated with ETTE ha^{-1}. The relation between the forbs and ETTE ha^{-1} during the second season was positive, but also non-significant ($P > 0.05$). The perennial grasses and ETTE ha^{-1} was positively correlated during the first season and negatively correlated during the second season. However, none of these relations were significant ($P > 0.05$).

The second point-observation readings of the percentage bare patches had similar results than the first point-observation readings during both seasons. For the perennial grass species, the relations with the ETTE ha^{-1} had negative correlations. The relations between some of the dominant perennial grass species and the ETTE ha^{-1} were also tested (Table 5.13). *Digitaria eriantha* and *U. mosambicensis* had negative correlations with ETTE ha^{-1}. *Eragrostis rigidior* had a positive correlation with ETTE ha^{-1} in the first season and a negative correlation in the second season. *Panicum maximum* had a negative correlation with ETTE ha^{-1} in the first season and a positive correlation in the second season. However, these relations were all non-significant ($P > 0.05$).

5.3.4 Veld condition assessment

5.3.4.1 *Ecological grouping*

The results of the correlation analyses are presented in Table 5.14. The Increaser Ia group was excluded because it was found that these species had a very low occurrence in the experimental plots. The Increaser Ia group (only *Cymbopogon pospischilii*) was, however, included in the veld condition score determination (see section 5.3.4.2). The ecological group in which each grass species were categorised is also given in the table. The same was done for the forbs and the results are presented in Table 5.15.

From Table 5.14 it is clear that the ecological grass species group that contributed the most to the species composition of the study area were Increaser IIb (grasses that increase when veld is heavily overgrazed for an extended period). The second dominant ecological group was Increaser IIa (grasses that increase when veld is moderately overgrazed in the long term), followed by Increaser IIc (grasses that increase when veld is heavily overgrazed for an extended period) and lastly the Decreasers (grasses that dominate in veld in good/excellent condition). All the forbs were classified as Increaser species (Table 5.15). The most abundant ecological forb species group was the Increaser IIc group, followed by Increaser IIb and lastly Increaser IIa species.

Table 5.13: Correlation analyses (n = 6) of the relations between percentage herbaceous species composition (including percentage bare patches) of all the experimental plots combined, and tree density {expressed as Evapotranspiration Tree Equivalents (ETTE) ha^{-1}} for the 2003/2004 and 2004/2005 seasons (ns = non-significant; P > 0.05).

Species	2003/2004				2004/2005			
	Regression equation	**r**	**r^2**	**P**	**Regression equation**	**r**	**r^2**	**P**
First reading of point-observations								
Bare patches	y = 5.011 + 0.0007635x	0.4548	0.2068	0.3648 ns	y = -1.650 + 0.0012480x	0.7396	0.5471	0.0929 ns
All herbaceous plants	y = 94.989 + -0.0007635x	-0.4548	0.2068	0.3648 ns	y = 101.65 + -0.0012480x	-0.7396	0.5471	0.0929 ns
Annual grasses	y = 28.217 + -0.0014100x	-0.5337	0.2848	0.2755 ns	y = 21.764 + -0.0008131x	-0.7774	0.6044	0.0688 ns
Perennial grasses	y = 11.313 + 0.0009128x	0.3234	0.1046	0.5318 ns	y = 42.489 + -0.0007760x	-0.3787	0.1434	0.4590 ns
Forbs	y = 55.459 + -0.0002667x	-0.0976	0.0095	0.8540 ns	y = 37.398 + 0.0003406x	0.1687	0.0285	0.7494 ns
Second reading of point-observations								
Bare patches	y = 10.538 + 0.0009221x	0.4349	0.1891	0.3885 ns	y = 10.179 + 0.0013280x	0.6834	0.4670	0.1345 ns
All perennial grasses	y = 89.462 + -0.0009221x	-0.4349	0.1891	0.3888 ns	y = 89.821 + -0.0013280x	-0.6834	0.4670	0.1345 ns
Digitaria eriantha	y = 12.560 + -0.0007560x	-0.6956	0.4839	0.1249 ns	y = 16.459 + -0.0007381x	-0.3903	0.1523	0.4443 ns
Eragrostis rigidior	y = 7.014 + 0.0001951x	0.1327	0.0176	0.8020 ns	y = 28.167 + -0.0010080x	-0.2796	0.0782	0.5915 ns
Panicum maximum	y = 12.640 + -1.941E-05x	-0.0197	0.0004	0.9705 ns	y = -2.863 + 0.0007138x	0.7080	0.5013	0.1154 ns
Urochloa mosambicensis	y = 11.188 + -6.092E-05x	-0.0319	0.0010	0.9522 ns	y = 16.551 + -0.0014270x	-0.6072	0.3687	0.2011 ns

Table 5.14: Cross tabulation of the correlations (r) (all seasons combined, n = 12) between the percentage composition of all the grass species as they occurred in the various experimental plots during the 2003/2004 and 2004/2005 seasons versus the typical grass species of each Decreaser and Increaser group. The statistical significance of the correlations is also indicated {* = significant ($P \leq 0.05$); ** = very significant ($P \leq 0.01$); *** = highly significant ($P \leq 0.001$); ns = non-significant ($P > 0.05$)} as well as the ecological classification of each species.

Species	**Decreaser (*Themeda triandra*)**		**Increaser IIa (*Heteropogon contortus*)**		**Increaser IIb (*Eragrostis rigidior*)**		**Increaser IIc (*Urochloa mosambicensis*)**		**Ecological group**
	r	**P**	**r**	**P**	**r**	**P**	**r**	**P**	
Aristida adscensionis	-0.20767	0.5172 ns	-0.56971	0.0531 ns	-0.13741	0.6702 ns	-0.66363	0.0186 *	Increaser IIb
Aristida congesta subsp. *barbicollis*	-0.24050	0.4515 ns	0.40168	0.1956 ns	0.22490	0.4822 ns	-0.23566	0.4609 ns	Increaser IIb
Aristida congesta subsp. *congesta*	-0.13689	0.6714 ns	0.27570	0.3857 ns	0.50650	0.0929 ns	0.22166	0.4887 ns	Increaser IIb
Bothriochloa insculpta	0.06636	0.8376 ns	0.18678	0.5611 ns	-0.56292	0.0567 ns	0.52351	0.0807 ns	Increaser IIc
Bothriochloa radicans	-0.04212	0.8966 ns	0.06675	0.8367 ns	-0.42069	0.1733 ns	0.77828	0.0029 **	Increaser IIc
Brachiaria deflexa	-0.15754	0.6248 ns	0.06560	0.8395 ns	-0.17430	0.5880 ns	-0.08212	0.7997 ns	Increaser IIa
Brachiaria nigropedata	0.42305	0.1706 ns	0.20494	0.5229 ns	-0.35178	0.2621 ns	0.13299	0.6803 ns	Decreaser
Cenchrus ciliaris	-0.05198	0.8725 ns	0.30394	0.3368 ns	0.44752	0.1446 ns	0.36884	0.2381 ns	Increaser IIa
Chloris virgata	0.14020	0.6639 ns	-0.00861	0.9788 ns	-0.23702	0.4582 ns	0.04041	0.9008 ns	Increaser IIc
Cymbopogon pospischilii	-0.27809	0.3815 ns	-0.09406	0.7712 ns	0.18983	0.5546 ns	-0.09452	0.7701 ns	Increaser Ia
Dactyloctenium giganteum	-0.28414	0.3708 ns	0.64153	0.0245 *	0.33202	0.2917 ns	0.14436	0.6544 ns	Increaser IIa
Digitaria eriantha	-0.09988	0.7574 ns	0.55062	0.0636 ns	0.46494	0.1278 ns	0.59725	0.0403 *	Increaser IIa
Enneapogon cenchroides	0.10783	0.7387 ns	-0.18057	0.5744 ns	0.67341	0.0164 *	0.02078	0.9489 ns	Increaser IIb
Enneapogon scoparius	-0.08238	0.7991 ns	-0.25332	0.4269 ns	0.78947	0.0023 **	-0.03804	0.9066 ns	Increaser IIb
Eragrostis biflora	-0.08648	0.7893 ns	-0.08368	0.7960 ns	-0.26380	0.4074 ns	-0.19965	0.5339 ns	Increaser IIc
Eragrostis chloromelas	-0.29243	0.3563 ns	0.77834	0.0029 **	0.27309	0.3904 ns	0.24650	0.4399 ns	Increaser IIa
Eragrostis gummiflua	-0.29243	0.3563 ns	-0.18788	0.5587 ns	0.16281	0.6132 ns	-0.11527	0.7213 ns	Increaser IIb
Eragrostis lehmanniana	-0.29080	0.3592 ns	0.23212	0.4697 ns	0.28449	0.3701 ns	-0.00408	0.9900 ns	Increaser IIb

…Continues

Table 5.14 continued…

Species	Decreaser (*Themeda triandra*)		Increaser IIa (*Heteropogon contortus*)		Increaser IIb (*Eragrostis rigidior*)		Increaser IIc (*Urochloa mosambicensis*)		Ecological group
	r	P	r	P	r	P	r	P	
Eragrostis pilosa	-0.04203	0.8968 ns	-0.29475	0.3524 ns	-0.67195	0.0167 *	-0.28031	0.3775 ns	Increaser IIc
Eragrostis rigidior	-0.10919	0.7355 ns	0.09923	0.7590 ns	1.00000	0.0000	-0.16945	0.5986 ns	Increaser IIb
Eragrostis superba	0.22991	0.4722 ns	0.49049	0.1055 ns	-0.27981	0.3784 ns	0.32078	0.3093 ns	Increaser IIa
Heteropogon contortus	0.22953	0.4730 ns	1.00000	0.0000	0.09923	0.7590 ns	0.38126	0.2214 ns	Increaser IIa
Melinis repens	0.27671	0.3839 ns	-0.19867	0.5359 ns	0.57537	0.0503 ns	-0.46163	0.1309 ns	Increaser IIb
Panicum coloratum	-0.49369	0.1028 ns	0.66154	0.0191 *	0.19506	0.5435 ns	0.15813	0.6235 ns	Increaser IIa
Panicum maximum	-0.34147	0.2773 ns	0.20827	0.5160 ns	-0.32055	0.3097 ns	0.48808	0.1074 ns	Increaser IIa
Pogonarthria squarrosa	0.23178	0.4685 ns	-0.04390	0.8922 ns	0.53941	0.0703 ns	-0.29731	0.3480 ns	Increaser IIb
Schmidtia pappophoroides	0.37209	0.2336 ns	-0.06311	0.8455 ns	0.64153	0.0245 *	-0.25148	0.4304 ns	Increaser IIb
Setaria pumila	0.26460	0.4059 ns	-0.21089	0.5106 ns	0.13875	0.6672 ns	-0.33914	0.2809 ns	Decreaser
Sporobolus ioclados	-0.07864	0.8081 ns	-0.06973	0.8295 ns	-0.11983	0.7107 ns	0.45669	0.1356 ns	Increaser IIb
Sporobolus nitens	0.13345	0.6793 ns	-0.06829	0.8330 ns	0.15250	0.6361 ns	0.50778	0.0919 ns	Increaser IIb
Sporobolus panicoides	-0.33519	0.2868 ns	-0.39464	0.2042 ns	-0.11659	0.7182 ns	-0.33387	0.2889 ns	Increaser IIb
Themeda triandra	1.00000	0.0000	0.22953	0.4730 ns	-0.10919	0.7355 ns	-0.12703	0.6940 ns	Decreaser
Tragus berteronianus	-0.17742	0.5812 ns	-0.14062	0.6629 ns	-0.39076	0.2091 ns	0.00976	0.9760 ns	Increaser IIc
Tragus racemosus	-0.07572	0.8151 ns	-0.04432	0.8912 ns	-0.07186	0.8244 ns	-0.02887	0.9290 ns	Increaser IIc
Trichoneura grandiglumis	0.22448	0.4830 ns	-0.13054	0.6859 ns	0.80202	0.0017 **	-0.27906	0.3797 ns	Increaser IIb
Urochloa mosambicensis	-0.12703	0.6940 ns	0.38126	0.2214 ns	-0.16945	0.5986 ns	1.00000	0.0000	Increaser IIc

Table 5.15: Cross tabulation of the correlations (r) (all seasons combined, n = 12) between the percentage composition of all the forb species as they occurred in the various experimental plots during the 2003/2004 and 2004/2005 seasons versus the typical grass species of each Decreaser and Increaser group. The statistical significance of the correlations is also indicated {* = significant ($P \leq 0.05$); ** = very significant ($P \leq 0.01$); *** = highly significant ($P \leq 0.001$); non-significant ($P > 0.05$)} as well as the ecological classification of each species.

Species	Decreaser (*Themeda triandra*)		Increaser IIa (*Heteropogon contortus*)		Increaser IIb (*Eragrostis rigidior*)		Increaser IIc (*Urochloa mosambicensis*)		Ecological group
	r	**P**	**r**	**P**	**r**	**P**	**r**	**P**	
Abutilon pycnodon	0.43260	0.1601 ns	0.20789	0.5167 ns	-0.05680	0.8608 ns	0.47766	0.1163 ns	Increaser IIc
Abutilon sonneratianum	0.61875	0.0320 *	-0.01853	0.9544 ns	-0.27254	0.3914 ns	-0.26206	0.4106 ns	Increaser IIc
Achyranthes aspera sicula	-0.39189	0.2077 ns	-0.07913	0.8069 ns	-0.27009	0.3959 ns	0.02020	0.9503 ns	Increaser IIc
Agathisanthemum bojeri	-0.17104	0.5951 ns	-0.52107	0.0824 ns	-0.01096	0.9730 ns	-0.51534	0.0864 ns	Increaser IIb
Albuca spp.	0.36700	0.2406 ns	-0.03918	0.9038 ns	-0.49138	0.1047 ns	-0.07546	0.8157 ns	Increaser IIa
Barleria galpinni	-0.03566	0.9124 ns	-0.18788	0.5587 ns	0.80878	0.0014 **	-0.24295	0.4467 ns	Increaser IIb
Bidens pilosa	-0.00055	0.9987 ns	-0.08164	0.8009 ns	-0.19789	0.5375 ns	-0.05218	0.8720 ns	Increaser IIc
Blepharis integrifolia	-0.43375	0.1589 ns	-0.23089	0.4703 ns	0.04284	0.8948 ns	0.53922	0.0704 ns	Increaser IIc
Blumea mollis	-0.22479	0.4824 ns	0.04306	0.8943 ns	-0.23097	0.4701 ns	-0.07418	0.8188 ns	Increaser IIc
Ceratotheca triloba	0.16277	0.6133 ns	0.14184	0.6601 ns	0.79164	0.0022 **	-0.14803	0.6461 ns	Increaser IIb
Chamaecrista mimosoides	0.32303	0.3058 ns	0.02890	0.9290 ns	0.21290	0.5065 ns	-0.19152	0.5510 ns	Increaser IIb
Chenopodium carinatum	0.30670	0.3322 ns	0.19861	0.5360 ns	-0.29410	0.3535 ns	0.18266	0.5699 ns	Increaser IIc
Commelina africana	-0.53430	0.0735 ns	0.20357	0.5257 ns	-0.03492	0.9142 ns	0.11037	0.7328 ns	Increaser IIa
Conyza podocephala	-0.42144	0.1724 ns	-0.20887	0.5147 ns	-0.27121	0.3938 ns	-0.22405	0.4839 ns	Increaser IIb
Corchorus asplenifolius	-0.11576	0.7202 ns	-0.21067	0.5110 ns	-0.11700	0.7173 ns	-0.04971	0.8781 ns	Increaser IIc
Crabbea angustifolia	-0.03566	0.9124 ns	-0.18788	0.5587 ns	0.80878	0.0014 **	-0.24295	0.4467 ns	Increaser IIb
Cucumis zeyheri	0.19227	0.5494 ns	-0.16732	0.6032 ns	-0.32629	0.3006 ns	-0.22110	0.4898 ns	Increaser IIb
Cyperus indecorus decurvatus	-0.03566	0.9124 ns	-0.18788	0.5587 ns	0.80878	0.0014 **	-0.24295	0.4467 ns	Increaser IIb

…Continues

Table 5.15 continued…

Species	Decreaser (*Themeda triandra*)		Increaser IIa (*Heteropogon contortus*)		Increaser IIb (*Eragrostis rigidior*)		Increaser IIc (*Urochloa mosambicensis*)		Ecological group
	r	P	r	P	r	P	r	P	
Cyperus rupestris	-0.53058	0.0759 ns	-0.40092	0.1965 ns	-0.09276	0.7743 ns	-0.33047	0.2941 ns	Increaser IIb
Dicoma spp.	0.30670	0.3322 ns	0.06978	0.8294 ns	-0.29410	0.3535 ns	0.03369	0.9172 ns	Increaser IIc
Evolvulus alsinoides	0.36835	0.2387 ns	-0.05816	0.8575 ns	-0.23594	0.4604 ns	-0.16745	0.6029 ns	Increaser IIc
Fuirena pubescens	-0.29243	0.3563 ns	-0.38112	0.2216 ns	-0.12079	0.7084 ns	-0.28551	0.3683 ns	Increaser IIb
Geigeria burkei	-0.29838	0.3462 ns	0.14088	0.6623 ns	0.42619	0.1671 ns	0.01085	0.9733 ns	Increaser IIb
Gossypium herbaceum	0.46706	0.1258 ns	-0.02244	0.9448 ns	0.05122	0.8744 ns	-0.19025	0.5537 ns	Increaser IIb
Helichrysum dregeanum	0.25397	0.4257 ns	-0.06933	0.8305 ns	0.81839	0.0011 **	-0.26564	0.4040 ns	Increaser IIb
Hemizygia canescens	-0.25373	0.4262 ns	0.00455	0.9888 ns	-0.05004	0.8773 ns	-0.18625	0.5622 ns	Increaser IIa
Hermannia glanduligera	-0.14888	0.6442 ns	-0.42166	0.1722 ns	-0.33591	0.2858 ns	-0.39726	0.2010 ns	Increaser IIb
Hermannia spp.	0.47788	0.1161 ns	0.06978	0.8294 ns	0.14705	0.6483 ns	-0.11527	0.7213 ns	Increaser IIb
Hermbstaedtia linearis	-0.29243	0.3563 ns	-0.38112	0.2216 ns	-0.12079	0.7084 ns	-0.28551	0.3683 ns	Increaser IIb
Hermbstaedtia odorata	-0.29243	0.3563 ns	0.00537	0.9868 ns	-0.23108	0.4699 ns	-0.07271	0.8223 ns	Increaser IIc
Hibiscus cannabinus	-0.29243	0.3563 ns	0.00537	0.9868 ns	-0.23108	0.4699 ns	-0.07271	0.8223 ns	Increaser IIc
Hibiscus engleri	0.23893	0.4545 ns	-0.02091	0.9486 ns	-0.10331	0.7494 ns	-0.10016	0.7568 ns	Increaser IIc
Hypoestes spp.	-0.29243	0.3563 ns	-0.12346	0.7023 ns	-0.10504	0.7453 ns	0.84236	0.0006***	Increaser IIc
Indigofera holubi	-0.29243	0.3563 ns	0.00537	0.9868 ns	-0.23108	0.4699 ns	-0.07271	0.8223 ns	Increaser IIc
Ipomoea obscura obscura	0.33745	0.2834 ns	0.49810	0.0933 ns	-0.49488	0.1019 ns	0.22296	0.4861 ns	Increaser IIc
Jatropha zeyheri	0.47788	0.1161 ns	0.06978	0.8294 ns	0.14705	0.6483 ns	-0.11527	0.7213 ns	Increaser IIb
Justicia flava	0.06971	0.8296 ns	0.16416	0.6102 ns	-0.71156	0.0095 **	0.42548	0.1679 ns	Increaser IIc
Justicia protracta	0.30007	0.3433 ns	0.04543	0.8885 ns	0.28501	0.3692 ns	0.27636	0.3846 ns	Increaser IIc

…Continues

Table 5.15 continued…

Species	Decreaser (*Themeda triandra*)		Increaser IIa (*Heteropogon contortus*)		Increaser IIb (*Eragrostis rigidior*)		Increaser IIc (*Urochloa mosambicensis*)		Ecological group
	r	**P**	**r**	**P**	**r**	**P**	**r**	**P**	
Kalanchoe lanceolata	-0.50651	0.0929 ns	-0.38120	0.2215 ns	-0.19102	0.5520 ns	-0.32252	0.3066 ns	Increaser IIb
Kalanchoe paniculata	-0.29243	0.3563 ns	0.00537	0.9868 ns	-0.23108	0.4699 ns	-0.07271	0.8223 ns	Increaser IIc
Kohautia virgata	0.14906	0.6438 ns	0.54596	0.0663 ns	-0.14634	0.6499 ns	0.28414	0.3708 ns	Increaser IIa
Kyphocarpa angustifolia	0.40412	0.1926 ns	-0.12007	0.7101 ns	-0.77441	0.0031 **	0.12701	0.6941 ns	Increaser IIc
Linum thunbergii	-0.14857	0.6449 ns	-0.13065	0.6857 ns	0.07419	0.8188 ns	-0.36436	0.2443 ns	Increaser IIb
Melhania prostrata	0.30989	0.3270 ns	0.33698	0.2841 ns	0.57799	0.0490 *	-0.09342	0.7728 ns	Increaser IIb
Melolobium spp.	0.24322	0.4462 ns	0.11367	0.7250 ns	-0.35817	0.2530 ns	0.76106	0.0040 **	Increaser IIc
Monsonia burkeana	-0.19810	0.5371 ns	-0.44726	0.1449 ns	-0.34759	0.2683 ns	-0.44957	0.1426 ns	Increaser IIb
Nemesia albiflora	-0.19650	0.5405 ns	0.05787	0.8582 ns	-0.22961	0.4728 ns	-0.07435	0.8184 ns	Increaser IIc
Osteospermum muricatum	-0.29823	0.3464 ns	-0.42849	0.1646 ns	0.10869	0.7367 ns	-0.34978	0.2651 ns	Increaser IIb
Oxalis depressa	-0.43375	0.1589 ns	-0.27867	0.3804 ns	-0.26096	0.4127 ns	-0.26567	0.4040 ns	Increaser IIb
Oxygonum sinuatum	0.00066	0.9984 ns	-0.26931	0.3973 ns	0.05197	0.8726 ns	-0.53123	0.0755 ns	Increaser IIb
Pavonia burchellii	0.46132	0.1312 ns	0.17141	0.5943 ns	-0.46290	0.1297 ns	0.42576	0.1676 ns	Increaser IIc
Pavonia transvaalensis	-0.29243	0.3563 ns	-0.38112	0.2216 ns	-0.12079	0.7084 ns	-0.28551	0.3683 ns	Increaser IIb
Portulaca quadrifida	-0.29243	0.3563 ns	-0.18788	0.5587 ns	0.16281	0.6132 ns	-0.11527	0.7213 ns	Increaser IIb
Polygala sphenoptera	0.05465	0.8660 ns	0.00316	0.9922 ns	-0.44418	0.1480 ns	-0.07630	0.8137 ns	Increaser IIc
Rhynchosia caribaea	0.47788	0.1161 ns	0.26303	0.4088 ns	0.00525	0.9871 ns	-0.00887	0.9782 ns	Increaser IIa
Rhynchosia totta	0.01425	0.9649 ns	-0.24326	0.4461 ns	0.11983	0.7107 ns	-0.30300	0.3384 ns	Increaser IIb
Schkuhria pinnata	-0.24284	0.4469 ns	-0.11089	0.7315 ns	-0.48842	0.1072 ns	-0.33151	0.2925 ns	Increaser IIc
Senecio latifolius	-0.27567	0.3858 ns	0.41468	0.1801 ns	0.35187	0.2620 ns	0.22800	0.4760 ns	Increaser IIc

…Continues

Table 5.15 continued…

Species	Decreaser (*Themeda triandra*)		Increaser IIa (*Heteropogon contortus*)		Increaser IIb (*Eragrostis rigidior*)		Increaser IIc (*Urochloa mosambicensis*)		Ecological group
	r	P	r	P	r	P	r	P	
Senna italica arachoides	-0.06244	0.8471 ns	-0.20364	0.5255 ns	-0.16476	0.6089 ns	-0.23029	0.4715 ns	Increaser IIc
Solanum panduriforme	0.68868	0.0133 *	0.37065	0.2356 ns	-0.42734	0.1659 ns	0.26421	0.4066 ns	Increaser IIc
Solanum rigescens	0.20585	0.5210 ns	0.07778	0.8101 ns	-0.31541	0.3180 ns	0.16841	0.6008 ns	Increaser IIc
Striga elegans	-0.36876	0.2382 ns	0.09251	0.7749 ns	0.11565	0.7204 ns	0.29543	0.3512 ns	Increaser IIc
Tephrosia capensis	-0.17151	0.5941 ns	-0.16900	0.5995 ns	0.19789	0.5376 ns	-0.14287	0.6578 ns	Increaser IIb
Tephrosia longipes	0.47788	0.1161 ns	0.26303	0.4088 ns	0.00525	0.9871 ns	-0.00887	0.9782 ns	Increaser IIa
Tephrosia lupinifolia	0.28240	0.3738 ns	-0.00452	0.9889 ns	-0.50547	0.0937 ns	-0.10233	0.7516 ns	Increaser IIc
Vahlia capensis	-0.11529	0.7213 ns	-0.33290	0.2904 ns	-0.11579	0.7201 ns	-0.31794	0.3139 ns	Increaser IIb
Vernonia poskeana	-0.29243	0.3563 ns	-0.38112	0.2216 ns	-0.12079	0.7084 ns	-0.28551	0.3683 ns	Increaser IIb
Zehneria marlothii	0.41726	0.1772 ns	0.22136	0.4893 ns	-0.22161	0.4888 ns	0.45477	0.1374 ns	Increaser IIc
Zinnia peruviana	0.30670	0.3322 ns	0.19861	0.5360 ns	-0.29410	0.3535 ns	0.18266	0.5699 ns	Increaser IIc
Zornia milneana	0.01847	0.9546 ns	-0.48949	0.1063 ns	-0.44513	0.1470 ns	-0.60551	0.0369 *	Increaser IIb

5.3.4.2 *Veld condition score*

The veld condition score of the experimental plots are given in Figure 5.1. The percentage contribution of each ecological group to the veld condition scores of each experimental plot is presented in Table 5.16. The veld condition score of the control plots decreased from the 2003/2004 to the 2004/2005 season, especially in the Ae-Dc Control plot. Contrarily, the veld condition score of all the treatment plots increased from the first to the second season.

The Am-Gf Treatment plot had a higher veld condition score than the Am-Gf Control plot, during both seasons. The Ca-Gf Treatment plot had a lower veld condition score than the Ca-Gf Control plot during the 2003/2004 season, but it had a higher veld condition score than the control plot during the 2004/2005 season. The Ae-Dc Treatment and Control plot had the same veld condition score during the first season, but the treatment plot had a much higher veld condition score during the second season in comparison to the control plot. Overall, the Ca-Gf plots had the highest veld condition score, followed by the Ae-Dc plots and then the Am-Gf plots.

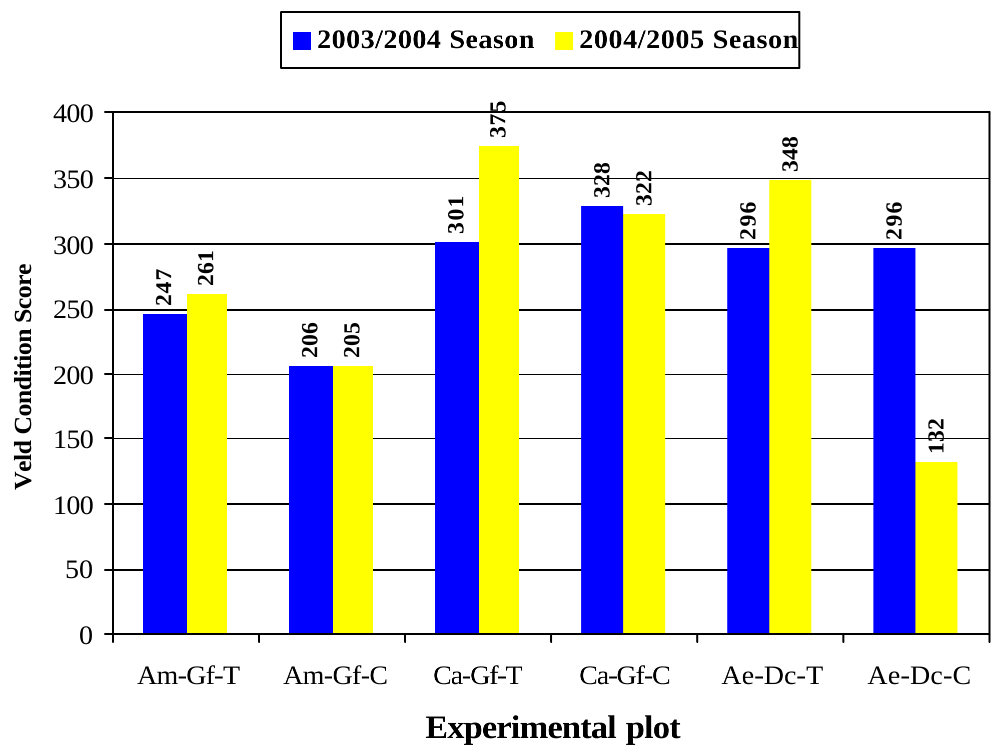


Figure 5.1: The veld condition scores of each experimental plot during the 2003/2004 and 2004/2005 seasons.

Table 5.16: The percentage (%) contribution of the Decreaser and different Increaser ecological groups within each experimental plot during the 2003/2004 and 2004/2005 seasons. The percentage (%) contribution of the bare patches was excluded from the table.

Experimental plot	**Decreasers**		**Increaser Ia**		**Increaser IIa**		**Increaser IIb**		**Increaser IIc**	
	2003/2004	**2004/2005**	**2003/2004**	**2004/2005**	**2003/2004**	**2004/2005**	**2003/2004**	**2004/2005**	**2003/2004**	**2004/2005**
Acacia mellifera – *Grewia flava* Treatment	6.00	2.25	0.00	0.25	14.50	11.75	6.50	26.00	59.75	50.75
Acacia mellifera – *Grewia flava* Control	3.75	0.00	0.00	0.00	11.25	10.50	7.50	17.75	59.75	61.00
Combretum apiculatum – *Grewia flava* Treatment	1.50	4.50	0.00	0.00	6.25	9.25	53.75	60.75	27.25	22.50
Combretum apiculatum – *Grewia flava* Control	1.75	1.00	0.00	0.00	4.00	6.25	65.00	62.75	22.50	16.75
Acacia erubescens – *Dichrostachys cinerea* Treatment	0.00	0.50	0.00	0.25	15.75	20.00	36.00	41.75	41.25	34.00
Acacia erubescens – *Dichrostachys cinerea* Control	0.00	1.50	0.00	2.75	9.75	6.25	48.00	50.00	35.25	33.50

From Table 5.16 it is clear that during the 2003/2004 season the Decreaser species were most abundant in the Am-Gf plots, followed by the Ca-Gf plots. No Decreaser species were recorded in the Ae-Dc plots. During the 2004/2005 season, the Decreaser group were most abundant in the Ca-Gf plots, followed by the Am-Gf plots, although no Decreaser species were recorded in the control plot, and lastly the Ae-Dc plots. Overall, this ecological group had a higher abundance in the treatment plots. No Increaser Ia species were recorded during the first season and during the second season they were only present in the Am-Gf Treatment, Ae-Dc Treatment and the Ae-Dc Control plots, but their occurrence was very low.

The Increaser IIa species was relatively abundant in all the experimental plots during both seasons. During the 2003/2004 season, the Increaser IIa species were most abundant in the Am-Gf plots, followed by the Ae-Dc plots and lastly the Ca-Gf plots. During the 2004/2005 season, the Increaser IIa species were most abundant in the Ae-Dc plots, followed by the Am-Gf plots and the Ca-Gf plots. The abundance of Increaser IIa species increased from the first to the second season in the Ca-Gf plots and the Ae-Dc Treatment plot, while they decreased from the first to the second season in the Am-Gf plots and the Ae-Dc Control plot. This ecological group was most abundant in the treatment plots.

The Increaser IIb group was more abundant than any other ecological group in the different experimental plots. During the first season the experimental plots that had the highest abundance of this ecological group was the Ca-Gf plots followed by the Ae-Dc plots and lastly the Am-Gf plots. The same result was found during the second season. The occurrence of this ecological group increased in all the experimental plots from the first to the second season, except for the Ca-Gf Control plot, but the decrease was not substantial. Overall, this ecological group was most abundant in the control plots.

Table 5.16 shows that the percentage contribution of the Increaser IIc group was the highest in the Am-Gf plots during the first season, followed by the Ae-Dc plots and lastly the Ca-Gf plots. The same result was found during the second season. The Increaser IIc group decreased in all the experimental plots from the first to the second season, except for the Am-Gf Control plot. Overall, this ecological group was most abundant in the treatment plots.

The treatment plots (compared to the control plots) had a higher abundance of the Decreaser group, except for the Ae-Dc plots. The Am-Gf Treatment plot had a higher abundance of Increaser Ia species, while the Ca-Gf plots had no Increaser Ia species and the Ae-Dc Treatment plot had a lower abundance of the Increaser Ia species than the Ae-Dc Control plot.

All the treatment plots had a higher abundance of Increaser IIa species than their corresponding control plots. Regarding the Increaser IIb group, the treatment plots had a lower abundance of these species than the control plots, except for the Am-Gf plots, where the Treatment had a higher abundance of these species than the control plot. All the Treatment plots had a higher abundance of the Increaser IIc species than the control plots, except for the Am-Gf plots, where the treatment had a lower abundance of these species.

5.4 DISCUSSION

The most important factors influencing the growth and sustainability of the herbaceous layer in semi-arid savanna vegetation types are primarily soil water, and secondary soil nutrients and herbivory (Anderson & Walker, 1974; Harrington & Ross, 1974; Boultwood & Rodel, 1981; Edroma, 1981; Grossman & Grunow, 1981; Dye & Spear, 1982; Stuart-Hill & Mentis, 1982; Brocket, 1983; Van Vegten, 1983; Edroma, 1984; Bredenkamp, 1985; Du Toit & Aucamp, 1985; Knoop & Walker, 1985; Stuart-Hill & Tainton, 1988; Moughalu & Isichei, 1991; Peel *et al.*, 1991; O'Connor, 1992; Teague & Smit, 1992; Smit & Swart, 1994; Tainton & Hardy, 1999; Oesterheld & McNaughton, 2000; Snyman, 2000; Wiegand *et al.*, 2004).

Liebig's law of the minimum states that in a stable ecosystem the factor present in critical quantities will determine the functioning of the ecosystem as a whole, regardless of the other factors optimally present. According to this, it was expected that competition from the woody layer would be the most limiting factor to the herbaceous layer in Marakele Park, due to its influence on soil water availability. Thus, after the tree thinning treatments were applied, it was expected that the competition for soil water between the woody and herbaceous layer would decline. More soil water would be available to the herbaceous plants, resulting in increased establishment and growth of herbaceous plants and fewer bare patches. However, the results of this study were variable and did not entirely reflect these expectations.

The total percentage bare patches, based on the first point-observation readings (all herbaceous species), decreased from the 2003/2004 season to the 2004/2005 season in all the experimental plots, except for the Ca-Gf Control plot. This decrease in percentage bare patches was due to the higher herbaceous species abundance and cover recorded during the second season. The decrease in the percentage bare patches of the Am-Gf plots can primarily be attributed to the higher percentage of forbs, pioneer grass species, e.g. *A. congesta congesta*, *A. congesta barbicollis* and subclimax species like *Eragrostis rigidior* that was recorded at the end of the 2004/2005 season.

In the Ca-Gf Treatment plot, the decrease can be attributed to forbs and annual pioneer grass species such as *Setaria pumila* and subclimax grass species such as *Enneapogon cenchroides* that can successfully colonise bare patches (Van Oudtshoorn, 1999). In the Ae-Dc plots, the decrease was mostly due to forbs and annual pioneer grasses such as *Aristida* species and *Chloris virgata*. The fact that forbs and pioneer grasses were the most prominent species recorded in association with a decreased percentage of bare patches, is supported by the negative correlations found between forbs and annual grasses with ETTE ha^{-1} (Table 5.13). These negative correlations indicate that annual grasses and forbs are the main colonisers of bare soil. The same result was also found by Smit & Rethman (1999) in Mopani veld.

The fact that all the treatment plots had a lower percentage bare patches (first point-observation readings) during the second season compared to the control plots, can also be attributed to a higher herbaceous species cover that is associated with a decreased tree density. This observation is supported by the positive correlation that was found between the percentage bare patches and the ETTE ha^{-1} (Table 5.13). The positive correlation indicates that as the tree density increases, so does the percentage bare patches. This is most likely the result of the expected severe competition interaction exerted by the woody species on the herbaceous species for soil water and nutrients. The fact that the relations between the percentage herbaceous species composition (all herbaceous species combined), as well as the perennial grass species only, and the ETTE ha^{-1} were negative during both seasons (Table 5.13) also indicates that the herbaceous species abundance would decrease as tree density increases. Similar results were reported by many scientists (Kennard & Walker, 1973; Dye & Spear, 1982; Knoop & Walker, 1985; Moore & Odendaal, 1987; Obot, 1988; Smit & Rethman, 1998a). It is thus clear that established woody species in semi-arid environments can reduce or even prevent the establishment of herbaceous plants by virtue of their superior adaptation to water limited ecosystems.

The changes in the veld condition score (Figure 5.1) of the different species dominated plots are also dependent on the dominant established woody species of each experimental plot. Different herbaceous species are associated with different tree species and other ecological factors such as soil type and temperature, also play an important role. Both the physical condition of soil and the microclimate directly influence productivity and are closely related to rangeland condition (O'Connor & Bredenkamp, 1997). *Combretum apiculatum* is associated with shallow soils (see Chapter 7), meaning that the herbaceous species occurring in these soils will vary from the herbaceous species that are adapted to grow in deeper soils in which the *Acacia* species occur.

The percentage bare patches, based on the second point-observation readings (perennial grasses only), increased in all the experimental plots from the first to the second season, except for the Am-Gf Control plot. The increase of the bare patch percentage can be an indication of veld degradation. Bare patches are probably the most common symptom of degraded veld. In time, should this condition persist, this is usually accompanied by a loss of topsoil and the formation of hard crusts, which cause water runoff to increase (Van Oudtshoorn, 1999). As mentioned, it was expected that the percentage bare patches would decrease due to the establishment of herbaceous plants after implementation of tree thinning. The fact that this did not happen in the treated experimental plots (based on the second point-observation readings) is an indication that competition from the woody layer still plays an important role. Another consideration is the possibility that the amount of woody plants that were removed was insufficient to make a considerable difference in the competition interaction of the woody plants with the herbaceous layer. The ETTE ha^{-1} values of the treatment plots (see section 4.3.2) were still high partly due to re-encroachment by woody plants. It is thus important to take the intensity of tree thinning into account to determine whether it will be effective enough to decrease the competition between woody and herbaceous plants to such an extent that it would favour herbaceous plant yield.

The Ca-Gf plots had a lower quantity of ETTE ha^{-1} than the other species dominated plots, resulting in a lower competition gradient between the woody and herbaceous species for nutrients and soil water and this can be the reason why the Ca-Gf plots had a better veld condition score than the other plots. This is also a possible reason for the low veld condition scores of the Am-Gf plots, which had very high ETTE ha^{-1} values. The fact that the Am-Gf plots had a higher percentage bare patches for both point-observation readings, also contribute to the lower veld condition score of these plots. The higher number of trees in the control plots might also be a possible reason why the veld condition score in the control plots was lower than in the treatment plots. Another important aspect of trees, which also contribute to veld condition, is the influence that subhabitats which is created by the tree canopies, have on herbaceous species. Tree canopies provide a favourable, nutrient rich environment in which herbaceous species can flourish (see Chapter 6).

The high grazing pressure present in the study area is another possible reason for the increase in the percentage bare patches and the low veld condition scores of the experimental plots. The fact that the veld condition scores of the control plots decreased from the 2003/2004 season to the 2004/2005 season in spite of high rainfall during the second season, clearly indicates that other factors, of which herbivory is the most important, are also influencing the veld condition.

The suppressive effect that herbivore species can have on the herbaceous layer is well documented (Edroma, 1981; Grossman *et al.*, 1981; Stuart-Hill & Mentis, 1982; Edroma, 1984; Du Toit & Aucamp, 1985; Stuart-Hill & Tainton, 1988; Westoby *et al.*, 1989; Peel *et al.*, 1991; Smit & Rethman, 1992; O'Connor & Roux, 1995; Oesterheld & McNaughton, 2000; Gedda, 2003). Abule *et al.* (2005) found that heavy grazing can even have a strong overriding effect on the positive influences of woody plants (the effect of subhabitats) and that the grass species associated with the heavily grazed areas are mostly annuals and less desirable species. This was also observed in most of the experimental plots of Marakele Park, explaining the low veld condition scores of the experimental plots. It is thus very important to determine the appropriate stocking rate of the study area to prevent the over-utilisation of herbaceous plant species and thus to improve the veld condition of Marakele Park.

As a plant community is never static, the concept of equilibrium must be considered. The vegetation composition of a rangeland ecosystem over a period of time indicates the ability of the plant community to remain relatively stable in a specific area. It is thus important to know if the succession theory is valid for an area (equilibrium or non-equilibrium) in order to determine which factors are influencing the development of the vegetation.

The terms equilibrium and non-equilibrium as used in rangelands, are strongly debated by scientists. The central aspect of this debate is a definition of the degree to which climate or consumers (herbivores) influence vegetation. One view is that consumers reach densities that degrade environments from a previous condition of equilibrium and the other view is that the dynamics of pastoral systems are non-equilibrial and primarily dictated by variability in rainfall (Ellis & Swift, 1988). Illius and O'Connor (1999) argued that the view that herbivory has little impact on climatically variable systems, is unjustified. They proposed an alternative model in which it is assumed that despite the apparent lack of an equilibrium, animal numbers are regulated in a density-dependent manner by the limited forage available in key resource areas utilised during the dry season. Their model asserts that strong equilibrial forces exist over a limited part of the system, with the animal population virtually uncoupled from resources elsewhere in the system. Higgins *et al.* (2000) suggested a non-equilibrium mechanism of coexistence for savanna ecosystems. According to their model, grasses and trees coexist for a wide range of environmental conditions and exhibit long periods of slow decline in adult tree numbers, interspersed with relative infrequent recruitment events. Recruitment is controlled by rainfall, which limits seedling establishment, and fire, which prevents recruitment into adult size classes.

From literature it would thus appear that ecosystems can display both equilibrial and non-equilibrial trends. In this regard the degree of aridity is important, where arid ecosystems are less stable (non-equilibrial), while mesic ecosystems are often more stable (equilibrial) (Smit, 2004). Since the study area is located in a semi-arid environment, it implies that this area would display the characteristics of a non-equilibrial system. However, the fact that forbs and pioneer grass species colonised the bare patched areas after tree thinning, supports the succession theory (an equilibrial system). In this regard the higher rainfall received during the 2004/2005 season would definitely also have played a role. The high rainfall would have masked the competition effect of the woody plants and this is supported by the fact that the percentage bare patches, based on the second point-observation readings (perennial grasses), increased in all, but one, of the experimental plots. On the contrary, the extreme change in the herbaceous species composition, based on frequency of occurrence and yield (also see Chapter 6), indicates that the vegetation of the study area also displays non-equilibrial trends.

Based on the first point-observation readings (all herbaceous species), all the experimental plots were mostly dominated by forb and grass species that are associated with disturbed areas. The Am-Gf plots (Tables 5.1 and 5.2) were characterised by weedy forb species, for example, *Senecio latifolius*, an indigenous toxic weed that occurs on road verges and in disturbed areas (Bromilow, 2001). Most of the grasses were pioneer, e.g. *Aristida* species, and subclimax species, e.g. *Bothriochloa* species, that are associated with disturbed areas such as overgrazed, trampled and/or eroded veld. The forbs that occurred in the Ca-Gf plots (Tables 5.5 and 5.6) varied from spreading annual to bushy perennial herb species that are associated with bushveld and open woodland (Fabian & Germishuizen, 1997). The most abundant grass species, e.g. *Aristida* species, *M. repens* and *E. rigidior*, that were present in the Ca-Gf plots, are also associated with overgrazed and eroded veld. *Melinis repens* can even sometimes be classified as a weed (Van Oudtshoorn, 1999). The Ae-Dc plots (Tables 5.9 and 5.10) were characterised by forb species which usually occur in marshy areas, e.g. the densely tufted perennial *Cyperus rupestris* (Fabian & Germishuizen, 1997). The latter species occurred predominantly in areas where water accumulated after heavy rains and are not normally found in the study area (see Chapter 3). The most abundant grasses in the Ae-Dc plots, were mostly grasses that colonise bare patches and which occur in overgrazed and trampled veld, for example *Chloris virgata*, *E. rigidior* and *U. mosambicensis*.

When the herbaceous species composition of the Am-Gf (Tables 5.3 and 5.4), Ca-Gf (Tables 5.7 and 5.8) and Ae-Dc (Tables 5.11 and 5.12) plots are compared, using the second point-observation readings, it is apparent that the perennial grass species of all these plots were predominantly tufted subclimax species, followed by climax grass species. Most of these perennial grasses are also associated with disturbed areas (Van Oudtshoorn, 1999) and the grazing value of the perennial grasses ranged from low, e.g *B. radicans*, in most cases, to high, e.g. *P. maximum*.

It is thus clear that heavy grazing and trampling, as determinant, played a very important role in the study area. Heavy grazing leads to the compaction of the soil (Bothma, 2002). This lowers the soil water content due to runoff and causes difficulties for seedlings of many herbaceous species to emerge from the soil. The increase in percentage bare patches (based on the first point-observation readings) in the Ca-Gf Control plot, which did not occur in the other experimental plots, can be attributed to the presence of large herbivore populations, especially impala and elephant frequently sited in this area, which increased grazing and thus trampling levels (Figure 5.2). Since no thinning treatments were used in this experimental plot, it also indicates that the veld is in a state of degradation, despite the high rainfall received during the second season. The fact that the Ca-Gf Control plot is characterised by shallow, gravelly soil (see Chapter 7) may have contributed to the increased percentage of bare patches. Not many herbaceous plant species can successfully establish in shallow soils, especially not if covered by gravel and rocks that can impede plant emergence from the soil. Shallow soils are normally characterised by a low soil nutrient content, which plays a very important role in determining herbaceous plant yield. However, the fact that the percentage bare patches (based on the second point-observation readings) increased in most of the experimental plots, indicates that herbivory is a very important determinant of the herbaceous layer in the study area. It is thus clear that both rainfall and herbivory play an important role in determining the vegetation development of Marakele Park and this indicates that this ecosystem is displaying both equilibrial and non-equilibrial trends.

All the experimental plots, with the exception of the Ae-Dc Treatment plot, had a higher number of herbaceous species during the 2004/2005 season compared to the 2003/2004 season. Large herbivore populations, especially plains zebra, blue wildebeest and elephants were frequently sited in the Ae-Dc plots. This shows that the objective to increase wildlife visibility for eco-tourism through implementation of the Barko Tractor was accomplished, but if the treated areas are not protected against severe utilisation until a stable herbaceous layer is formed, or if herbivore numbers are not managed, the other objectives aimed at increasing herbaceous species diversity and grazing capacity, will not be achieved.

Figure 5.2: Trampling levels as determinant of heavy grazing by herbivores found on the soil of the *Combretum apiculatum – Grewia flava* Control plot.

The treatment plots had more forb species than the control plots during both seasons, except for the Ae-Dc plots during the second season, but the difference was not large. Forbs are associated with disturbed areas and support the fact that herbivory plays an important role in the study area. The initial disturbance caused by the Barko Tractor could also have been a contributing factor. The impact that the weight of the Barko Tractor had on the soil, could thus, in part, explain why the treatment plots in particular were characterised by plant species that usually occur in disturbed areas and why the percentage bare patches were so high in the treatment plots during the 2003/2004 season (Figure 5.3).

Figure 5.3: A demonstration of how the Barko Tractor caused soil disturbance during the tree thinning operations (Van Staden, 2002b).

It is obvious that a large percentage of the herbaceous species were generally of low grazing value and most of them are normally associated with veld in poor condition and in a state of degradation. This is further accentuated by the fact that desirable, climax grass species that usually occur in veld in good condition, e.g. *Brachiaria nigropedata* and *P. maximum*, were absent during the second season in many of the experimental plots in which they occurred in the first season.

The unselective manner in which the Barko Tractor cuts trees might even have intensified these results due to the loss of desirable trees and palatable grasses, like *P. maximum*, which are associated with mature trees. The association of *Panicum maximum* with tree canopies is well documented in southern African savannas (Bosch & Van Wyk, 1970; Kennard & Walker, 1973; Belsky, 1987; Smit & Rethman, 1992; Smit & Van Romburgh, 1993; Smit & Swart, 1994; Smit, 2005a). Removal of trees will thus affect the grasses associated with their canopies, notably *P. maximum* (Smit & Swart, 1994; Smit, 2005a). Louw & Van der Merwe (1973) reported a rapid increase of *Cymbopogon pospischilii* (Synonym: *Cymbopogon plurinodis*), *Heteropogon contortus* and *Themeda triandra* at the expense of *P. maximum* on totally cleared plots in savanna comprising red clay soils. This resulted in a reduction of the palatability of the herbaceous layer. It was concluded that selective thinning of woody plants was more desirable since some of the 'sweet' grasses were retained, while the dry matter production was significantly increased.

Mature trees provide subhabitats that are favourable for the growth of many herbaceous species. The positive correlation between the perennial grass species and the ETTE ha^{-1} during the 2003/2004 season might be due to the contribution of perennial herbaceous species that are associated with tree canopies, e.g. *P. maximum*, while the negative correlation that was found during the 2004/2005 season can be attributed to the high grazing pressure that was present in the experimental plots. Certain perennial grass species such as *P. maximum* will increase with an increasing tree density, until it reaches a critical point of competition between woody and herbaceous plant species for soil water and nutrients, whereafter they will decline again.

It is thus clear that areas that are dominated by different plant species react differently to tree thinning treatments. However, it is important to keep in mind that the different species dominated experimental plots do not necessarily have the same potential in terms of herbaceous yield and the utilisation of ecological elements such as rainfall. The important effect of rainfall and veld condition on the production capacity and water-use efficiency of veld is well documented (Danckwerts, 1982; Booysen, 1983; Van den Berg, 1983; Fouché, 1984; Fourie *et al.*, 1985; Snyman, 1988; Snyman & Fouché, 1993; Snyman, 1999). Veld varying in condition reacts differently to different amounts of rainfall. In terms of herbaceous yield, veld in poor condition resulted in inefficient use of available water, leading to apparent droughts (Snyman & Fouché, 1991) even during periods of reasonable rainfall. The smaller response of veld in a poor rather than good condition may largely be attributed to higher surface runoff due to the low basal cover and poor water-use efficiency of the plants dominating this veld (Snyman & Fouché, 1993). Snyman (1997a) found that basal cover decreased linearly with deterioration in veld condition. This is in contrast to high rainfall areas (Danckwerts & Stuart-Hill, 1988). The dense plant cover of veld in good condition, not only provides a situation in which water runoff and soil loss rates are lower than those of veld in poor condition, but also leads to efficient water use, high production and relative sustainable soil organic matter.

Another important factor that should be taken into consideration is the history of the study area, e.g. application of previous tree thinning treatments, the implementation of other conservation methods such as sowing of grass species, etc. The history of an area plays a vital role in determining the current dominant vegetative state in that specific area.

5.5 CONCLUSIONS

An important objective and one of the motivations for the initial tree thinning treatments were to increase plant species diversity to improve the biodiversity of Marakele Park.

From the results of this investigation, it is clear that the number of herbaceous species in the experimental plots, especially the treated plots, did indeed increase. However, the herbaceous species that increased the most were forbs and annual grass species that are associated with overgrazed and disturbed veld. The high percentage bare patches that were found, especially in the control plots, are also an indication that the veld is not stable and still in a poor condition.

The fact that probably not enough woody plants were removed during the tree thinning treatments and since no follow-up treatments were used after the initial thinning operation, which leads to the regrowth and re-encroachment of woody species, are the reasons why the herbaceous layer is not in a good condition and in a state of deterioration. The competition of the woody plants for soil water and nutrients is most likely still too high to allow the herbaceous layer to improve.

It is clear that both rainfall and herbivory (associated with high levels of trampling) play a very important role in determining the condition of the herbaceous layer. The current herbivore populations of Marakele Park are too large, especially those of high density, selective short grass grazers. The severe impact of the current herbivore regime was demonstrated by the fact that not even the above average rainfall recorded during the 2003/2004 season resulted in any substantial improvement of the poor veld condition. If the high grazing pressure is maintained, it would effectively neutralise the anticipated positive effect of the reduced competition from the woody layer. The nutrient status of the soil can also be an important determinant of the composition of the herbaceous layer, but its importance will only be relevant under conditions of adequate rainfall and moderate grazing. These results indicate that the ecosystem of Marakele Park display both equilibrial and non-equilibrial (disequilibrium) trends.

The unselective manner in which the Barko Tractor cuts trees, proved to be detrimental to the herbaceous layer. The unselective thinning removed large trees that create subhabitats, which is favoured by some highly desirable climax grass species, e.g. *P. maximum*. The reduction of these suitable subhabitats after tree thinning, resulted in the disappearance of these climax species which are then replaced by herbaceous species which offer less protection to the soil and which usually have a lower grazing value.

It is obvious that the herbaceous layer of Marakele Park is in a poor ecological condition and there are indications that it is deteriorating further. It is thus very important that immediate action, such as the reduction of short grass grazer numbers and the removal of higher tree quantities, be taken to prevent further deterioration of the herbaceous layer and to reverse this process in order to meet the conservation objectives of the park.

CHAPTER 6

THE INFLUENCE OF THE TREE THINNING TREATMENTS ON THE HERBACEOUS DRY MATTER YIELD

6.1 INTRODUCTION

In extensive semi-arid savannas, the productivity of herbaceous plants, notably Poaceae (grasses) that are the major food source of grazers, is of primary importance. The suppressive effect of an increase in tree density on the yield of the herbaceous layer and, consequently grazing capacity, is often the main reason why tree thinning/clearing is considered (Richter, 1991; Smit, 1994). Results of tree thinning may, however, differ between veld types (Donaldson, 1978; Scholes, 1987; Smit, 2003b) and are complicated by the existence of not only negative tree-grass interactions, but also positive interactions. The effect of these interactions is greatly determined by environmental factors, especially rainfall (Dye & Spear, 1982; Harrington & Johns, 1990).

Negative competition interactions between woody plants and herbaceous plants, mainly involving available soil water as the primary determinant of dry matter yield (Dye & Spear, 1982), have been documented in numerous studies (Scifres *et al.*, 1982; Walker *et al.*, 1986; Scholes, 1987; Winter *et al.*, 1989; Harrington & Johns, 1990; Scanlan & Burrows, 1990; Bozzo *et al.*, 1992; Rigueiro-Rodríguez *et al.*, 2005; Smit, 2005b). It is known that grass yield usually increases if woody plants are thinned or removed in areas that are encroached (Grossman *et al.*, 1980; Dye & Spear, 1982; Moore *et al.*, 1985; Pieterse & Grunow, 1985; Stuart-Hill & Tainton, 1988; Richter, 1991; Smit, 1994; Richter *et al.*, 2001).

The thinned area will contain newly formed, nutrient rich herbaceous leaf material, which will attract herbivores (Smit *et al.*, 1999). If the herbaceous species are thus not protected from excessive utilisation by these herbivores the plants will not be able to increase in density and biomass. Marakele Park is currently stocked with large populations of herbivores, especially white rhinoceros, blue wildebeest, plains zebra and elephant, which are selective and/or bulk grazers (Cillié, 2004). The short grass grazers like white rhinoceros and blue wildebeest in particular, as well as the long grass grazers like zebra, can do considerable damage to newly formed plant material (Grunow, 1980).

The effect that trees have on herbaceous plants may not always be negative. Positive interactions are a result of subhabitat differentiation, which is dependant on tree density, tree species, tree size and interactions with the soil (e.g. soil type and soil fertility).

Established trees create subhabitats, which differ from open areas, with subsequent influences on the herbaceous layer (Kennard & Walker, 1973; Tiedemann & Klemmedson, 1973; Kellman, 1979; Grossman *et al.*, 1980; Yavitt & Smith, 1983; Stuart-Hill *et al.*, 1987; Belsky *et al.*, 1989; Smit & Rethman, 1989; Smit & Rethman, 1992; Smit & Swart, 1994; Ludwig *et al.*, 2004; Troncoso *et al.*, 2005). The most common association of herbaceous plants with tree canopies is that of *Panicum maximum* (Bosch & Van Wyk, 1970; Kennard & Walker, 1973; Belsky *et al.*, 1989; Smit & Rethman, 1992; Smit & Van Romburgh, 1993; Smit & Swart, 1994; Smit, 2005a). *Panicum maximum* is highly palatable to cattle and other grazers (Jordaan, 1991; Premaratne & Premalal, 2005) and has a high yield potential (Smit & Rethman, 1992; Mello *et al.*, 2005).

From literature there is thus sufficient evidence that high tree densities suppress herbaceous yield in semi-arid savannas, but the decision to thin or clear woody species for purposes of increased herbaceous yield should also include additional considerations like browse yield and the influence of the remaining woody plants on the growth rate of the remaining woody plants as well as the re-establishment of woody plants (Smit, 1994). These aspects are even more important in conservation areas, such as Marakele Park.

The objectives of this study were:

- to compare the herbaceous dry matter yield of the thinned (treatment) and control plots, exposed to and protected from grazing,
- to evaluate the role of subhabitat differentiation (under and between tree canopies) on the herbaceous yield differentiation within the various experimental plots,
- to determine and evaluate herbaceous species differences between the experimental plots and defined subhabitats (under and between tree canopies),
- to establish relations between tree density and the dry matter yield of all herbaceous plants, combined, as well as grasses only, and
- to determine the grazing capacity of each experimental plot.

6.2 PROCEDURE

6.2.1 Quantification of the woody layer

The same procedure of woody plant biomass estimates in terms of Evapotranspiration Tree Equivalents (ETTE) ha^{-1} as described in Chapter 4 in section 4.2 (procedure) is applicable.

6.2.2 Quantification of the herbaceous layer

The above-ground dry matter (DM) yield of the herbaceous layer was determined by using a harvest method (Grunow *et al.*, 1980) (Figure 6.1). The yield determinations were done at the end of the 2003/2004 growing season (April/May) and were repeated during the same period of the 2004/2005 season.

Two subhabitats were distinguished: between tree canopies and under tree canopies. The areas covered by the various subhabitats in each experimental plot were based on the measurements of the percentage canopy cover as described in section 4.2 in Chapter 4. All rooted herbaceous plants were harvested in quadrates of 0.5 m x 0.5 m (0.25 m^2) in size. A total of 40 quadrates per experimental plot was harvested, 20 randomly allocated per subhabitat. Herbaceous plants were clipped to stubble height using hand clippers. Stubble height varied from 0.1 to 3.0 cm, depending on whether the species was tufted or not. The clipped material was dried to a constant mass (70ºC) and weighed.

Figure 6.1: An illustration of a quadrate that was used during this study to determine the dry matter yield of the herbaceous layer.

During the 2004/2005 season an additional 36 quadrates were harvested from under enclosures in each experimental plot (Figure 6.2). The enclosures were placed at the onset of the 2004/2005 growing season (October 2004) and the herbaceous plants protected under them were harvested at the end of the growing season (April 2005). A total of 9 enclosures were placed in each experimental plot, both between tree canopies and under tree canopies (Appendix F), where possible. The pyramid shaped enclosures consisted of a 12 mm solid round iron rod frame.

The frames were covered with wire netting (50 mm), which not only kept grazing animals out, but also smaller herbivores such as hares (*Lepus* spp.). The basal dimensions of the enclosures were 1.8 m x 1.8 m, which tapered to a top of 1.2 m x 1.2 m and a height of 0.9 m. In order to minimise the effect of the enclosures on the micro-climate, extensions at the four corners of the frame prevented the base of the enclosure to touch the ground.

Figure 6.2: Illustration of an enclosure that was used to protect the herbaceous plants from utilisation during the 2004/2005 growing season.

A total of 4 quadrates were harvested under each enclosure. Only the central 1.2 m x 1.2 m area of each enclosure was used for harvesting in order to prevent the influence of any edge effect that the enclosures may have had on the herbaceous growth underneath them. Unfortunately, only a set number of enclosures were available, which limited the number of quadrates that could be harvested under enclosures in each plot. For this reason no enclosures were placed under trees in the treatment plots. In addition, elephants destroyed a number of the enclosures during the season (Figure 6.3).

Figure 6.3: Damage caused to some of the enclosures by elephants.

The herbaceous DM yield (kg ha^{-1}) was calculated using the following formula:

$$\text{Total DM yield } ha^{-1} = [\{(DM_u \times H_u) \times A_u\} + \{(DM_b \times H_b) \times A_b\}]$$

Where: DM_u = kg DM harvested in quadrates under trees (all species combined)
DM_b = kg DM harvested in quadrates between trees (all species combined)
H_u = 10 000/total quadrate area of quadrates harvested under trees
H_b = 10 000/total quadrate area of quadrates harvested between trees
A_u = % canopy cover of woody plants, expressed as a decimal (e.g. % canopy cover of 25% = 0.25)
A_b = % of experimental plot with no canopy cover of woody plants, expressed as a decimal.

($A_u + A_b$ always equals 1)

This formula was used to account for the fact that the quadrates were clipped under and between trees and to take the percentage canopy cover into account. The herbaceous yield was also determined under and between trees within the areas exposed to and protected from grazing.

6.2.3 Calculation of the grazing capacity

The formula of Moore & Odendaal (1987) was used to calculate the grazing capacity of the herbaceous layer for each experimental plot:

$$y = d \div \frac{(DM \times f)}{r}$$

Where: y = Grazing capacity (ha GU^{-1})
d = Number of days in a year (365)
DM = Total herbaceous DM yield (kg ha^{-1})
f = Utilisation factor
r = Daily grass DM required per GU {2.5% of body mass = 4.5 kg day^{-1} (Owen-Smith, 1999)}

The formula was adapted to express the grazing capacity in hectares per grazer unit (GU) (Smit, 2003b). A GU is defined as the metabolic equivalent of a blue wildebeest (*Connochaetus taurinus*), a 100% grazer with a mean body mass of 180 kg (Dekker, 1997).

An utilisation factor (f) was allocated to each plant species according to the grazing value of the specific species (Smit, undated). The following f-values were used for the individual herbaceous species:

Grazing value	**f-value**
High	0.4
Intermediate	0.3
Low	0.2

Due to a lack of verified (researched) data available for the study area these utilisation factors were used for comparison purposes only. Studies to determine the grazing preferences of the various herbivore species are necessary to be able to derive appropriate utilisation values for the herbaceous species that are preferred by the different types of grazers, e.g. short and long grass grazers. For example, *Themeda triandra* (a tall grass) would have a higher utilisation factor for grazers like plains zebra, which prefer to utilise tall grasses, than it would have for grazers like blue wildebeest, which prefer to utilise short grasses. It is important to reach a compromise between the preservation of desirable climax grasses and grass species with a lower ecological status that are suitable for the grazing preference of some destructive short grass grazers, especially Type III species (see section 6.4).

Due to the lack of scientific data on the contribution and value of forb species to the diet of herbivore game species (relatively few data is available on the palatability of forbs and on how game species utilise forb species), it was assumed that all the forb species in this study had an utilisation factor of 0.2.

6.2.4 Data analyses

Relations between tree leaf biomass (dry basis) and the DM yield of herbaceous plants, combined, (grasses and forbs) were established using regression analyses (SAS, 1988; GraphPad, 1997). In addition, simple descriptive statistics were used.

6.3 RESULTS

6.3.1 Quantification of the woody layer

The quantification of the woody layer in terms of ETTE ha^{-1} is presented in Chapter 4, section 4.3.2. In this chapter those results serve to quantify the leaf biomass of the woody plants in the various experimental plots for purposes of establishing relations between leaf biomass of the woody plants and herbaceous DM yield.

6.3.2 Quantification of the herbaceous layer

6.3.2.1 *Total dry matter yield*

The total DM yields of all herbaceous plants, combined, and of only the grasses in each experimental plot for the 2003/2004 and 2004/2005 seasons are presented in Figure 6.4. During the 2003/2004 season, all the treatment plots had a lower DM yield for all herbaceous plants, combined, in the areas exposed to grazing in comparison to their corresponding control plots (Figure 6.4a). Similar results were found for the DM yield of all herbaceous plants, combined, during the 2004/2005 season, except for the Ca-Gf Treatment plot, which had a much higher DM yield of all herbaceous plants, combined, in comparison to the Ca-Gf Control plot. The total grass DM yield of all the treatment plots in the areas exposed to grazing were also lower than their corresponding control plots in the 2003/2004 season, except for the Ca-Gf Treatment plot, which had a higher grass DM yield than the Ca-Gf Control plot (Figure 6.4b). During the 2004/2005 season, the grass DM yield of all the treatment plots was lower than those of the control plots in the areas exposed to grazing.

The DM yield of all herbaceous plants, combined, in the areas exposed to grazing was higher during the 2004/2005 season than the 2003/2004 season in most of the experimental plots (Figure 6.4a). Only the Ca-Gf Control plot and the Ae-Dc Treatment plot had a lower DM yield for all herbaceous plants, combined, in the 2004/2005 season. In the areas exposed to grazing, the total grass DM yield of all the experimental plots was higher during the 2004/2005 season compared to the 2003/2004 season (Figure 6.4b).

Only the Am-Gf Treatment plot had a higher DM yield for all herbaceous plants, combined, in comparison to its control plot in the areas protected from grazing (Figure 6.4a). The Ca-Gf and Ae-Dc Treatment plots had a lower DM yield for all herbaceous plants, combined, in comparison to their control plots. The DM yield of all herbaceous plants, combined, of the areas protected from grazing was higher than the areas exposed to grazing. The Am-Gf plots had a much higher DM yield increase for all herbaceous plants, combined, in comparison to the Ca-Gf and Ae-Dc plots. The total grass DM yield in the areas protected from grazing was also higher in all the experimental plots than in the areas exposed to grazing (Figure 6.4b). The Am-Gf plots had a much higher grass DM yield in the areas protected from grazing than the Ca-Gf and Ae-Dc plots. All the treatment plots, compared to their corresponding control plots, had a slightly higher grass DM yield in the areas protected from grazing, except for the Ae-Dc Treatment plot.

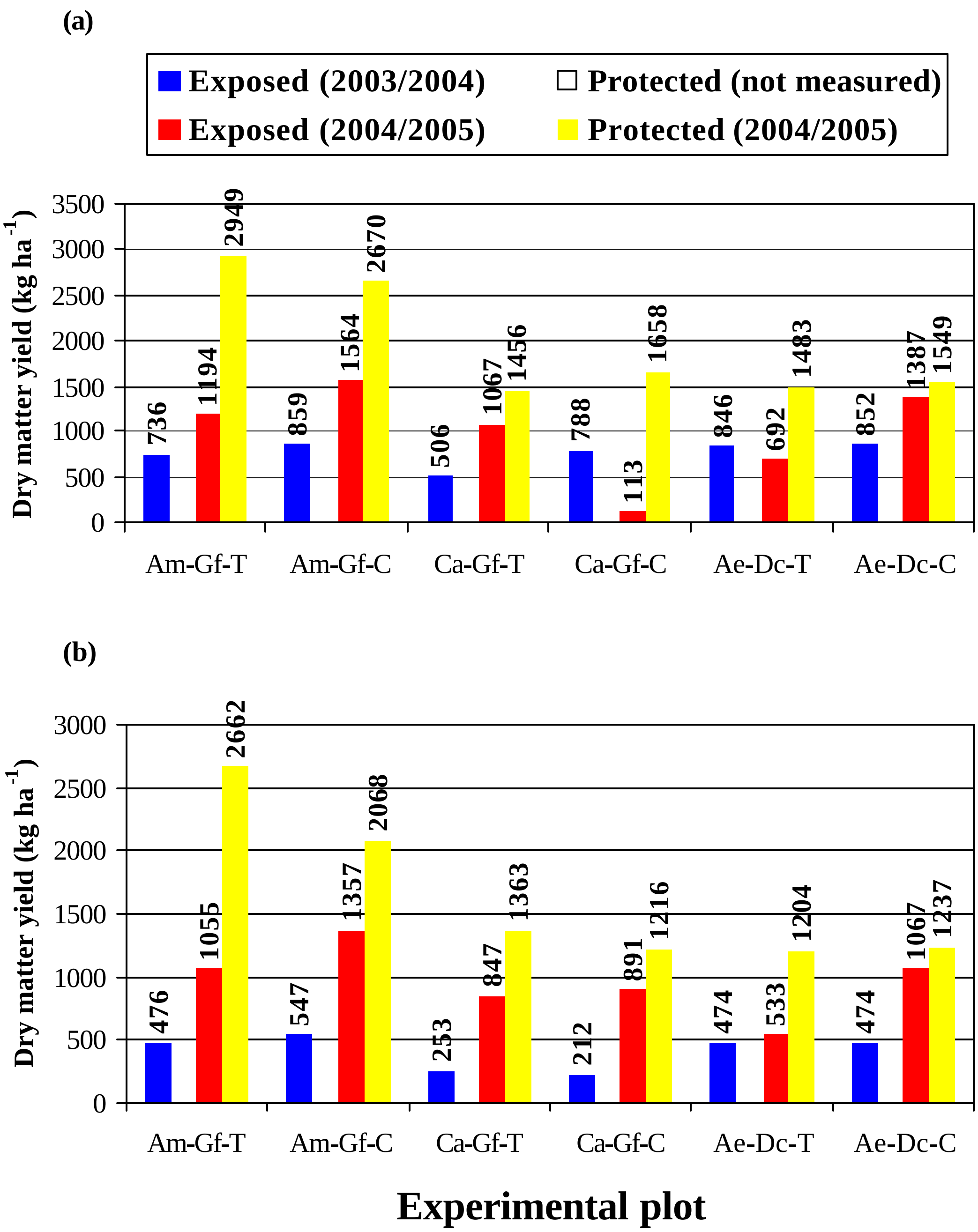


Figure 6.4: Herbaceous dry matter yields of each experimental plot as measured at the end of the 2003/2004 and 2004/2005 growing seasons. (a) All herbaceous plants, combined, and (b) grasses only.

6.3.2.2 *Influence of subhabitat differentiation*

The DM yield of all herbaceous plants, combined, within the different subhabitats of each experimental plot (for the 2003/2004 and 2004/2005 seasons) exposed to grazing is presented in Figure 6.5, while the proportional contribution of the subhabitats to the total DM yield of all herbaceous plants, combined, in each experimental plot that was exposed to grazing is presented in Figure 6.6. The DM yield and the proportional contribution of the subhabitats to the total DM yield of all herbaceous plants, combined, for the control plots protected from grazing are presented in Figure 6.7 and Figure 6.8, respectively. The treatment plots were not included in these graphs since no enclosures were placed in the subhabitat under trees.

During the 2003/2004 season, the DM yield (all herbaceous plants combined) between the under tree and between tree subhabitats did not differ substantially for each experimental plot in the areas exposed to grazing (Figure 6.5a). The largest difference was found in the Am-Gf Treatment plot, which had a higher DM yield in the between tree subhabitat. The highest DM yield (all herbaceous plants combined) for this season in the under tree subhabitat was found in the Ae-Dc Treatment plot, while the highest DM yield (all herbaceous plants combined) in the between tree subhabitat was found in the Am-Gf Control plot. The lowest DM yield (all herbaceous plants combined) for the 2003/2004 season for both subhabitats was found in the Ca-Gf Treatment plot.

Similar results were found during the 2004/2005 season in the areas exposed to grazing, except that the variation in DM yield (all herbaceous plants combined) between the subhabitats for each experimental plot was much larger and the DM yield for both subhabitats was higher during the second season for most of the experimental plots (Figure 6.5b). The variation between the treatment and their corresponding control plots was also larger. The highest DM yield (all herbaceous plants combined) during this season for the under tree subhabitat was found in the Ae-Dc Control plot, while the highest DM yield (all herbaceous plants combined) for the between tree subhabitat was found in the Am-Gf Control plot. The lowest DM yield (all herbaceous plants combined) for the 2004/2005 season in the under tree subhabitat was found in the Ca-Gf Treatment plot, while the lowest DM yield (all herbaceous plants combined) for the between tree subhabitat was found in the Ae-Dc Treatment plot.

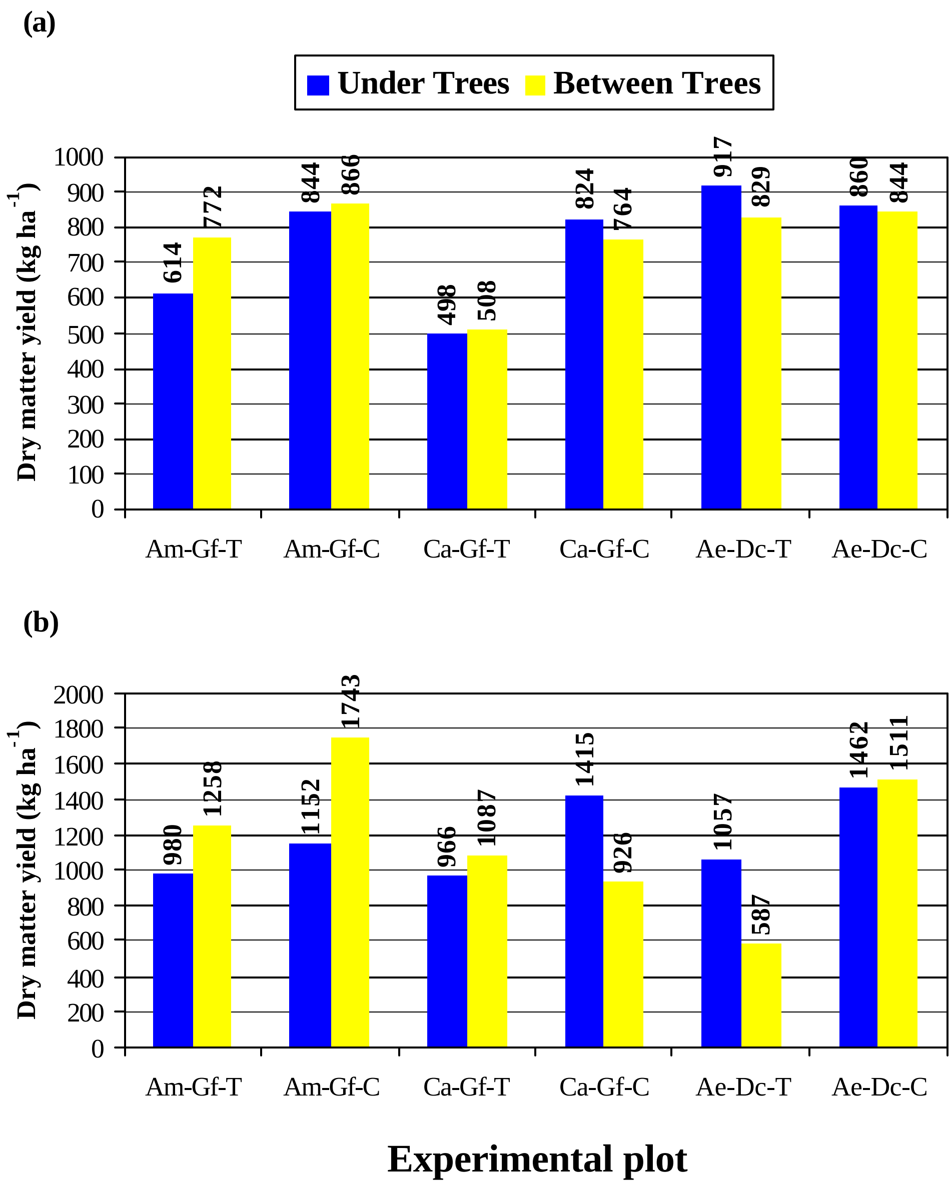


Figure 6.5: The dry matter yield of all herbaceous plants, combined, within the different subhabitats (under and between trees) exposed to grazing in each experimental plot during the (a) 2003/2004 and (b) 2004/2005 seasons.

During the 2003/2004 season the proportional contribution of the subhabitats to the total DM yield of all herbaceous plants, combined, was higher in the between tree subhabitat than the under tree subhabitat in all the experimental plots exposed to grazing, except for the Ae-Dc Control plot (Figure 6.6a). The highest proportional contribution of the under tree subhabitat to the total DM yield (all herbaceous plants combined) during this season was found in the Ae-Dc Control plot, while the highest proportional contribution of the between tree subhabitat to the total DM yield (all herbaceous plants combined) was found in the Ae-Dc Treatment plot.

Similar results were found during the 2004/2005 season for all the experimental plots in the areas exposed to grazing. The proportional contribution of the different subhabitats to the total DM yield (all herbaceous plants combined) was higher for most of the experimental plots, especially in the between tree subhabitat (Figure 6.6b). The highest proportional contribution of the under tree subhabitat to the total DM yield (all herbaceous plants combined) was also found in the Ae-Dc Control plot, while the highest proportional contribution of the between tree subhabitat to the total DM yield (all herbaceous plants combined) was found in the Am-Gf Control plot.

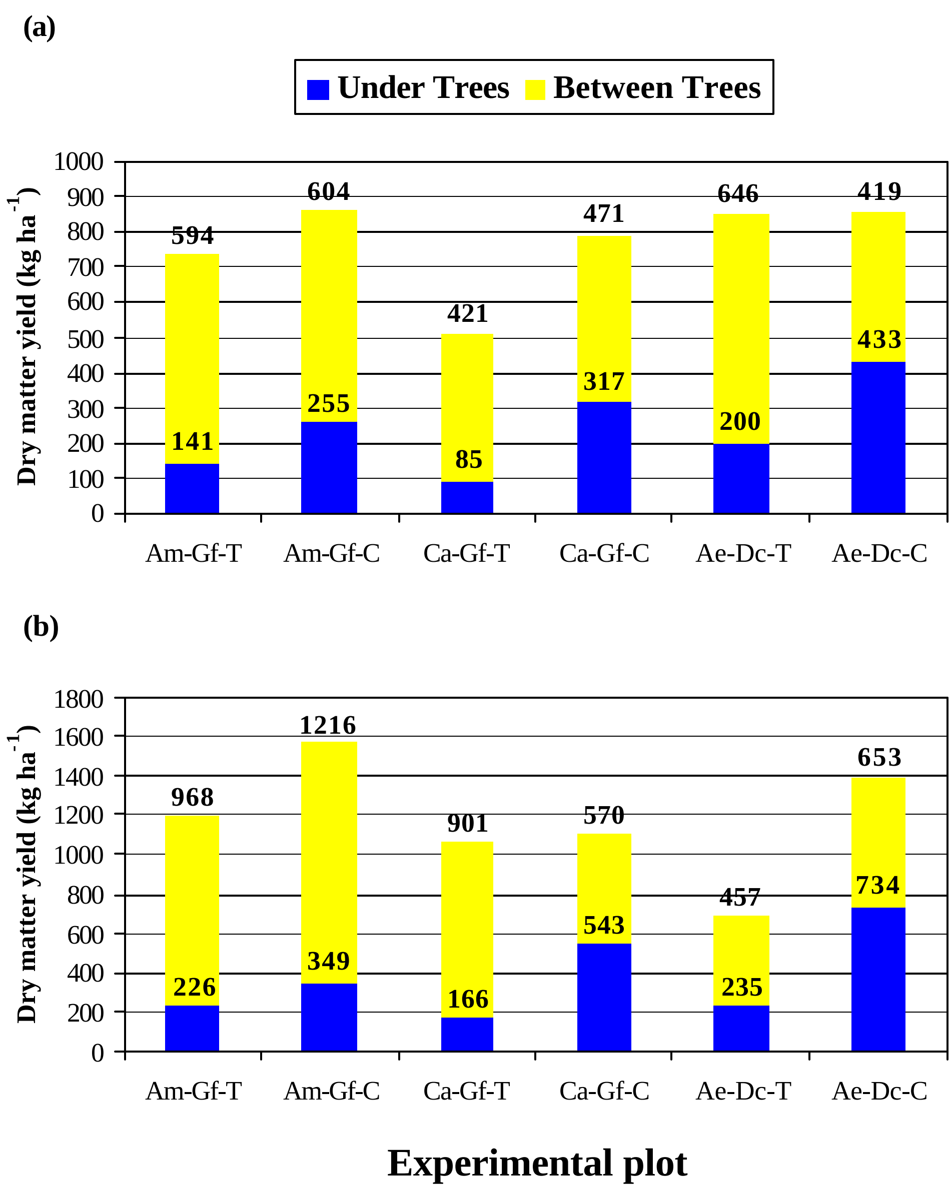


Figure 6.6: The proportional contribution of the different subhabitats (under and between trees) to the total dry matter yield of all herbaceous plants, combined, that were exposed to grazing within each experimental plot during (a) the 2003/2004, and (b) 2004/2005 growing season.

In the 2004/2005 season, the DM yield of all herbaceous plants, combined, in the areas protected from grazing varied substantially between the subhabitats of the control plots (Figure 6.7). The highest DM yield (all herbaceous plants combined) in the under tree subhabitat was found in the Am-Gf Control plot, while the highest DM yield (all herbaceous plants combined) in the between tree subhabitat was found in the Ae-Dc Control plot. The proportional contribution of both subhabitats to the total DM yield (all herbaceous plants combined) during the 2004/2005 season in the areas protected from grazing was the highest in the Am-Gf Control plot (Figure 6.8).

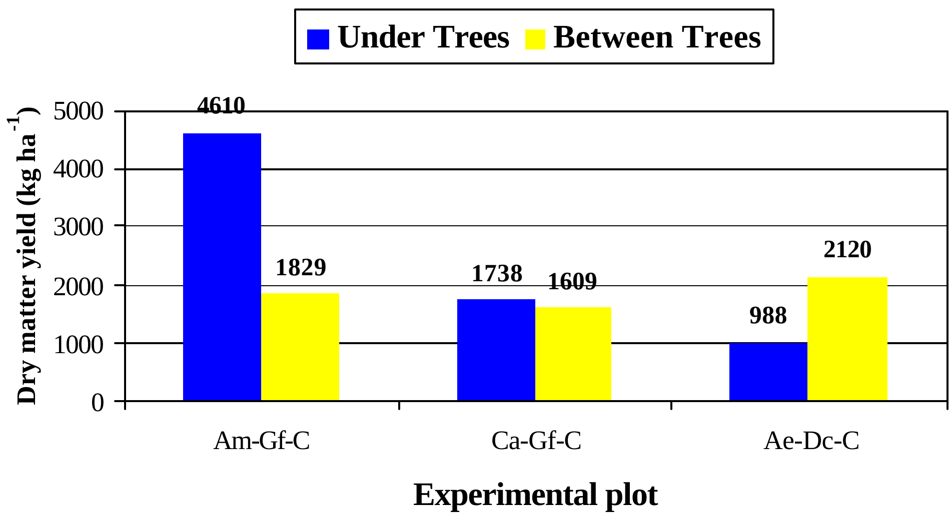


Figure 6.7: The dry matter yield of all herbaceous plants, combined, in the different subhabitats (under and between trees) of the control plots in the areas protected from grazing during the 2004/2005 season.

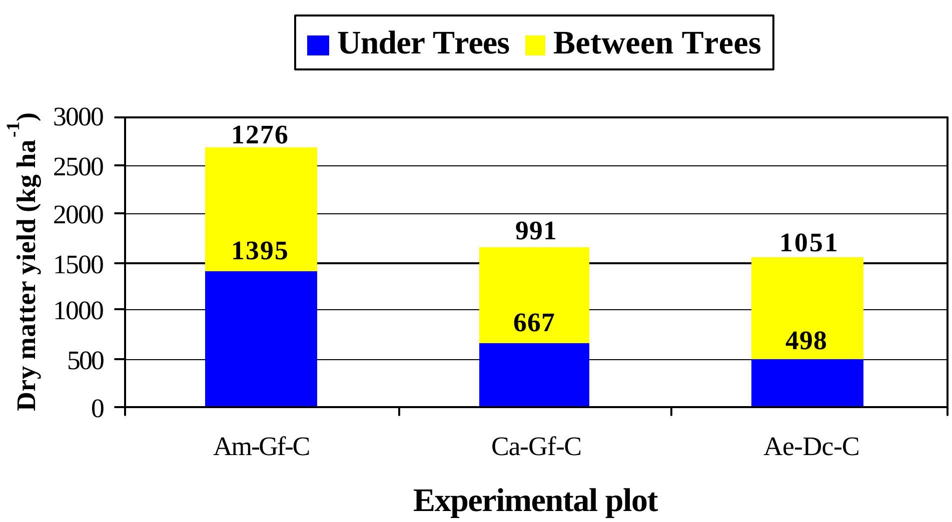


Figure 6.8: The proportional contribution of the different subhabitats (under and between trees) to the total dry matter yield of all herbaceous plants, combined, that were protected from grazing within the control plots during the 2004/2005 season.

When the DM yield and the proportional contribution of the different subhabitats to the total DM yield (all herbaceous plants combined) in the areas exposed to grazing (Figure 6.5 and 6.6) are compared to the areas protected from grazing (Figures 6.7 and 6.8), it is clear that the protected areas had a much higher DM yield (all herbaceous plants combined) than the exposed areas, especially the subhabitats in the Am-Gf Control plot. The subhabitat under trees of the Ae-Dc Control plot was the only exception. Also, the DM yield and proportional contribution of the between tree subhabitat to the total DM yield (all herbaceous plants combined) of the Ae-Dc Control plot was higher in the areas exposed to grazing than in the areas protected from grazing for the 2004/2005 season.

6.3.2.3 *Contribution of individual herbaceous species*

The proportional contribution of individual herbaceous species to the total DM yield in each experimental plot is presented in Tables 6.1 to 6.6. The herbaceous species that contributed most to the total DM yield of the experimental plots in the areas exposed to and protected from grazing, were the grasses *Aristida congesta* (*A. congesta* subsp. *congesta* and *A. congesta* subsp. *barbicollis* combined due to their similar ecological properties), *Bothriochloa insculpta*, *B. radicans*, *Digitaria eriantha*, *Eragrostis rigidior*, *Heteropogon contortus*, *Panicum maximum* and *Urochloa mosambicensis*, and the forbs *Evolvulus alsinoides*, *Justicia flava* and *Tephrosia* species. These were the dominant herbaceous species in the study area. However, variations were found in the dominance of these species between the areas exposed to and protected from grazing, as well as between the different experimental plots.

In the Am-Gf Treatment plot (Table 6.1), *A. congesta*, which was mostly found between trees, increased in DM yield from the 2003/2004 to the 2004/2005 season, but it had a low DM yield in the areas protected from grazing. The same result was found for *D. eriantha*, except that this grass species was not recorded during the first season. *Bothriochloa insculpta*, *B. radicans*, *H. contortus*, *P. maximum* and *U. mosambicensis* all increased in DM yield from the first to the second season, especially in the areas protected from grazing. All these grass species were mainly found between trees, except for *P. maximum* and *U. mosambicensis*, which had a relatively high proportional contribution to the total DM yield under trees. *Eragrostis rigidior* decreased in DM yield from the first to second season and had the lowest yield in the areas protected from grazing.

Table 6.1: The yield of individual herbaceous species in the *Acacia mellifera* – *Grewia flava* Treatment plot. A differentiation was made between subhabitats and the yield of areas exposed to and protected from grazing. Numbers in parenthesis indicate the ranking order of the species during each season of the study period.

Species	Dry matter yield (kg ha^{-1})								
	2003/2004			2004/2005					
	Exposed			Exposed			Protected		
	Under Trees	Between Trees	Total	Under Trees	Between Trees	Total	Under Trees*	Between Trees	Total
Bothriochloa insculpta	104.3	101.3	102.0 (1)	0.0	243.1	187.1 (2)	-	357.8	~
Eragrostis rigidior	14.2	126.3	100.5 (2)	34.4	106.8	90.1 (6)	-	34.2	~
Bothriochloa radicans	54.3	67.4	64.4 (3)	104.4	265.9	228.7 (1)	-	521.5	~
Tephrosia lupinifolia	0.0	65.7	50.6 (4)	2.0	1.1	1.4 (30)	-	-	-
Urochloa mosambicensis	191.0	0.0	44.0 (5)	319.7	138.9	180.5 (3)	-	599.0	~
Tragus racemosus	0.0	54.5	41.9 (6)	1.8	9.1	7.4 (17)	-	11.1	~
Eragrostis pilosa	32.0	39.0	37.4 (7)	-	-	-	-	-	-
Corchorus asplenifolius	10.5	40.8	33.8 (8)	2.1	1.5	1.7 (28)	-	-	-
Rhynchosia caribaea	2.3	37.8	29.6 (9)	1.6	0.0	0.4 (36)	-	22.1	~
Themeda triandra	28.8	28.7	28.7 (10)	29.6	129.2	106.2 (4)	-	208.4	~
Justicia flava	13.4	31.8	27.6 (11)	38.5	20.1	24.4 (11)	-	34.1	~
Hermannia spp.	0.0	29.3	22.5 (12)	-	-	-	-	-	-
Melhania prostrata	0.0	28.4	21.9 (13)	-	-	-	-	1.3	~
Melolobium spp.	22.9	16.1	17.7 (14)	-	-	-	-	-	-
Aristida congesta	2.4	16.9	13.6 (15)	30.4	59.5	52.8 (7)	-	18.7	~
Justicia protracta	11.5	13.0	12.7 (16)	0.0	48.9	37.6 (8)	-	27.8	~
Linum thunbergii	5.4	14.2	12.2 (17)	-	-	-	-	12.6	~
Kyphocarpa angustifolia	7.6	12.4	11.3 (18)	-	-	-	-	1.0	~
Chloris virgata	47.9	0.0	11.0 (19)	22.9	0.0	5.3 (20)	-	43.2	~
Sporobolus ioclados	0.0	14.1	10.8 (20)	0.0	3.8	2.9 (23)	-	-	-
Tragus berteronianus	43.9	0.0	10.1 (21)	0.0	6.4	4.9 (22)	-	4.6	~
Pavonia burchellii	0.0	11.5	8.9 (22)	20.4	33.3	30.3 (10)	-	46.5	~
Evolvulus alsinoides	2.3	10.7	8.7 (23)	2.1	13.7	11.1 (14)	-	4.0	~
Aristida adscensionis	4.4	4.7	4.6 (24)	-	-	-	-	-	-
Heteropogon contortus	0.0	4.4	3.4 (25)	11.3	16.0	14.9 (13)	-	211.1	~

…Continues

Table 6.1 continued…

Species	Dry matter yield (kg ha?^{1})								
	2003/2004			2004/2005					
	Exposed			Exposed			Protected		
	Under Trees	Between Trees	Total	Under Trees	Between Trees	Total	Under Trees*	Between Trees	Total
Eragrostis superba	0.8	3.1	2.6 (26)	-	-	-	-	-	-
Albuca spp.	5.6	0.0	1.3 (27)	-	-	-	-	-	-
Panicum maximum	5.2	0.0	1.2 (28)	103.5	9.6	31.2 (9)	-	457.3	~
Ipomoea obscura subsp. *obscura*	3.3	0.0	0.8 (29)	2.0	0.0	0.5 (35)	-	-	-
Digitaria eriantha	-	-	-	81.7	109.4	103.0 (5)	-	81.3	~
Microchloa caffra	-	-	-	0.0	30.8	23.7 (12)	-	4.7	~
Enneapogon cenchroides	-	-	-	38.5	0.0	8.9 (15)	-	11.3	~
Rhynchosia totta	-	-	-	32.9	0.0	7.6 (16)	-	-	-
Zehneria marlothii	-	-	-	29.6	0.0	6.8 (18)	-	-	-
Cymbopogon pospischilii	-	-	-	26.7	0.0	6.1 (19)	-	-	-
Blepharis integrifolia	-	-	-	0.0	6.6	5.0 (21)	-	-	-
Indigofera holubii	-	-	-	11.1	0.0	2.6 (24)	-	-	-
Solanum panduriforme	-	-	-	10.5	0.0	2.4 (25)	-	-	-
Abutilon pycnodon	-	-	-	10.0	0.0	2.3 (26)	-	-	-
Kohautia virgata	-	-	-	0.0	2.2	1.7 (27)	-	-	-
Kalanchoe lanceolata	-	-	-	5.8	0.0	1.3 (29)	-	-	-
Conyza podocephala	-	-	-	0.0	1.6	1.2 (32)	-	-	-
Commelina africana	-	-	-	2.3	0.0	0.5 (33)	-	9.4	~
Dactyloctenium giganteum	-	-	-	2.2	0.0	0.5 (34)	-	-	-
Brachiaria deflexa	-	-	-	1.3	0.0	0.3 (37)	-	-	-
Nemesia albiflora	-	-	-	0.0	0.3	0.2 (38)	-	-	-
Hermbstaedtia linearis	-	-	-	0.8	0.0	0.2 (39)	-	-	-
Cenchrus ciliaris	-	-	-	-	-	-	-	97.5	~
Gossypium herbaceum	-	-	-	-	-	-	-	49.3	~
Senecio latifolius	-	-	-	-	-	-	-	27.8	~
Barleria galpinii	-	-	-	-	-	-	-	20.6	~
Hibiscus cannabinus	-	-	-	-	-	-	-	10.4	~

…Continues

Table 6.1 continued…

Species	Dry matter yield (kg ha^{-1}) 2003/2004 Exposed			2004/2005 Exposed			2004/2005 Protected		
	Under Trees	Between Trees	Total	Under Trees	Between Trees	Total	Under Trees*	Between Trees	Total
Jatropha zeyheri	-	-	-	-	-	-	-	7.1	~
Schkuhria pinnata	-	-	-	-	-	-	-	6.2	~
Vahlia capensis	-	-	-	-	-	-	-	5.7	~
Striga elegans	-	-	-	-	-	-	-	1.5	~
TOTAL	**614.0**	**772.1**	**735.8**	**980.1**	**1257.8**	**1193.7**	-	**2949.1**	~

- Indicates that the species was not recorded in the survey of that specific season.
*****No enclosures were placed under trees in the treatment plot due to a limitation on the available enclosures.
~No total could be calculated for the treatment plot due to a lack of data for the under tree subhabitat.

Table 6.2: The yield of individual herbaceous species in the *Acacia mellifera – Grewia flava* Control plot. A differentiation was made between subhabitats and the yield of areas exposed to and protected from grazing. Numbers in parenthesis indicate the ranking order of the species during each season of the study period.

Species	**Dry matter yield (kg ha?^{1})**								
	2003/2004			**2004/2005**					
	Exposed			**Exposed**			**Protected**		
	Under Trees	**Between Trees**	**Total**	**Under Trees**	**Between Trees**	**Total**	**Under Trees**	**Between Trees**	**Total**
Justicia flava	315.1	105.8	169.1 (1)	189.0	32.9	80.1 (4)	278.1	35.6	109.0 (8)
Bothriochloa radicans	80.3	174.0	145.7 (2)	252.0	720.7	578.9 (1)	1133.4	381.7	609.1 (1)
Bothriochloa insculpta	54.8	122.1	101.8 (3)	125.5	454.2	354.8 (2)	238.7	409.9	358.1 (3)
Urochloa mosambicensis	72.1	110.9	99.2 (4)	301.4	277.9	285.0 (3)	878.9	312.4	483.8 (2)
Aristida congesta	28.1	64.8	53.7 (5)	7.3	8.6	8.2 (14)	0.0	10.3	7.2 (18)
Justicia protracta	68.1	38.3	47.3 (6)	21.9	64.3	51.5 (6)	0.0	60.1	41.9 (14)
Eragrostis pilosa	21.2	54.2	44.2 (7)	-	-	-	-	-	-
Aristida adscensionis	49.3	33.1	38.0 (8)	-	-	-	-	-	-
Melolobium spp.	9.7	29.7	23.6 (9)	-	-	-	-	-	-
Hermannia spp.	19.5	16.8	17.6 (10)	-	-	-	-	-	-
Tragus racemosus	53.6	0.0	16.2 (11)	5.1	9.1	7.9 (15)	0.0	7.3	5.1 (19)
Digitaria eriantha	10.6	17.2	15.2 (12)	8.5	47.8	36.0 (7)	11.8	154.2	111.1 (7)
Heteropogon contortus	0.0	20.3	14.1 (13)	-	-	-	-	-	-
Tragus berteronianus	11.6	13.4	12.8 (14)	0.0	13.1	9.1 (12)	-	-	-
Commelina africana	0.0	15.4	10.7 (15)	-	-	-	-	-	-
Corchorus asplenifolius	5.8	9.5	8.4 (16)	-	-	-	0.0	5.7	4.0 (21)
Evolvulus alsinoides	9.6	6.3	7.3 (17)	4.5	78.2	56.0 (5)	0.0	63.3	44.2 (13)
Albuca spp.	8.5	5.7	6.6 (18)	-	-	-	-	-	-
Kyphocarpa angustifolia	0.0	8.2	5.7 (19)	22.5	0.0	6.8 (16)	0.0	236.0	164.6 (5)
Pavonia burchellii	15.6	0.0	4.7 (20)	14.6	0.0	4.4 (17)	210.9	0.0	63.8 (10)
Ipomoea obscura subsp. *obscura*	0.0	6.5	4.5 (21)	-	-	-	-	-	-
Rhynchosia caribaea	0.0	5.8	4.1 (22)	-	-	-	-	-	-
Eragrostis rigidior	0.0	4.8	3.3 (23)	14.4	11.2	12.2 (11)	0.0	88.9	62.0 (11)
Melhania prostrata	10.7	0.0	3.2 (24)	-	-	-	-	-	-
Brachiaria deflexa	0.0	3.4	2.4 (25)	-	-	-	-	-	-

…Continues

Table 6.2 continued…

Species	Dry matter yield (kg ha?¹)								
	2003/2004			2004/2005					
	Exposed			Exposed			Protected		
	Under Trees	Between Trees	Total	Under Trees	Between Trees	Total	Under Trees	Between Trees	Total
Chloris virgata	-	-	-	63.4	2.0	20.6 (8)	-	-	-
Panicum maximum	-	-	-	61.7	0.0	18.7 (9)	881.0	32.8	289.4 (4)
Sporobolus ioclados	-	-	-	4.5	18.9	14.6 (10)	-	-	-
Panicum coloratum	-	-	-	29.6	0.0	8.9 (13)	-	-	-
Schkuhria pinnata	-	-	-	4.7	2.4	3.1 (18)	-	-	-
Hermbstaedtia linearis	-	-	-	5.7	0.0	1.7 (19)	-	-	-
Abutilon pycnodon	-	-	-	5.5	0.0	1.7 (19)	-	-	-
Enneapogon cenchroides	-	-	-	5.3	0.0	1.6 (20)	-	-	-
Senecio latifolius	-	-	-	5.1	0.0	1.5 (21)	-	-	-
Blumea dregeanoides	-	-	-	0.0	1.5	1.1 (22)	-	-	-
Brachiaria nigropedata	-	-	-	-	-	-	470.0	0.0	142.2 (6)
Zehneria marlothii	-	-	-	-	-	-	209.3	1.8	64.5 (9)
Solanum panduriforme	-	-	-	-	-	-	153.7	0.0	46.5 (12)
Kalanchoe lanceolata	-	-	-	-	-	-	79.5	0.0	24.1 (15)
Cucumis zeyheri	-	-	-	-	-	-	64.2	0.0	19.4 (16)
Indigofera holubii	-	-	-	-	-	-	0.0	20.6	14.4 (17)
Indigofera filipes	-	-	-	-	-	-	0.0	6.7	4.7 (20)
Kohautia virgata	-	-	-	-	-	-	0.0	1.1	0.8 (22)
Conyza podocephala	-	-	-	-	-	-	0.0	0.7	0.5 (23)
TOTAL	**844.2**	**866.2**	**859.4**	**1152.2**	**1742.8**	**1564.4**	**4609.5**	**1829.1**	**2670.4**

- Indicates that the species was not recorded in the survey of that specific season.

Table 6.3: The yield of individual herbaceous species in the *Combretum apiculatum – Grewia flava* Treatment plot. A differentiation was made between subhabitats and the yield of areas exposed to and protected from grazing is also indicated. Numbers in parenthesis indicate the ranking order of the species during each season of the study period.

Species	Dry matter yield (kg ha?¹)								
	2003/2004			2004/2005					
	Exposed			Exposed			Protected		
	Under Trees	Between Trees	Total	Under Trees	Between Trees	Total	Under Trees*	Between Trees	Total
Aristida congesta	64.0	80.4	77.5 (1)	191.5	94.0	110.7 (2)	-	127.3	~
Eragrostis rigidior	14.0	67.1	58.0 (2)	174.7	259.5	245.0 (1)	-	340.4	~
Agathisanthemum bojeri	118.8	35.0	49.3 (3)	35.0	0.0	6.0 (26)	-	-	-
Linum thunbergii	34.8	26.4	27.8 (4)	-	-	-	-	8.5	~
Brachiaria nigropedata	15.6	28.8	26.6 (5)	0.0	46.3	38.4 (8)	-	73.2	~
Melinis repens	32.8	24.1	25.6 (6)	30.5	62.6	57.1 (3)	-	157.8	~
Tephrosia longipes	0.0	27.6	22.8 (7)	19.7	52.9	47.3 (4)	-	1.6	~
Aristida adscensionis	10.7	24.1	21.7 (8)	18.7	41.7	37.7 (11)	-	-	-
Hermannia glanduligera	17.5	22.3	21.5 (9)	-	-	-	-	-	-
Abutilon sonneratianum	0.0	25.0	20.7 (10)	8.3	0.0	1.4 (36)	-	-	-
Melhania prostrata	0.0	23.1	19.2 (11)	7.9	12.9	12.1 (21)	-	6.9	~
Justicia flava	35.1	14.3	17.8 (12)	45.3	0.0	7.7 (24)	-	-	-
Evolvulus alsinoides	0.0	20.6	17.0 (13)	6.1	30.3	26.2 (13)	-	3.4	~
Heteropogon contortus	0.0	20.5	17.0 (13)	0.0	50.8	42.1 (5)	-	100.2	~
Polygala sphenoptera	6.4	13.6	12.4 (14)	-	-	-	-	-	-
Themeda triandra	13.2	8.7	9.5 (15)	-	-	-	-	31.8	~
Urochloa mosambicensis	52.6	0.0	9.0 (16)	29.0	41.5	39.4 (7)	-	82.7	~
Zornia milneana	4.4	9.8	9.0 (16)	-	-	-	-	-	-
Kyphocarpa angustifolia	0.0	10.1	8.4 (17)	-	-	-	-	-	-
Senna italica subsp. *arachoides*	0.0	8.9	7.4 (18)	3.1	5.8	5.3 (28)	-	0.5	~
Digitaria eriantha	9.4	4.8	5.5 (19)	29.1	62.8	57.1 (3)	-	224.5	~
Albuca spp.	10.0	3.6	4.7 (20)	-	-	-	-	-	-
Corchorus asplenifolius	18.8	0.8	3.8 (21)	-	-	-	-	-	-
Rhynchosia totta	20.8	0.0	3.6 (22)	18.0	5.8	8.0 (23)	-	3.4	~
Solanum rigescens	0.0	4.0	3.3 (23)	-	-	-	-	-	-
Tephrosia lupinifolia	1.6	3.4	3.1 (24)	-	-	-	-	-	-

…Continues

Table 6.3 continued…

Species	Dry matter yield (kg ha⁻¹)								
	2003/2004			2004/2005					
	Exposed			Exposed			Protected		
	Under Trees	Between Trees	Total	Under Trees	Between Trees	Total	Under Trees*	Between Trees	Total
Sporobolus panicoides	10.2	0.0	1.7 (25)	47.1	0.0	8.1 (22)	-	-	-
Justicia protracta	0.0	1.2	1.0 (26)	12.1	14.6	14.2 (19)	-	10.6	~
Panicum maximum	5.3	0.0	0.9 (27)	111.4	0.0	19.1 (15)	-	-	-
Enneapogon cenchroides	1.1	0.0	0.2 (28)	38.8	38.1	38.2 (10)	-	-	-
Monsonia burkeana	0.7	0.0	0.1 (29)	-	-	-	-	-	-
Pogonarthria squarrosa	-	-	-	0.0	50.1	41.5 (6)	-	155.0	~
Schmidtia pappophoroides	-	-	-	18.5	42.3	38.3 (9)	-	15.9	~
Tragus racemosus	-	-	-	21.6	35.0	32.7 (12)	-	-	-
Schkuhria pinnata	-	-	-	0.0	29.6	24.5 (14)	-	1.2	~
Tragus berteronianus	-	-	-	14.3	19.1	18.3 (16)	-	-	-
Setaria pumila	-	-	-	17.9	18.0	18.0 (17)	-	7.0	~
Stachys spp.	-	-	-	0.0	19.8	16.4 (18)	-	-	-
Barleria galpinii	-	-	-	0.0	17.0	14.1 (20)	-	-	-
Chamaecrista mimosoides	-	-	-	0.0	8.0	6.6 (25)	-	17.4	~
Blepharis integrifolia	-	-	-	0.0	7.1	5.9 (27)	-	1.8	~
Chloris virgata	-	-	-	30.4	0.0	5.2 (29)	-	-	-
Indigofera filipes	-	-	-	0.0	5.8	4.8 (30)	-	-	-
Conyza podocephala	-	-	-	0.0	5.6	4.7 (31)	-	-	-
Hemizygia canescens	-	-	-	0.0	5.1	4.2 (32)	-	11.5	~
Zornia milneana	-	-	-	0.0	5.0	4.1 (33)	-	-	-
Senecio latifolius	-	-	-	18.2	0.0	3.1 (34)	-	1.5	~
Pavonia burchellii	-	-	-	12.5	0.0	2.1 (35)	-	-	-
Commelina africana	-	-	-	3.3	0.0	0.6 (37)	-	-	-
Portulaca quadrifida	-	-	-	3.1	0.0	0.5 (38)	-	-	-
Microchloa caffra	-	-	-	-	-	-	-	24.3	~
Trichoneura grandiglumis	-	-	-	-	-	-	-	12.8	~
Nemesia albiflora	-	-	-	-	-	-	-	11.0	~
Eragrostis pilosa	-	-	-	-	-	-	-	10.1	~

…Continues

Table 6.3 continued…

Species	**Dry matter yield (kg ha^{-1})**								
	2003/2004			**2004/2005**					
	Exposed			**Exposed**			**Protected**		
	Under Trees	**Between Trees**	**Total**	**Under Trees**	**Between Trees**	**Total**	**Under Trees***	**Between Trees**	**Total**
Hermannia spp.	-	-	-	-	-	-	-	9.5	~
Pavonia transvaalensis	-	-	-	-	-	-	-	1.8	~
Haworthia spp.	-	-	-	-	-	-	-	1.3	~
Indigofera holubii	-	-	-	-	-	-	-	1.2	~
TOTAL	**497.8**	**508.2**	**506.1**	**966.1**	**1087.1**	**1066.7**	**-**	**1456.1**	**~**

- Indicates that the species was not recorded in the survey of that specific season.
*****No enclosures were placed under trees in the treatment plot due to a limitation on the available enclosures.
~No total could be calculated for the treatment plot due to a lack of data for the under tree subhabitat.

Table 6.4: The yield of individual herbaceous species in the *Combretum apiculatum – Grewia flava* Control plot. A differentiation was made between subhabitats and the yield of areas exposed to and protected from grazing is also indicated. Numbers in parenthesis indicate the ranking order of the species during each season of the study period.

Species	**Dry matter yield (kg ha^{-1})**								
	2003/2004			**2004/2005**					
	Exposed			**Exposed**			**Protected**		
	Under Trees	**Between Trees**	**Total**	**Under Trees**	**Between Trees**	**Total**	**Under Trees**	**Between Trees**	**Total**
Agathisanthemum bojeri	223.8	232.1	228.9 (1)	14.1	57.5	40.8 (9)	46.4	16.7	28.1 (18)
Barleria galpinii	39.8	104.7	79.8 (2)	15.6	7.4	10.5 (20)	0.0	145.7	89.8 (6)
Eragrostis rigidior	55.8	56.4	56.2 (3)	120.1	150.6	138.9 (2)	86.3	344.3	245.2 (1)
Linum thunbergii	27.5	65.7	51.1 (4)	-	-	-	0.0	11.6	7.2 (27)
Aristida congesta	60.3	34.1	44.2 (5)	113.6	73.3	88.7 (4)	138.8	117.5	125.7 (3)
Enneapogon cenchroides	105.3	0.0	40.4 (6)	147.9	47.2	85.9 (5)	0.0	13.3	8.2 (26)
Tephrosia capensis	0.0	63.3	39.0 (7)	-	-	-	-	-	-
Vahlia capensis	0.0	63.3	39.0 (7)	-	-	-	0.0	7.9	4.9 (28)
Justicia flava	30.0	24.1	26.4 (8)	36.0	34.8	35.2 (10)	106.4	0.0	40.9 (16)
Monsonia burkeana	62.8	3.6	26.3 (9)	-	-	-	-	-	-
Melinis repens	42.8	13.9	25.0 (10)	155.6	69.5	102.6 (3)	54.7	81.3	71.1 (9)
Abutilon sonneratianum	46.7	10.6	24.7 (11)	9.1	8.4	8.7 (21)	45.6	46.9	46.4 (15)
Evolvulus alsinoides	17.6	16.1	16.7 (12)	8.8	19.9	15.7 (17)	0.0	11.6	7.2 (27)
Hermannia glanduligera	11.4	16.9	14.8 (13)	-	-	-	-	-	-
Melhania prostrata	0.0	21.8	13.4 (14)	8.4	3.7	5.5 (27)	36.8	10.4	20.5 (21)
Aristida adscensionis	5.7	17.3	12.8 (15)	-	-	-	85.2	0.0	32.7 (17)
Digitaria eriantha	17.7	8.4	12.0 (16)	216.5	150.6	176.0 (1)	43.5	105.2	81.5 (7)
Sporobolus ioclados	17.0	4.3	9.2 (17)	-	-	-	236.3	0.0	90.7 (5)
Chloris virgata	19.1	0.0	7.4 (18)	-	-	-	-	-	-
Tephrosia longipes	16.7	0.0	6.4 (19)	0.0	43.6	26.9 (13)	53.0	62.5	58.8 (12)
Ipomoea obscura subsp. *obscura*	9.6	0.0	3.7 (20)	-	-	-	-	-	-
Brachiaria nigropedata	0.0	5.0	3.1 (21)	20.4	0.0	7.8 (23)	0.0	38.3	23.6 (20)
Tephrosia lupinifolia	6.8	0.0	2.6 (22)	-	-	-	20.7	3.7	10.3 (24)
Albuca spp.	5.6	0.0	2.2 (23)	-	-	-	-	-	-
Themeda triandra	0.0	2.7	1.7 (24)	-	-	-	0.0	86.1	53.0 (13)
Zornia milneana	2.1	0.0	0.8 (25)	-	-	-	3.5	0.0	1.3 (35)

...Continues

Table 6.4 continued…

Species	Dry matter yield (kg ha?¹)								
	2003/2004			2004/2005					
	Exposed			Exposed			Protected		
	Under Trees	Between Trees	Total	Under Trees	Between Trees	Total	Under Trees	Between Trees	Total
Pogonarthria squarrosa	-	-	-	26.0	107.1	76.0 (6)	108.6	39.2	65.8 (10)
Panicum maximum	-	-	-	137.0	0.0	52.6 (7)	241.8	0.0	92.8 (4)
Schmidtia pappophoroides	-	-	-	69.7	35.0	48.4 (8)	0.0	27.3	16.8 (22)
Eragrostis gummiflua	-	-	-	80.0	0.0	30.7 (11)	0.0	76.2	46.9 (14)
Sporobolus nitens	-	-	-	76.1	0.0	29.2 (12)	-	-	-
Enneapogon scoparius	-	-	-	56.0	0.0	21.5 (14)	-	-	-
Justicia protracta	-	-	-	0.0	34.2	21.0 (15)	0.0	100.5	61.9 (11)
Cyperus indecorus subsp. *decurvatus*	-	-	-	0.0	29.8	18.3 (16)	-	-	-
Heteropogon contortus	-	-	-	38.4	0.0	14.8 (18)	0.0	119.3	73.5 (8)
Tragus racemosus	-	-	-	0.0	17.8	11.0 (19)	0.0	15.7	9.6 (25)
Rhynchosia totta	-	-	-	15.4	3.6	8.1 (22)	-	-	-
Tragus berteronianus	-	-	-	0.0	11.5	7.1 (24)	0.0	4.4	2.7 (31)
Ceratotheca triloba	-	-	-	0.0	11.3	6.9 (25)	-	-	-
Blepharis integrifolia	-	-	-	10.8	3.6	6.3 (26)	-	-	-
Osteospermum muricatum	-	-	-	9.1	0.0	3.5 (28)	0.0	38.3	23.6 (20)
Commelina africana	-	-	-	8.9	0.0	3.4 (29)	-	-	-
Indigofera holubii	-	-	-	0.0	5.3	3.3 (30)	-	-	-
Kyphocarpa angustifolia	-	-	-	8.2	0.0	3.1 (31)	-	-	-
Haworthia spp.	-	-	-	7.3	0.0	2.8 (32)	-	-	-
Pavonia burchellii	-	-	-	5.7	0.0	2.2 (33)	-	-	-
Urochloa mosambicensis	-	-	-	-	-	-	428.1	0.0	164.4 (2)
Jatropha zeyheri	-	-	-	-	-	-	0.0	44.6	27.5 (19)
Microchloa caffra	-	-	-	-	-	-	0.0	19.8	12.2 (23)
Chamaecrista mimosoides	-	-	-	-	-	-	2.0	5.5	4.2 (29)
Geigeria burkei	-	-	-	-	-	-	0.0	5.1	3.1 (30)
Conyza podocephala	-	-	-	-	-	-	0.0	4.0	2.4 (32)
Striga elegans	-	-	-	-	-	-	0.0	3.8	2.3 (33)
Schkuhria pinnata	-	-	-	-	-	-	0.0	2.5	1.5 (34)
TOTAL	**824.1**	**764.3**	**787.8**	**1414.7**	**925.7**	**1113.4**	**1737.7**	**1609.2**	**1658.3**

- Indicates that the species was not recorded in the survey of that specific season.

Table 6.5: The yield of individual herbaceous species in the *Acacia erubescens* – *Dichrostachys cinerea* Treatment plot. A differentiation was made between subhabitats and the yield of areas exposed to and protected from grazing is also indicated. Numbers in parenthesis indicate the ranking order of the species during each season of the study period.

Species	**Dry matter yield (kg ha^{-1})**								
	2003/2004			**2004/2005**					
	Exposed			**Exposed**			**Protected**		
	Under Trees	**Between Trees**	**Total**	**Under Trees**	**Between Trees**	**Total**	**Under Trees***	**Between Trees**	**Total**
Aristida congesta	69.2	152.7	134.2 (1)	119.7	52.0	67.0 (5)	-	71.8	~
Hermannia spp.	10.9	124.8	99.6 (2)	-	-	-	-	-	-
Urochloa mosambicensis	187.8	71.4	97.2 (3)	133.9	78.1	90.5 (4)	-	249.8	~
Panicum coloratum	18.9	96.6	79.4 (4)	57.5	19.2	27.7 (7)	-	54.6	~
Tephrosia capensis	0.0	84.7	66.0 (5)	-	-	-	-	-	-
Chloris virgata	101.0	41.8	55.0 (6)	-	-	-	-	-	-
Tephrosia lupinifolia	2.7	60.2	47.5 (7)	-	-	-	-	-	-
Bothriochloa radicans	0.0	60.9	47.4 (8)	57.3	0.0	12.7 (8)	-	34.2	~
Justicia flava	116.1	13.6	36.3 (9)	38.8	0.0	8.6 (10)	-	1.6	~
Bothriochloa insculpta	145.1	0.0	32.1 (10)	-	-	-	-	-	-
Schkuhria pinnata	33.6	18.7	21.9 (11)	0.0	0.8	0.6 (21)	-	1.3	~
Zornia milneana	1.1	21.9	17.3 (12)	-	-	-	-	-	-
Kyphocarpa angustifolia	66.5	0.0	14.7 (13)	-	-	-	-	-	-
Brachiaria deflexa	0.0	13.5	10.8 (14)	-	-	-	-	-	-
Hemizygia canescens	0.0	13.8	10.7 (15)	0.0	0.6	0.4 (23)	-	-	-
Eragrostis rigidior	39.9	0.0	8.8 (16)	116.3	156.9	147.9 (1)	-	410.9	~
Abutilon pycnodon	0.0	9.7	7.6 (17)	30.6	0.0	6.8 (11)	-	-	-
Monsonia burkeana	5.2	7.8	7.2 (18)	-	-	-	-	-	-
Abutilon sonneratianum	2.2	8.5	7.1 (19)	-	-	-	-	-	-
Solanum panduriforme	28.6	0.0	6.3 (20)	-	-	-	-	-	-
Kalanchoe lanceolata	27.3	0.0	6.0 (21)	-	-	-	-	-	-
Chamaecrista mimosoides	0.0	7.7	6.0 (21)	-	-	-	-	-	-
Evolvulus alsinoides	0.0	6.4	5.0 (22)	2.1	0.0	0.5 (22)	-	0.2	~
Aristida adscensionis	0.5	5.6	4.5 (23)	-	-	-	-	-	-
Solanum rigescens	18.2	0.0	4.0 (24)	-	-	-	-	-	-
Justicia protracta	13.7	0.0	3.0 (25)	-	-	-	-	8.1	~

…Continues

Table 6.5 continued…

Species	Dry matter yield (kg ha^{-1})								
	2003/2004			2004/2005					
	Exposed			Exposed			Protected		
	Under Trees	Between Trees	Total	Under Trees	Between Trees	Total	Under Trees*	Between Trees	Total
Sporobolus ioclados	1.0	3.0	2.6 (26)	-	-	-	-	-	-
Oxalis depressa	0.0	3.1	2.4 (27)	-	-	-	-	-	-
Conyza podocephala	5.5	0.7	1.7 (28)	4.4	0.0	1.0 (19)	-	-	-
Digitaria eriantha	6.1	0.0	1.4 (29)	153.3	75.6	92.9 (3)	-	-	-
Linum thunbergii	11.2	1.0	1.0 (30)	-	-	-	-	-	-
Hibiscus engleri	0.0	1.0	0.8 (31)	-	-	-	-	-	-
Eragrostis superba	2.0	0.0	0.4 (32)	24.9	0.0	5.5 (13)	-	11.4	~
Pavonia burchellii	1.9	0.0	0.4 (32)	10.1	0.0	2.2 (16)	-	-	-
Blumea dregeanoides	0.4	0.0	0.1 (33)	-	-	-	-	-	-
Senecio latifolius	-	-	-	26.5	163.3	133.0 (2)	-	234.7	~
Heteropogon contortus	-	-	-	230.1	18.8	65.6 (6)	-	247.6	~
Tragus racemosus	-	-	-	0.0	13.2	10.3 (9)	-	-	-
Tragus berteronianus	-	-	-	0.0	7.8	6.1 (12)	-	-	-
Melinis repens	-	-	-	16.6	0.0	3.7 (14)	-	15.3	~
Eragrostis lehmanniana	-	-	-	14.2	0.0	3.1 (15)	-	91.6	~
Nemesia albiflora	-	-	-	5.7	0.0	1.4 (17)	-	-	-
Vahlia capensis	-	-	-	5.0	0.3	1.3 (18)	-	1.4	~
Commelina africana	-	-	-	2.7	0.5	1.0 (19)	-	6.5	~
Portulaca kermesina	-	-	-	3.1	0.0	0.7 (20)	-	-	-
Portulaca quadrifida	-	-	-	2.3	0.0	0.5 (22)	-	-	-
Blepharis integrifolia	-	-	-	2.3	0.0	0.5 (22)	-	1.4	~
Microchloa caffra	-	-	-	-	-	-	-	16.6	~
Unknown	-	-	-	-	-	-	-	9.6	~
Jatropha zeyheri	-	-	-	-	-	-	-	7.9	~
Ipomoea obscura subsp. *obscura*	-	-	-	-	-	-	-	5.0	~
Dicoma spp.	-	-	-	-	-	-	-	1.1	~
TOTAL	**916.6**	**829.1**	**846.4**	**1057.4**	**587.1**	**691.5**	**-**	**1482.6**	**~**

- Indicates that the species was not recorded in the survey of that specific season.
*****No enclosures were placed under trees in the treatment plot due to a limitation on the available enclosures.
~No total could be calculated for the treatment plot due to a lack of data for the under tree subhabitat.

Table 6.6: The yield of individual herbaceous species in the *Acacia erubescens – Dichrostachys cinerea* Control plot. A differentiation was made between subhabitats and the yield of areas exposed to and protected from grazing is also indicated. Numbers in parenthesis indicate the ranking order of the species during each season of the study period.

Species	Dry matter yield (kg ha?^{1})								
	2003/2004			2004/2005					
	Exposed			Exposed			Protected		
	Under Trees	Between Trees	Total	Under Trees	Between Trees	Total	Under Trees	Between Trees	Total
Sansevieria pearsonii	213.7	0.0	107.7 (1)	-	-	-	-	-	-
Urochloa mosambicensis	42.3	164.0	102.7 (2)	154.8	168.5	161.6 (1)	237.2	321.7	279.0 (3)
Chloris virgata	90.4	112.8	101.5 (3)	-	-	-	16.1	29.2	22.6 (12)
Justicia flava	23.0	142.6	81.9 (4)	55.1	18.6	37.0 (13)	54.7	13.8	34.5 (8)
Bothriochloa insculpta	60.2	69.5	64.9 (5)	165.5	0.0	83.4 (7)	-	-	-
Bothriochloa radicans	102.2	21.6	62.2 (6)	221.2	0.0	111.5 (3)	-	-	-
Aristida congesta	0.0	86.0	42.7 (7)	26.3	119.9	72.7 (9)	27.3	25.9	26.6 (10)
Oxygonum sinuatum	60.4	0.0	30.4 (8)	-	-	-	-	-	-
Panicum maximum	60.3	0.0	30.4 (8)	160.9	0.0	81.1 (8)	-	-	-
Kalanchoe lanceolata	38.5	0.0	19.4 (9)	-	-	-	-	-	-
Solanum rigescens	0.0	38.9	19.3 (10)	-	-	-	-	-	-
Heteropogon contortus	12.0	21.3	16.7 (11)	116.6	64.7	90.9 (5)	16.2	47.2	31.6 (9)
Tephrosia lupinifolia	30.6	0.0	15.4 (12)	0.0	9.2	4.6 (31)	-	-	-
Vernonia poskeana	27.0	0.0	13.6 (13)	-	-	-	-	-	-
Cyperus rupestris	26.4	0.0	13.3 (14)	-	-	-	-	-	-
Schkuhria pinnata	10.1	16.1	13.1 (15)	-	-	-	0.0	12.4	6.2 (19)
Digitaria eriantha	9.1	17.1	13.1 (15)	109.9	64.6	87.4 (6)	0.0	33.7	16.7 (15)
Fuirena pubescens	1.6	22.1	11.7 (16)	-	-	-	-	-	-
Bidens pilosa	13.4	7.1	10.3 (17)	-	-	-	-	-	-
Kyphocarpa angustifolia	0.0	20.4	10.1 (18)	-	-	-	-	-	-
Conyza podocephala	4.2	15.7	9.9 (19)	-	-	-	-	-	-
Cymbopogon pospischilii	0.0	19.1	9.5 (20)	68.1	43.4	55.8 (10)	0.0	36.5	18.1 (13)
Melinis repens	0.0	14.1	7.0 (21)	20.7	45.2	32.9 (16)	-	-	-
Eragrostis rigidior	0.0	10.9	5.4 (22)	25.0	246.7	35.1 (14)	204.0	455.2	328.6 (2)
Zornia milneana	0.0	10.6	5.3 (23)	0.0	21.1	10.5 (23)	0.0	12.5	6.2 (19)
Pavonia burchellii	8.6	0.0	4.3 (24)	-	-	-	-	-	-

…Continues

Table 6.6 continued…

Species	Dry matter yield (kg ha^{-1})								
	2003/2004			2004/2005					
	Exposed			Exposed			Protected		
	Under Trees	Between Trees	Total	Under Trees	Between Trees	Total	Under Trees	Between Trees	Total
Tragus berteronianus	0.0	8.1	4.0 (25)	0.0	13.6	6.7 (29)	-	-	-
Hemizygia canescens	0.0	7.5	3.7 (26)	-	-	-	43.7	33.9	38.8 (7)
Eragrostis superba	0.0	7.1	3.5 (27)	-	-	-	-	-	-
Enneapogon cenchroides	6.9	0.0	3.5 (27)	22.8	0.0	11.5 (22)	-	-	-
Eragrostis biflora	5.8	0.0	2.9 (28)	0.0	97.3	48.3 (11)	-	-	-
Tragus racemosus	5.8	0.0	2.9 (28)	0.0	20.2	10.0 (24)	-	-	-
Abutilon sonneratianum	0.0	4.3	2.1 (29)	0.0	70.2	34.8 (16)	-	-	-
Hermannia spp.	4.1	0.0	2.1 (29)	-	-	-	-	-	-
Oxalis depressa	1.7	2.2	2.0 (30)	-	-	-	-	-	-
Albuca spp.	0.0	2.5	1.2 (31)	-	-	-	-	-	-
Aristida adscensionis	0.0	2.3	1.2 (31)	-	-	-	-	-	-
Justicia protracta	2.1	0.0	1.1 (32)	0.0	56.5	28.0 (19)	-	-	-
Panicum coloratum	-	-	-	131.2	106.4	118.9 (2)	193.0	17.8	106.1 (4)
Senecio latifolius	-	-	-	113.4	71.4	92.6 (4)	134.4	37.2	86.2 (5)
Geigeria burkei	-	-	-	0.0	77.9	38.6 (12)	43.7	81.3	62.3 (6)
Eragrostis lehmanniana	-	-	-	0.0	62.6	31.1 (17)	0.0	796.1	394.8 (1)
Eragrostis gummiflua	-	-	-	0.0	56.7	28.1 (18)	-	-	-
Barleria galpinii	-	-	-	35.4	0.0	17.8 (20)	0.0	18.3	9.1 (16)
Jatropha zeyheri	-	-	-	0.0	26.8	13.3 (21)	-	-	-
Vahlia capensis	-	-	-	0.0	17.4	8.6 (25)	-	-	-
Commelina africana	-	-	-	9.3	7.7	8.5 (26)	17.8	16.1	17.0 (14)
Linum thunbergii	-	-	-	0.0	16.7	8.3 (27)	0.0	11.6	5.8 (21)
Tephrosia longipes	-	-	-	16.2	0.0	8.1 (28)	-	-	-
Ceratotheca triloba	-	-	-	4.9	7.8	6.4 (30)	-	-	-
Melhania prostrata	-	-	-	5.1	0.0	2.6 (32)	0.0	46.6	23.1 (11)
Tephrosia capensis	-	-	-	-	-	-	0.0	33.7	16.7 (15)
Microchloa caffra	-	-	-	-	-	-	0.0	13.7	6.8 (17)
Evolvulus alsinoides	-	-	-	-	-	-	0.0	12.8	6.4 (18)

…Continues

Table 6.6 continued…

Species	Dry matter yield (kg ha^{-1})								
	2003/2004			2004/2005					
	Exposed			Exposed			Protected		
	Under Trees	Between Trees	Total	Under Trees	Between Trees	Total	Under Trees	Between Trees	Total
Setaria pumila	-	-	-	-	-	-	0.0	12.4	6.1 (20)
TOTAL	**860.4**	**843.9**	**852.0**	**1462.4**	**1511.1**	**1386.7**	**988.1**	**2119.6**	**1549.3**

- Indicates that the species was not recorded in the survey of that specific season.

The dominant forb species in the Am-Gf Treatment plot displayed varying trends regarding the DM yield and subhabitat preference, but overall the DM yield of the dominant forb species decreased from the first to the second season. Except for *J. flava*, they were absent, or had a low DM yield in the areas protected from grazing. However, several other forb species increased in DM yield over the seasons.

In the Am-Gf Control plot (Table 6.2), the DM yield of *A. congesta* decreased from the 2003/2004 to 2004/2005 season, while *H. contortus* was not recorded during the second season. The same subhabitat preference trend that was found for the dominant grass species in the Am-Gf Treatment plot was found in the Am-Gf Control plot. The overall DM yield of the dominant grasses was much higher in the control plot than in the treatment plot. The DM yield of the dominant forbs decreased from the first to the second season, except for *Evolvulus alsinoides*, which increased slightly in DM yield. The *Tephrosia* species were absent in the Am-Gf Control plot. The relatively high DM yield of the forb *Kyphocarpa angustifolia*, which occurred both under and between trees in the areas protected from grazing, was conspicuous in this control plot.

All the dominant grass species increased in DM yield in the Ca-Gf Treatment plot (Table 6.3) from the 2003/2004 to the 2004/2005 season and the subhabitat preference of these species was the same as in the previously mentioned experimental plots. A striking feature of this treatment plot was the absence of the *Bothriochloa* species and the absence of *P. maximum* in the areas protected from grazing. The dominant forb species in the Ca-Gf Treatment plot decreased in DM yield from the first to the second season and were absent in the areas protected from grazing. Not many forb species were recorded in the areas protected from grazing, but they were abundant in the areas exposed to grazing.

The *Bothriochloa* species were also absent in the Ca-Gf Control plot (Table 6.4). All the dominant grass species increased in DM yield from the 2003/2004 to the 2004/2005 season, especially in the areas protected from grazing. *Heteropogon contortus* and *P. maximum* were not recorded during the first season. *Urochloa mosambicensis* was not recorded in the areas exposed to grazing during both seasons. *Aristida congesta* and *D. eriantha* had a higher proportional contribution to the total DM yield under trees in this control plot, than between trees during both seasons in the areas exposed to grazing. The dominant forb species showed an increased DM yield from the first to the second season, except for *E. alsinoides*. The dominant forbs also had a higher proportional contribution to the total DM yield under trees than between trees.

The DM yield of *A. congesta*, *B. insculpta* and *B. radicans* decreased from the 2003/2004 to the 2004/2005 season in the Ae-Dc Treatment plot (Table 6.5). *Digitaria eriantha*, *Eragrostis rigidior*, *H. contortus* and *U. mosambicensis* increased in DM yield. *Eragrostis rigidior* showed a drastic DM yield increase in the areas protected from grazing. The DM yield of all the dominant forbs decreased from the first to the second season.

In the Ae-Dc Control plot (Table 6.6), *A. congesta*, *D. eriantha* and *H. contortus* increased in DM yield from the 2003/2004 to the 2004/2005 season, but had a lower DM yield in the areas protected from grazing. *Bothriochloa insculpta*, *B. radicans* and *P. maximum* also had a higher DM yield during the second season compared to the first season, but was not recorded in the areas protected from grazing. *Panicum coloratum* had a high DM yield in the areas protected from grazing. The other dominant grasses also increased in DM yield and had the highest yield in the areas protected from grazing. The dominant forb species decreased in DM yield, but other forb species had relatively high DM yields in this control plot, especially *Senecio latifolius*. *Sansevieria pearsonii* had a high DM yield during the first season, but not during the second season. However, it was still present in the control plot.

6.3.3 Relations between tree leaf biomass and herbaceous dry matter yield

Relations between tree leaf biomass, expressed as ETTE ha^{-1}, and the DM yield (total and per subhabitat) of all herbaceous plants, combined, as well as the DM yield (total and per subhabitat) of grasses only, were established for all the experimental plots combined. This was done independently for both seasons in the areas exposed to grazing and the areas protected from grazing. The results of the relations between the DM yield of all herbaceous plants, combined, and the ETTE ha^{-1} are presented in Table 6.7. The relations between the ETTE ha^{-1} and total DM yield, as well as DM yield per subhabitat of all herbaceous plants, combined, were all positive. From the probability (P) values it is apparent that most of the relations were non-significant ($P > 0.05$), except in the case of the DM yield of all herbaceous plants, combined, for the second season and the DM yield between trees for the second season in the areas exposed to grazing.

The correlation coefficients between the DM yield per subhabitat of all herbaceous plants, combined, and the ETTE ha^{-1} were higher between trees in the areas exposed to grazing compared to the areas under trees. In the areas protected from grazing the correlation coefficients were higher under trees than between trees. The correlation coefficients between the total DM yield and the ETTE ha^{-1} were higher in the areas protected from grazing than in the areas exposed to grazing, however, the correlations were non-significant ($P > 0.05$).

Table 6.7: Results of the regression analyses of the relations between the total dry matter yield and the dry matter yield per subhabitat of all herbaceous plants, combined (in the areas exposed to grazing and the areas protected from grazing) of all the experimental plots (dependent variable) and Evapotranspiration Tree Equivalents (ETTE) ha^{-1} (independent variable). {* = significant (P = 0.05); ns = non-significant (P > 0.05)}.

Subhabitat	Season	Regression equation	r	r^2	n	P
Exposed						
Total	Combined	y = 461.78 + 0.06928x	0.5504	0.3029	12	0.0637 ns
	2003/2004	y = 551.57 + 0.02963x	0.5813	0.3379	6	0.2263 ns
	2004/2005	y = 368.61 + 0.10830x	0.8821	0.7782	6	0.0200 *
Exposed						
Under Trees	Combined	y = 736.02 + 0.03151x	0.2703	0.0731	12	0.3955 ns
	2003/2004	y = 618.55 + 0.01961x	0.3157	0.0997	6	0.5422 ns
	2004/2005	y = 897.22 + 0.03717x	0.4163	0.1733	6	0.4116 ns
Between Trees	Combined	y = 351.60 + 0.08543x	0.5667	0.3211	12	0.0547 ns
	2003/2004	y = 533.30 + 0.03208x	0.6472	0.4188	6	0.1648 ns
	2004/2005	y = 146.48 + 0.14050x	0.8254	0.6813	6	0.0431 *
Protected						
Total[a]	2004/2005	y = -1934.4 + 0.4358x	0.9063	0.8214	3	0.2778 ns
Under Trees[a]	2004/2005	y = -8911.8 + 1.2710x	0.8549	0.7309	3	0.3472 ns
Between Trees	2004/2005	y = 943.63 + 0.1303x	0.5590	0.3124	6	0.2489 ns

[a]Only the control plots were used (n = 3) because no data were available for the under tree subhabitats of the treatment plots.

The results of the correlation coefficients between the ETTE ha^{-1} and the total DM yield and DM yield per subhabitat of grasses only (annual and perennial) are presented in Table 6.8. The correlation coefficients for most of the subhabitats were also positive. The only negative correlations were those of perennial grasses under trees during the 2003/2004 season, the total annual grass DM yield during the 2004/2005 season, the DM yield of the annual grasses under trees during the 2004/2005 season and the DM yield of the annual grasses between trees for the 2004/2005 season in the areas exposed to grazing. For the areas protected from grazing the relations between the ETTE ha^{-1} and the total annual grass DM yield as well as the proportional DM yield of the annual grasses under trees, were negative. Most of the correlations were non-significant (P > 0.05).

Table 6.8: Results of the regression analyses of the relations between the total dry matter yield and the dry matter yield per subhabitat of grasses only (in the areas exposed to grazing and the areas protected from grazing) of all the experimental plots (dependent variable) and Evapotranspiration Tree Equivalents (ETTE) ha^{-1} (independent variable). {* = significant (P = 0.05); ** = highly significant (P = 0.01); ns = non-significant (P > 0.05)}.

Subhabitat	Season	Regression equation	r	r^2	n	P
Exposed						
All grasses	Combined	y = 210.46 + 0.064670x	0.4425	0.1958	12	0.1497 ns
	2003/2004	y = 236.42 + 0.023580x	0.4543	0.2064	6	0.3654 ns
	2004/2005	y = 201.77 + 0.102300x	0.9057	0.8203	6	0.0129 *
Perennial grasses	Combined	y = 185.87 + 0.062170x	0.4343	0.1887	12	0.1583 ns
Total	2003/2004	y = 262.50 + 0.014950x	0.3268	0.1068	6	0.5272 ns
	2004/2005	y = 114.60 + 0.107300x	0.9391	0.8819	6	0.0055 **
Under Trees	Combined	y = 572.48 + 0.012180x	0.0823	0.0068	12	0.7994 ns
	2003/2004	y = 436.21 + -0.010250x	-0.2018	0.0407	6	0.7014 ns
	2004/2005	y = 764.81 + 0.026400x	0.2806	0.0788	6	0.5901 ns
Between Trees	Combined	y = 38.941 + 0.081820x	0.4901	0.2402	12	0.1058 ns
	2003/2004	y = 195.15 + 0.023980x	0.3909	0.1528	6	0.4435 ns
	2004/2005	y = -130.01 + 0.139800x	0.8420	0.7089	6	0.0355 *
Annual grasses	Combined	y = 26.033 + 0.002309x	0.1343	0.0180	12	0.6774 ns
Total	2003/2004	y = -30.964 + 0.010570x	0.6078	0.3694	6	0.2006 ns
	2004/2005	y = 95.598 + -0.007418x	-0.4376	0.1915	6	0.3855 ns
Under Trees	Combined	y = -2.321 + 0.004151x	0.2288	0.0523	12	0.4745 ns
	2003/2004	y = -54.482 + 0.013480x	0.6610	0.4369	6	0.1529 ns
	2004/2005	y = 60.247 + -0.006327x	-0.5308	0.2817	6	0.2786 ns
Between Trees	Combined	y = 25.982 + 0.003365x	0.1772	0.0314	12	0.5816 ns
	2003/2004	y = -22.947 + 0.009525x	0.5832	0.3402	6	0.2243 ns
	2004/2005	y = 86.273 + -0.004159x	-0.1931	0.0373	6	0.7140 ns
Protected						
All grasses[a]	2004/2005	y = -1690.4 + 1.27100x	0.9063	0.8214	3	0.2778 ns
Perennial grasses Total[a]	2004/2005	y = -1854.0 + 0.37430x	0.9586	0.9189	3	0.1838 ns
Under Trees[a]	2004/2005	y = -7158.6 + 1.01200x	0.8467	0.7168	3	0.3572 ns
Between Trees	2004/2005	y = 907.33 + 0.08873x	0.3757	0.1411	6	0.4630 ns
Annual grasses Total[a]	2004/2005	y = 141.96 + -0.01379x	-0.7793	0.6074	3	0.4311 ns
Under Trees[a]	2004/2005	y = 290.04 + -0.02928x	-0.7654	0.5858	3	0.4451 ns
Between Trees	2004/2005	y = 9.732 + 4.08E-05x	0.0112	0.0001	6	0.9832 ns

[a]Only the control plots were used (n = 3) because no data were available for the under tree subhabitats of the treatment plots.

In the areas exposed to grazing the correlation coefficients of the perennial grasses with ETTE ha^{-1} were higher between trees, while the correlation coefficients of the annual grasses were higher under trees (Table 6.8). In the areas protected from grazing the correlation coefficients of the perennial and annual grasses were higher under trees. The perennial grasses had higher correlation coefficients in the areas protected from grazing, except between trees, while the annual grasses had higher correlation coefficients in the areas exposed to grazing.

The results of the correlation coefficients between the ETTE ha^{-1} and the total DM yield and DM yield per subhabitat of forbs only, are presented in Table 6.9. From the P-values it is clear that all the correlations were non-significant (P > 0.05). The only negative correlation was found for the 2003/2004 season between trees. All the other correlations were positive. The correlation coefficients of the areas protected from grazing were higher than in the areas exposed to grazing.

Table 6.9: Results of the regression analyses of the relations between the total dry matter yield and dry matter yield per subhabitat of forbs only (in the areas exposed to grazing and the areas protected from grazing) of all the experimental plots (dependent variable) and Evapotranspiration Tree Equivalents (ETTE) ha^{-1} (independent variable). {ns = non-significant (P > 0.05)}.

Subhabitat	Season	Regression equation	r	r^2	n	P
Exposed						
Forbs - Total	Combined	y = 251.32 + 0.004605x	0.0940	0.0088	12	0.7714 ns
	2003/2004	y = 315.14 + 0.006044x	0.1348	0.0182	6	0.7990 ns
	2004/2005	y = 166.84 + 0.006000x	0.2312	0.0535	6	0.6594 ns
Under Trees	Combined	y = 171.91 + 0.014080x	0.2442	0.0597	12	0.4443 ns
	2003/2004	y = 236.82 + 0.016370x	0.2744	0.0753	6	0.5988 ns
	2004/2005	y = 85.478 + 0.014770x	0.6823	0.4656	6	0.1354 ns
Between Trees	Combined	y = 273.25 + 0.001833x	0.0332	0.0011	12	0.9185 ns
	2003/2004	y = 361.10 + -0.001424x	-0.0263	0.0007	6	0.9601 ns
	2004/2005	y = 160.18 + 0.008408x	0.2085	0.0435	6	0.6918 ns
Protected						
Forbs - Total[a]	2004/2005	y = -243.99 + 0.07791x	0.6894	0.4752	3	0.5158 ns
Under Trees[a]	2004/2005	y = -1323.8 + 0.20010x	0.9271	0.8595	3	0.2446 ns
Between Trees	2004/2005	y = -469.10 + 0.09483x	0.7464	0.5571	6	0.0883 ns

[a]Only the control plots were used (n = 3) because no data were available for the under tree subhabitats of the treatment plots.

The results of the correlation coefficients between the total DM yield and DM yield per subhabitat of *P. maximum* and the ETTE ha^{-1} are presented in Table 6.10. The correlation coefficients between the ETTE ha^{-1} and the DM yield (total and per subhabitat) of *P. maximum* were all positive. However, none of these correlations were significant (P > 0.05).

As expected the correlations of *P. maximum* were much higher under trees than between trees. The correlations were also much higher in the areas protected from grazing than in the areas exposed to grazing.

Table 6.10: Results of the regression analyses of the relations between the total dry matter yield and dry matter yield per subhabitat of *Panicum maximum* (in the areas exposed to grazing and the areas protected from grazing) of all the experimental plots (dependent variable) and Evapotranspiration Tree Equivalents (ETTE) ha^{-1} (independent variable). {ns = non-significant ($P > 0.05$)}.

Subhabitat	Season	Regression equation	r	r^2	n	P
Exposed						
Total	Combined	y = -5.907 + 0.003498x	0.3288	0.1081	12	0.2967 ns
	2003/2004	y = -3.486 + 0.001238x	0.2683	0.0712	6	0.6072 ns
	2004/2005	y = -7.685 + 0.005607x	0.4716	0.2240	6	0.3451 ns
Under Trees	Combined	y = -5.362 + 0.003338x	0.3165	0.1001	12	0.3163 ns
	2003/2004	y = -3.486 + 0.001238x	0.2683	0.0712	6	0.6072 ns
	2004/2005	y = -6.524 + 0.005283x	0.4400	0.1936	6	0.3826 ns
Between Trees	Combined	y = -5.453 + 0.000159x	0.1812	0.0328	12	0.5730 ns
	2003/2004	-	-	-	-	-
	2004/2005	y = -1.161 + 0.000324x	0.2607	0.0678	6	0.6177 ns
Protected						
Total[a]	2004/2005	y = -679.16 + 0.09027x	0.7854	0.6169	3	0.4249 ns
Under Trees[a]	2004/2005	y = -600.42 + 0.08060x	0.7661	0.5868	3	0.4444 ns
Between Trees	2004/2005	y = -84.738 + 0.02228x	0.2929	0.0858	6	0.5732 ns

-*Panicum maximum* was not recorded in the between tree subhabitat during this season.
[a]Only the control plots were used (n = 3) because no data were available for the under tree subhabitats of the treatment plots.

6.3.4 Grazing capacity

The seasonal grazing capacity values of each experimental plot, based on the total herbaceous DM yields (habitats and subhabitats combined), are presented in Figure 6.9. Only the DM yields of the areas exposed to grazing were used to determine the grazing capacity. The areas protected from grazing were not used due to the limitation of available enclosures and due to the damage caused to the enclosures by elephants. It is clear that the grazing capacity of the 2004/2005 season for each experimental plot was much higher than during the 2003/2004 season, except for the Ae-Dc Treatment plot.

The grazing capacity of the Am-Gf, Ca-Gf and Ae-Dc Treatment plots was lower than that of their corresponding control plots for the 2003/2004 and 2004/2005 seasons. The Ae-Dc plots had the highest grazing capacity during the first season, followed by the Am-Gf plots, and the Ca-Gf plots had the lowest grazing capacity. In the second season the Am-Gf plots had the highest grazing capacity followed by the Ca-Gf plots and then the Ae-Dc plots.

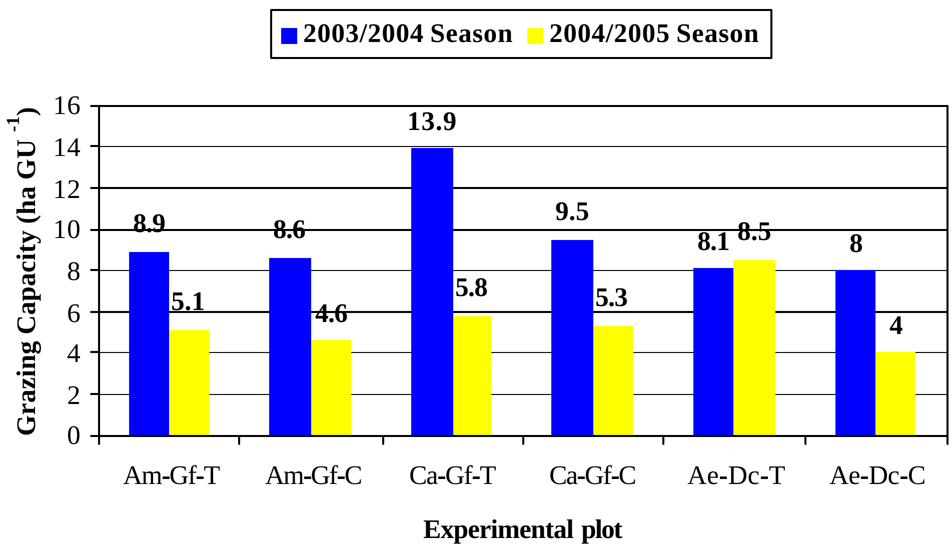


Figure 6.9: Seasonal grazing capacity values calculated for the various experimental plots based on the total herbaceous dry matter yields of each experimental plot (habitats and subhabitats combined for the areas exposed to grazing).

6.4 DISCUSSION

Variation in DM yield between different areas is the result of numerous determinants that can exert an influence individually, or more likely in interaction with each other. These determinants include various environmental factors, for example temperature (Christie, 1981; Epstein *et al.*, 1997), soil texture and soil water-holding capacity (Sala *et al.*, 1988; Snyman, 2000), evapotranspiration (Snyman, 1998), nutrient availability (Chapin, 1991; Du Preez & Snyman, 1993), species composition (Milchunas & Lauenroth, 1993), basal cover (Wiegand *et al.*, 2004), fire (Trollope & Tainton, 1986; Trollope, 1999; Oesterheld & McNaughton, 2000) and the effects of subhabitats created by tree canopies (the number, species and size of trees present in each area) on the herbaceous layer (Frost & McDougald, 1989; Asferachew *et al.*, 1998; Gedda, 2003; Abule *et al.*, 2005). The effects that grazing (herbivory) and trampling can have on herbaceous DM yield are also well documented (Frost *et al.*, 1986; Westoby *et al.*, 1989; O'Connor, 1994; O'Connor & Roux, 1995; Teague & Smit, 1992; Moleele & Perkins, 1998; Drawe, 1999).

Normally after tree thinning the DM yield and thus the grazing capacity of the herbaceous layer is expected to increase. This was found to be true in numerous savanna vegetation types (Grossman *et al.*, 1980; Dye & Spear, 1982; Moore *et al.*, 1985; Pieterse & Grunow, 1985; Stuart-Hill & Tainton, 1988; Richter, 1991; Teague & Smit, 1992; Smit, 1994; Cafe *et al.*, 1999; Smit & Rethman, 1999; Richter *et al.*, 2001). In this study the DM yield of all herbaceous plants, combined, as well as grasses only, in most of the treated plots, increased from the 2003/2004 season to the 2004/2005 season (for the areas exposed to and protected from grazing). This can mainly be contributed to the higher rainfall received during the second season. The competition between herbaceous and woody plants for available soil water, which is the primary determinant of DM yield (Richter, 1991; Smit & Rethman, 1999), would not have been as high as in a dry season. However, the Ae-Dc Treatment plot had a lower herbaceous DM yield during the 2004/2005 season than in the 2003/2004 season and all the treatment plots had a lower DM yield than their corresponding control plots in the areas exposed to and protected from grazing (except the Am-Gf Treatment plot in the areas protected from grazing). The treatment plots also had a lower grazing capacity than their corresponding control plots.

The lower DM yields in the treatment plots in comparison to their corresponding control plots may be ascribed to the number of woody plants removed from the treated areas. When the ETTE ha^{-1} values of the treatment and control plots are compared (see section 4.3.2) it is clear that the treatment plots did not have much lower values than their corresponding control plots, indicating that the number of woody plants removed from the treated areas were not enough to cause a considerable difference in the herbaceous DM yields (assuming the treatment and control plots had a comparative number of ETTE ha^{-1} before the thinning treatments were applied). The regrowth and/or re-encroachment of woody plants after the thinning treatments also contributed to a higher woody DM yield, especially since no follow-up treatments were used and this can suppress herbaceous DM yield. The competition effect of the woody layer on the herbaceous layer in the treatment plots is thus still too high. A further reason for the lower herbaceous DM yield of the treatment plots, in comparison to their corresponding control plots, is the more suitable habitat presented to herbivores in the treatment plots. It is known that most grazing herbivores prefer to graze in open areas and are thus attracted to areas where the woody plants have been thinned.

The high rainfall received during the study period may also have been the reason for the unexpected positive relations between the ETTE ha^{-1} and the DM yield of all the herbaceous plants, combined in the areas exposed to and protected from grazing.

The above average rainfall during the study period would have reduced the negative grass-tree competition interaction for soil water. A complete gradient of tree densities with which to evaluate the effect of grass-tree interactions more accurately was also not present in the study area. The relations between ETTE ha^{-1} and the DM yields of grasses in particular, were expected to be negative. The high grazing pressure due to the large herbivore populations, especially plains zebra and blue wildebeest, would definitely have contributed to this lack of clear grass-tree interactions. Zebra are classified as Type I species, which are capable of causing an initial drastic change in the climax vegetation and the physical environment. Blue wildebeest are Type III species which increase as a result of the impact of Type I species. Type III species have the ability to exploit the new vegetation state created by the impact of Type I species. They further modify the vegetation and perpetuate this new state by their selective feeding habits (Collinson & Goodman, 1982).

The higher DM yield measured in the areas protected from grazing, gives an indication of the potential yield of the herbaceous layer under the current rainfall regime. However, the DM yield measured in the protected areas is only the result of one season’s protection. Thus, recovery and plant succession did not have sufficient time to take place and the DM yield of these areas was still subject to the effects of the heavy grazing of the previous seasons. Therefore, the DM yield of these protected areas in the thinned plots can be expected to increase if protected for a longer period of time, keeping in mind that DM yield is dependent on rainfall. The fact that mainly perennial and more palatable grass species increased in DM yield when the herbaceous species were protected from herbivore utilisation is further proof of a too high grazing pressure in the study area. If the treated areas are protected against excessive herbivore utilisation, the herbaceous yield can be much higher and a grass layer in good condition would provide additional benefits such as better nutrition for the animals, increased protection to the soil and improved infiltration of rainwater.

The positive relations between the ETTE ha^{-1} and DM yield of forbs (in the areas exposed to grazing) indicate that forb DM yield increases with tree density. The same results were found by Smit (1994) in the Mopani veld. This implies that the forbs should be negatively affected by tree thinning. However, in this study the forb species increased substantially, even after the tree thinning treatments. Since many of the forb species are favoured by soil disturbance that was caused to the soil by the Barko Tractor (see Figure 5.3) is a possible reason why forbs were so prominent in the treated areas. This contributed to a lower yield of grasses and a higher yield of forbs (Tables 6.1 to 6.6).

The lower DM yield under trees in the treatment plots in comparison with the DM yield between trees (in areas exposed to grazing) can most likely be ascribed to heavy grazing. The areas under tree canopies became more accessible to herbivores after tree thinning treatments and the plants stay greener for a longer period of time after thinning which will also attract herbivores. It is known that the soil under trees is more nutrient rich than in open areas (Bosch & Van Wyk, 1970; Tiedemann & Klemmedson, 1973; Kellman, 1979; Grossman *et al.*, 1980; Yavitt & Smith, 1983; Stuart-Hill *et al.*, 1987; Belsky *et al.*, 1989; Smit & Rethman, 1989; Smit & Rethman, 1992; Campbell *et al.*, 1993; Smit & Swart, 1994; Ludwig *et al.*, 2004; Hagos & Smit, 2005; Troncoso *et al.*, 2005) mostly due to stemflow and throughfall (Williams *et al.*, 1987; Potter, 1992). The grass species associated with tree canopies e.g. *P. maximum*, usually have a high grazing value. Due to the accessibility of these areas, these grass species were most likely the first plants to be utilised by the herbivores. The higher nutrient status of the soil under trees is reflected in the higher herbaceous DM yield under trees in the areas protected from grazing.

The herbaceous species composition, especially for purposes of veld condition and grazing capacity assessments, is important and thus it is essential to know the characteristics of the dominant herbaceous species (Kellner, 1994; Van Oudtshoorn, 1999). The herbaceous species that contributed most to the DM yield of the experimental plots were mostly species with low or medium grazing value which are associated with the subhabitat between trees, e.g. *Bothriochloa insculpta*, *B. radicans*, *Eragrostis rigidior* and *Heteropogon contortus*. Similar results were found by Smit & Rethman (1989) in the Sourish Mixed Bushveld. *Bothriochloa insculpta* has a good leave yield and due to its size, it is a strong competitive grass that is not easily overtaken by other grasses. *Bothriochloa radicans* is a tufted grass with a spreading shrub-like growth form and it has a low grazing value due to its aromatic leaves and inflorescence. *Eragrostis rigidior* is hard with relatively few leaves, while *H. contortus*, a hardy grass, is described as a good hay and pasture grass, but it is only palatable in early summer (Van Oudtshoorn, 1999).

As expected, *U. mosambicensis* and *P. maximum* were the two grass species that contributed most to the DM yield of the under tree subhabitat. *Urochloa mosambicensis* often grows in light shade (Van Oudtshoorn, 1999) and it is well known that *P. maximum* is associated with tree canopies (Bosh & Van Wyk, 1970; Kennard & Walker, 1973; Belsky *et al.*, 1989; Smit & Rethman, 1992; Smit & Van Romburgh, 1993; Smit & Swart, 1994; Smit, 2005a). The reason why *P. maximum* was recorded in the subhabitat between trees of some treatment plots, especially in the areas where grazing was absent, might be due to tufts of this grass species that remained after tree thinning took place in areas previously overspanned by tree canopies.

These areas can still have a higher soil nutrient status after tree thinning methods were implemented (Smit & Swart, 1994). The positive relations between the ETTE ha^{-1} and the DM yield of *P. maximum* confirm the documented preference of *P. maximum* for areas under tree canopies. Thus if the ETTE ha^{-1} increases, it can be expected that the yield of *P. maximum* will also increase, but only up to a certain tree density, whereafter the competition for soil water and nutrients would become so high that *P. maximum* would show a negative reaction to an increasing ETTE ha^{-1} (Smit & Swart, 1994). The high rainfall during the study period most likely masked this negative reaction of *P. maximum* to high ETTE ha^{-1} values.

The dominant forb species that contributed most to the DM yield in the majority of the experimental plots (*Evolvulus alsinoides*, *Justicia flava* and *Tephrosia* species) had a lower DM yield in most of the experimental plots during the second season, especially in the areas protected from grazing. This does not imply that the veld is in a better ecological state or that the DM yield of desired herbaceous species has increased. This is accentuated by the fact that many other forb species increased in DM yield and most of these forbs are associated with disturbed areas, like bare patches and overgrazed veld (Fabian & Germishuizen, 1997). This, once again, confirms that herbivore populations in the study area are too large which reduce the positive effect the thinning treatments were supposed to have in the form of higher grass DM yields.

The occurrence of overgrazing in the study area, especially in the Am-Gf plots, was further demonstrated by the fact that grass species such as *Brachiaria nigropedata*, a climax grass with a high DM yield, which is well utilised by grazers (Van Oudtshoorn, 1999), was only recorded in the areas protected from grazing. This is one of the first grasses to disappear under sustained heavy grazing. *Panicum maximum* also had a low DM yield in the areas exposed to grazing and its absence under tree canopies in the Am-Gf Treatment plot (with no enclosure to protect it from grazing) is evidence of the intolerance of this species to sustained heavy grazing. *Panicum maximum* is a preferred grazing species and under heavy grazing, *P. maximum* is often replaced by species with a lower succession status. In this study *P. maximum* was largely replaced by *U. mosambicensis* under tree canopies.

Other evidence of the negative effect of overgrazing was also found in the study area, such as the decrease of the most desirable forb species in the Ca-Gf Treatment plot together with the increase of other less desirable forbs and the relatively high DM yields of *Melinis repens* and *Pogonarthria squarrosa*. The latter two grass species are both weak perennial grasses with a low grazing value that normally occur in disturbed places (Van Oudtshoorn, 1999).

The relatively high DM yields of palatable climax species such as *Brachiaria nigropedata*, *Schmidtia pappophoroides* and *Themeda triandra* in the areas protected from grazing in the Ca-Gf plots, also support the fact that restoration of the encroached areas will not be achieved unless the current heavy grazing regime is reduced substantially. The total absence of *P. maximum* in the Ca-Gf Treatment plot and the absence of *D. eriantha* in the areas protected from grazing are of importance. *Digitaria eriantha* was present in this treatment plot, but in such low numbers that it was not recorded in the enclosures.

Other examples of the result of overgrazing include the drastic DM yield increase of *Eragrostis rigidior*, a relatively palatable species, from the 2003/2004 to the 2004/2005 season in the areas exposed to grazing in the Ae-Dc Treatment plot. Heavy grazing is, once again, the most likely reason why *P. maximum* was not recorded in the Ae-Dc Treatment plot. The high DM yield of forb species, especially *Senecio latifolius* (an annual weed that can survive for more than one season; Bromilow, 2001), and unpalatable grass species, like *Melinis repens* and *Microchloa caffra*, indicates that the herbaceous layer of the Ae-Dc Treatment plot was not in a good condition. However, other highly palatable climax grass species like *Panicum coloratum* (Van Oudtshoorn, 1999) had a relatively high DM yield in this experimental plot, which can be the result of the above average rainfall received during the study period. *Eragrostis lehmanniana*, a sub-climax grass species that is a valuable grazing species in arid parts, had a high DM yield in the areas protected from grazing in the Ae-Dc Control plot. This grass species is usually associated with previously disturbed areas, such as in overgrazed veld (Van Oudtshoorn, 1999). This grass species can thus in time be replaced by climax species, provided that the areas are not exposed to heavy grazing again.

These results indicate that the classical theory of plant succession does apply to some extent to the study area. The fact that forb species and grasses with a low succession status were the most abundant species in the treatment plots in the areas exposed to heavy grazing indicates that herbivores play an important role in determining the succession status of the study area. The drastic change in the herbaceous species that contributed over the two seasons to the DM yield of each experimental plot between the areas exposed to and protected from grazing (mostly due to rainfall) indicates non-equilibrial ecosystem trends. This substantiates the results of Chapter 5. Thus, both equilibrial (a stable ecosystem) and non-equilibrial trends seem to apply to the study area.

Soil characteristics are another important determinant of the DM yield and grazing capacity of the study area. Soil characteristics, like texture and water-holding capacity, can contribute to the differences in DM yield between the different species dominated plots. The Ca-Gf plot had shallow, gravelly soil, while the Am-Gf and Ae-Dc plots had deeper, sandier soil. The gravelly soil of the Ca-Gf Treatment plot can impede herbaceous plant growth and only herbaceous plants with relatively shallow, wide-spreading root systems and relatively small above-ground plant parts are adapted to this habitat. The absence of the *Bothriochloa* species in the Ca-Gf plots can be a result of the soil of these experimental plots. The soil was relatively shallow and gravelly and it is known that these *Bothriochloa* species prefer relatively heavy, fertile soil (Van Oudtshoorn, 1999). The soil characteristics of each experimental plot are described in more detail in Chapter 7.

The changes in DM yield and grazing capacity in the different plant species dominated plots can also be attributed to plant species composition differences that are dependent on various ecological factors as mentioned in the beginning of the discussion. The fact that species composition differences, which can be attributed to differences in ecological factors such as rainfall, can contribute to differences in DM yield and grazing capacity of different areas, is reported worldwide (Dye & Spear, 1982; Scanlan & Burrows, 1990; Vetaas, 1992; Smit & Rethman, 1992; O'Connor, 1994; Moyo & Campbell, 1998; Drawe, 1999; Hacker *et al.*, 1999; Abule *et al.*, 2005; Snyman & Du Preez, 2005).

Although the grazing capacity values found in the various experimental plots were low during the 2003/2004 season and increased relatively during the 2004/2005 season, it is important to keep in mind that the grazing capacity values given for the experimental plots in Marakele Park are only a broad guideline and should not be seen as absolute values. It is better to use conservative values as a guideline to prevent the total number of grazer units from exceeding the grazing capacity during dry seasons. It is important that the stocking rate must be of such a manner that the veld can still sustain the animals during dry seasons. Specific research on the utilisation of forbs by herbivore game species and on the contribution of specific grass species to the diet of herbivore game species, depending on the type of grazers (e.g. long and short grass grazers) is necessary in this specific study area to give a more accurate estimation of the grazing capacity of Marakele Park.

6.5 CONCLUSIONS

An important objective and main motivation for the initial tree thinning treatments were to increase the herbaceous DM yield, and thus the grazing capacity, of the herbaceous layer. From the results of this investigation it is clear that this objective was not effectively met. The herbaceous layer did not respond to the tree thinning treatments as expected and the DM yield of the herbaceous layer in the treatment plots did not differ substantially from the control plots.

The main reasons for the lack of the expected response to tree thinning are the number of ETTE ha^{-1}, grazing pressure, subhabitat differentiation, rainfall, soil characteristics and the interactive effect that these factors have on each other.

The ETTE ha^{-1} present in the treatment plots was still too high, mostly due to regrowth and re-encroachment, to make a considerable difference in the DM yield of the herbaceous layer. The competition effect that the woody species exert on the herbaceous layer for soil water and nutrients is still a limiting factor in the areas where tree thinning took place.

The current grazing pressure, especially of high density, selective, short grass grazers, appears to have effectively neutralised the anticipated positive effect of reduced competition from the woody layer. This is demonstrated by the substantial differences in DM yield between areas protected from grazing, compared to areas exposed to grazing.

Subhabitat differentiation proves to be an important consideration since there are indications that the subhabitat presented under the canopies of mature trees, in particular, is valuable. This is especially clear in the occurrence of grass species with high grazing values, e.g. *P. maximum*, and in soil enrichment.

The dominant and most abundant species that were found in the areas exposed to grazing, in each experimental plot, were species with a low grazing value, which normally occur in disturbed, overgrazed veld. The fact that more valuable grazing species were recorded in the areas protected from grazing indicates that the plant succession theory does play a role in the study area, and that if the areas are protected for a longer period, climax species would probably prevail as the dominant species. However, due to the effects of the variability in rainfall and the high grazing pressure, it appears that the study area displays both equilibrial and non-equilibrial trends.

Rainfall also proved to be a very important determinant in the response of herbaceous plants to competition from the woody plants and to grazing. Under the current grazing regime present in Marakele Park, the herbaceous plants were only able to partially overcome the effect of heavy grazing during above-normal wet seasons.

The inherent potential of the soil of an area also proved to be an important determinant of the magnitude of the response of the herbaceous layer. The plots on deeper, more fertile soil, e.g. the Am-Gf and Ae-Dc plots, responded better to the thinning treatment in terms of DM yield than the plots on shallow, gravelly soil, e.g. the Ca-Gf plots. This effect is particularly notable during a wet season, where the limited availability of nutrients in the shallow, gravelly soils reduces the potential effective use of soil water.

Thinning of woody species with the objective of increasing productivity of the herbaceous layer, especially grasses, would invariably involve a compromise situation where some trees should be left for the sake of the qualitative benefits on the herbaceous layer. However, the decision on how many trees should be left during thinning operations must preferably be based on an integrated approach where other considerations like browse yield are also incorporated.

CHAPTER 7

THE INFLUENCE OF THE TREE THINNING TREATMENTS ON THE PHYSICAL PROPERTIES OF SOIL

7.1 INTRODUCTION

Soil is an integral part of the biosphere. It consists of organic and inorganic matter in the form of solids, liquids and gases, but in addition to these inert materials the soil provides a habitat for many organisms that are essential for the maintenance of the overlying plant communities. Soil is the principal source of nutrients and water for most terrestrial plant species and they in turn provide the bulk of the organic litter necessary for the maintenance of the living soil community. Differences in soil properties produced over time by the interaction of parent materials, climate, topography and vegetation, have a profound effect on the biological systems that they support. The inorganic mineral fraction of a soil influences physical properties such as texture and structure and consequently affects soil moisture, aeration and other properties. Similarly, soil chemistry is partly determined by the breakdown of primary minerals through weathering processes, although the supply of plant-available nutrients is principally controlled by the amount and type of organic matter that is present (Archibold, 1995).

Addition of organic matter and other materials to the soil and losses from leaching, seepage and erosion, together with transfers and transformations within the soil itself, result in the gradual development of different soil types (Simonson, 1959; Troeh & Thompson, 1993). The distinctive combination of factors functioning in different parts of the world has resulted in many unique soil types. Soil and the parent material from which it originates, have a great influence on the composition and structure of the vegetation of different areas (Brady & Weil, 1996). The soil and its processes do not form an independent system, but are rather part of the larger ecosystem, which includes vegetation and its comprising environment. The properties of a mature soil profile are partially produced by the vegetation and their formation is possible only because of the kind of vegetation supported by that soil in a given climate (Troeh & Thompson, 1993).

While the base-richness of the parent material is initially important in determining soil fertility, biological activities are important in the establishment and maintenance of localised areas of enhanced soil fertility (Scholes, 1991). Nutrients, such as nitrates, phosphorus, a series of anions and cations and various trace elements are essential to the nutrition of plants (Bell, 1982), and act as determinants of the composition, structure and productivity of vegetation (Smit, 1994).

The geographic distribution of natural plant communities is dependent on several interrelated factors, including: (i) the environment, i.e. climatic, biotic and edaphic factors; (ii) the physiological reaction of plants within their limits of tolerance for environmental conditions; and (iii) genetic factors that determine tolerance limits, generate variability and create potential for adaptation and population development (Fraser *et al.*, 1987).

The objectives of this study were:

- to provide an accurate description of the soil properties of each individual experimental plot,
- to determine if there were variations in the soil properties of the different experimental plots,
- to establish whether the tree thinning treatments resulted in any short-term changes of the soil properties, and
- to determine whether differences in soil type contributed to the differences in plant species composition between vegetation units.

7.2 PROCEDURE

7.2.1 Soil sampling

Topsoil samples (to a depth of 150 mm) were taken with a soil auger at ten random locations in each experimental plot (the 2 coppice plots were also included in the soil analyses). Each set of ten samples was bulked, thoroughly mixed, and one subsample of approximately 1 kg was taken for analyses. The soil samples were taken in April 2004 and stored in sealed plastic bags until analyses could be conducted.

7.2.2 Soil analyses

Before analyses, each soil subsample was placed in an oven for a period of one week to ensure that the soil was completely dry. Analyses conducted on the soil samples included exchangeable cations, viz. calcium (Ca), potassium (K), magnesium (Mg) and sodium (Na), total nitrogen (N), organic carbon (C), phosphate (P), pH (H_2O) and pH (KCl), electrical resistance (?) and texture (% silt, clay and sand). A saturation extract of the soil was also done to determine the Sodium Adsorption Ratio (SAR) (from the exchangeable cations present in the saturation extract), the pH and the soil conductivity of the extract. The soil analyses were done in the soil chemistry laboratory of the Department of Soil, Crop and Climate Sciences of the University of the Free State, South Africa, according to the standards of The Non-affiliated Soil Analyses Work Committee (1990).

7.2.3 Data analyses

The Cation Exchange Capacity (CEC) values for each experimental plot were calculated from the exchangeable cation contents. It was assumed that the CEC was a function of only the cation (Ca, K, Mg and Na) contents of the soil. The Al^{3+} and H^{-} values also contributed to the CEC values, but they were not measured in this study. In order to convert the exchangeable cation values (mg kg^{-1}) to equivalent values ($cmol_c$ kg^{-1}), which can be compared with each other, the values for calc ium (Ca^{2+}), potassium (K^{+}), magnesium (Mg^{2+}) and sodium (Na^{+}) were divided by 200, 391, 122 and 230 (Du Preez, personal communication*****), respectively. The ratios between the different cations were also determined and compared to the accepted 'normal' values of soil (F.S.S.A., 2003). It is important to keep in mind that the 'normal' values are only relative values and that small variations from these values may not be significant.

The Exchangeable Sodium Percentage (ESP) and Exchangeable Potassium Percentage (EPP) were also calculated. It is known that the ESP can have an influence on plant species. The permeability (infiltration ability) of a soil also depends largely on the ESP and it is an important determinant of crusting of exposed soil surfaces (Smit, 1994). The mean ESP and EPP values for each experimental plot were calculated using the following formulas:

$$ESP = \frac{\text{Exchangeable Na}}{\text{CEC}} \times 100 \quad \text{and} \quad EPP = \frac{\text{Exchangeable K}}{\text{CEC}} \times 100$$

Where: CEC = Cation Exchange Capacity ($cmol_c$ $kg^{?1}$)

The saturation extract was also used to verify the ESP values. The SAR has a good correlation to the ESP and is much easier to calculate accurately. The SAR was estimated using the following formula:

$$SAR = \frac{Na}{\sqrt{1/2(Ca + Mg)}}$$

The cation values determined during the saturation extract were also converted to equivalent values to determine the SAR. Due to the lack of replicates of the experimental plots, analysis of the data was restricted to simple descriptive techniques.

*****Du Preez, C.C., Department of Soil, Crop and Climate Sciences, P.O. Box 339, University of the Free State, Bloemfontein, 9300.

7.3 RESULTS

7.3.1 Cation concentrations

7.3.1.1 *Calcium (Ca)*

The calcium (Ca) contents of the plots dominated by *Acacia mellifera* were much higher than in the *Acacia erubescens* and *Combretum apiculatum* dominated plots (Figure 7.1; Appendix G1). The Am-Gf Treatment plot and especially the Am-Gf Coppice plot had a higher Ca contents than the control plot. The same result was found for the Ae-Dc Treatment and Control plot. However, the opposite was found in the *C. apiculatum* dominated plots. The Ca-Gf Treatment and Coppice plot had a lower Ca contents than the control plot.

7.3.1.2 *Potassium (K)*

Small differences in the potassium (K) contents of the different plant species dominated plots were found, but they were not substantial. The Am-Gf plots had the highest K contents, while the Ae-Dc plots had the lowest K contents (Figure 7.1; Appendix G1). The K contents displayed little change after tree thinning took place. The treatment plots had lower K contents in comparison to the control plots, except for the Ae-Dc plots, where the treatment and control had the same K contents.

7.3.1.3 *Magnesium (Mg)*

From Figure 7.1 (also see Appendix G1) it is evident that all the treatment plots had marginally lower Mg contents than the control plots. The Am-Gf and Ae-Dc plots had higher Mg contents than the plots dominated by *C. apiculatum*.

7.3.1.4 *Sodium (Na)*

The sodium (Na) contents for the *A. mellifera*, *C. apiculatum* and *A. erubescens* dominated plots did not differ to a great extent (Figure 7.1; Appendix G1). A larger difference was, however, found between the Am-Gf Treatment and Am-Gf Control plots with the treatment plot having a higher Na contents than the control plot. The difference in Na contents was not considerable for the Ca-Gf plots, where the treatment plot had a marginally lower Na contents compared to the control plot. A lower Na contents was also found in the Ae-Dc Treatment plot in comparison to its control plot.

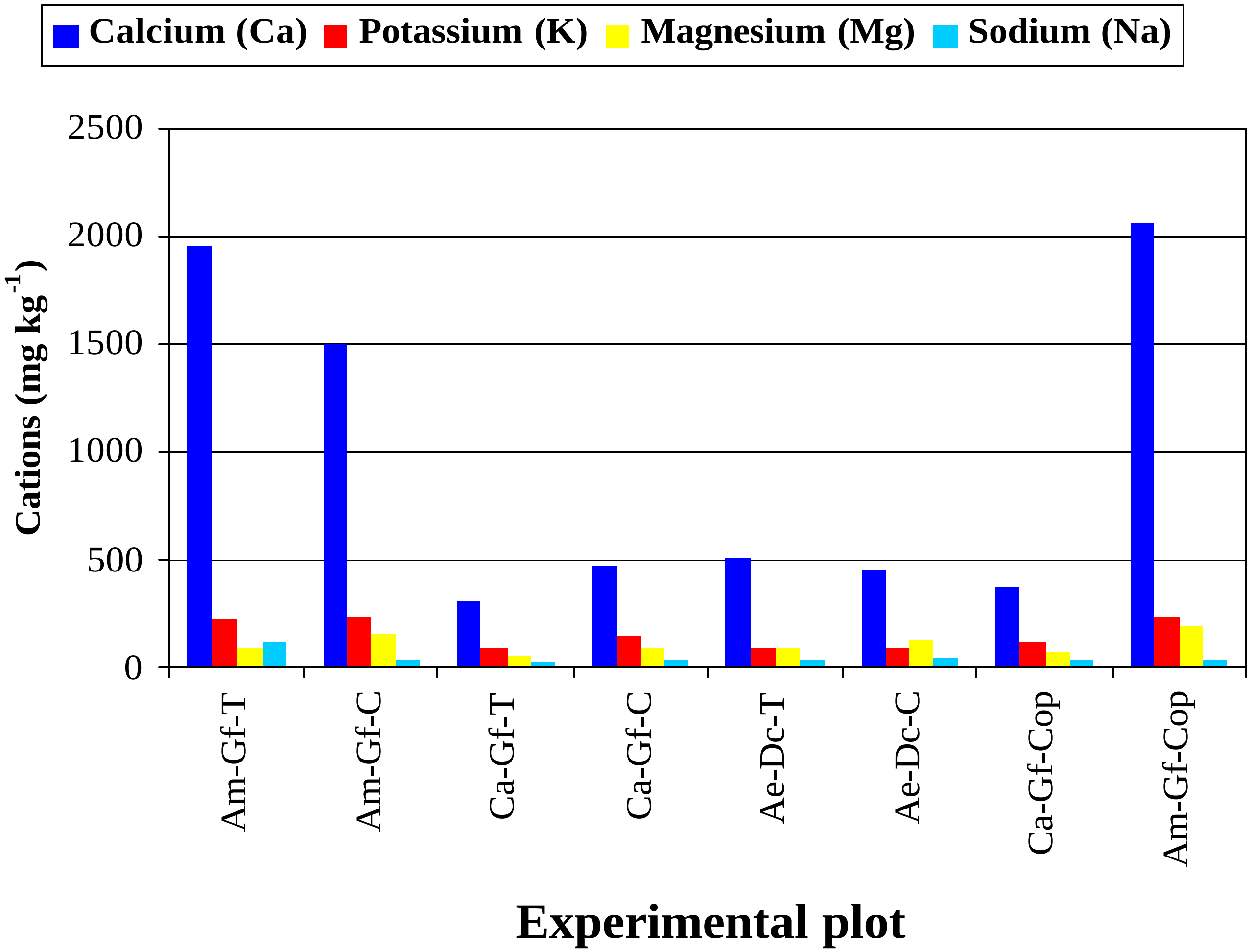


Figure 7.1: The exchangeable cation contents (mg kg?¹) of topsoil samples taken in each experimental plot during April 2004.

7.3.1.5 *Cation ratios*

The ratios between Mg and K, calculated from the equivalent values, are presented in Table 7.1. When these values were compared to the normal values (3 – 4 $cmol_c\ kg^{-1}$) expected for this cation ratio (F.S.S.A., 2003), it was found that all the experimental plots, except the Ae-Dc Treatment and Control plots, had values lower than the normal. It is also noteworthy that the treatment plots also had lower values than the control plots.

The association between the Ca/Mg and the (Ca + Mg)/K ratios is also presented in Table 7.1. When the values of the Ca/Mg ratio were compared to the expected normal values (1.5 – 4.5 $cmol_c\ kg^{-1}$) (F.S.S.A., 2003), it was found that all the experimental plots, except the Am-Gf dominated plots (including the coppice plot), had ratios within the normal range. The Am-Gf dominated plots had ratios higher than normal, especially the treatment and coppice plots. All treatment plots had higher ratios than the control plots.

When the values of the (Ca + Mg)/K ratio were compared to the normal range (10 – 20 $cmol_c\ kg^{-1}$) (F.S.S.A., 2003), it was evident that all the *Acacia* dominated plots had ratios within the normal range, but the *C. apiculatum* dominated plots had ratios below normal. All the treatment plots had higher ratios than the control plots.

When the ordinary cation ratio (Ca:Mg:K:Na) of the different experimental plots was compared to the expected normal values (65:25:8:2) (F.S.S.A., 2003), it was found that the Am-Gf dominated plots were the only plots where the ratio, especially the Ca and Mg percentages, differed considerably from the normal ratio (Table 7.1).

7.3.1.6 *Cation Exchange Capacity (CEC), Exchangeable Sodium Percentage (ESP) and Exchangeable Potassium Percentage (EPP)*

The CEC, ESP and EEP values of each experimental plot is presented in Table 7.1. It is clear that the CEC values of the Am-Gf plots were much higher than the Ca-Gf and Ae-Dc plots. The Ca-Gf and Ae-Dc Treatment plots had marginally lower CEC values than the control plots, while the Am-Gf Treatment plot had a higher CEC value than the control plot. The ESP values of all the plots are well below the level (ESP – 15%) at which dispersion will normally occur. When the EPP values were compared to the expected normal values (3 – 7%) (F.S.S.A., 2003), it was found that the *Acacia* dominated plots had values in the normal range, but the *C. apiculatum* dominated plots had much higher values. This corresponds with the lower K contents that were found in these plots (see section 7.3.1.2). Differences between the EPP values of the treatment and control plots were small.

Table 7.1: A summary of all the cation ratios that were tested during this study (values were calculated from the equivalent values (cmol$_c$ kg^{-1}) of the measured values). The range of normal expected values, where known, was included in the table to assist in comparison purposes.

Experimental plot	**CEC* (cmol$_c$ kg$^{?1}$)**	**CEC$_{Clay}$ (cmol$_c$ kg$^{?1}$)**	**Ca ÷ Mg**	**Mg ÷ K**	**(Ca + Mg) ÷ K**	**Ca:Mg:K:Na**	**EPP (%)**	**ESP (%)**
Normal values			**1.5 – 4.5**	**3 – 4**	**10 – 20**	**65:25:8:2**	**3 – 7**	
Acacia mellifera – Grewia flava Treatment	11.63	72.69	12.50	1.34	18.16	84:7:5:4	4.99	4.47
Acacia mellifera – Grewia flava Control	9.51	39.63	6.01	2.08	14.60	79:13:6:2	6.31	1.58
Combretum apiculatum – Grewia flava Treatment	2.40	17.14	3.36	2.04	8.91	66:19.5:9.5:5	9.58	5.00
Combretum apiculatum – Grewia flava Control	3.62	24.13	3.11	2.05	8.43	65:21:10:4	10.22	3.59
Acacia erubescens – Dichrostachys cinerea Treatment	3.76	26.86	3.23	3.33	14.08	69:21:6:4	6.38	3.72
Acacia erubescens – Dichrostachys cinerea Control	3.78	22.24	2.17	4.38	13.88	60:28:6:6	6.35	5.56
Combretum apiculatum – Grewia flava Coppice	2.87	28.70	3.25	1.84	7.81	64:20:11:5	10.80	4.88
Acacia mellifera – Grewia flava Coppice	12.61	45.04	6.69	2.52	19.43	82:12:5:1	4.84	1.19

*****Generalised relationship between soil texture and Cation Exchange Capacity (Miller & Gardiner, 1998):

Soil Texture	CEC (cmol$_c$ kg$^{?1}$) (Normal Range)
Sands:	1 – 5
Fine sandy loams:	5 – 10
Loams and silt loams:	5 – 15
Clay loams:	15 – 30
Clays:	> 30

7.3.2 Soil pH

The pH values for each experimental plot measured from the saturation extract are presented in Figure 7.2. The pH values of the Am-Gf dominated plots were near neutral (pH 7) with a tendency towards alkalinity. The same result was found for the plots dominated by *C. apiculatum*, except for the Ca-Gf Treatment plot, which had a lower pH (more acidic). The Ae-Dc dominated plots also had a marginally lower pH (more acidic). The *Acacia* dominated treatment plots (including the coppice plot) had a higher pH than the control plot; whereas the *C. apiculatum* dominated treatment plots (including the coppice plot) had a lower pH than the control plot. These results correspond with those of the pH (H_2O) (Figure 7.3) and pH (KCl) (Figure 7.4).

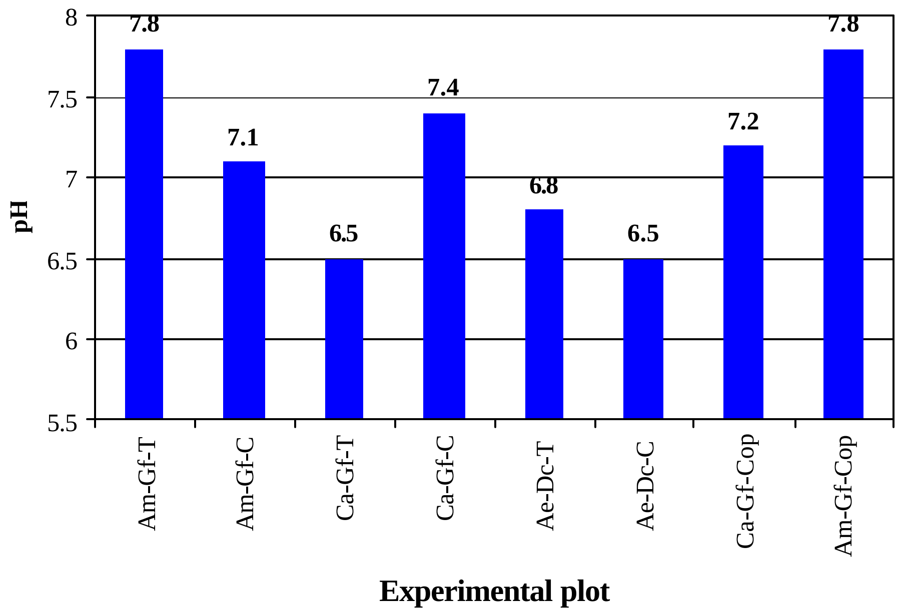


Figure 7.2: The pH value of the saturation extract of topsoil samples taken in each experimental plot during April 2004.

Figure 7.3 shows the variation in pH (H_2O) values between the experimental plots. In the plots dominated by *Acacia* species, the pH (H_2O) values were higher in the treatment plots than in the control plots. There was, however, a considerable difference between the pH (H_2O) of the Am-Gf and Ae-Dc plots. The pH (H_2O) of the Am-Gf plots were much higher (more alkaline) than that of the Ae-Dc plots, which were more acidic. Figure 7.4 shows that the pH (KCl) for the experimental plots was very similar to that of the pH (H_2O) values. The only difference was that the pH (KCl) values were lower than those of the pH (H_2O).

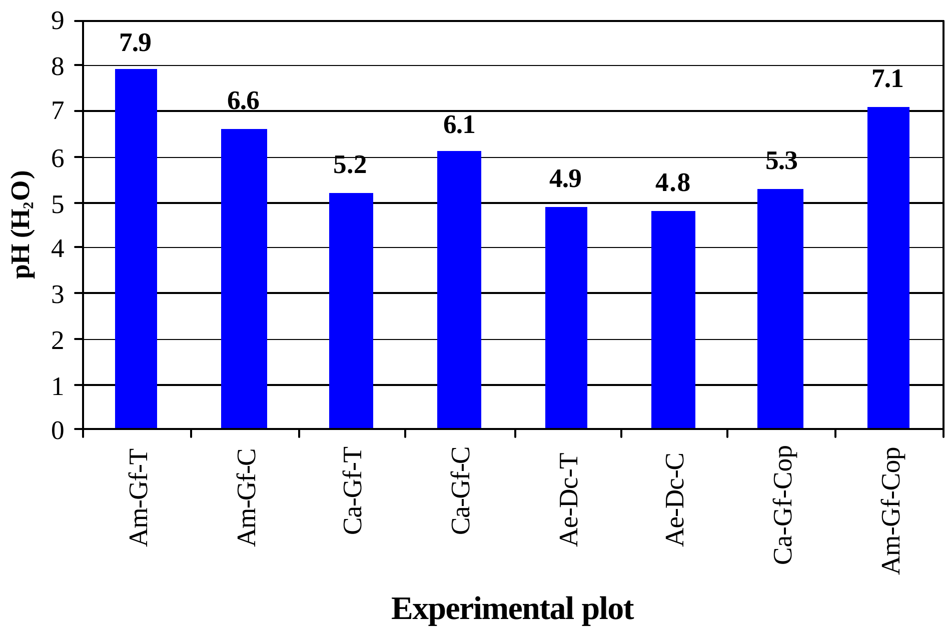


Figure 7.3: The pH (H_2O) of topsoil samples taken in each experimental plot during April 2004.

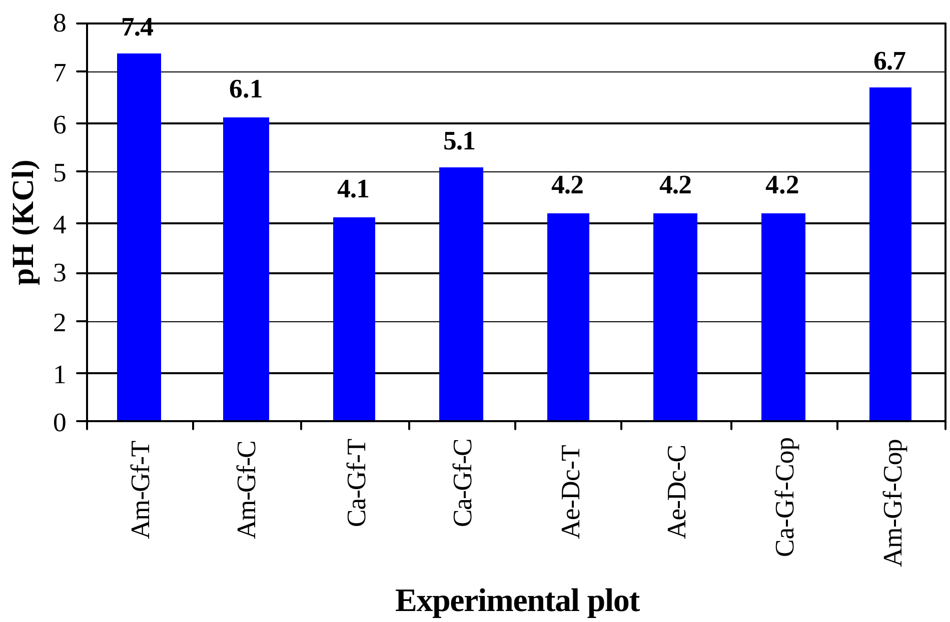


Figure 7.4: The pH (KCl) of topsoil samples taken in each experimental plot during April 2004.

7.3.3 Electrical conductivity and Electrical resistance

The electrical conductivity values of each experimental plot are presented in Figure 7.5. When these conductivity values are compared to the electrical resistance values (Figure 7.6) it is clear that the higher the electrical conductivity the lower the electrical resistance of the soil. Only the Ae-Dc Control plot and especially the Am-Gf Control plot had relatively higher conductivity values. The treatment plots of the Am-Gf, Ca-Gf and the Ae-Dc dominated plots all had lower conductivity values than the control plots.

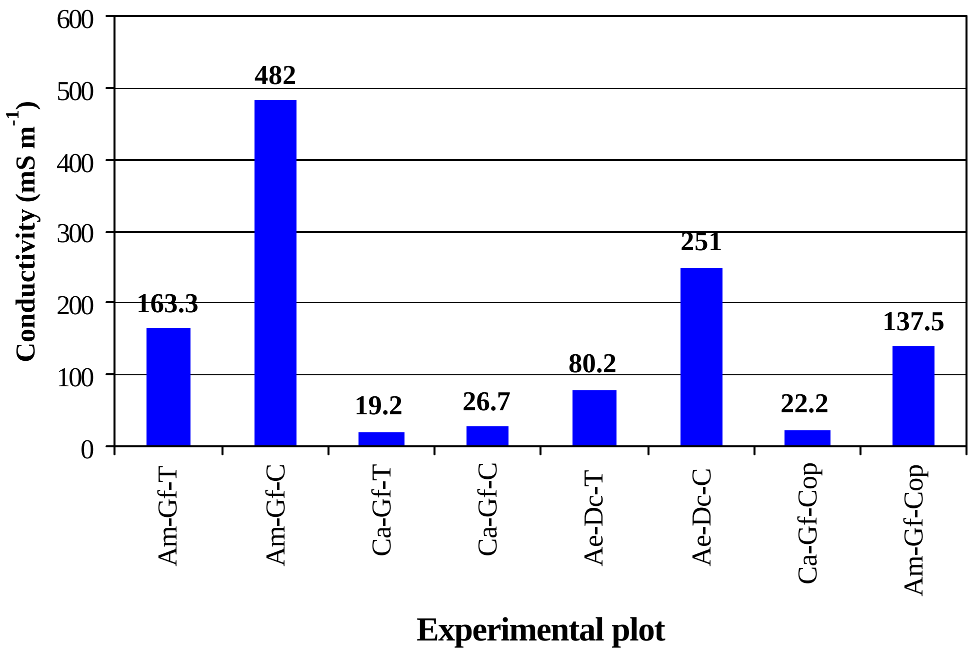


Figure 7.5: The electrical conductivity values ($mS\ m^{-1}$) of the saturation extract of topsoil samples taken in each experimental plot during April 2004.

From Figure 7.6 a considerable difference is evident between the electrical resistances of the experimental plots dominated by *C. apiculatum* and the plots dominated by *Acacia* species. The electrical resistance of the soil of the Ca-Gf plots was much higher than that of the *Acacia* plots. It was found that the electrical resistance of the soil of all treatment plots was higher than that of the control plots. The soil of the Ca-Gf Coppice plot also showed a much higher electrical resistance than the soil of the Am-Gf Coppice plot.

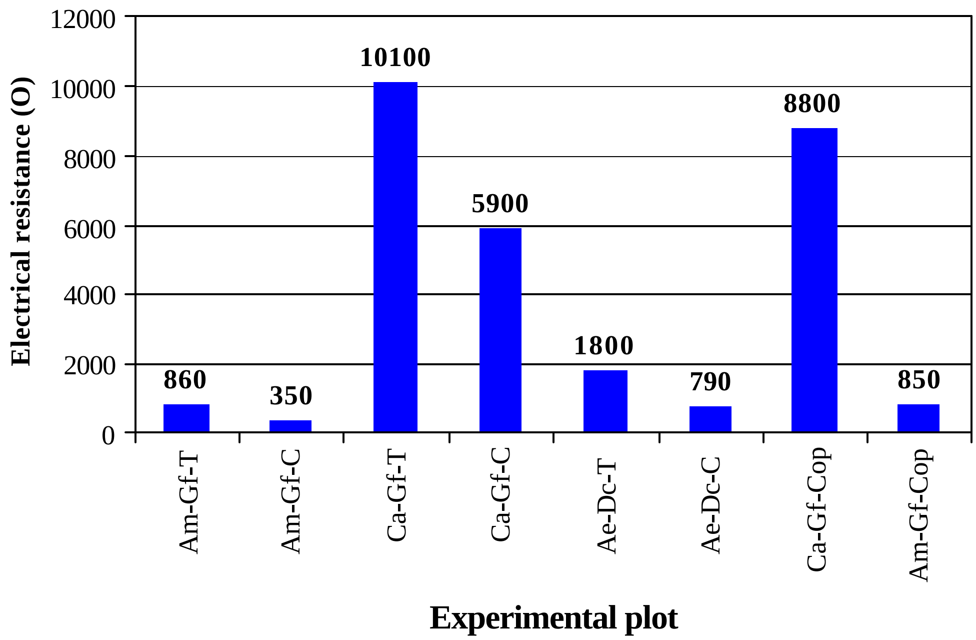


Figure 7.6: The electrical resistance (?) of topsoil samples taken in each experimental plot during April 2004.

7.3.4 Sodium Adsorption Ratio (SAR)

The SAR for each experimental plot is presented in Table 7.2 (also see Appendix G2). The SAR values of the various species dominated plots were relatively variable. The Am-Gf and Ae-Dc Treatment plots had lower values than the control plots, while the Ca-Gf Treatment plot had a higher value than the control plot, especially the Ca-Gf Coppice plot.

Table 7.2: The Sodium Adsorption Ratio (SAR) of the saturated extract of topsoil sampled in April 2004 for each experimental plot.

Experimental plot	SAR ($cmol_c$ kg?¹)
Acacia mellifera-Grewia flava Treatment	0.08
Acacia mellifera-Grewia flava Control	0.24
Combretum apiculatum-Grewia flava Treatment	0.30
Combretum apiculatum-Grewia flava Control	0.24
Acacia erubescens-Dichrostachys cinerea Treatment	0.13
Acacia erubescens-Dichrostachys cinerea Control	0.70
Combretum apiculatum-Grewia flava Coppice	1.33
Acacia mellifera-Grewia flava Coppice	0.10

7.3.5 Nitrogen (N), Organic carbon (C) and Carbon:Nitrogen ratio

From Figure 7.7 it is evident that there were not large differences in the N contents of the different experimental plots. It does, however, show that the total N contents of the treatment plots were lower than those of the control plots, except for the Am-Gf Coppice plot. The N content of the latter plot was considerably higher than that of the other plots.

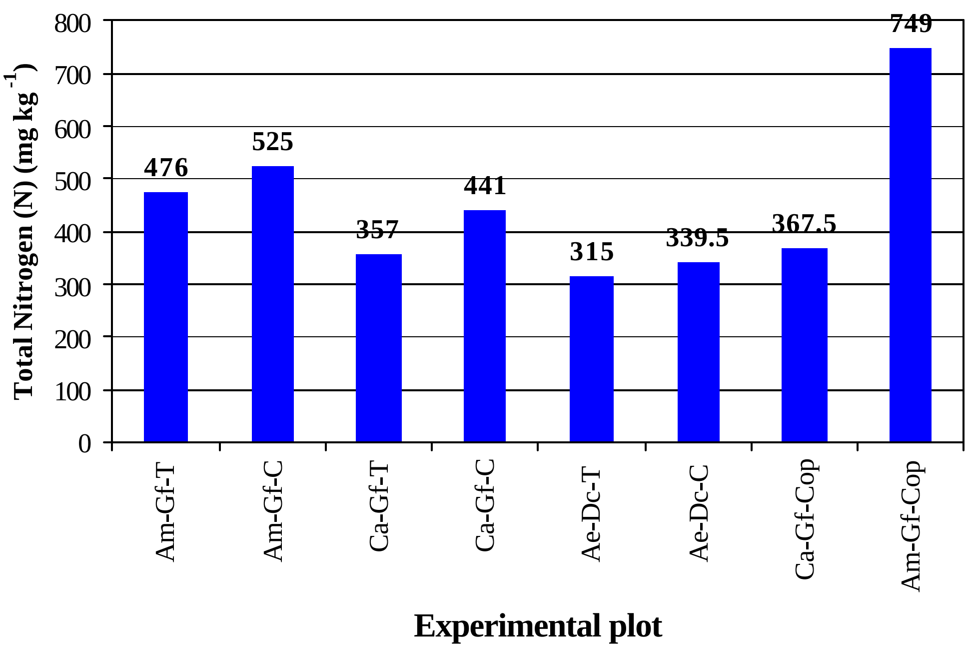


Figure 7.7: The total nitrogen (N) contents (mg kg^{-1}) of topsoil samples taken in each experimental plot during April 2004.

The results presented in Figure 7.8 shows no clear pattern following tree thinning. The C contents of the control plots were higher in comparison to the treatment plots in the Am-Gf and Ae-Dc dominated plots, but the differences were relatively small. The Am-Gf Coppice plot did however, have a lower C contents than the Am-Gf Control plot. A slight increase in C was also found in the Ca-Gf Treatment plot in contrast to the Ca-Gf Control plot, except for the Ca-Gf Coppice plot. When the control plots of the various species dominated plots were compared, it was found that the leguminous *A. mellifera* dominated plot had a relatively higher organic C content than the non-leguminous *C. apiculatum* plot. The C content of the leguminous Ae-Dc Control plot was relatively lower than that of the other control plots.

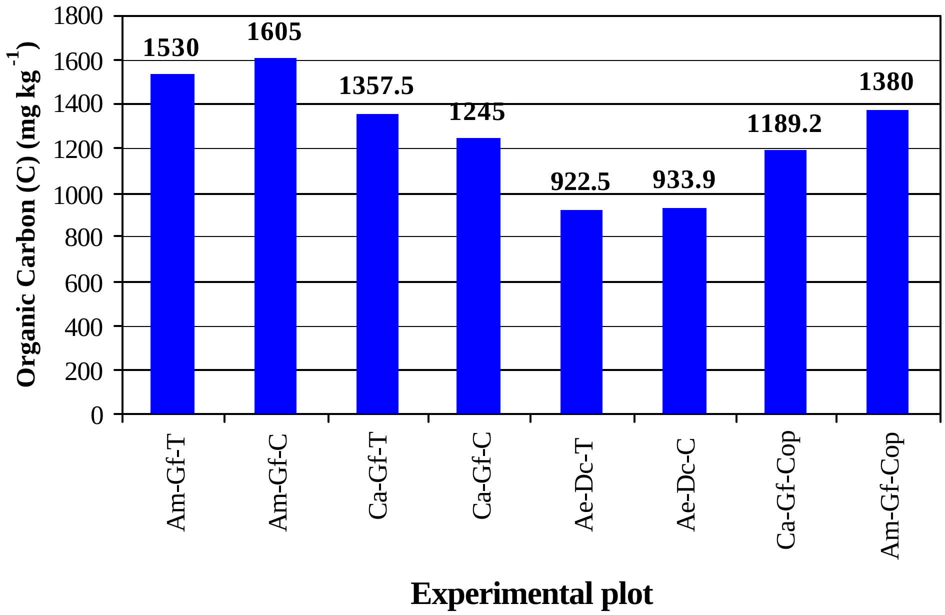


Figure 7.8: The organic carbon (C) contents (mg kg^{-1}) of topsoil sampled in each experimental plot during April 2004.

The C:N ratio for each experimental plot in the study area was extremely low (Table 7.3). All the treatment plots had higher ratios than the control plots, except for the Am-Gf Coppice plot in comparison with the Am-Gf Control plot. The latter plot had the lowest C:N ratio in comparison to all the other experimental plots. The C:N ratios of the different species dominated plots did not differ to a great extent. There was only a substantial difference between the C:N ratio of the Ca-Gf Treatment and Control plots. Combined, the Ca-Gf plots had the highest C:N ratios, followed by the Am-Gf plots and lastly the Ae-Dc plots.

Table 7.3: The organic carbon:total nitrogen ratio (C:N ratio) for each experimental plot.

Experimental plot	C:N ratio
Acacia mellifera-Grewia flava Treatment	3.2 : 1
Acacia mellifera-Grewia flava Control	3.1 : 1
Combretum apiculatum-Grewia flava Treatment	3.8 : 1
Combretum apiculatum-Grewia flava Control	2.8 : 1
Acacia erubescens-Dichrostachys cinerea Treatment	2.9 : 1
Acacia erubescens-Dichrostachys cinerea Control	2.8 : 1
Combretum apiculatum-Grewia flava Coppice	3.2 : 1
Acacia mellifera-Grewia flava Coppice	1.8 : 1

7.3.6 Phosphorus (P)

Phosphorus displayed no apparent trend of change following tree thinning and there was not a large difference between the different experimental plots (Figure 7.9). The Am-Gf Treatment plot had a slightly lower P contents than the Am-Gf Control plot, while the Ae-Dc Treatment plot had a slightly higher P contents than the Ae-Dc Control plot. The P values of the Ca-Gf Treatment and Control plots were the same. However, a noticeable increase in P was found in the two coppice plots when compared to the other treated plots.

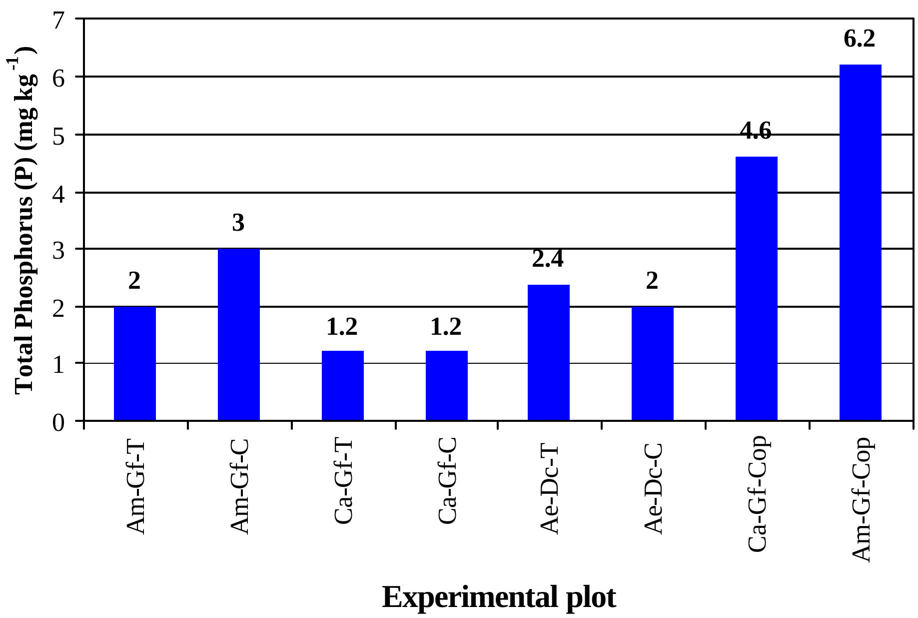


Figure 7.9: The total phosphorus (P) contents (mg kg^{-1}) of topsoil sampled in each experimental plot during April 2004.

7.3.7 Soil texture

The results of the soil texture analysis are presented in Table 7.4. It was found that the silt contents of the treatment plots where *Acacia* species were dominant were lower than in the control plots. Where *C. apiculatum* were dominant, the silt contents were higher in the treatment plots than in the control plots. The clay contents of all the treatment plots were lower than in the control plots and the areas where *Acacia* species were dominant, the clay contents were higher than in the *C. apiculatum* dominated plots. The percentage sand contribution in each plot was considerably higher than the silt and clay contribution. The *Acacia* dominated treatment plots had higher sand contents than the control plots, while the Ca-Gf Treatment plot had a lower sand content than the control plot. However, the difference was small.

The sand contents of the Ae-Dc plots were relatively higher than those of the Am-Gf plots and they had much lower silt and clay contents. From Table 7.4 it is clear that, as expected, there was no major difference between the soil particle size of the treatment and the corresponding control plots. It is also clear that the soil particle size classes (coarse, medium and fine) of the area dominated by *A. mellifera* were more evenly distributed than in the areas where *A. erubescens* is dominant, which had a very small amount of coarse sand.

Table 7.4: The percentage silt, clay and sand contribution to the soil of each experimental plot. The total mass (g) of the soil particle size classes that were measured is also given.

Experimental plot	**Silt (%)**	**Clay (%)**	**Sand**		
			Sand (%)	**Soil particle size class**	**Total mass (g)**
Acacia mellifera-Grewia flava Treatment	6	16	77.50	Coarse	27.08
				Medium	20.28
				Fine	30.14
Acacia mellifera-Grewia flava Control	8	24	67.68	Coarse	17.86
				Medium	19.22
				Fine	30.60
Combretum apiculatum-Grewia flava Treatment	8	14	77.82	Coarse	8.26
				Medium	12.98
				Fine	56.58
Combretum apiculatum-Grewia flava Control	5	15	79.50	Coarse	10.62
				Medium	11.98
				Fine	56.90
Acacia erubescens-Dichrostachys cinerea Treatment	2	14	82.64	Coarse	2.34
				Medium	41.62
				Fine	38.68
Acacia erubescens-Dichrostachys cinerea Control	3	17	78.28	Coarse	1.62
				Medium	35.94
				Fine	40.72
Combretum apiculatum-Grewia flava Coppice	8	10	81.44	Coarse	10.62
				Medium	21.06
				Fine	49.76
Acacia mellifera-Grewia flava Coppice	6	28	65.18	Coarse	4.18
				Medium	19.10
				Fine	41.90

7.4 DISCUSSION

7.4.1 Cation concentrations

Cations are positively charged ions. Soil colloids have various surface sites that have negative charges at which the cations are adsorbed through electrostatic attraction (positive to negative). The adsorbed cations resist removal by leaching water but can be replaced by other cations in solution by mass action (competition for the negative site because of the large number of ions present). This exchange of one positive ion by another is called cation exchange (Miller & Gardiner, 1998).

Cations perform many important functions, but are especially important to vegetation growth because plants absorb nutrients from the soil mostly in the form of ions. For example, Ca plays an important role in plant nutrition. It tends to make plant cells more selective in their absorption and it is a constituent of the middle lamella of each cell wall. Rapidly growing root tips are especially high in Ca, indicating that it is needed in large quantities for cell division. Potassium in plants stays in a mobile form rather than as an integral part of any fixed compound. It helps to retain cell permeability, aids in the translocation of carbohydrates, keeps iron (Fe) more mobile in the plant and increases the resistance of plants to certain infections. Half or more of the K used by plants comes from exchangeable K and the other half is soluble K. Chlorophyll contains one atom of Mg in each molecule. Without the presence of Mg in the soil, there would be no green plants. Magnesium also aids in the uptake of phosphorus. The quantity of Na in the soil influences the permeability of the soil and thus the efficiency with which plant species will emerge from the soil (Donahue *et al.*, 1977).

Variations in Ca contents of different soil types can be great, because many Ca minerals are fairly soluble. Calcium normally dominates the cation exchange capacity because of the large amounts of Ca that is found in soil solutions (Le Roux, personal communication*****). Calcium minerals are so abundant that it is seldom deficient except in sandy soil (which contains none or only a few Ca minerals) and in strongly acidic mineral soil, which usually have resulted from prior leaching of Ca minerals. This might be the reason why the Ae-Dc plots had lower Ca contents than the other experimental plots.

*****Le Roux, P.A.L., Department of Soil, Crop and Climate Sciences, P.O. Box 339, University of the Free State, Bloemfontein, 9301.

Many organic soils (also known as histosols: saturated with water for prolonged periods unless artificially drained and having at least 12% or 18% organic carbon by weight, depending on the mineral fraction and the kind of organic materials) (Miller & Gardiner, 1998) are acidic and low in Ca because of a low Ca content in the original plant residues. This corresponds with the results of this study. The experimental plots which had a lower pH (more acidic) had lower Ca contents than the plots which had a higher pH (more basic) with a higher Ca content (see section 7.3.2).

The fact that the *A. mellifera* dominated plots had higher Ca contents than the *C. apiculatum* and *A. erubescens* dominated plots is supported by the findings of Smit (1999). He reported that *A. mellifera* that occurs in sandveld is often associated with more calcium-rich soil. The exact reason why most of the treatment plots had higher Ca contents than the control plots is not known. Because no soil analyses were done before tree thinning commenced, the higher Ca contents of soil in some treatment plots cannot unconditionally be ascribed to the thinning treatments, but it remains a possibility.

The amount of total K in most soils is sufficient to last several decades, but some soil K is a constituent of very slowly soluble minerals, such as orthoclase feldspar, so the resulting soluble K is only sparsely accessible to plants. Soil may contain up to 2% total K of which only a small fraction is in a readily available form. Two percent K means the soil may contain a total of 89 600 kg ha^{-1} K (to a depth of 30 cm), while only about 168 kg ha^{-1} is needed for plant growth (Donahue *et al.*, 1977). In many acidic soils, the exchangeable plus soluble K in the top 15 cm may be less than 100 kg ha^{-1} to 200 kg ha^{-1}, a level that is inadequate or marginal for plant growth. The lower K contents of the Ae-Dc dominated plots may thus be one reason why these plots had a lower plant species diversity than the other experimental plots (see Chapter 5). Due to a lack of previous soil analyses data to which the results could be compared, the lower K contents of most of the treatment plots can also not unconditionally be ascribed to the thinning treatments.

In most soils the amount of exchangeable Mg, the major source to plants, is usually less than the quantity of exchangeable Ca in most soils (Donahue *et al.*, 1977). The same was found to be true for all the experimental plots of the study area. The fact that all the treatment plots had lower Mg contents than the control plots, might be an indication that tree thinning, as it was done in the study area, can have an effect on soil nutrients. This was, however, not immediately apparent for every soil characteristic. The fact that the Ca-Gf plots had lower Mg contents indicates that these plots had a lower soil fertility than the plots dominated by *Acacia* species.

The reason for this can be ascribed to the shallow, gravelly soil in which the *C. apiculatum* species dominate. These soils are easily leached and nutrients are lost in runoff water after rain. The heavy rains that occurred during the study period might have intensified this effect.

The reason for the differences in Na contents of the corresponding treatment and control plots is not known and further investigation is required to determine the precise reason for these differences. Exchangeable Na in concentrations above about 15% exerts its greatest effect on plant growth by dispersing the soil. An exchangeable Na concentration as low as 10% exchangeable Na in fine-textured (clayey) soil and 20% in sandier soil are considered problem levels for soil with these texture classes. Colloid dispersal makes the soil partially permeable or impermeable and causes it to form hard surface crusts when dry. Soil structure in general is damaged, except perhaps for very coarse subsoil prismatic structures, which are not particularly favourable to plant growth. The upper soil pores are filled with lodged dispersed particles and both air and water exchange into and out of the soil is reduced. The hardened crusts can completely inhibit seedling emergence when structural deterioration is severe, however, plant species vary in their tolerance to exchangeable Na (Donahue *et al.*, 1977).

7.4.2 Cation ratios

The fact that the ratios between Mg and K were lower than the normal values expected for the soil in most of the experimental plots indicates that an imbalance may be present in the cation contents. This was also found for the Ca/Mg ratio for the Am-Gf dominated plots, which had much higher values than the normal expected values. The Ca contents of soil in relation to its ratio to Mg are very important. This influences the formation of crusts on the soil surface. The higher the Mg in relation to the Ca, the more susceptible the soil will be to the formation of crusts (Smit, 1994). Crust formation can lead to reduced soil infiltration and substantial rainwater runoff losses. This sequentially leads to reduced plant coverage and soil erosion which is not desirable. The Am-Gf Treatment and Control, as well as the Am-Gf Coppice plot, had areas where crust formation occurred. However, the Ca-Gf and Ae-Dc plots, as well as the Ca-Gf Coppice plot had larger areas where crust formation occurred than in the Am-Gf plots. This indicates that the degree of crust formation is determined by multiple factors and further research is necessary to determine what the specific factors are that play a role in the study area.

The results that were found for the (Ca + Mg)/K ratios of each experimental plot show that the thinning treatments can possibly have an effect on soil properties and that cation ratios can play a role in determining which plant species will occur on a certain soil type.

It was observed that in the areas where crust formations occurred, the most dominant grass species were pioneers, e.g. *Aristida* species, and that many weed species, e.g. *Bidens pilosa* and *Senecio latifolius*, also occurred. This was especially prominent in the treatment plots and can be the result of the soil compaction caused by the weight and action of the Barko Tractor (Figure 5.3). The reason why the Ca:Mg:K:Na ratios of the Am-Gf dominated plots, in particular were out of proportion, can probably be contributed to the high occurrence of leguminous plants in these plots. Leguminous plants deposit much more Ca to the soil than other plants (Du Preez, personal communication*****). Further research is needed to determine the exact mechanism how these imbalances are established.

It is clear that tree thinning can have an effect on the cation contents of the soil and thus the fertility of the soil. The changes in the soil properties are, however, not always immediately apparent. Evidence exists that soil enrichment under tree canopies is a slow process (Smit, 1994). This is demonstrated by correlations between total carbon (C) and nitrogen (N) in soil under tree canopies and tree girth, an index of age (Bernhard-Reversat, 1982). Different results in soil enrichment by trees can also be found depending on the geographical location of the area (Bosch & Van Wyk, 1970; Kennard & Walker, 1973; Kellman, 1979; Palmer *et al.*, 1988; Smit & Swart, 1994; Hagos & Smit, 2005). It is thus important to keep in mind that there is a variety of determinants that influence the enrichment of soil by trees.

7.4.3 Cation Exchange Capacity (CEC), Exchangeable Sodium Percentage (ESP) and Exchangeable Potassium Percentage (EPP)

The CEC is the amount of exchangeable cations per unit weight of soil (dry basis) (Donahue *et al.*, 1977). It is measured in $centimoles_c$ of cations per kilogram of dry soil ($cmol_c\ kg^{?1}$). The exchange takes place on the surfaces of clay and humus colloids as well as on the surfaces of plant root cell walls (Miller & Gardiner, 1998). Cation exchange is an important reaction that influences soil fertility. It contributes to the correction of soil acidity and alkalinity, assists in the alteration of some physical properties of soil and acts as a mechanism whereby water is purified or altered during percolation (Donahue *et al.*, 1977).

When the CEC values of the experimental plots were compared to the range of normal values for different soil textures, it was concluded that the Am-Gf plots (including the coppice plot) occur on fine sandy loam to loam soil. The other plots occur mainly on sandy soil.

*****Du Preez, C.C., Department of Soil, Crop and Climate Sciences, P.O. Box 339, University of the Free State, Bloemfontein, 9300.

This concurs with the results of the soil texture analysis (see section 7.3.7). The CEC of soil remains approximately the same for a given soil if the soil pH, humus and clay contents remain the same, but it will change as these soil properties changes. Soil higher in humus and in montmorillonite clay, a smectite, will have high CEC's and as a result, it is clear why some sandy soils may have low fertility (Miller & Gardiner, 1998). The higher CEC value of the Am-Gf Treatment plot is probably due to the high cation contents, especially the Ca contents, found in the Am-Gf Treatment plot in comparison with the control plot.

The ESP of a soil is a function of the exchangeable Na ions as a percentage of the total soil exchangeable cations. Soil through which salty water flows frequently adsorb too much Na on the soil particle exchange sites. This effect can take place in both saline (brackish) and non-saline soil. If a high proportion of the exchange sites are occupied by Na ions, soil can become very alkaline with pH values ranging between 8.5 and 10.5 and the soil aggregates (which are desirable for plant growth) disintegrate and disperse. These soils can become resistant to water infiltration because small soil particles that are dispersed by the Na are lodged in the pores and seal them. These impermeable soils keep water on the surface. They appear to be wet for longer periods than other soil and because of this they are often called 'slick spots' (Miller & Gardiner, 1998).

The value of ESP is used extensively to indicate the likelihood of the dispersal of the soil whereby its hydraulic conductivity (rate of water flow through it) will be reduced. Different soils can have different soil distribution complications at the same ESP. For fine-textured soil with montmorillonite clays (common in soil that have had little or no leaching), the usual condition in regions with salty soil, an ESP of 15% is considered the threshold at which dispersion (the breaking down of soil aggregates into individual particles; the more easily dispersed the soil, the more erodible it is) will occur. Soil with low clay contents can tolerate greater exchangeable Na percentages because it is more permeable (Donahue *et al.*, 1977). However, in South Africa it was found that soil with an ESP of 5% and higher can already cause problems if the clay contents of the specific soil are above 15% and if the CEC_{clay} (Table 7.1) percentage is more than 50% (Le Roux, personal communication*). The comparison of these factors for the Ca-Gf and Ae-Dc plots indicate that these combined factors do not pose an immediate threat to the permeability of the soil, but possibly to the permeability of the soil of the Am-Gf plots.

*Le Roux, P.A.L., Department of Soil, Crop and Climate Sciences, P.O. Box 339, University of the Free State, Bloemfontein, 9301.

If the permeability of soil decreases the water runoff increases and the soil dries more rapidly, which will increase soil erosion. This will also result in a lower production of the herbaceous layer and provide woody plant seedlings with an opportunity to increase in numbers, as a result of less competition for nutrients and space (especially since the removal of large trees that normally suppresses seedling growth is one of the negative aspects of the thinning treatments used in Marakele Park). This could result in a state of more severe bush encroachment that is contrary to the objectives of the bush thinning process. The fact that the Ca-Gf plots had much higher EPP values than the expected normal values, also indicate a likely imbalance in the cation contents. An imbalance in the K contents of the soil may lead to increased plant diseases and growth impairment of the plants.

According to Bell (1982), nutrients such as nitrates, phosphorus, a series of anions and cations and various trace elements are essential for the nutrition of plants and act as determinants of the composition, structure and productivity of vegetation. Many studies have shown that soil nutrients under tree canopies, especially those of large trees, are higher than in open areas (Bosch & Van Wyk, 1970; Williams *et al.*, 1987; Potter, 1992; Smit & Swart, 1994; Ludwig *et al.*, 2004; Hagos & Smit, 2005). Large trees suppress the development of woody seedlings, which in turn gives dominant grass species the ability to compete successfully for nutrients and thus to sustain a high quality herbaceous layer. The inability of the Barko Tractor to cut tree species selectively may have contributed to the lower cation values found in the treatment plots. Some of the large dominant trees, as well as smaller trees, were removed by the Barko Tractor, which gave woody seedlings the ability to compete for nutrients, leading to a higher tree density (see Chapter 4). These woody seedlings can compete with the herbaceous layer for nutrients, while they do not contribute to soil enrichment as mature trees are able to do. This may lead to a herbaceous layer of poorer quality and decreased phytomass, and ultimately a lower soil nutrient status.

7.4.4 Soil pH

Soil reaction (pH) is an indication of the acidity or alkalinity of the soil and is measured in pH units. Soil pH is defined as the negative logarithm of the hydrogen ion (H^+) concentration. Different forms of pH testing exist and the soil pH of the study area was tested during the saturation extract, in a water solution and in a potassium chloride (KCl) solution. The soil pH is easily determined and provides various clues about other soil properties (Miller & Gardiner, 1998).

From pH 7 to 0 the soil is increasingly more acidic; from pH 7 to 14 the soil is increasingly more alkaline (basic). Most soils have pH values between 4 and 8. The most universal effect of pH on plant growth is nutritional. The soil pH influences the rate of plant nutrient release by weathering, the solubility of all materials in the soil and the amounts of nutrient ions stored on the cation exchange sites (Troeh & Thompson, 1993). The soil pH can also influence plant growth through the effect on the activity of beneficial micro-organisms. Most nitrogen-fixing bacteria are not very active in strongly acidic soil. Bacteria that decompose the organic matter of soil during which N and other nutrients are released for plant use, are also hindered by strong acidity (Miller & Gardiner, 1998).

A high soil alkalinity, although more difficult to alter than soil acidity, may be just as undesirable for plants. Soil, unleached or high in Ca (low rainfall areas), have pH values of up to 8.5. With increased exchangeable Na, soil may reach values over pH 10. Plants on soil of pH greater than about 9, usually have reduced growth, or may even suffer mortality. The major effect of an alkaline pH is the reduced solubility of all micronutrients, especially those of Fe, zinc (Zn) and manganese (Mn). Also, phosphate is often not readily available to some plants because of its precipitation in the soil solution by Ca or precipitation on solid Ca carbonate (Donahue *et al.*, 1977).

Vegetation influences soil pH in complex ways because it produces organic matter and influences leaching. The addition of decomposable organic matter to a soil results in the formation of organic acids. These acids add to the CEC, but the percentage base saturation and pH is lowered. In temperate regions, soils formed under grass are usually less acidic than soil under trees. The reason for this appears to be that since grasses produce new growth each year, they utilise more bases (Ca^{2+}, K^{+}, Mg^{2+}, Na^{+}) and therefore deposit more bases on the soil surface than trees do. Thus, grasses help to keep the soil from becoming too acidic (Troeh & Thompson, 1993). The lower grass production that was found in the Ae-Dc plots might be a possible reason why these plots had a lower pH than the Am-Gf and Ca-Gf plots. However, the opposite was found for the Ca-Gf dominated plots, indicating that there are other factors that also play a role in determining the pH of the soil.

Strongly acidic soil (pH 4.0 – 5) usually has high and even toxic concentrations of soluble Al and Mn. Most minerals are more soluble in acid soil than in neutral or slightly alkaline solutions. Plants normally grow well between about pH 5 and pH 8.5 (Donahue *et al.*, 1977).

Soil becomes acidic when substantial portions of the exchangeable cations are hydrogen, H^+ and various forms of hydrated Al. Acidity increases as soil is more leached and the soil is lower in the basic cations, Ca^{2+}, Mg^{2+}, Na^+ and K^+. The fact that the *Acacia* dominated treatment plots had higher pH and pH (H_2O) values than their corresponding control plots and that the Ca-Gf Treatment plots had lower pH values than the Ca-Gf Control plot, shows that the pH value can have an effect on the plant species that occur in a certain area and that the tree thinning treatments can have different effects on the soil properties in which different plant species are dominant.

Potassium chloride (KCl) is often used to mask variation in salt concentration resulting from fertiliser residues, irrigation water and microbial decomposition of organic material. Hydrogen ion activity in 1 mol dm^{-3} KCl may be as much as 1 or 2 pH units lower or higher than that measured in water, using the same soil/water ratio. This was found for all the experimental plots, which showed an average decrease of 1 pH unit per plot between the pH (H_2O) and pH (KCl). These results indicate that microbial decomposition is present in the soil. The pH (KCl) values are especially important when determining whether the alkali or acid contents of the soil must be altered to balance the soil pH in order to improve plant growth and production. These values are of greater value to agriculture, especially when crop planting is involved.

7.4.5 Electrical conductivity and Electrical resistance

Soluble salts are measured by electrical conductivity and the units of conductance used are mili-siemens per meter (mS m^{-1}). The range of plant tolerance to salt is approximately as given below for the conductivity of the soil's saturation paste extract (Miller & Gardiner, 1998):

- 0 – 200: few plants affected;
- 200 – 400: some sensitive plants affected;
- 400 – 800: many plants affected;
- 800 – 1 600: most plants (especially crop plants) affected; and
- 1 600+: few plants can survive.

A comparison between the electrical conductivity results found for this study and the plant tolerance to salt given above, showed that the salt contents of the soil of the study area would not have a major effect on plants, because the contents are low. The higher conductivity values that were found in the Am-Gf and Ae-Dc Control plots indicate that a higher salt content is present in these plots, which could affect the development of sensitive plants and several other plant species.

The fact that all the treatment plots had lower conductivity values than their corresponding control plots indicates that the treatments may have a lower cation contents which can lead to lower nutrient contents for plant growth and ultimately poorer quality plants for animal utilisation. The unselective thinning by the Barko Tractor could thus lead to undesirable consequences, especially since no follow-up treatments, e.g. herbicides, were used after thinning.

The electrical resistance of the soil is an indication of the amount of dissolved salts in the soil and it is measured in ohms (?) (MacVicar *et al.*, 1977; Soil Classification Working Group, 1991). Most soluble salts in soil are composed of the anions chloride ($Cl^{?}$), sulphate ($SO_4^{2?}$) and bicarbonate ($HCO_3^{?}$) and the cations Na^{+}, Ca^{2+} and Mg^{2+}. Reasonably smaller quantities of other ions also occur in soil. The anions and cations that form soluble salts come from the weathering process of minerals. A large content of soluble salts act osmotically to lower the water potential, making it more strenuous for plants in salty (saline) soil to absorb water from the soil solution. High salt concentrations increase the forces that hold water in the soil and necessitate plant roots to expend more energy in order to extract the water. Salts are usually most damaging to young plants, but not necessarily at the time of germination, but high salt concentrations can slow or inhibit seed germination. Plant species have variable tolerances to soil salt contents and the specific effects on different plant parts may also vary (Miller & Gardiner, 1998).

The fact that the Ca-Gf plots had a much higher electrical resistance than the *Acacia* dominated plots indicates that the soil of the Ca-Gf plots is more saline (brackish). The higher electrical resistance of the treatment plots in comparison to the control plots, indicates that a higher electrical conductivity is present in the treatment plots and this is due to high cation contents (Du Preez, personal communication*****). This implies that the thinning of woody species can influence soil properties through its effect on the woody as well as the herbaceous plant species. The Ca-Gf Coppice plot having a higher electrical resistance than the Am-Gf Coppice plot, indicates that *C. apiculatum* is much more salt tolerant than *A. mellifera* and *A. erubescens*. The excessively high electrical resistance of the *C. apiculatum* dominated plots cannot be explained. Further research on the soil properties of the study area is required to obtain a possible explanation for these results.

*****Du Preez, C.C., Department of Soil, Crop and Climate Sciences, P.O. Box 339, University of the Free State, Bloemfontein, 9300.

7.4.6 Sodium Adsorption Ratio (SAR)

High concentrations of Na are undesirable in water because Na adsorbs onto the soil cation exchange sites, causing soil aggregates to break down (disperse), sealing the pores of the soil and making it less permeable to water flow. The tendency of Na to increase on the cation exchange sites at the expense of other cations is estimated by the ratio of Na contents to the contents of the square root of Ca plus Mg in the water. This is called the Sodium Adsorption Ratio (SAR). The SAR is used to estimate what the exchangeable Na percentage of a soil is. A small SAR value indicates a low Na content, which is desirable (Miller & Gardiner, 1998). When the SAR is 13, the soil will probably lose permeability as salts are removed.

Normal soil has an electrical conductivity of less than 400 mS m^{-1} for the saturation extract and a SAR of less than 13. Salt-affected soil can be divided into three types, namely saline, sodic or saline-sodic.

- Saline soil (formerly called white alkali soil): This soil has a saturation extract conductivity of 4 dS m^{-1} or greater and has a SAR of less than 13.
- Sodic soil (formerly called black alkali soil): This soil has a SAR of 13 or more for the saturation extract, but has low salt contents.
- Saline-sodic soil (formerly called white alkali or black alkali, depending on the visual appearance of the individual soil): This soil has both the salt concentration to qualify as saline and a SAR of 13 or more to qualify as sodic (Miller & Gardiner, 1998).

The reason for the higher SAR value of the Ca-Gf Treatment plots in comparison to the Ca-Gf Control plot and the lower SAR values of the *Acacia* dominated treatment plots in comparison to their corresponding control plots, is due to the much higher Na contents of the *C. apiculatum* dominated plots in ratio to the Ca and Mg contents in contrast with the *Acacia* dominated plot ratios. This indicates that the tree thinning treatments can have differing effects depending on the plant species of certain areas. The normal values expected for the SAR (F.S.S.A., 2003) specifies that if the value is smaller than 1 the soil is good (not too brackish), if the value is more than 4, it is brackish and if the value is more than 5, the soil is permanently brackish. Thus, it is clear that the soil of the study area does not have a high salt content and can be classified as normal, except for the Am-Gf Control plot that had an electrical conductivity of more than 4 dS m^{-1} and a SAR of less than 13, which can thus be classified as a saline soil.

Salts not only decrease the production of most plants, but also, as a result of their effect on soil physicochemical properties, adversely affect the associated ecological balance of the area. Some of the harmful impacts of salt are:

- low plant production;
- soil erosion, by both water and wind, due to high dispersibility of soil and decrease in shear stress;
- increase in water-flow due to higher runoff as a result of decreased permeability of soil;
- low groundwater recharge; and
- ecological imbalance due to change in plant cover from mesophytes to halophytes, from trees to bushes, etc. (Chhabra, 1996).

With an increase in the salt concentration of the soil, the osmotic pressure of the soil solution increases and plants are not able to extract water as easily as they can from a relatively non-saline soil. This can become a problem in the treatment areas, because the risk of compaction of the soil by the Barko Tractor can lead to more water runoff and erosion and it will impede salt leaching through the soil. This will have a negative effect on the growth and production of plants, especially herbaceous plants. Saline soils are characterised by patchy plant growth and this was found in the Am-Gf Control plot. Salinity affects the nutrient availability by modifying the retention, fixation and transformation of the nutrients in the soils and interfering with the uptake and/or absorption of nutrients by roots due to ionic competition and reduced root growth (Chhabra, 1996).

7.4.7 Nitrogen (N), Organic carbon (C) and Carbon:Nitrogen ratio

Nitrogen is the most critical element in plant growth and development. It is a constituent of plant proteins, chlorophyll, nucleic acids and other plant substances (Miller & Gardiner, 1998). Adequate N often produces thinner cell walls, which results in more tender, more succulent plants and it also means larger plants and thus greater forage yields. Poor plant yields are most often due to a deficiency of N. As with all other plant nutrients, it is not a matter of lack of total N in the soil but a lack of enough N that can be utilised by plants (Donahue *et al.*, 1977). Van de Vijver (1999) found that the removal of grass tufts in a semi-arid area increased grass leaf N contents of the remaining tufts because of an increased availability of soil N per individual grass tuft due to the reduction of the number of grass tufts per area. Thus, the abundance of plant species in an area plays a role in N intake. Snyman (1997b) also found that N could be more limiting during years of above average rainfall.

The fact that the treatment plots had lower N contents than the control plots, concur with the results of numerous studies which reported that the total percentage N is higher in canopied areas than in uncanopied areas (Bosch & Van Wyk, 1970; Tiedemann & Klemmedson, 1973; Kellman, 1979; Belsky *et al*., 1989; Smit & Swart, 1994; Ludwig *et al.*, 2004; Hagos & Smit, 2005), which is most probably due to an increased amount of leaf litter and mineral inputs through stemflow and throughfall (Williams *et al.*, 1987; Potter, 1992). The higher N content of the Am-Gf Coppice plot in comparison to the other experimental plots was probably due to the higher tree density that occurred in this specific plot, combined with the dominance of leguminous trees (see Chapter 4). It has been found that the occurrence of N-fixation due to microbial activities under leguminous trees, is a possible source of N enrichment (Virginia & Delwiche, 1982; Högberg, 1986; Smit & Swart, 1994).

Biotic and abiotic organic materials supply nutrients to most living organisms. The major sources of organic matter to the soil are plant roots and unused above-ground plant parts of all plant types, e.g. woody, herbaceous, and succulent plants. The decomposition of the material by micro-organisms results in the use of some of the C, N and other elements by the micro-organisms, the release of some carbon dioxide (CO_2), water and other elements in the soil solution or atmosphere, and a changed and partially modified organic residue called humus. Organic matter is primarily C (about 58% by weight), with lesser amounts of hydrogen (H_2), oxygen (O_2) and other elements. As progressive decay of organic materials continues, much of the C escapes into the atmosphere as CO_2 (Miller & Gardiner, 1998). Loss of organic material contributes to the degradation of the soil structure, decrease in water permeability, increase in surface sealing, reduction of the soil's water retention ability and richness, and also acceleration of wind and water erosion (Du Preez & Snyman, 1993).

Normally, it would be expected that a higher organic C contents would occur in the control plots than in the treatment plots, due to a higher leaf litter percentage and stemflow input (Stuart-Hill *et al*., 1987; Potter, 1992; Belsky, 1994). The higher C contents in the Ca-Gf Treatment plot can possibly be attributed to the decay of some roots of the thinned woody species. The dung of large mammals that were attracted to these thinned areas (for example elephant, kudu, plains zebra, blue wildebeest and impala – that were sited frequently in these plots) because of the new growth from woody seedlings, coppice and herbaceous species, could also have been a contributing factor to the higher C contents of the treatment plot. However, the transformation of organic soil material involves a long process and the changes in C found in the experimental plots are most likely the result of processes that took place long before the tree thinning was done. Further investigation is required to obtain more precise explanatory reasons for these results.

The differences that were established in the various control plots can possibly be due to the leaf structure of the most dominant tree species in each of the plots. The *A. erubescens* plot had a joint dominance with *Dichrostachys cinerea* and both these trees have microphyllous leaves. The *A. mellifera* and *C. apiculatum* plots had a joint dominance with *Grewia flava*, which is a broad-leafed shrub/tree. Smit & Swart (1994) and Hagos & Smit (2005) also found that the organic C contents of soil under *A. mellifera* were higher than under *C. apiculatum*. One reason for this is that some of the large leaves of *C. apiculatum* are carried away from the tree by wind, while most of the fallen microphyllous leaves of *A. mellifera* remained under the tree canopies. The soil of the study area, however, was only tested between trees, so further investigation is required to determine whether the leaf structure of the dominant woody species does have an influence on the C contents. Herbaceous species, especially grasses, may also play an important role and most likely have a larger influence on the C contents of soils. Further investigation of all the possible contributing ecological factors is needed to give an accurate explanation for the various C contents values.

An important factor influencing plant growth is the ratio of C:N, because the amount of available N, either present in residue or in the soil, greatly affects the rate of decomposition (Donahue *et al*., 1977). A large organic C to total N ratio indicates a material relatively low in N contents. The extremely low ratios that were found for each experimental plot indicates that the N contents are high and that decomposition can take place effectively (N is mineralised and not immobilised; Troeh & Thompson, 1993).

A possible reason for the high N contents of the soil is a high presence of bacteria (especially nitrogen-fixing *Rhizobium* bacteria, which are associated with leguminous plant species that occurred commonly in the study area) and fungi in the soil. When these micro-organisms die, their bodies, which have high N contents, are decomposed by other living micro-organisms, breaking down C and releasing CO_2 to the atmosphere and some N to the soil. Leguminous plants can add exceptional amounts of available N to the soil (Donahue *et al*, 1977).

7.4.8 Phosphorus (P)

Phosphorus is the second most critical plant nutrient. The nucleus of each plant cell contains P, so cell division and growth are dependent on adequate amounts of this element. Phosphorus is concentrated in rapidly dividing plant cells – the vigorous growing parts of roots and shoots.

Phosphorous nutrition is especially critical because the total supply of P in most soils is low and the P is not readily accessible for plant use. The mineral P forms have low solubility. The P used by plants is derived primarily from the phosphates released during organic matter decomposition in the soil (Miller & Gardiner, 1998).

A possible reason why the coppice plots had higher P values than the treatment plots could be attributed to the higher tree density of these plots (see Chapter 4). Numerous other studies have shown that there was an increase in the P value of canopied areas in comparison to uncanopied areas (Kellman, 1979; Belsky *et al.*, 1989; Smit & Swart, 1994; Hagos & Smit, 2005). The overall P values for the study area were very low. Another reason could be the inherent soil differences between the experimental plots.

Phosphorus deficiency interferes with the normal opening of the stomata of certain plants, resulting in leaf temperatures as much as 10% higher during periods of sunshine that would normally have occurred in plant leaves that received adequate P. High leaf temperatures can critically affect plant growth in areas where growing season temperatures are high. Soil P is fixed, or made less available by the formation of less soluble phosphates or iron aluminium (from clays) and Ca. At a soil pH below 5.5 (acidic), both Fe and aluminium (Al) will fix P. At a pH above 7.0 (alkaline), Ca will fix P. Maximum P availability is at a pH of 5.5 for organic soil (Donahue *et al.*, 1977). The relative variation from pH 5.5 that was determined for the experimental plots can thus be a reason for the low P values of the study area. Phosphorus levels also influence micronutrient availability (Miller & Gardiner, 1998).

7.4.9 Soil texture

The physical properties of soil, namely texture, structure, density, porosity, water contents, consistency (strength), temperature and colour – are dominant factors affecting the use of a soil. These properties determine the availability of oxygen in soil, the mobility of water into or through the soil and the ease of root penetration (Miller & Gardiner, 1998). Natural soil is comprised of soil particles of varying sizes. The soil particle size groups, called soil separates, are sands (the coarsest), silts and clays (the smallest). The relative proportions of soil separates in a particular soil, determine its soil texture. Texture is an important soil property because it determines water intake rates (absorption), water storage in the soil, the amount of aeration (vital to root growth), and it influences soil fertility.

A coarse, sandy soil has plenty of aeration for good root growth and is easily wetted, but it also dries rapidly and loses plant nutrients quite quickly as a result of leaching. High clay soil (over 30% clay) has very small particles that fit closely together, leaving little open pore space, which means there is little space for water to penetrate the soil. This inhibits the wetting and drainage of clay soils (Donahue *et al.*, 1977). Soil that does not exhibit the dominant physical properties of any of these three groups (such as a soil with 40% sand, 40% silt and 20% clay), is called loam (Miller & Gardiner, 1998).

Different plant species have adaptations to and preferences for specific soil types. This also applies to the different dominant woody species of the study area. According to Smit (1999), *A. erubescens* can grow on a variety of soil types ranging from sandy soil to fine textured, poorly drained soil. Coates Palgrave (2002) described *D. cinerea* as a shrub or small deciduous tree occurring on a variety of soil, forming secondary bush encroachment (or thickening) especially in degraded (overgrazed) areas. Smit (1999) stated that *A. mellifera* can grow on a variety of soil types, ranging from Kalahari sands to heavy, clayey soil and is usually found in arid regions. According to Van Wyk *et al.* (2000), *G. flava* often occurs in arid areas on sandy soil. These findings correspond with the results of this study, which indicate that the soil of the experimental plots is predominantly sandy with clay contents ranging mostly from 12% to 20% clay. The results also indicated that the areas dominated by *C. apiculatum* had much finer sand than the areas where *Acacia* species are dominant.

The variation in soil texture of the experimental plots indicates that soil texture can play a role in determining which plant species will grow in a certain region. In woodland-grassland transition areas it is common to find grasses growing on finer-textured soils and trees on sandier soils. The finer textured soils are usually higher in bases and provide a favourable nutrient supply for grasses. The sandier soils are usually deeper and provide a more favourable root zone for trees (Troeh & Thompson, 1993). The differences in the silt, clay and sand contents of the different experimental plots indicate that the soil is derived from different parent materials which results in geological differences in the study area (Le Roux, personal communication*****).

*****Le Roux, P.A.L., Department of Soil, Crop and Climate Sciences, P.O. Box 339, University of the Free State, Bloemfontein, 9301.

7.4.10 The influence of variable soil properties on soil water

Although the soil water percentage of the soil in the study area was not examined, it is important to know what influence the above mentioned soil properties have on the availability of soil water for utilisation by plant species. It would be beneficial to examine the soil water properties of an area to have even more insight in determining why certain plant species react differently to various soil properties. The effect of various soil properties are only discussed briefly in this section.

In the extensive grazing areas of South Africa, which have a mean annual rainfall of 500 mm or less (which includes most parts of the study area), water availability is the most limiting environmental factor to plant production (Snyman, 1993b). Water contents in soil have an effect on soil formation, erosion and structure stability, but the primary concern is the availability of water for plant growth. Water is responsible for four main functions in plants: it is the major constituent of plant protoplasm (85 – 95%); it is essential for photosynthesis and the conversion of starches to sugars; it is the solvent in which nutrients move into and through plant parts and it provides plant turgidity, which maintains the proper form and position of plant parts to capture sunlight (Donahue *et al.*, 1977). Available water is the portion of stored soil water that can be absorbed fast enough by plant roots to sustain life. It is defined as the weight percentage of total soil moisture held with forces of suction between 0.3 and 15 bars (Donahue *et al.*, 1977). The water held within these suction forces comprises most of the storage water used by plants and are also called plant-available water (Miller & Gardiner, 1998). Plants will wilt when only 15 bar water is present, because the water lost through transpiration (loss through the stomata of the leaves of the plant) is faster and greater than that quantity absorbed by the roots at these elevated suctions.

Soil texture and organic matter contents are important in estimating the amount of water that different soil types can hold. Increased clay and organic matter contents increase total water retention and the exceptionally large total surface areas of clay particles and organic materials cause a large quantity of water to be held closely to the soil surfaces by adhesion. In less clayey soil with a reduced surface area or in soil with less organic matter, a greater percentage of the total water will be held with a lower force. Medium-textured soil such as loams can hold large amounts of available water for plants (Donahue *et al.*, 1977).

Water moves as a result of force gradients in the soil caused predominantly by gravity, osmosis and capillarity. When water mainly moves due to gravity, which is at suctions of less than 0.3 bar, the movement is defined as saturated flow. Saturated flow begins with water infiltration, which is water movement into soil when rain (or irrigation water) is on the soil surface. When the soil profile is wetted, the movement of more water flowing through the wetted soil is termed percolation. It is percolating water moving through the soil and substrata, ultimately reaching the groundwater, which carries away the nutrients dissolved from the upper soil layers (Miller & Gardiner, 1998). According to Snyman (1997a) it appears that in the arid and semi-arid areas, deep percolation only occurs under extremely high rainfall conditions.

The controlling factors that determine the rate of water movement into the soil include:

- The percentage of sand, silt and clay. Coarse sands permit rapid infiltration. Clays have slow infiltration that becomes even slower as the soil swells in response to the additional water. The quantity of water which can be stored in the soil profile varies mainly according to the silt plus clay contents and depth, while the type of clay minerals and organic material contents can also be a contributing factor (Bennie, 1991).
- The soil structure. Fine-textured soil with large water-stable aggregates (granular structure) has higher infiltration rates than unstructured (massive) soil. Blocky and prismatic structures are intermediate.
- Compaction. Soil compaction, resultant of vehicle traffic or heavy grazing, reduces pore space and slows infiltration (Miller & Gardiner, 1998).

Infiltration rates can be classified as:

- Very low. Soil having infiltration rates of less than 0.25 cm per hour; in this group is soil of a high percentage clay content.
- Low. Infiltration rates of 0.25 – 1.25 cm per hour; most of these soils are shallow, high in clay or low in organic matter.
- Medium. Infiltration rates of 1.25 – 2.5 cm per hour; soils in this group are loams and silts.
- High. Rates of greater than 2.5 cm per hour; these are deep sands, deep well-aggregated silt loams, and some virgin black clays (Donahue *et al.*, 1977).

Another important component of the soil-water balance for semi-arid rangelands is evapotranspiration (Snyman, 1997a). Snyman & Van Rensburg (1986) estimated that as much as 93% to 96% of the incoming precipitation from rangelands in good condition was returned directly to the atmosphere as evapotranspiration. The contribution of evaporation to evapotranspiration increased with veld degradation. Soil evaporation is 24%, 20% and 16% less, respectively, for veld in good, moderate and poor condition (Snyman, 1997a).

The nature of rainfall, soil type, slope, plant cover and soil conservation practices have an effect on surface runoff. An increase in surface runoff and sediment loss because of veld degradation results in increased drought risk and facilitates so-called man-made droughts. Runoff losses, as high as 30% of mean annual rainfall, can be expected from bare soil surfaces (Snyman, 1997b). Although runoff is increased by clay contents in the topsoil and steepness of slope, these variables are less important than plant cover. When low plant cover is dominant, slope and clay contents play an increasing role in determining runoff rates (Snyman, 1985). A decrease in soil permeability accompanied by an increase in stocking density is common in rangelands and can be ascribed to compaction of the soil by hoof action of animals.

It is clear that soil water availability is a very important factor in the maintenance of a good vegetation cover. Many contributing soil properties influence the available water contents of soil in particular. Ample knowledge of the soil of a specific study area is thus required to determine the specific factors that will influence the species composition and vegetation abundance of a specific area.

7.5 CONCLUSIONS

Despite the lack of statistical evaluation, apparently few of the investigated soil variables changed considerably as a direct result of the tree thinning treatments. This result was not unexpected since changes in soil properties normally occur over longer periods of time. There are, however, indications that changes may occur over a longer period of time. The cation results clearly showed that the Am-Gf experimental plots had higher values than the other plots. This indicates that the soil properties, especially pH, determine what type of plant species occur on a specific soil type. The ESP values of the Am-Gf plots also showed that this was the only area where permeability of the soil could be a problem.

The soil of the Ca-Gf Treatment, Ca-Gf Control, Ae-Dc Treatment, Ae-Dc Control and Ca-Gf Coppice plots featured characteristics which favour the formation of surface crusts. These include a relatively high Na contents, combined with a low Ca content, a high Mg contents in relation to the Ca contents, as well as a relatively low organic C contents. The high Ca and organic C contents of the soil of the *A. mellifera* dominated plots proved to be effective in countering the high Na contents of these soils and preventing the formation of surface crusts.

The saturation extract indicated that the soil of the study area does not have a high salt content and can be classified as normal, except for the Am-Gf Control plot which can be classified as a saline soil. The electrical conductivity of the soil was fairly normal and showed that the Am-Gf and Ae-Dc Coppice plots were the only areas where the salt contents could possibly affect the growth of the plant species. The treatment plots had a reasonably higher electrical resistance than the control plots and this concur with the higher conductivity in the control plots in comparison to the treatment plots, because the higher the conductivity of a soil, the lower the soil electrical resistance. The Ca-Gf experimental plots had a very high electrical resistance that could not be explained and consequently implies the need for further investigation.

No clear pattern could be found in the C and P contents of the study area. However, the experimental plots dominated by the leguminous *A. mellifera* had a higher C content than the non-leguminous *C. apiculatum* dominated plots. The C:N ratio and P contents of the experimental plots were very low and the exact reason for this is unknown.

The soil of the study area is predominantly sandy (clay content between 12% and 20%), consisting mostly of fine sand. However, the sand in which *C. apiculatum* is dominant, is much finer than the sand where *A. mellifera* and *A. erubescens* are dominant. The differences between the silt, clay and sand contents of the experimental plots showed that the soils are derived from different parent materials.

It can be concluded that it is very important to analyse as many soil properties as possible to determine whether the soil does indeed have any effect on the plant species that grow in a specific area and whether the soil is a possible contributing factor to changes in the state of vegetation growth. Milchunas & Lauenroth (1993) stated that evaluating any one variable could provide misleading perceptions concerning the potential for shifting a system to an alternate state. Soil properties can also vary under different climatic conditions and can differ from region to region. It is also important to keep in mind that soil enrichment by trees is a slow process and it would take a long period of time before significant changes in soil properties as a result of thinning treatments, would be observed.

CHAPTER 8

GENERAL CONCLUSIONS AND RECOMMENDATIONS

8.1 INTRODUCTION

Bush encroachment is currently of great concern in Marakele Park. The main objective of this study was to determine whether mechanical bush thinning with the Barko Tractor was successful in solving the bush encroachment problem in the areas where it was applied.

8.2 GENERAL CONCLUSIONS

The following general conclusions could be drawn from the results of this study:

- The plant species diversity increased after the thinning treatments, but the plant communities within the specific study area were still characterised by herbaceous plant species (forbs and grasses) that are mostly associated with disturbed and overgrazed veld;
- the mechanical thinning treatments resulted in an initial decrease in the number of woody plants, but since no follow-up treatments were used, a large number of new woody seedlings were recorded and the majority of cut plants coppiced vigorously;
- approximately three years after the thinning treatments the leaf biomass (ETTE ha^{-1}) of the woody layer increased due to regrowth and re-encroachment to a point where negative competition interactions between the woody and herbaceous plants, as a result of competition for soil water and nutrients, were evident again;
- as expected, the control plots had a higher browsing capacity than the treatment plots in most of the browsing height strata. It is, however, important to keep in mind which browser species are present in the study area as well as their numbers, so that the thinning treatment does not impact negatively on the browse production;
- currently the herbaceous layer of Marakele Park is in a poor ecological condition and indications are that it is still deteriorating, even after the thinning treatments, e.g. the grazing capacity of the treatment plots were lower than those of the control plots during both seasons of the study period;
- due to the size of the Barko Tractor, it operated in a very unselective manner, resulting in the loss of important ecological features, such as subhabitat differentiation of large trees. It also caused soil disturbances and compaction of the soil due to its weight;

- rainfall and herbivory play an extremely important role in Marakele Park with indications that both equilibrial and non-equilibrial characteristics apply to the vegetation of the study area;
- in terms of herbaceous dry matter yield, the herbaceous layer did not respond as expected to the thinning treatments, except in those areas protected from grazing herbivores;
- Marakele Park is currently overstocked with various game species, especially high density, selective short grass grazers. The high grazing pressure exerted by these herbivores effectively neutralised the positive effects expected after the thinning treatments; and
- soil enrichment by trees is a slow process and significant changes in soil properties as a result of tree thinning, would only be observed long afterwards. It is thus important to monitor soil properties over a longer period of time to determine the effect of tree thinning on the soil nutrients in particular.

All factors considered, it can be concluded that the mechanical bush thinning that was applied in Marakele Park, was not very successful, notably due to the fact that no follow-up treatments were applied.

8.3 RECOMMENDATIONS

Successful management and utilisation of any game ranch, nature reserve or conservation area is dependent on the availability of regular and appropriate information on which to base decisions. Components such as rainfall, soil type, soil nutrient status, availability of water, vegetation characteristics such as structure, cover, composition and productivity, as well as herbivore game species and numbers, act as key determinants and indicators of the health of the ecosystem. The regular monitoring of these determinants is necessary to evaluate habitat and game population trends.

The vegetation of Marakele Park consists of different ecological units, which demonstrate the heterogeneity of the vegetation in the area. From the phytosociological study it was evident that the most important factors influencing the characteristics of the vegetation, were various soil properties, rainfall, and disturbances such as trampling by herbivore game species. It is thus recommended that a complete phytosociological study of the rest of Marakele Park be initiated to obtain information on the plant communities and to compile a complete vegetation map. As the study in Marakele Park was mainly done on the plains, it is important to do separate studies in the other topographical locations present in Marakele Park, e.g. hills, vleis, and riverine vegetation, so that the correct management decisions can be made. Each of these topographical areas has its own ecological problems and requires different management practices.

The results of this study clearly indicated that re-growth (coppicing) and re-encroachment of woody species is a serious problem in the thinned areas in Marakele Park. This can be attributed to the mechanical bush thinning method used in this park and, more importantly, the lack of follow-up treatments. The Barko Tractor operates very unselectively, which resulted in the loss of some mature trees. Mature trees are capable of preventing woody seedling establishment and it can suppress the growth of neighbouring woody plants (Smith & Goodman, 1986; Teague & Smit, 1992; Smit & Rethman, 1998a; Smit *et al.*, 1999). Another problem associated with the Barko Tractor is the soil disturbance it causes during operation. This most probably contributed to the germination of seed present in the soil seed bank and the stimulation of young emerging seedlings of problem woody species. The results of this study clearly indicate that the most problematic woody species in Marakele Park, namely *Acacia mellifera*, *A. erubescens*, *Combretum apiculatum* and *Dichrostachys cinerea*, have the ability to coppice vigorously and to establish quickly. Due to the coppice growth of woody plants after thinning, many plants changed from single-stemmed trees to multi-stemmed bushes. It is thus clear that if the coppicing of these plants are not prevented and controlled in time, the thinned areas in Marakele Park may become worse than the initial bush encroached state.

It is clear that the mechanical bush control method used in Marakele Park, alone, was not effective in combating bush encroachment. It is recommended that a combination of control methods be used and that the thinned areas be treated again. Due to the negative impact of the Barko Tractor, it should not be used again. Though slower and more labour intensive, cutting with brush cutters is recommended. This will allow for better control in selecting appropriate plants to cut without the risk of cutting larger trees.

Despite the negative sentiments toward chemical herbicides, and lacking a better alternative, the application of an environmentally safe herbicide is recommended. Effective chemical herbicides are available and if applied correctly they will reduce regrowth (coppice) to a large extent without any risk to the environment. Two broad types of herbicide are available for use. The first type is applied to the soil surface and is taken up by plant roots and the second is sprayed onto the plant and directly absorbed by the above ground parts of the plants. After application of soil applied herbicides, these herbicides remain inactive until rain carries the active ingredient into the soil, to be absorbed by the tree roots. However, because tree roots often extend well beyond the perimeter of their canopy, trees at some distance from the treated trees may be affected, even if selective applications are used. This can be a problem in conservation areas where the loss of large trees must be prevented and the use of these soil applied herbicides is not recommended. Herbicides applied directly to the plant are applied either to the stem or the leaves of the plant.

They can be sprayed onto the whole plant, the cut stumps, or coppice growth. The latter method is recommended for Marakele Park. A herbicide which is suited for this type of application is water soluble Picloram (Access). Chemical control is an expensive process, but the long-term advantages exceed the disadvantages, provided the treated areas are managed correctly and sustainably.

Even with good management, however, woody species often re-invade the area and attention needs to be paid to slowing down this process as much as possible. The following procedures can be used to delay or prevent re-encroachment:

- the occasional use of a hot fire to kill the topgrowth of established woody plants and also young seedlings of woody species;
- browsers could slow the regrowth of woody plants; and
- follow-up spot application of herbicides.

Only head-fires (a fire burning with the wind) should be used in controlled burning programs because they cause less damage to the grass layer than do back-fires (a fire burning against the wind). When burning to control undesirable woody plants, high intensity fires (in excess of 2 000 kJ s^{-1} m^{-1}) are required. These can be achieved when the grass fuel load is in excess of 4 000 kg ha^{-1}, the air temperature is between 25ºC and 30ºC and the relative humidity is less than 30%. Such fires should cause a significant topkill of trees and shrubs up to 3 m. In all cases, wind speeds should not exceed 20 km h^{-1} (Trollope, 1999). The burns should be applied before the first spring rains while the grass is dry and dormant so as to produce an intense fire. Post-fire management will depend on the ecological characteristics of the plants being controlled. Post-fire grazing in wildlife areas is, however, difficult to control. Where possible the burnt areas should be large so that the forage producing capacity of the burnt area will soon exceed the forage demands of the game that are likely to be attracted to the area. The types of fire required are determined by climate, especially rainfall, and the amount of available fuel, which is influenced by the number of grazing herbivores. However, the low and highly variable rainfall of Marakele Park presents a risk for the practical incorporation of controlled burning in the park.

Stem burning, in which a low intensity fire burns or smoulders for an extended period around the stem of the woody plant, can be used to selectively kill individual trees. This procedure is quite effective when *Acacia* species needs to be removed, however, it is not well suited for trees with small stems or for multi-stemmed woody plants such as *Grewia* spp. (Smit *et al.*, 1999).

Apart from tree seedlings, which can be impacted by small browsers, the use of browsers to exercise control over woody plants, largely excludes game. Elephants are, however, an exception but their use is confined to large game reserves and even here the population required to provide any appreciable impact on the woody vegetation, would be so large that serious management problems could arise. Elephants are already present in Marakele Park and it was observed that they only aggravate the bush encroachment problem in the park because they damage mature trees, causing a similar negative impact as mentioned in the case of the Barko Tractor.

The results of this study also clearly indicate that herbivory is a significant problem in Marakele Park. The herbivore populations of especially high density, selective, short grass grazers such as blue wildebeest, and long grass grazers such as plains zebra are too large in the Park. This is substantiated by the fact that not even the above average rainfall recorded during the study period resulted in any substantial improvement of the poor veld condition present in Marakele Park. This is also further demonstrated by the substantial differences in DM yield between areas protected from grazing and areas exposed to grazing. It is thus recommended that the herbivore populations of especially the above-mentioned species be reduced to more conservative populations. If the herbivore populations of the park are not reduced, no bush control operation aimed at increasing herbaceous (grass) production, will be successful.

The inherent potential of the soil also proved to have an influence on the reaction of the vegetation to thinning treatments in Marakele Park. Vegetation that occur on deeper, more fertile soil, responded better to the thinning treatments in terms of DM yield than vegetation that was found in shallow, gravelly soil. The soil variables in Marakele Park indicated that most of the soil in the experimental plots had a tendency to form surface crusts. Few of the soil variables changed considerably as a direct result of the thinning treatments applied in Marakele Park. However, it is important to note that changes in soil properties is a very slow process and it would take a long time before significant changes would be observed. It is thus recommended that the soil of the thinned areas be analysed again at a later stage to determine if the thinning treatments had a negative or positive effect. It is also recommended that surveys of the soil be done for the rest of the park to obtain an accurate description of the soil and to determine if differences in soil properties of the rest of the park have any influence on the vegetation.

It is clear that there is not a simple, once-off solution to the problem of bush encroachment. It is an ongoing process and the management applied to the bush encroached areas must be adapted as changes in the environment occur, making constant monitoring after bush control a necessity.

Only a holistic approach to land reclamation in semi-arid areas will be successful in the long-term. It can be concluded that a land user should not even consider implementing a bush control programme if a proper follow-up programme is not planned or budgeted for. Intervals of follow-up applications differ from one area to the next and are mainly influenced by environmental factors, type of problem species as well as the success rate of the initial control method (Barac, 2003).

ABSTRACT

A PLANT ECOLOGICAL EVALUATION OF MECHANICAL BUSH THINNING IN MARAKELE PARK, LIMPOPO PROVINCE

by

FRANCINA CHRISTINA PIENAAR

Supervisor: Prof. G.N. Smit
Co-supervisor: Dr. P.J. Du Preez

Department of Animal, Wildlife and Grassland Sciences
University of the Free State

MAGISTER SCIENTIAE

Bush encroachment is currently of great concern in Marakele Park. The main motivation for this study, conducted during the 2003/2004 and 2004/2005 seasons, was to determine whether mechanical bush thinning, executed with a mechanical mulcher, namely the Barko Tractor, was successful in solving the bush encroachment problem in the areas where it was applied. The specific objectives of this study were to identify, describe and interpret the plant communities of a section of Marakele Park, and to establish the influences of the thinning treatments on the dynamics of the ecosystem, more specifically the regrowth and browse production of the woody plants, the species composition and dry matter (DM) yield of the herbaceous layer and the short term changes in the soil.

Eight experimental plots (3 treatments, 3 controls, 2 coppice) were selected in three veld types (*Acacia mellifera – Grewia flava*, *Combretum apiculatum – Grewia flava* and *Acacia erubescens – Dichrostachys cinerea*), in which tree thinning was applied during 2002 and 2003. Each plot was 100 m x 200 m (20 000 m^2 = 2 ha) in size. The vegetation of the plots was phytosociologically studied during the 2003/2004 season with the aid of the Braun-Blanquet vegetation sampling method. A total of 80 relevés were surveyed and upon analysis 3 major communities, 7 communities, 6 sub-communities and 3 variants were identified. The woody layer was quantified with a quantitative description technique, which is incorporated in the BECVOL-model. A step point-method and the Ecological Index Method were used to determine the species composition and veld condition of the herbaceous layer, respectively, and a harvesting method was used to determine the DM yield and the associated grazing capacity.

The thinning treatments resulted in an initial decreased number of woody plants, but since no follow-up treatments were applied, a large number of new seedlings have since established and the majority of cut-plants coppiced vigorously. However, approximately three years after the thinning treatments the leaf biomass (ETTE ha^{-1}) of the woody layer increased due to regrowth and re-encroachment to a point where negative interactions between the woody and herbaceous plants, as a result of competition for soil water and nutrients, were evident again.

The species diversity of the herbaceous layer increased after the thinning treatments, but species normally associated with disturbed and overgrazed veld still dominated. It was concluded that the herbaceous layer of Marakele Park is in a poor ecological state and indications are that it is still deteriorating. The herbaceous DM yield did not respond to the thinning treatments as expected, except in areas protected from grazing herbivores. As a result, the grazing capacity of the Park was comparatively low. It is clear that Marakele Park is currently overstocked with various game species, especially of high density, selective short grass grazers. Thinning treatments will therefore not be successful unless the herbivore game numbers are reduced.

Few soil variables changed significantly as a result of the thinning treatments, but in view of the fact that soil enrichment is a slow process, monitoring of the soil variables is recommended. The specific soil properties did, however, have a decisive influence on the vegetation type. The *Combretum apiculatum – Grewia flava* plots occurred on relatively shallow, gravelly soil, while the *Acacia* dominated plots occurred on deeper, more fertile soil. It was also concluded that the Barko Tractor, due to its size and weight, had a negative impact on the soil, mainly in the form of soil compaction.

Subhabitat differentiation, rainfall and herbivory played an important role in the study area and indicated that the vegetation of Marakele Park displays both equilibrial and non-equilibrial trends. The high grazing pressure, together with the high incidence of coppice and re-encroachment of woody plants after the initial thinning treatments, as well as the lack of follow-up treatments, effectively neutralised the success of the mechanical bush thinning treatments. In order to restore these thinned areas from re-encroachment it will be necessary to cut the plants again and combine this effort with a cut-stump treatment (chemical herbicide). Due to the negative impact of the Barko Tractor, it should not be used again during any follow-up operation.

Keywords: Barko Tractor; BECVOL-model; Braun-Blanquet; Bush encroachment; Competition; Dry matter yield; Herbaceous layer; Herbivory; Mechanical bush thinning; Rainfall; Savanna; Soil enrichment; Woody layer

OPSOMMING

‘N PLANT EKOLOGIESE EVALUERING VAN MEGANIESE BOSUITDUNNING IN MARAKELE PARK, LIMPOPO PROVINSIE

deur

FRANCINA CHRISTINA PIENAAR

Studieleier: Prof. G.N. Smit
Mede-studieleier: Dr. P.J. Du Preez

Departement Vee, Wild en Weidingkunde
Universiteit van die Vrystaat

MAGISTER SCIENTIAE

Bosverdigting is op die oomblik ‘n groot bron van kommer in Marakele Park. Die hoof motivering vir die studie, uitgevoer tydens die 2003/2004 en 2004/2005 seisoen, was die evaluering van die sukses van meganiese bosuitdunning met ‘n meganiese maler, naamlik die Barko Trekker, toegepas op verdigte areas. Die spesifieke doelwitte van die studie was die identifisering, beskrywing en interpretasie van ‘n deel van Marakele Park se plantegroei gemeenskappe. Hierbenewens is die invloed van die uitdunningsbehandelings op houtagtige plante; die spesiesamestelling en droëmateriaal (DM) produksie van die kruidlaag en die korttermyn veranderinge van die grond ook bepaal.

Agt eksperimentele plotte (3 behandelings, 3 kontroles, 2 hergroei) is in drie veldtipes (*Acacia mellifera – Grewia flava*, *Combretum apiculatum – Grewia flava* en *Acacia erubescens – Dichrostachys cinerea*) waar boomuitdunning toegepas is tydens 2002 en 2003, geselekteer. Elke plot was 100 m x 200 m (20 000 m^2 = 2 ha) in grootte. Die plantegroei van die plotte is fitososiologies bestudeer tydens die 2003/2004 seisoen met behulp van die Braun-Blanquet plantopnamemetode. ‘n Totaal van 80 relevés is ondersoek waarna 3 hoof gemeenskappe, 7 gemeenskappe, 6 subgemeenskappe en 3 variante geïdentifiseer is. Die houtagtige komponent is gekwantifiseer met ‘n kwantitatiewe beskrywingstegniek wat in die BECVOL-model geïnkorporeer is. ‘n Stappunt metode en die Ekologiese Indeks Metode is gebruik om onderskeidelik die spesiesamestelling en veld toestand van die kruidlaag te bepaal. ‘n Oestegniek is gebruik om die DM produksie en geassosieërde weidingskapasiteit te bepaal.

Die uitdunningsbehandelings het tot ‘n aanvanklike verlaging in die hoeveelheid houtagtige plante gelei, maar aangesien geen opvolg behandelings toegepas is nie, het ‘n groot aantal nuwe saailinge gevestig en die meerderheid van die gesnyde plante het sterk hergroei. As gevolg van die hergroei en herverdigting was die blaar biomassa (ETTE ha^{-1}) van die houtagtige plante ongeveer drie jaar na die aanvanklike uitdunningsbehandelings weer by ‘n punt waar die negatiewe interaksie, as gevolg van kompetisie, tussen die houtagtige and kruidagtige plante, vir grondwater en nutriënte, sigbaar was.

Die spesie diversiteit van die kruidlaag het verhoog na die uitdunningsbehandelings, maar dit was steeds gedomineer deur spesies wat normaalweg met versteurde en oorbeweide veld geassosieer word. Die afleiding is gemaak dat die kruidlaag van Marakele Park in ‘n swak ekologiese toestand is en volgens alle aanduidings steeds besig is om te verswak. Die DM produksie van die kruidlaag het nie na verwagting op die uitdunningsbehandelings gereageer nie, behalwe in die areas wat teen beweiding beskerm was. Gevolglik was die weidingskapasiteit van die park vergelykend laag. Dit is duidelik dat Marakele Park oorbewei word deur ‘n verskeidenheid wildspesies – veral hoë digtheid, selektiewe grasvreters – en dat die uitdunningsbehandelings nie suksesvol sal wees tensy die herbivoor wildgetalle verminder word nie.

Weinig van die grondveranderlikes het verander as gevolg van die uitdunningsbehandelings, maar omdat grondverryking ‘n stadige proses is, word monitering van grondveranderlikes aanbeveel. Die spesifieke grondeienskappe het egter ‘n betekenisvolle effek op die plantegroei tipes gehad. Die *Combretum apiculatum* – *Grewia flava* persele het op relatief vlak, klipperige grond voorgekom, terwyl die *Acacia* gedomineerde persele op dieper, meer vrugbare grond voorgekom het. Die gevolgtrekking is gemaak dat die Barko Trekker, as gevolg van sy grootte en gewig, ‘n negatiewe impak op die grond gehad het, veral ten opsigte van grond kompaksie.

Subhabitat verskille, reënval en beweiding het ‘n belangrike rol in die studie area gespeel en aanduidings is dat die plantegroei van Marakele Park beide ekwilibriale and nie-ekwilibriale neigings toon. Die hoë weidruk, tesame met die groot mate van hergroei en herverdigting van houtagtige plante na die aanvanklike uitdunningsbehandelings, asook die gebrek aan opvolg aksies, het die sukses van die meganiese bosuitdunningsbehandelings effektief geneutraliseer. Om die uitgedunde areas van herverdigting te laat herstel, sal dit nodig wees om die plante weer the sny, gekombineerd met die spuit van die gesnyde stompe met ‘n chemiese boomdoder. As gevolg van die grootte en onselektiewe werking van die Barko Trekker, word die gebruik daarvan vir die opvolgbehandeling nie aanbeveel nie.

Sleutelterme: Barko Trekker; BECVOL-model; Beweiding; Bosverdigting; Braun-Blanquet; Droëmateriaalproduksie; Grondverryking; Houtagtige komponent; Kompetisie; Kruidlaag; Meganiese bosuitdunning; Reënval; Savanna

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APPENDIX A

List of all plant species that were recorded during the study surveys. The plant species are ordened according to Family names and the authors are given after each species name. The common names are also given where possible.

FAMILY[1]	SPECIES NAME & AUTHORS[1]	COMMON NAME
ACANTHACEAE	*Barleria* L.	
	B. galpinii C.B.Clarke	
	Blepharis Juss.	
	B. integrifolia (L.f.) E.Mey. ex Schinz	Rankklits[2]
	Crabbea Harv.	
	C. angustifolia Nees	
	Hypoestes Sol. ex R.Br.	
	Justicia L.	
	J. flava (Vahl) Vahl	
	J. protracta (Nees) T.Anderson	
AMARANTHACEAE	*Achyranthes* L.	
	A. aspera L. var. *sicula* L.	Burweed[2]
	Aerva Forssk.	
	A. leucura Moq.	Aambeibossie[2]
	Hermbstaedtia Rchb.	
	H. linearis Schinz	Woolflower[3]
	H. odorata (Burch.) T.Cooke	Katstert[2]
	Kyphocarpa (Fenzl) Lopr.	
	K. angustifolia (Moq.) Lopr.	Silky Burweed[3]
	Pupalia Juss.	
	P. lappacea (L.) A.Juss.	Sweethearts[2]
ANACARDIACEAE	*Rhus* L.	
	R. pyroides Burch.	Common Wild Currant[4]
APOCYNACEAE	*Carissa* L.	
	C. bispinosa (L.) Desf. ex Brenan	Common Num-num[8]

…Continues

Appendix A continued…

FAMILY[1]	SPECIES NAME & AUTHORS[1]	COMMON NAME
ASPARAGACEAE	*Asparagus* L.	
	A. suaveolens Burch.	Wild Asparagus[3]
ASPHODELACEAE	*Haworthia* Duval	
ASTERACEAE	*Acanthospermum* Schrank	
	Bidens L.	
	B. pilosa L.	Common Blackjack[6]
	Blumea DC.	
	B. dregeanoides Sch.Bip. ex A.Rich.	
	Conyza Less.	
	C. podocephala DC.	Conyza[2]
	Dicoma Cass.	
	Geigeria Griess.	
	G. burkei Harv.	Vermeersiektebossie[2]
	Helichrysum Mill.	
	H. dregeanum Sond. & Harv.	Bergankerkaroo[2]
	Osteospermum L.	
	O. muricatum E.Mey. ex DC.	Boegoebossie[2]
	Schkuhria Roth	
	S. pinnata (Lam.) Cabrera	Dwarf Marigold[6]
	Senecio L.	
	S. latifolius DC.	Ragwort[6]
	Vernonia Schreb.	
	V. poskeana Vatke & Hildebr.	
	Zinnia L.	
	Z. peruviana (L.) L.	Redstar Zinnia[6]
BORAGINACEAE	*Ehretia* P.Browne	
	E. rigida (Thunb.) Druce	Puzzle-bush[4]

…Continues

Appendix A continued…

FAMILY[1]	SPECIES NAME & AUTHORS[1]	COMMON NAME
CELASTRACEAE	*Gymnosporia* (Wight & Arn.) Hook.f.	
	G. heterophylla (Eckl. & Zeyh.) Loes.	Dune Spikethorn[4]
	G. senegalensis (Lam.) Loes.	Confetti Spikethorn[4]
CHENOPODIACEAE	*Chenopodium* L.	
	C. carinatum R.Br.	Green Goosefoot[6]
COMBRETACEAE	*Combretum* Loefl.	
	C. apiculatum Sond.	Red Bushwillow[4]
	C. hereroense Schinz	Russet Bushwillow[4]
	C. imberbe Wawra	Leadwood[4]
	C. molle R.Br. ex G.Don	Velvet Bushwillow[5]
	Terminalia L.	
	T. sericea Burch. ex DC.	Silver Cluster-leaf[4]
COMMELINACEAE	*Commelina* L.	
	C. africana L.	Yellow Wondering Jew[6]
CONVOLVULACEAE	*Evolvulus* L.	
	E. alsinoides (L.) L.	
	Ipomoea L.	
	I. obscura (L.) Ker Gawl. var. *obscura*	
CRASSULACEAE	*Kalanchoe* Adans.	
	K. lanceolata (Forssk.) Pers.	Lance Leaf Air Plant[3]
	K. paniculata Harv.	Krimpsiektebos[2]
CUCURBITACEAE	*Cucumis* L.	
	C. zeyheri Sond.	Wild Cucumber[3]
	Zehneria Endl.	
	Z. marlothii (Cogn.) R.& A.Fern.	

...Continues

Appendix A continued…

FAMILY[1]	SPECIES NAME & AUTHORS[1]	COMMON NAME
CYPERACEAE	*Cyperus* L.	
	C. indecorus Kunth var. *decurvatus* (C.B.Clarke) Kük.	
	C. rupestris Kunth	
	Fuirena Rottb.	
	F. pubescens (Poir.) Kunth	
DRACAENACEAE	*Sansevieria* Thunb.	
	S. pearsonii N.E.Br.	Elephant Toothpick[3]
EBENACEAE	*Diospyros* L.	
	D. lycioides Desf.	Bluebush Star-apple[5]
	Euclea Murray	
	E. undulata Thunb.	Small-leaved Guarri[5]
EUPHORBIACEAE	*Jatropha* L.	
	J. zeyheri Sond.	Verfbol[2]
	Phyllanthus L.	
	P. reticulatus Poir.	Potato-bush[3]
	Spirostachys Sond.	
	S. africana Sond.	Tamboti[4]
FABACEAE	*Acacia* Mill.	
	A. caffra (Thunb.) Willd.	Common Hook Thorn[7]
	A. erubescens Welw. ex Oliv.	Blue Thorn[7]
	A. karroo Hayne	Sweet Thorn[7]
	A. luederitzii Engl. var. *retinens* (Sim) J.H.Ross & Brenan	Balloon Thorn[7]
	A. mellifera (Vahl) Benth.	Black Thorn[7]
	A. robusta Burch.	Ankle Thorn[7]
	A. tortilis (Forssk.) Hayne	Umbrella Thorn[7]
	Chamaecrista Moench	
	C. mimosoides (L.) Greene	Fish-bone Cassia[3]

…Continues

Appendix A continued…

FAMILY[1]	SPECIES NAME & AUTHORS[1]	COMMON NAME
FABACEAE	*Dichrostachys* (A.DC.)	
	D. cinerea (L.) Wight & Arn.	Sickle-bush[4]
	Indigofera L.	
	I. filipes Benth. ex Harv.	
	I. holubii N.E.Br.	
	Melolobium Eckl. & Zeyh.	
	Peltophorum (Vogel) Benth.	
	P. africanum Sond.	African-wattle[4]
	Pterocarpus Jacq.	
	P. rotundifolius (Sond.) Druce	Round-leaved Bloodwood[4]
	Rhynchosia Lour.	
	R. caribaea (Jacq.) DC.	Caribbean Snoutbean[3]
	R. totta (Thunb.) DC.	
	Senna Mill.	
	S. italica Mill. subsp. *arachoides* (Burch.) Lock	Eland's Pea[3]
	Tephrosia Pers.	
	T. capensis (Jacq.) Pers.	
	T. longipes Meisn.	Vingerblaarertjie[2]
	T. lupinifolia DC.	
	Zornia J.F.Gmel.	
	Z. milneana Mohlenbr.	
GERANIACEAE	*Monsonia* L.	
	M. burkeana Planch. ex Harv.	Dysentery Weed[3]
HYACINTHACEAE	*Albuca* L.	
IRIDACEAE	*Freesia* Klatt	
	F. laxa (Thunb.) Goldblatt & J.C.Manning	
LAMIACEAE	*Hemizygia* (Benth.) Briq.	
	H. canescens (Gürke) M.Ashby	

…Continues

Appendix A continued…

FAMILY[1]	SPECIES NAME & AUTHORS[1]	COMMON NAME
LAMIACEAE	*Hyptis* Jacq.	
	Stachys L.	
LENTIBULARIACEAE	*Linum* L.	
	L. thunbergii Eckl. & Zeyh.	Wild Flax[3]
	Abutilon Mill.	
MALVACEAE	*A. pycnodon* Hochr.	Wild Abutilon[3]
	A. sonneratianum (Cav.) Sweet	Wild Hibiscus[4]
	Gossypium L.	
	G. herbaceum L.	Wild Cotton[3]
	Hibiscus L.	
	H. cannabinus L.	Wild Stockrose[3]
	H. engleri K.Schum.	
	Pavonia Cav.	
	P. burchellii (DC.) R.A.Dyer	
	P. transvaalensis (Ulbr.) A.Meeuse	
OROBANCHACEAE	*Striga* Lour.	
	S. elegans Benth.	Witchweed[3]
OXALIDACEAE	*Oxalis* L.	
	O. depressa Eckl. & Zeyh.	
PEDALIACEAE	*Ceratotheca* Endl.	
	C. triloba (Bernh.) Hook.f.	Wild Foxglove[3]
POACEAE	*Aristida* L.	
	A. adscensionis L.	Annual Three-awn[8]
	A. congesta Roem. & Schult. subsp. *barbicollis* (Trin. & Rupr.) De Winter	Spreading Three-awn[8]
	A. congesta Roem. & Schult. subsp. *congesta*	Tassel Three-awn[8]

…Continues

Appendix A continued…

FAMILY[1]	SPECIES NAME & AUTHORS[1]	COMMON NAME
POACEAE	*Bothriochloa* Kuntze	
	B. insculpta (A.Rich.) A.Camus	Pinhole Grass[8]
	B. radicans (Lehm.) A.Camus	Stinking Grass[8]
	Brachiaria (Trin.) Griseb.	
	B. deflexa (Schumach.) C.E.Hubb. ex Robyns	False Signal Grass[8]
	B. nigropedata (Ficalho & Hiern) Stapf	Black-footed Grass[8]
	Cenchrus L.	
	C. ciliaris L.	Foxtail Buffalo Grass[8]
	Chloris Sw.	
	C. virgata Sw.	Feather-top Chloris [8]
	Cymbopogon Spreng.	
	C. pospischilii (K.Schum.) C.E. Hubb.	Narrow-leaved Turpentine[8]
	Dactyloctenium Willd.	
	D. giganteum Fisher & Schweick.	Gaint Crowfoot[8]
	Digitaria Haller	
	D. eriantha Steud.	Common Finger Grass[8]
	Elionurus Kunth ex Willd.	
	E. muticus (Spreng.) Kuntze	Wire Grass[8]
	Enneapogon Desv. Ex P.Beauv.	
	E. cenchroides (Roem. & Schult.) C.E.Hubb.	Nine-awned Grass[8]
	E. scoparius Stapf	Bottlebrush Grass[8]
	Eragrostis Wolf	
	E. biflora Hack. ex Schinz	Shade Eragrostis[8]
	E. gummiflua Nees	Gum Grass[8]
	E. lehmanniana Nees	Lehmann's Love Grass[8]
	E. pilgeriana Dinter ex Pilg.	
	E. pilosa (L.) P.Beauv.	
	E. rigidior Pilg.	(Broad) Curly Leaf[8]
	E. superba Peyr.	Saw-tooth Love Grass[8]
	Heteropogon Pers.	
	H. contortus (L.) Roem. & Schult.	Spear Grass[8]

…Continues

Appendix A continued…

FAMILY[1]	SPECIES NAME & AUTHORS[1]	COMMON NAME
POACEAE	*Melinis* P.Beauv.	
	M. repens (Willd.) Zizka	Natal Red Top[8]
	Microchloa R.Br.	
	M. caffra Nees	Pincushion Grass[8]
	Panicum L.	
	P. coloratum L.	Small Buffalo Grass[8]
	P. maximum Jacq.	Guinea Grass[8]
	Paspalum L.	
	P. dilatatum Poir.	Dallis Grass[8]
	Pogonarthria Stapf	
	P. squarrosa (Roem. & Schult.) Pilg.	Herringbone Grass[8]
	Schmidtia Steud. ex J.A.Schmidt	
	S. pappophoroides Steud.	Sand Quick[8]
	Setaria P.Beauv.	
	S. pumila (Poir.) Roem. & Schult.	Garden Bristle Grass[8]
	Sporobolus R.Br.	
	S. ioclados (Trin.) Nees	Pan Dropseed[8]
	S. nitens Stent	Curly-leaved Dropseed[8]
	S. panicoides A.Rich.	Christmas Tree Grass[8]
	Themeda Forssk.	
	T. triandra Forssk.	Red Grass[8]
	Tragus Haller	
	T. berteronianus Schult.	Carrot-seed Grass[8]
	T. racemosus (L.) All.	Hartjiesgras[2]
	Trichoneura Andersson	
	T.grandiglumis (Nees) Ekman	Small Rolling Grass[8]
	Urochloa P.Beauv.	
	U. mosambicensis (Hack.) Dandy	Bushveld Signal Grass[8]
POLYGALACEAE	*Polygala*	
	P. sphenoptera Fresen.	

…Continues

Appendix A continued…

FAMILY[1]	SPECIES NAME & AUTHORS[1]	COMMON NAME
POLYGONACEAE	*Oxygonum* Burch. ex Campd.	
	O. sinuatum (Hochst. & Steud. ex Meisn.) Dammer	Dubbeltjie[2]
PORTULACACEAE	*Portulaca* L.	
	P. kermesina N.E.Br.	
	P. quadrifida L.	Wild Purslane[6]
RHAMNACEAE	*Ziziphus* Mill.	
	Z. mucronata Willd.	Buffalo-thorn[4]
RUBIACEAE	*Agathisanthemum* Klotzsch	
	A. bojeri Klotzsch	
	Cephalanthus L	
	C. natalensis Oliv.	Strawberry-bush[5]
	Kohautia Cham. & Schltdl.	
	K. virgata (Willd.) Bremek.	
SCROPHULARIACEAE	*Nemesia* Vent.	
	N. albiflora N.E.Br.	
SOLANACEAE	*Solanum* L.	
	S. panduriforme E.Mey.	Bitter Apple[3]
	S. rigescens Jacq.	Wildelemoentjie[3]
STERCULIACEAE	*Hermannia* L.	
	H. glanduligera K.Schum.	
	H. transvaalensis Schinz	
	Melhania Forssk.	
	M. prostrata DC.	
TILIACEAE	*Corchorus* L.	
	C. asplenifolius Burch.	Besembossie[2]

...Continues

Appendix A continued…

FAMILY[1]	SPECIES NAME & AUTHORS[1]	COMMON NAME
TILIACEAE	*Grewia* L.	
	G. bicolor Juss.	White-leaved Raisin[5]
	G. flava DC.	Velvet Raisin[5]
	G. flavescens Juss.	Sandpaper Raisin[5]
	G. monticola Sond.	Grey Raisin[5]
	Triumfetta L.	
	T. pilosa Roth	
VAHLIACEAE	*Vahlia* Thunb.	
	V. capensis (L.f.) Thunb.	
VITACEAE	*Cyphostemma* (Planch.) Alston	
	C. oleraceum (Bolus) J.J.M.van der Merwe	
ZYGOPHYLLACEAE	*Zygophyllum* L.	

According to:

[1]Germishuizen & Meyer (2003)
[2]Smith (1966)
[3]Fabian & Germishuizen (1997)
[4]Van Wyk *et al*. (2000)
[5]Coates Palgrave (2002)
[6]Bromilow (2001)
[7]Smit (1999)
[8]Van Oudtshoorn (1999)

APPENDIX C

Field names used by the BECVOL program and their units are given in parenthesis:

PL_HA – Plants per hectare (plants ha^{-1})
LVOL – Leaf volume per hectare (m^3 ha^{-1})
ETTE – Evapotranspiration Tree Equivalents per hectare (ETTE ha^{-1})
LMAS – Leaf dry mass per hectare (kg ha^{-1})
LM_15 – Leaf dry mass per hectare below a browsing height of 1.5 m (kg ha^{-1})
LM_20 – Leaf dry mass per hectare below a browsing height of 2.0 m (kg ha^{-1})
LM_50 – Leaf dry mass per hectare below a browsing height of 5.0 m (kg ha^{-1})
BTE – Browse Tree Equivalents per hectare (BTE ha^{-1})
BTE_15 – Browse Tree Equivalents per hectare below a browsing height of 1.5 m (BTE ha^{-1})
BTE_20 – Browse Tree Equivalents per hectare below a browsing height of 2.0 m (BTE ha^{-1})
BTE_50 – Browse Tree Equivalents per hectare below a browsing height of 5.0 m (BTE ha^{-1})
CSI_2 – Canopied Subhabitat Index based on trees with a minimum height of 2 m
CSI_4 – Canopied Subhabitat Index based on trees with a minimum height of 4 m

Appendix C1: Data obtained from the secondary calculations of the BECVOL (version 2.0) computer programme for the *Acacia mellifera* – *Grewia flava* Treatment plot during the 2003/2004 season.

SPECIES	PL_HA	LVOL	ETTE	LMAS	LM_15	LM_20	LM_50	BTE	BTE_15	BTE_20	BTE_50	CSI_2	CSI_4
Acacia erubescens (N)	160	435	871	206	25	43	206	822	100	172	822	7.8	4.3
Acacia erubescens (C)	20	6	11	3	3	3	3	11	11	11	11	0.0	0.0
Acacia mellifera (N)	240	2368	4736	1127	76	195	904	4509	304	782	3615	40.3	27.1
Acacia mellifera (C)	40	1	1	0	0	0	0	1	1	1	1	0.0	0.0
Acacia tortilis (N)	200	596	1192	281	17	26	260	1125	67	103	1038	10.8	10.8
Acacia tortilis (C)	20	4	8	2	2	2	2	7	7	7	7	0.0	0.0

...Continues

Appendix C1 continued...

SPECIES	PL_HA	LVOL	ETTE	LMAS	LM_15	LM_20	LM_50	BTE	BTE_15	BTE_20	BTE_50	CSI_2	CSI_4
Asparagus suaveolens (N)	120	14	28	6	6	6	6	25	25	25	25	0.0	0.0
Asparagus suaveolens (C)	260	3	6	1	1	1	1	5	5	5	5	0.0	0.0
Carissa bispinosa (C)	20	0	1	0	0	0	0	1	1	1	1	0.0	0.0
Combretum apiculatum (N)	20	38	76	17	6	9	17	67	23	36	67	0.6	0.0
Grewia bicolor (N)	80	80	160	29	22	29	29	117	86	115	117	0.7	0.0
Grewia bicolor (C)	20	9	19	5	5	5	5	19	19	19	19	0.0	0.0
Grewia flava (N)	520	446	892	164	119	149	164	657	477	597	657	3.3	0.0
Grewia flava (C)	460	67	134	34	34	34	34	137	137	137	137	0.0	0.0
Grewia monticola (N)	120	51	103	18	17	18	18	73	67	73	73	0.0	0.0
Grewia monticola (C)	20	11	22	6	6	6	6	22	22	22	22	0.0	0.0
Rhus pyroides (C)	20	1	3	1	1	1	1	3	3	3	3	0.0	0.0
Ziziphus mucronata (N)	40	93	185	41	4	7	41	165	15	30	165	1.3	1.3
Totals	2440	4224	8449	1942	343	535	1697	7767	1372	2140	6787	64.8	43.5

Appendix C2: Data obtained from the secondary calculations of the BECVOL (version 2.0) computer programme for the *Acacia mellifera* – *Grewia flava* Control plot during the 2003/2004 season.

SPECIES	PL_HA	LVOL	ETTE	LMAS	LM_15	LM_20	LM_50	BTE	BTE_15	BTE_20	BTE_50	CSI_2	CSI_4
Acacia erubescens (N)	80	805	1610	383	26	51	285	1531	102	205	1142	14.6	11.4
Acacia mellifera (N)	300	1565	3130	741	80	144	568	2965	320	578	2273	25.3	21.1
Acacia tortilis (N)	280	876	1752	410	113	215	410	1640	454	862	1640	15.0	4.9
Asparagus suaveolens (N)	240	291	583	138	49	77	138	551	196	307	551	5.8	0.0
Combretum apiculatum (N)	20	4	7	2	2	2	2	6	6	6	6	0.0	0.0
Combretum hereroense (N)	20	2	3	1	1	1	1	3	3	3	3	0.0	0.0
Grewia bicolor (N)	80	154	308	59	51	59	59	238	202	238	238	1.4	0.0
Grewia flava (N)	620	1351	2701	529	346	494	529	2118	1383	1974	2118	24.1	0.0
Grewia monticola (N)	100	119	238	45	36	43	45	178	145	173	178	1.1	0.0
Totals	1740	5166	10331	2308	703	1086	2037	9231	2812	4346	8149	87.2	37.4

Appendix C3: Data obtained from the secondary calculations of the BECVOL (version 2.0) computer programme for the *Combretum apiculatum* – *Grewia flava* Treatment plot during the 2003/2004 season.

SPECIES	PL_HA	LVOL	ETTE	LMAS	LM_15	LM_20	LM_50	BTE	BTE_15	BTE_20	BTE_50	CSI_2	CSI_4
Acacia erubescens (N)	60	149	298	70	8	16	70	280	32	64	280	2.6	2.6
Acacia luederitzii retinens (N)	20	1	2	1	1	1	1	2	2	2	2	0.0	0.0
Acacia tortilis (N)	80	8	16	4	4	4	4	14	15	15	15	0.0	0.0
Acacia tortilis (C)	20	3	5	1	1	1	1	5	5	5	5	0.0	0.0
Asparagus suaveolens (N)	80	4	7	2	2	2	2	6	6	6	6	0.0	0.0
Asparagus suaveolens (C)	20	0	1	0	0	0	0	0	0	0	0	0.0	0.0

...Continues

Appendix C3 continued...

SPECIES	PL_HA	LVOL	ETTE	LMAS	LM_15	LM_20	LM_50	BTE	BTE_15	BTE_20	BTE_50	CSI_2	CSI_4
Combretum apiculatum (N)	600	594	1188	262	54	98	262	1047	217	393	1047	10.3	2.2
Combretum apiculatum (C)	920	82	165	36	36	36	36	145	145	145	145	0.0	0.0
Combretum hereroense (N)	80	269	538	120	5	14	120	479	19	57	479	5.1	5.1
Combretum hereroense (C)	40	13	27	7	7	7	7	27	27	27	27	0.0	0.0
Combretum molle (N)	40	4	8	2	2	2	2	7	7	7	7	0.0	0.0
Dichrostachys cinerea (N)	120	19	39	8	8	8	8	31	31	31	31	0.0	0.0
Grewia bicolor (N)	100	95	189	34	34	34	34	135	134	135	135	0.0	0.0
Grewia flava (N)	500	331	662	116	107	115	116	463	427	462	464	1.4	0.0
Grewia flava (C)	140	42	84	21	21	21	21	86	85	85	85	0.0	0.0
Grewia flavescens (N)	80	42	84	14	14	14	14	57	57	57	57	0.0	0.0
Grewia flavescens (C)	40	15	31	8	8	8	8	32	32	32	32	0.0	0.0
Grewia monticola (N)	240	185	370	69	69	69	69	277	277	277	277	0.0	0.0
Grewia monticola (C)	140	18	37	9	9	9	9	37	37	37	37	0.0	0.0
Peltophorum africanum (N)	20	1	2	1	1	1	1	2	2	2	2	0.0	0.0
Peltophorum africanum (C)	20	1	3	1	1	1	1	2	2	2	2	0.0	0.0
Totals	3360	1877	3753	784	390	460	784	3135	1559	1841	3134	19.5	10.0

Appendix C4: Data obtained from the secondary calculations of the BECVOL (version 2.0) computer programme for the *Combretum apiculatum* – *Grewia flava* Control plot during the 2003/2004 season.

SPECIES	PL_HA	LVOL	ETTE	LMAS	LM_15	LM_20	LM_50	BTE	BTE_15	BTE_20	BTE_50	CSI_2	CSI_4
Acacia erubescens (N)	180	677	1354	318	71	115	274	1272	285	460	1095	11.6	4.2
Acacia mellifera (N)	20	125	250	59	1	3	52	235	4	11	207	1.7	1.7
Acacia tortilis (N)	60	61	122	28	14	25	28	112	57	100	112	1.1	0.0
Combretum apiculatum (N)	1840	1427	2854	626	223	354	626	2505	891	1416	2504	24.1	6.7
Combretum hereroense (N)	80	92	185	41	11	18	41	165	45	73	165	1.3	0.0
Combretum molle (N)	20	11	22	5	3	5	5	20	14	20	20	0.0	0.0
Dichrostachys cinerea (N)	140	43	85	17	17	17	17	68	68	68	68	0.0	0.0
Grewia bicolor (N)	60	55	110	20	16	20	20	81	65	80	81	0.8	0.0
Grewia flava (N)	500	862	1724	332	260	320	332	1327	1041	1279	1327	8.0	0.0
Grewia flavescens (N)	120	196	392	76	58	74	76	304	232	296	304	2.8	0.0
Grewia monticola (N)	220	183	366	65	60	65	65	260	242	260	260	0.0	0.0
Peltophorum africanum (N)	40	107	213	49	26	36	49	198	105	143	198	1.1	0.0
Pterocarpus rotundifolius (N)	40	56	113	25	4	13	25	101	14	52	101	1.8	0.0
Terminalia sericea (N)	60	4	7	1	1	1	1	5	5	5	5	0.0	0.0
Totals	3380	3899	7799	1663	767	1066	1612	6653	3066	4262	6447	54.4	12.6

Appendix C5: Data obtained from the secondary calculations of the BECVOL (version 2.0) computer programme for the *Acacia erubescens – Dichrostachys cinerea* Treatment plot during the 2003/2004 season.

SPECIES	PL_HA	LVOL	ETTE	LMAS	LM_15	LM_20	LM_50	BTE	BTE_15	BTE_20	BTE_50	CSI_2	CSI_4
Acacia erubescens (N)	200	1062	2125	504	39	86	491	2016	156	343	1965	21.6	16.6
Acacia erubescens (C)	960	37	73	17	17	17	17	68	68	68	68	0.0	0.0
Acacia karroo (N)	60	15	30	7	7	7	7	27	27	27	27	0.0	0.0
Acacia karroo (C)	80	6	12	3	3	3	3	11	11	11	11	0.0	0.0
Acacia tortilis (C)	60	12	24	5	5	5	5	21	21	21	21	0.0	0.0
Asparagus suaveolens (N)	40	1	3	1	1	1	1	2	2	2	2	0.0	0.0
Asparagus suaveolens (C)	20	0	1	0	0	0	0	1	1	1	1	0.0	0.0
Combretum apiculatum (N)	120	184	367	81	6	12	81	324	23	46	322	3.0	3.0
Combretum apiculatum (C)	400	27	55	12	12	12	12	48	48	48	48	0.0	0.0
Combretum hereroense (N)	20	3	6	1	1	1	1	5	5	5	5	0.0	0.0
Combretum imberbe (N)	20	0	1	0	0	0	0	1	1	1	1	0.0	0.0
Combretum imberbe (C)	40	2	4	1	1	1	1	4	4	4	4	0.0	0.0
Combretum molle (C)	60	7	15	4	4	4	4	15	15	15	15	0.0	0.0
Dichrostachys cinerea (N)	180	7	14	3	3	3	3	10	10	10	10	0.0	0.0
Dichrostachys cinerea (C)	540	46	92	19	19	19	19	78	78	78	78	0.0	0.0
Grewia bicolor (N)	40	38	77	14	13	14	14	54	54	54	54	0.0	0.0
Grewia bicolor (C)	20	7	15	4	4	4	4	15	15	15	15	0.0	0.0
Grewia flava (N)	280	189	377	66	66	66	66	263	263	263	263	0.0	0.0
Grewia flava (C)	440	191	383	98	98	98	98	390	390	390	390	0.0	0.0
Grewia flavescens (N)	20	2	4	0	0	0	0	2	2	2	2	0.0	0.0

...Continues

Appendix C5 continued...

SPECIES	PL_HA	LVOL	ETTE	LMAS	LM_15	LM_20	LM_50	BTE	BTE_15	BTE_20	BTE_50	CSI_2	CSI_4
Grewia flavescens (C)	40	18	37	9	9	9	9	37	37	37	37	0.0	0.0
Grewia monticola (N)	40	28	57	10	10	10	10	39	39	39	39	0.0	0.0
Gymnosporia senegalensis (N)	20	4	9	2	2	2	2	8	8	8	8	0.0	0.0
Pterocarpus rotundifolius (C)	20	5	10	3	3	3	3	10	10	10	10	0.0	0.0
Ziziphus mucronata (N)	20	156	311	69	13	34	69	277	53	134	277	4.7	0.0
Ziziphus mucronata (C)	80	14	28	7	7	7	7	28	28	28	28	0.0	0.0
Totals	3820	2064	4128	939	343	416	926	3757	1371	1663	3704	29.3	19.7

Appendix C6: Data obtained from the secondary calculations of the BECVOL (version 2.0) computer programme for the *Acacia erubescens – Dichrostachys cinerea* Control plot during the 2003/2004 season.

SPECIES	PL_HA	LVOL	ETTE	LMAS	LM_15	LM_20	LM_50	BTE	BTE_15	BTE_20	BTE_50	CSI_2	CSI_4
Acacia erubescens (N)	2000	2334	4668	1095	238	414	1028	4381	954	1654	4112	39.0	23.4
Acacia karroo (N)	120	139	278	67	37	61	67	267	148	243	267	2.0	0.0
Combretum apiculatum (N)	80	805	1610	358	8	18	256	1432	31	72	1026	14.4	14.4
Combretum hereroense (N)	80	549	1098	244	9	23	210	977	37	90	838	9.8	9.8
Dichrostachys cinerea (N)	720	87	173	34	32	34	34	135	129	135	135	0.0	0.0
Grewia flava (N)	360	265	530	93	86	93	93	371	344	370	370	1.0	0.0
Grewia flavescens (N)	80	41	81	13	13	13	13	54	54	54	54	0.0	0.0
Gymnosporia senegalensis (N)	120	114	229	51	31	43	51	205	123	174	205	1.1	0.0
Ziziphus mucronata (N)	40	4	9	2	2	2	2	8	8	8	8	0.0	0.0
Totals	3600	4338	8676	1957	457	700	1754	7829	1828	2799	7016	67.3	47.6

Appendix C7: Data obtained from the secondary calculations of the BECVOL (version 2.0) computer programme for the *Combretum apiculatum* – *Grewia flava* Coppice plot during the 2003/2004 season.

SPECIES	PL_HA	LVOL	ETTE	LMAS	LM_15	LM_20	LM_50	BTE	BTE_15	BTE_20	BTE_50	CSI_2	CSI_4
Acacia caffra (C)	20	9	17	4	4	4	4	16	16	16	16	0.0	0.0
Acacia erubescens (N)	140	113	226	53	5	7	53	210	20	29	210	1.6	1.6
Acacia erubescens (C)	100	19	38	9	9	9	9	37	37	37	37	0.0	0.0
Acacia tortilis (N)	60	84	167	39	7	10	39	155	27	42	155	1.4	0.0
Acacia tortilis (C)	60	17	34	8	8	8	8	31	31	31	31	0.0	0.0
Asparagus suaveolens (N)	20	1	3	1	1	1	1	2	2	2	2	0.0	0.0
Combretum apiculatum (N)	960	379	758	166	65	99	166	663	261	397	662	6.6	0.0
Combretum apiculatum (C)	2000	244	488	107	107	107	107	428	428	428	428	0.0	0.0
Combretum hereroense (N)	240	456	911	203	19	35	199	813	78	139	798	7.3	7.3
Combretum hereroense (C)	80	30	60	15	15	15	15	61	61	61	61	0.0	0.0
Combretum imberbe (N)	60	69	137	31	5	9	31	122	21	36	122	1.3	0.0
Combretum imberbe (C)	240	45	90	23	23	23	23	92	92	92	92	0.0	0.0
Combretum molle (N)	200	31	62	14	12	14	14	56	49	55	55	0.2	0.0
Combretum molle (C)	140	15	30	8	8	8	8	31	31	31	31	0.0	0.0
Dichrostachys cinerea (N)	40	5	10	2	2	2	2	8	8	8	8	0.0	0.0
Dichrostachys cinerea (C)	40	5	9	2	2	2	2	8	8	8	8	0.0	0.0
Grewia flava (N)	340	360	720	130	125	130	130	522	499	520	522	0.8	0.0
Grewia flava (C)	100	31	62	16	16	16	16	63	63	63	63	0.0	0.0
Grewia flavescens (N)	140	99	197	35	35	35	35	140	139	140	140	0.0	0.0
Grewia monticola (N)	200	237	475	87	82	86	87	347	329	345	346	0.7	0.0

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Appendix C7 continued...

SPECIES	PL_HA	LVOL	ETTE	LMAS	LM_15	LM_20	LM_50	BTE	BTE_15	BTE_20	BTE_50	CSI_2	CSI_4
Peltophorum africanum (N)	40	207	413	98	5	10	98	390	21	40	390	4.1	4.1
Peltophorum africanum (C)	20	5	10	2	2	2	2	9	9	9	9	0.0	0.0
Pterocarpus rotundifolius (N)	140	3	7	2	2	2	2	6	6	6	6	0.0	0.0
Pterocarpus rotundifolius (C)	180	26	52	13	13	13	13	53	53	53	53	0.0	0.0
Terminalia sericea (N)	100	119	238	42	18	27	42	169	71	110	169	1.5	0.0
Ziziphus mucronata (N)	40	12	24	5	5	5	5	21	21	21	21	0.0	0.0
Ziziphus mucronata (C)	20	1	2	0	0	0	0	2	2	2	2	0.0	0.0
Totals	5720	2620	5240	1113	596	680	1110	4454	2384	2721	4438	25.5	13.0

Appendix C8: Data obtained from the secondary calculations of the BECVOL (version 2.0) computer programme for the *Acacia mellifera* – *Grewia flava* Coppice plot during the 2003/2004 season.

SPECIES	PL_HA	LVOL	ETTE	LMAS	LM_15	LM_20	LM_50	BTE	BTE_15	BTE_20	BTE_50	CSI_2	CSI_4
Acacia erubescens (N)	80	34	69	16	10	15	16	63	40	60	63	0.5	0.0
Acacia erubescens (C)	100	8	16	4	4	4	4	16	16	16	16	0.0	0.0
Acacia mellifera (N)	400	2461	4921	1167	68	146	895	4667	271	584	3579	47.0	39.5
Acacia mellifera (C)	360	15	30	6	6	6	6	26	26	26	26	0.0	0.0
Acacia robusta (N)	40	139	278	65	11	26	65	259	43	104	259	2.5	0.0
Acacia tortilis (N)	40	150	299	70	4	14	70	282	16	57	282	2.4	2.4
Acacia tortilis (C)	40	20	40	9	9	9	9	36	36	36	36	0.0	0.0
Carissa bispinosa (N)	80	0	1	0	0	0	0	1	1	1	1	0.0	0.0
Carissa bispinosa (C)	140	4	8	2	2	2	2	8	8	8	8	0.0	0.0

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Appendix C8 continued...

SPECIES	PL_HA	LVOL	ETTE	LMAS	LM_15	LM_20	LM_50	BTE	BTE_15	BTE_20	BTE_50	CSI_2	CSI_4
Combretum apiculatum (N)	60	199	398	88	13	26	88	353	50	102	352	4.5	3.8
Combretum apiculatum (C)	300	14	29	6	6	6	6	25	25	25	25	0.0	0.0
Combretum hereroense (N)	40	58	116	26	7	13	26	103	28	52	103	1.1	0.0
Combretum hereroense (C)	60	9	19	5	5	5	5	19	19	19	19	0.0	0.0
Combretum molle (N)	180	208	416	92	9	12	55	370	36	46	220	1.8	1.8
Combretum molle (C)	160	26	51	13	13	13	13	53	53	53	53	0.0	0.0
Dichrostachys cinerea (N)	60	13	27	5	5	5	5	21	21	21	21	0.0	0.0
Dichrostachys cinerea (C)	40	1	2	0	0	0	0	2	2	2	2	0.0	0.0
Euclea undulata (C)	40	30	59	15	15	15	15	60	60	60	60	0.0	0.0
Grewia flava (N)	460	577	1153	212	199	212	212	849	794	848	849	1.4	0.0
Grewia flava (C)	540	402	804	204	204	204	204	818	818	818	818	0.0	0.0
Grewia flavescens (N)	120	92	184	32	32	32	32	130	130	130	130	0.0	0.0
Grewia flavescens (C)	40	23	46	12	12	12	12	47	47	47	47	0.0	0.0
Grewia monticola (N)	40	65	130	25	24	25	25	99	95	99	99	0.0	0.0
Grewia monticola (C)	20	11	22	6	6	6	6	22	22	22	22	0.0	0.0
Gymnosporia senegalensis (N)	60	11	22	5	5	5	5	19	18	19	19	0.0	0.0
Gymnosporia senegalensis (C)	200	35	71	18	18	18	18	72	72	72	72	0.0	0.0
Peltophorum africanum (N)	100	493	987	233	28	57	233	931	113	228	931	9.3	5.5
Peltophorum africanum (C)	40	5	11	2	2	2	2	9	9	9	9	0.0	0.0
Asparagus suaveolens (N)	80	4	7	2	2	2	2	7	6	6	6	0.0	0.0
Asparagus suaveolens (C)	120	3	6	1	1	1	1	5	5	5	5	0.0	0.0

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Appendix C8 continued...

SPECIES	PL_HA	LVOL	ETTE	LMAS	LM_15	LM_20	LM_50	BTE	BTE_15	BTE_20	BTE_50	CSI_2	CSI_4
Pterocarpus rotundifolius (N)	80	3	7	2	2	2	2	6	6	6	6	0.0	0.0
Pterocarpus rotundifolius (C)	40	8	15	4	4	4	4	16	16	16	16	0.0	0.0
Spirostachys africana (N)	40	1	1	0	0	0	0	1	1	1	1	0.0	0.0
Spirostachys africana (C)	40	1	3	1	1	1	1	3	3	3	3	0.0	0.0
Terminalia sericea (N)	60	25	51	9	3	8	9	36	14	32	36	0.5	0.0
Terminalia sericea (C)	40	5	9	2	2	2	2	10	10	10	10	0.0	0.0
Ziziphus mucronata (N)	80	305	609	136	24	53	136	543	95	211	543	7.1	4.2
Totals	4420	5458	10916	2496	756	964	2187	9986	3026	3854	8748	78.1	57.1

Appendix C9: Data obtained from the secondary calculations of the BECVOL (version 2.0) computer programme for the *Acacia mellifera* – *Grewia flava* Treatment plot during the 2004/2005 season.

SPECIES	PL_HA	LVOL	ETTE	LMAS	LM_15	LM_20	LM_50	BTE	BTE_15	BTE_20	BTE_50	CSI_2	CSI_4
Acacia erubescens (C)	120	4	7	2	2	2	2	7	7	7	7	0.0	0.0
Acacia mellifera (C)	40	2	3	1	1	1	1	3	3	3	3	0.0	0.0
Acacia tortilis (C)	120	4	8	2	2	2	2	7	7	7	7	0.0	0.0
Combretum apiculatum (C)	40	1	2	0	0	0	0	1	1	1	1	0.0	0.0
Dichrostachys cinerea (C)	120	2	4	1	1	1	1	3	3	3	3	0.0	0.0
Grewia bicolor (C)	280	54	107	27	27	27	27	110	110	110	110	0.0	0.0
Grewia flava (C)	1160	144	288	74	74	74	74	296	295	295	295	0.0	0.0
Gymnosporia senegalensis (C)	80	8	17	4	4	4	4	17	17	17	17	0.0	0.0
Ziziphus mucronata (C)	40	6	12	3	3	3	3	12	12	12	12	0.0	0.0
Totals	2000	224	448	114	114	114	114	455	455	455	455	0.0	0.0

Appendix C10: Data obtained from the secondary calculations of the BECVOL (version 2.0) computer programme for the *Combretum apiculatum – Grewia flava* Treatment plot during the 2004/2005 season.

SPECIES	PL_HA	LVOL	ETTE	LMAS	LM_15	LM_20	LM_50	BTE	BTE_15	BTE_20	BTE_50	CSI_2	CSI_4
Acacia erubescens (C)	120	5	10	2	2	2	2	9	9	9	9	0.0	0.0
Acacia tortilis (C)	120	31	62	14	14	14	14	56	56	56	56	0.0	0.0
Combretum apiculatum (C)	1760	126	252	55	55	55	55	221	221	221	221	0.0	0.0
Combretum hereroense (C)	80	17	34	9	9	9	9	35	35	35	35	0.0	0.0
Grewia bicolor (C)	80	43	86	22	22	22	22	88	88	88	88	0.0	0.0
Grewia flava (C)	720	343	686	175	175	175	175	699	700	700	700	0.0	0.0
Pterocarpus rotundifolius (C)	80	7	14	4	4	4	4	15	15	15	15	0.0	0.0
Ziziphus mucronata (C)	40	1	3	1	1	1	1	3	3	3	3	0.0	0.0
Totals	3000	574	1148	282	282	282	282	1126	1127	1127	1127	0.0	0.0

Appendix C11: Data obtained from the secondary calculations of the BECVOL (version 2.0) computer programme for the *Acacia erubescens – Dichrostachys cinerea* Treatment plot during the 2004/2005 season.

SPECIES	PL_HA	LVOL	ETTE	LMAS	LM_15	LM_20	LM_50	BTE	BTE_15	BTE_20	BTE_50	CSI_2	CSI_4
Acacia erubescens (C)	1640	34	68	15	15	15	15	62	61	61	61	0.0	0.0
Acacia mellifera (C)	320	3	5	1	1	1	1	4	4	4	4	0.0	0.0
Acacia tortilis (C)	120	2	5	1	1	1	1	4	4	4	4	0.0	0.0
Combretum apiculatum (C)	560	18	36	8	8	8	8	32	31	31	31	0.0	0.0
Dichrostachys cinerea (C)	560	21	41	9	9	9	9	34	34	34	34	0.0	0.0
Grewia flava (C)	1200	396	792	200	200	200	200	800	800	800	800	0.0	0.0
Totals	4400	474	947	234	234	234	234	937	936	936	936	0.0	0.0

Appendix C12: Data obtained from the secondary calculations of the BECVOL (version 2.0) computer programme for the *Combretum apiculatum* – *Grewia flava* Coppice plot during the 2004/2005 season.

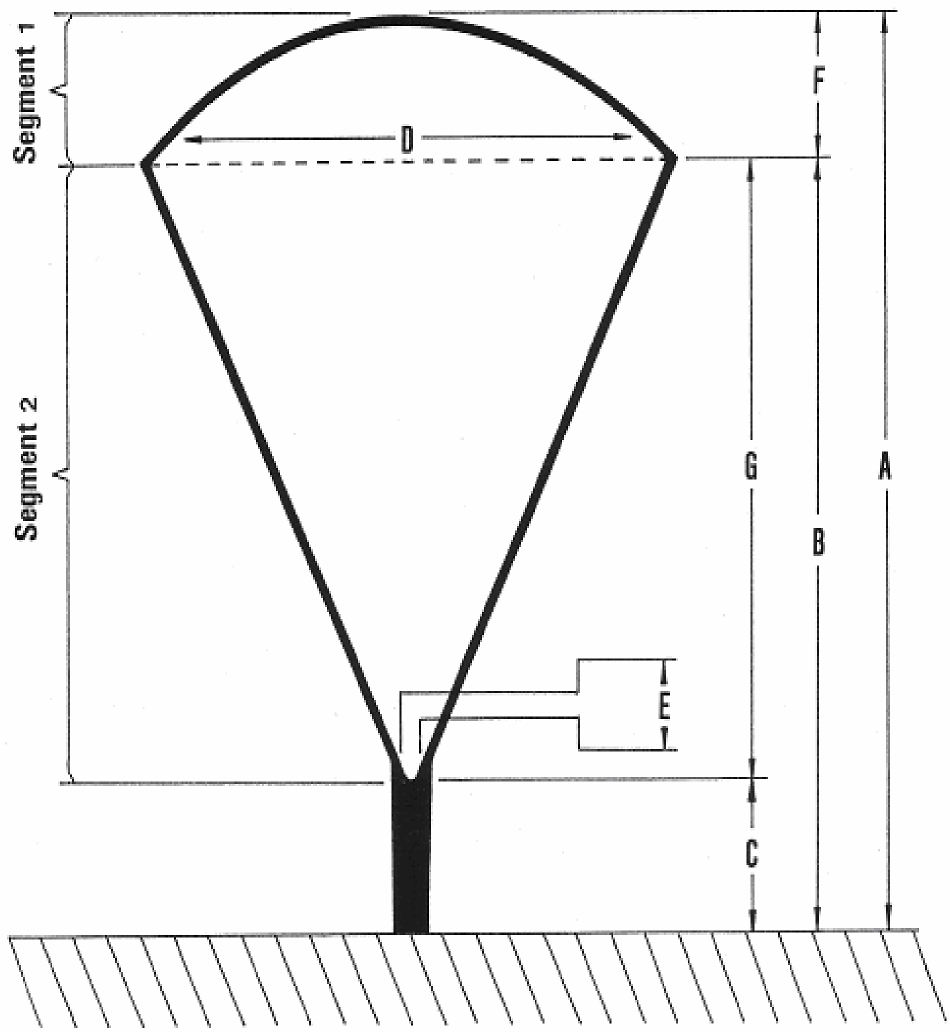
SPECIES	PL_HA	LVOL	ETTE	LMAS	LM_15	LM_20	LM_50	BTE	BTE_15	BTE_20	BTE_50	CSI_2	CSI_4
Acacia erubescens (C)	200	6	12	2	2	2	2	11	11	11	11	0.0	0.0
Acacia tortilis (C)	200	34	69	15	15	15	15	61	61	61	61	0.0	0.0
Combretum apiculatum (C)	4680	624	1249	274	274	274	274	1095	1094	1095	1095	0.0	0.0
Combretum hereroense (C)	120	12	24	6	6	6	6	24	23	23	23	0.0	0.0
Dichrostachys cinerea (C)	40	6	12	2	2	2	2	10	10	10	10	0.0	0.0
Grewia bicolor (C)	240	241	482	123	123	123	123	490	490	490	490	0.0	0.0
Grewia flava (C)	560	360	720	183	183	183	183	733	733	733	733	0.0	0.0
Peltophorum africanum (C)	40	25	50	11	11	11	11	46	46	46	46	0.0	0.0
Pterocarpus rotundifolius (C)	80	6	13	3	3	3	3	13	13	13	13	0.0	0.0
Ziziphus mucronata (C)	80	15	30	8	8	8	8	30	30	30	30	0.0	0.0
Totals	6240	1330	2660	628	628	628	628	2512	2511	2512	2512	0.0	0.0

Appendix C13: Data obtained from the secondary calculations of the BECVOL (version 2.0) computer programme for the *Acacia mellifera* – *Grewia flava* Coppice plot during the 2004/2005 season.

SPECIES	PL_HA	LVOL	ETTE	LMAS	LM_15	LM_20	LM_50	BTE	BTE_15	BTE_20	BTE_50	CSI_2	CSI_4
Acacia erubescens (C)	160	7	13	3	3	3	3	12	12	12	12	0.0	0.0
Acacia mellifera (C)	640	36	72	15	15	15	15	62	61	61	61	0.0	0.0
Carissa bispinosa (C)	40	7	14	3	3	3	3	12	12	12	12	0.0	0.0
Combretum apiculatum (C)	1080	38	76	17	17	17	17	67	67	67	67	0.0	0.0
Combretum hereroense (C)	680	175	351	89	85	89	89	358	339	358	358	0.8	0.0
Dichrostachys cinerea (C)	80	3	6	1	1	1	1	5	5	5	5	0.0	0.0
Grewia bicolor (C)	120	103	206	52	39	52	52	209	154	209	209	1.7	0.0
Grewia flava (C)	1480	1198	2396	609	590	609	609	2436	2359	2436	2436	2.2	0.0
Grewia flavescens (C)	200	325	650	165	146	165	165	660	582	660	660	0.0	0.0
Gymnosporia senegalensis (C)	360	36	71	18	18	18	18	73	73	73	73	0.0	0.0
Peltophorum africanum (C)	40	10	21	5	5	5	5	18	18	18	18	0.0	0.0
Pterocarpus rotundifolius (C)	200	50	99	25	25	25	25	101	100	101	101	0.0	0.0
Totals	5080	1987	3974	1004	946	1004	1004	4014	3784	4015	4015	4.7	0.0

APPENDIX D

An illustration of the measurements required by the BECVOL-model. A – Tree height, B – Height of maximum canopy diameter, C – Height of first leaves or potential leaf bearing stems, D – Maximum canopy diameter, and E – Base diameter of the foliage at height C (from Smit, 1989a).



APPENDIX E

Ecological group classification of herbaceous species according to the Ecological Index Method (EIM) of Vorster (1982) revised by Tainton *et al.* (undated) as cited by Heard *et al.* (1986).

Decreasers

Decreaser species are those which dominate in veld in good/excellent condition, i.e. that community which is considered to be the most productive for that site and one which is stable if well managed. They decrease in abundance when veld is under- or over-utilised (Anon., 1981). Most of the so-called climax grasses will be classified into this group.

Increaser Ia

This species increase in abundance with moderate under-utilisation. These grasses are usually unpalatable climax species that can grow without any defoliation.

Increaser IIa

Species in this group are rare in veld in excellent condition, but increase when veld is moderately over-grazed in the long term (Anon., 1981). Their relative frequency usually increases when that of Decreaser species declines. The sub-climax and dis-climax grasses, as well as the more palatable karoo bushes and taller shrubs, belong to this group. When these species dominate, the veld may be agro-ecologically classified as being in a good to fair condition.

Increaser IIb

Members of this group are rare in veld in excellent condition, but increase as veld is heavily over-grazed for an extended period (Anon., 1981). An increase in their relative abundance is coupled with a decrease of the species of the Increaser IIa category. Species which belong to this group are the perennial pioneer grasses and the moderately hardy and less palatable karoo bushes and taller shrubs. Dominance of this group is generally a sign of veld in an agro-ecologically fair to poor condition.

Increaser IIc

Members of this group are rare in veld in excellent condition and increase when veld is heavily over-grazed for an extended period (Anon., 1981). Their numbers increase when the abundance of Increaser IIb species declines. This group is represented mainly by rain-dependent annual grasses, ephemerals, hardy unpalatable karoo bushes and taller shrubs, as well as a number of poisonous plants. Dominance of this group signifies that the veld is in an agro-ecological poor to very poor condition.

APPENDIX F

(a)

(b)

Appendix F1: Illustration of the difference in production of herbaceous plants in enclosed areas of the *Acacia mellifera – Grewia flava* Treatment plot at the end of the wet 2004/2005 season compared to the surrounding, unprotected areas. (a) Between trees and (b) under trees. Photos were taken during April 2005.

(a)

(b)

Appendix F2: Illustration of the difference in production of herbaceous plants in enclosed areas of the *Acacia mellifera – Grewia flava* Control plot at the end of the 2004/2005 season compared to the surrounding, unprotected areas. (a) Between trees and (b) under trees. Photos were taken during April 2005.

(a)

(b)

Appendix F3: Illustration of the difference in production of herbaceous plants in enclosed areas of the *Combretum apiculatum – Grewia flava* Treatment plot at the end of the 2004/2005 season compared to the surrounding, unprotected areas. (a) Between trees and (b) under trees. Photos were taken during April 2005.

(a) (b)

Appendix F4: Illustration of the difference in production of herbaceous plants in enclosed areas of the *Combretum apiculatum – Grewia flava* Control plot at the end of the 2004/2005 season compared to the surrounding, unprotected areas. (a) Between trees and (b) under trees. Photos were taken during April 2005.

(a) (b)

Appendix F5: Illustration of the difference in production of herbaceous plants in enclosed areas of the *Acacia erubescens – Dichrostachys cinerea* Treatment plot at the end of the 2004/2005 season compared to the surrounding, unprotected areas. (a) Between trees and (b) under trees. Photos were taken during April 2005.

(a) (b)

Appendix F6: Illustration of the difference in production of herbaceous plants in enclosed areas of the *Acacia erubescens – Dichrostachys cinerea* Control plot at the end of the 2004/2005 season compared to the surrounding, unprotected areas. (a) Between trees and (b) under trees. Photos were taken during April 2005.

APPENDIX G

Appendix G1: Summary of the results of the soil analyses of soil collected in the various experimental plots.

Experimental plot	Cations (mg kg⁻¹)				pH	pH (H_2O)	pH (KCl)	Electrical conductivity (dS m^{-1})	Electrical resistance (O)	Nitrogen (mg kg^{-1})	Carbon (mg kg^{-1})	Phosphate (mg kg^{-1})
	Ca	K	Mg	Na								
Acacia mellifera – Grewia flava Treatment	1 950.0	227.5	95.0	120.0	7.85	7.90	7.40	1.63	860	476.0	1 530.0	2.0
Acacia mellifera – Grewia flava Control	1 502.5	235.0	152.5	35.0	7.14	6.65	6.10	4.82	350	525.0	1 605.0	3.0
Combretum apiculatum – Grewia flava Treatment	315.0	90.0	57.5	27.5	6.57	5.20	4.10	0.19	10 100	357.0	1 357.5	1.2
Combretum apiculatum – Grewia flava Control	472.5	145.0	92.5	30.0	7.44	6.10	5.15	0.27	5 900	441.0	1 245.0	1.2
Acacia erubescens – Dichrostachys cinerea Treatment	515.0	92.5	97.5	32.5	6.82	4.95	4.20	0.80	1 800	315.0	922.5	2.4
Acacia erubescens – Dichrostachys cinerea Control	455.0	92.5	127.5	47.5	6.57	4.80	4.20	2.51	790	339.5	933.9	2.0
Combretum apiculatum – Grewia flava Coppice	370.0	120.0	70.0	32.5	7.27	5.30	4.25	0.22	8 800	367.5	1 189.2	4.6
Acacia mellifera – Grewia flava Coppice	2 062.5	240.0	187.5	35.0	7.83	7.10	6.70	1.38	850	749.0	1 380.0	6.2

Appendix G2: Summary of the results of the saturation extracts done on soil collected in the various experimental plots.

Experimental plot	Cations (mg kg^{-1})				SAR (%)
	Ca	K	Mg	Na	
Acacia mellifera – Grewia flava Treatment	262.0	50.7	22.0	15.8	0.08
Acacia mellifera – Grewia flava Control	781.0	63.0	119.0	87.0	0.24
Combretum apiculatum – Grewia flava Treatment	10.9	12.9	4.1	12.7	0.30
Combretum apiculatum – Grewia flava Control	12.7	19.3	7.2	14.7	0.24
Acacia erubescens – Dichrostachys cinerea Treatment	61.1	12.9	31.0	20.3	0.13
Acacia erubescens – Dichrostachys cinerea Control	138.8	25.4	116.0	146.0	0.70
Combretum apiculatum – Grewia flava Coppice	9.7	14.1	4.6	14.4	1.33
Acacia mellifera – Grewia flava Coppice	150.0	30.1	32.0	16.3	0.10

APPENDIX B

Phytosociological table of Marakele Park.

Major community	1		2								
Community	1 . 1	1 . 2	2 . 1			2 . 2					
Sub-community			2 . 1 . 1	. 2	. 3	2 . 2 . 1			. 2 . 2	2 . 2 . 3	
Variant						. 1	. 2	. 3			
Relevé nr	1 1 1 1 1 1 1	1 2	7 4 7 7 7 7 7	8 6 6 6	7 7 7	4 4 5 6 5 4 5	5 7 5 4	5 4 4 4 6	6 6 5 5	5 1 6 2 3 4	6
	6 2 4 8 3 8 9 7	1 5 0 7 2	3 2 4 2 5 7 1	0 3 8 6	6 9 0	3 7 7 0 4 4 1	2 8 5 8	6 5 9 6 7	9 5 9 3	8 0 4 5 7 1	1
SPECIES GROUP A:											
Diospyros lycioides	1 . 2 2	. . . . .	. . . .	. . . .	. . .	. . . .	. . . .	. . . . .	. . . .	. . . . . .	.
SPECIES GROUP B:											
Abutilon pycnodon	. . . .	. + r . 3	. . . .	. . . .	. . .	. . . .	. . . .	+	. . . .	. r	.
SPECIES GROUP C:											
Melolobium species	1 1 . 2 1 + 2 1	2 . 1 + +	. . . .	. . . .	. . .	r . 1 1 . . .	. . + .	1	. . . .	1	.
Zehneria marlothii	1 1 1 1 . 2 2 2	. . 1 1 .	. . . .	. . . .	. . .	. . . .	. . . .	1 . . r .	. . . .	+	.
Hibiscus engleri	r . r 1 . . 1 1	. r . + .	. . . .	. . . .	. . .	. . . .	. . . .	. . . . .	r r . .	. . . . . .	.
Hermannia species	. r 2 . . . 2 .	. r . 2 .	. . . .	. . . .	. . .	. . . . . 1 .	. . . .	. . . . .	. . . .	. . . . . .	.
Corchorus asplenifolius	+ 1 + + . . . 1	2 2 . 1 1	. . . .	. . . .	. . .	. . . . + . .	. . . .	+ . + . +	+ . . .	+ . . 2 . 1	.
SPECIES GROUP D:											
Terminalia sericea	. . . .	. . . . .	3 2 4 2 . . 2	. . . .	. . .	. . . .	. . . .	. . . . .	. . . .	. . . . . .	.
Sansevieria pearsonii	. . . .	. . . . .	r . 2 1 2 1 .	. . . .	. 2 .	. . . .	. . . .	. . . . .	. . . .	. . . . . .	.
Cymbopogon pospischilii	. . . . +	. . . . .	+ . . . + + 3	. . . .	. . .	. . . .	. r . .	. . . . .	. . . .	. . . . . .	.
Fuirena pubescens	. . . .	. . . . .	. . . + . + +	+ . . .	. . .	. . . .	. . . .	. . . . .	. . . .	. . . . . .	.
Solanum rigescens	. . . .	. . . . .	r . . . . r +	r . . .	. . r	. . . .	. . . .	. . . . .	. . . .	. . . . . .	.
SPECIES GROUP E:											
Oxalis depressa	. . . .	. . . . .	. . . . . r +	+ + + +	. . .	. . . .	. . . .	. . . . .	. . . .	. . . . . .	.
SPECIES GROUP F:											
Sporobolus panicoides	. . . .	. . . . .	2 . 3 2 1 + .	+ 2 1 .	. . .	. . . . + . .	. . . .	. . . . .	. + 1 .	. . . . 1 .	.
SPECIES GROUP G:											
Combretum imberbe	. . . .	. . . . .	. . . .	. . . .	1 2 .	. . . .	. . . .	. . . . .	. . . .	. . . . . .	.
Grewia bicolor	. . . .	. . . . .	. . . . . 1 .	. . . .	. 2 .	. . . .	. 1 . .	. . . . .	. . . .	. . . . . .	.
SPECIES GROUP H:											
Rhus pyroides	. . . .	. . . . .	. 2 . r . . 1	. r . .	r 1 2	. . . .	. . . .	. . . . .	. . . .	. . . . . .	.
Cyperus rupestris	. . . .	. . . . .	2 . 2 1 1 . +	+ . . .	+ + .	. . . .	. . . .	. . . . .	. . . .	. . . . . .	.
Hemizygia canescens	. . . .	. . . . .	1 . . . 1 . 1	. + r r	. 2 +	. . . .	. . . .	. . . . .	. . . .	. . . . . .	+
Gymnosporia senegalensis	. . . .	. . . . .	. . 3 . . . 2	1 . 2 .	. 2 .	. . . .	. . . .	. . . . .	. . . .	. . . . . .	.
SPECIES GROUP I:											
Carissa bispinosa	. . . .	. . . . .	. . . .	. . . .	. . .	2 1 2 2 2 2 2	. . . .	. . . . .	. . . .	2	.
Pupalia lappacea	. + ...	. . . . .	. + ...	. . . .	. . .	+ . . + 1 2 .	. . . .	. . . . .	. . . .	. + . . . 2	.
Kohautia virgata	. . . .	. . . . .	. . . .	. . . .	. . .	. r r . r + .	. . . r	. + . . .	. . . .	. . . . . .	.
SPECIES GROUP J:											
Peltophorum africanum	. . . .	. . . . .	. . . . . 4 .	. . . .	. . .	1 5 . 3 3 4 .	4 4 . 4	2 1 2 + 3	. . . .	. . . . . .	.

Combretum molle	. . . .	. . . . . .	. 1 . . r . .	. 1 . .	. . .	. . 2 2 . . 1	. . . .	2 1 2 2 1	. . . .	. . . .	.
Achyranthus aspera v. sicula	. . . .	. . . . . .	. . . .	. . . .	. . .	2 . r . . 1 .	. . . .	. 1 . 1 .	. . . .	. . . .	.
SPECIES GROUP K:											
Tephrosia capensis	. . . 1	. . . . . .	. . . .	. . . .	r . .	. . 1	. . . . .	. . . . . .	1 2 1 1	. . . .	.
SPECIES GROUP L:											
Grewia flavescens	. . 1	. . . . . .	2	. . . .	. . .	2 2 1 . + . .	. . . 1	2 2 2 . 2	2 . + 2	. . . 2 . . .	.
Blumea mollis	. . . .	. . . . + .	. . . .	. . . .	. . r	+ 2 . 1 . 1 .	. . r 1	+ + . . +	. . . .	. . . . 1 . .	+
Indigofera filipes	. . . .	. . . . . .	. 2	. . . .	. . .	. . . + 1 + .	. . . +	. 1 1 . .	. . . .	. . . . . 2 2	.
Cyphostemma oleraceum	. . . .	. . . . . .	. . . .	. . . .	. . .	. + ... +	. . . .	r . . . r	. . . r	. . . .	.
SPECIES GROUP M:											
Conyza podocephala	. . . .	. . . . . .	1 2 . 2 2 + 2	. 2 . 1	2 . .	3 . . . 2 2 +	+ + . .	. 1 . . +	1 2 2 .	1 . . 3 2 .	.
Dichrostachys cinerea	. . . .	. . . . . .	. 1 1 3 3 2 4	2 2 . .	2 . .	. . 1 . 1 . .	. 1 . 1	. 1 . + 2	1 3 1 .	 2	.
Acacia tortilis	 3	. . . . . .	. 3	. 1 2 2	. 1 .	4 . 2 2 . 3 .	. . 2 .	. . 1 . .	1 1 1 .	. . . . 3 . .	.
Ziziphus mucronata	. . . .	. . . . . .	. . 3 . . 1 .	. . . . .	. 2 1	3 3 . 1 1 3 2	. 2 1 .	. . . . . .	. . . . .	. . . + . . 2	.
Grewia monticola	. . . .	. . . . . .	. . . 1 . . .	. . 1 2	. . . .	. . 2 . 2 2 2	. . 1 2	1 . . 2 .	2 2 2 .	. . . 2 . 2 1	.
Urochloa mosambicensis	. 1	. . . . . .	1 . . . . 3 1	1 1 . 1	2 . .	1 . 1 . . . 1	. . . .	. . . . . .	2 1 1 .	. . . . 1 . .	.
Combretum hereroense	. . . .	. . . . . .	. . 2	4 . 2 .	2 . .	2 . 3 . . 3 1	. 2 3 .	. 1	. 2 . .	. . . .	.
Bidens pilosa	. . . .	. . . . . .	2 . 1 . . + .	+	+ . .	. 2 . . + + .	+ . . .	. . r + .	. . 2 .	. . . . 2 . 2	.
Geigeria burkei	. . . .	. . . . . .	. r	. . . . .	. . .	2	. . r .	. . . . . .	. . + r	. . . .	.
SPECIES GROUP N:											
Bothriochloa insculpta	2 + 3 1 + 1 2 4	. 4 5 1 .	r . 2 . 2 . .	2 2 2 1	+ . 2	2 . 2 2 . 1 2	1 2 + 1	2 + . 1 2	2 2 . 1	. 5 2 2 . .	.
Bothriochloa radicans	. . 2 2 + + . 1	. 2 1 2 .	. . 2 . 1 . .	2 2 1 1	+ . 1	. . + 1 . . 1	+ 1 1 .	1 . . . 2	. 1 + 2	. 3 1 . . .	.
Chloris virgata	r + + . . 2 3 .	2 . 2 1 +	1 . . + 1 1 .	2 1 2 2	1 . 2	1 . 1 . . 2 1	1 2 1 .	. . 1 . 1	. 1 1 +	. . + . . .	.
Asparagus suaveolens	. 1 1 . . 1 2 r	r . 2 + .	+ . . + . 1 .	. + . +	. . +	r 1 1 1 1 1 1	. + . .	1 . . + .	. 1 . +	1 r . . 1 .	.
Eragrostis superba	1 . . . r 1 1 1	r . . r 1	. . . . . . +	+ . . .	+ . +	. . r r . . .	r r . .	r . . . r	. r . .	. . . .	.
Brachiaria nigropedata	1 . . + 1 + 2 1	2 + . 1 2	. . . . 2 . .	2 . . .	. . .	. . . . 1 . .	. 2 . .	1 . . . 1	. . + +	+ . 1 2 . .	2
Themeda triandra	. . . . . 1 1 .	. . + . .	. . . .	. . . . .	. . .	. . + . + . .	. . + .	. . . . . .	. . . . .	. . . .	.
Kalanchoe lanceolata	r 1 r . . . r .	. . . 1 .	. . . r . . .	r . . .	1 . .	+ . 2 . . r 1	. . + .	. . . . . r	. . . r	. . . .	.
Acacia karroo	. 3 . . . . 1 .	. . . 2 .	2 3	. . . . .	. . . .	. . . .	. 2 . .	 1	. 3 . .	. . . .	.
Brachiaria deflexa	+ . 1 + + . + .	. . . . . .	 1	. + . .	. . +	+	. . . . .	. . r . +	. . . . .	. . + . . .	.
Pavonia burchellii	2 . 1 . + 2 2 2	1 . 2 2 .	. . r . . r .	. . 1 .	. r .	2 1 . . . . +	. . + .	. . . . . .	. . 1 .	. 2 . 2 . .	.
SPECIES GROUP O:											
Acacia erubescens	. . . . 5 .	. . . . . .	3 1 4 3 2 3 2	2 3 . 1	. 3 3	2 1 . 3 . . 4	. . . .	4 . 1 1 3	3 1 . 1	2 . 1 . 1 1	+
Rhynchosia totta	. . . .	. . . . . .	 1	. r . .	1 . r	. + + + . . .	. . . 2	+ . 2 1 r	. . . .	. . . . . 2 1	.
Eragrostis biflora	. . . .	r	. 1 2	. . . .	r . .	. . . .	. . + .	. . . . . .	+ . . r	. . . .	1
SPECIES GROUP P:											
Polygala sphenoptera	. . . .	+ 1	. . . .	. . . .	. . .	. . . .	. . . .	. . . . . .	. . . .	. . . .	.
Gossypium herbaceum	. . . .	. . . . . .	. . . .	. . . .	. . .	. . . .	. . . .	. . . . . .	. . . .	. . . . + . .	.
Pogonarthria squarrosa	. . . .	. . . . . .	. . . .	. . . .	. . .	. . . + . . .	+ . . .	. 1 . . .	. . . .	. . . .	.
SPECIES GROUP Q:											
Vahlia capensis	. . . .	. . . . . .	. + ...	. . . .	. . .	. . . . . + .	. . . +	. . . . . .	. . . r	. . . . . . r	.
SPECIES GROUP R:											
Senna italica s. arachoides	. . . r	. . . . . .	. . . .	. r + .	. . .	. . . .	. . . .	+	+ . . .	+ . . r . . .	.
SPECIES GROUP S:											
Aristida adscensionis	 1	+	2 + 3 . 2 2 .	1 2 . .	+ + .	. . + 1 . 2 2	+ + + 2	. 2 2 2 +	2 2 . 2	. . + 1 . . .	.
Combretum apiculatum	. . . .	. . . . . .	2 4 2 . + 2 2	. 2 . 1	. 1 2	3 3 . . . 2 2	. 2 2 3	. 4 2 3 3	. 4 2 2	3 . . 1 4 4	+
Triumfetta pilosa	. . . .	. . . . r .	+ 2 2 r . . .	. + . r	. r +	2 2 . 1 + 1 .	1 r 1 2	+ + 2 1 .	+ + . .	1 . r . 1 1	3
Chamaecrista mimosoides	. . . . . . + . .	. . . . . .	. 1	. r r r	. . r	. 2 . 1 + . .	. . . 1	r	. . . . .	+ . . 2 . . .	+

Eragrostis rigidior	. . . .	. . . . . .	. . . . 1 1 .	. . . +	1 + .	. . . .	. . . .	 2	1 . . .	. . 1 2 . .	.
Aristida congesta s. congesta	. . . . +	. . . . r	. . . . + + 3	1 . 2 2	. . +	+ 1 + ...	2 . . +	1	1 . 3 .	2 . . . . +	+
Monsonia burkeana	. . . .	. . + . 1	. 1 . r . . .	+ 1 . +	. + r	r + + ...	. . 2 r	. + . . +	. + . +	. . . . 2 +	+
Digitaria eriantha	. . r	. . r . .	. . . . +	+ r . .	. + +	. . + r . . .	. r . .	. . . . . .	. r . .	. . . . r .	+
Sporobolus ioclados	r . . . . + . .	. . . . . .	1	. . . . .	. . +	. . . . + . .	. . . 1	1 . . + +	. . . .	. . . . r .	.
Melinis repens	. . . .	. . . . . .	+ 1 1 . r . r	+ r . .	. . +	. . . . + . .	. r . 1	+ . 2 r r	. r r +	. . . . 1 r	.
Agathisanthemum bojeri	. . . .	. . . . . .	. . . . 2 1 +	1 r 1 .	. + 1	. 2	+ . . 1	. . + 2 .	1 . 1 +	2 . r . r .	r
Zornia milneana	. . . . r	+	r . . . r . .	+ 1 + 1	+ . +	. . + r + . .	. . . .	. r . . .	. + . .	. . + . . .	1
Ceratotheca triloba	. . . .	. . . . . .	. 2	. . . .	. . .	. + ...	. . . 1	. + . 1 .	. . . .	. . . . 1 3	.
SPECIES GROUP T:											
Grewia flava	2 2 4 . 3 . 3 3	. . . . . .	. 1 . 1 3 2 .	. 2 3 2	3 3 2	2 1 2 2 2 2 3	2 2 2 2	3 2 2 2 2	3 3 3 3	2 . 2 4 4 2	+
Evolvulus alsinoides	1 1 + 1 2 + + +	1 + . + 1	. 3 . . . r r	. 1 1 +	+ r 2	2 1 + . . 1 .	. . . .	. 2 1 2 .	r r r .	. . . 1 + 2	1
Panicum maximum	1 2 1 2 1 1 1 2	+ . . 3 +	. 1 . . . 2 .	. 2 2 1	2 . .	1 2 . . 1 1 1	+ . 1 .	+	. 2 + .	1 + r + 2 1	3
Abutilon sonneratianum	1 2 . + . . 1 1	2 . + 1 2	. 2 . 1 . . .	r . + .	. . .	1 1 1 . . + +	. + . +	2 1 1 . .	+ + + +	+ . . 1 1 2	1
Aristida congesta s. barbicollis	1 r . 2 . 1 1 .	1 . . . 2	. 2 + . + . .	+ . + .	1 1 2	1 + 2 . 2 . r	1 1 1 .	. 1 . + 2	. + 1 .	. . 1 3 2 2	2
Justicia protracta	2 2 2 2 2 3 2 2	1 2 2 2 +	+ 2 1 . + . +	. 2 + .	. . +	. . . . . 1 .	. r . .	+ . 2 1 .	. 1 . .	. 2 . 2 2 3	+
Tephrosia lupinifolia	2 . + + . . 1 1	2 . . . 2	. . . + . . .	. 2 1 2	. + 1	. 1 . 1 2 1 +	2 . 2 1	. 2 2 2 .	2 . . .	. . + + + 2	2
Schkuhria pinnata	. 1 + . . . 2 .	. . + r r	1 . + . . + +	+ + + .	. 1 1	. + ...	. . . +	+ . . + 1	. + . r	r . + 1 . 1	2
Eragrostis pilosa	+ . + . + r . .	1 . . 1 1	2 1 1 . 2 . 2	. . . .	. . .	. 1 1	. 1 1 1	. + 2 3 .	+ . 1 r	+ . + + . 2	.
Tragus racemosus	2 1 + 1 1 . 1 .	2 + . 1 3	. 1	. . . . .	3 . 2	. . . + . 1 .	+ . . 1	. + + 2 +	. . . +	1	1
Enneapogon cenchroides	+ r . . . . + .	. . . . + .	. 2 . + . + 1	. . . . .	. + .	1 . . . . 1 .	. + . .	. . . 1 .	. . . .	. . . + 2 +	.
Commelina africana	+ + 2 r . + r .	r . 1 + .	. + ...	. + r .	. . .	1 . . . . 1 r	. . . .	+	. 1 . .	. . . 1 2 .	.
Linum thunbergii	. + + . . 1 . .	. . . . . .	. 1	. . . . .	. . +	. 1 1 + . . .	. . . .	. . 3 + +	. . . .	. . . . . . +	.
Albuca species	+ + r . 1 . + .	. r . + r	r . . . . r .	. . r r	. . .	. . . . + . .	. r r .	. r . . .	r . . +	r	r
Ipomoea obscura v. obscura	. 1 . . . . 2 1	. . . 2 .	. . . .	. 1 . .	. . .	2 + ... 1	. . . .	2 . . . 1	1 2 2 +	1 1 . 1 . .	1
Acacia mellifera	3 4 1	1 . . 4 .	. . . .	. . . . +	2 2 1	. . 4 4 2 . +	1 . 3 .	3 1 . . .	. . 2 3	3	.
Heteropogon contortus	1 . . . . + + 1	. . . . . .	2 . 1 . + 1 1	+ + + +	. . .	. . . .	. . . .	. . . . . .	+ + + +	. . . .	r
Solanum panduriforme	. . . . 2 .	2 1 1 3 2	. + ...	. . . . .	. . .	r 2 r . . . r	. . . r	r 2 . . r	r . . .	. . . .	.
Tragus berteronianus	+ . . . 2 1 . .	2	. . . . . . + .	+	. . .	. 1 . 2 . . +	. . . .	. 2 . . .	+ . . .	. . + . . .	+
Kyphocarpa angustifolia	. . 1 . . . 1 +	. 1 . . .	. . . .	. 1 . . .	. . .	. . . .	. . . .	r	. . . .	. . . . . + .	.
Rhynchosia caribaea	. . . . . . 1 2 .	1 . 1 . 1	. . . .	. . . . .	. . .	. . . .	. . . .	. . . . . .	. . . .	. . . . 1 . .	.
Phyllanthus reticulatus	+ . . r . . 1 1	. . . + .	. . . .	. . . . .	. . .	. . . .	. . . .	. . . . . .	. r . .	. . . .	.

Insignificant species with an occurrence of 4 or less have been ommitted.

Gymnosporia heterophylla	. . . .	. . . + .	. . . .	. + . .	. . .	. . . .	. . . .	. . . . . .	. . . .	. . 1	.
Helichrysum dregeanum	. . . .	. . . . . .	. . . .	. . . .	. . .	. . . .	. . . .	. r . . .	. . . .	. . . .	.
Cenchrus ciliaris	. . . .	. . . . . .	. . . .	. . . .	. . .	. . . .	. . . .	. . . . . .	. . . .	. . . . 1 . .	.
Hypoestes species	. 1	. . . . . .	. . . .	. . . .	. . .	. r	. . . .	. + 1 . .	. . . .	. . . .	.
Hermannia transvaalensis	. . . .	. . . . . .	. . . .	. . . .	. . .	. . . .	. . . .	. . . . . .	. . . .	. . . . r . .	.
Osteospermum muricatum	. . . .	. . . . . .	. . . .	. . . .	. . .	. 1	. . . .	. . . . . .	. . . .	. . . . . + .	.
Chenopodium carinatum	. . . . + .	. . . . . .	. . . .	. . . .	. . .	. . . .	. . . .	. . . . . .	. . . .	. . . .	.
*24635**	. . r	. . . . . .	. . . .	. . . .	. . .	. . . .	. . . .	. . . . . .	. . . .	. . . .	.
Ehretia rigida	. . . .	. . . . . .	. . . 1 . . .	. . . .	. . .	. . . .	. . . .	. . . . . .	. . . .	. . . .	.
Vernonia poskeana	. . . .	. . . . . .	. . . . +	. . . .	r . .	. . . .	. . . .	. . . . . .	. . . .	. . . .	.
Zygophyllum species	. . . .	. . . . . .	. . . .	. . . .	. . .	. . . . r . . .	. . . .	. . . . . .	. . . .	. . . .	.

Portulaca quadrifida	. . . .	. . . . .	. . . .	. . . .	. . .	. . + ...	. . . .	. . . . .	. . . .	. . . . . .	.
Portulaca kermesina	. . . .	. . . . .	. . . .	. . . .	. . .	. . . r . . .	. . . .	. . . . .	. . . .	. . . . . .	.
Kalanchoe paniculata	. . . .	. . . . .	. . . .	. r . r	. . .	. . . .	. . . .	. . . . .	. . . .	. . . . . .	.
Hermannia glanduligera	. . . .	. . . . .	. . . .	. . . .	. . .	. . . .	. . . .	. . . . .	. . . .	. . + . . .	.
Eragrostis pilgeriana	. . . .	. . . . .	. . . .	. . . .	. . .	. . . .	. . . .	. . . . +	. . . .	. . . . . .	.
Indigofera holubii	. . . .	. . . . .	. . . .	. . . .	. . .	. . . .	. . . .	. 2 . . .	. . . .	. . 2 . . .	.
Hermbstaedtia linearis	. . . .	. . . . .	. . . . . r .	r . . .	. . .	. . . .	. . . .	. . . . .	. . . .	. . . . . .	.
Cucumis zeyheri	. . . .	. . . . .	. . . .	. . . .	. . .	. . . .	. . . .	. . . . .	. . + .	. . . . . +	.
Nemesia albiflora	. . . .	. . . . .	. . . .	. . . .	. . .	. . . .	. . . .	. . . . .	. . . .	. . . . . .	.
Hermbstaedtia odorata	. . . .	. . . . .	. . . r . . .	. . . .	. . .	. . . .	. . . .	. . . . .	. . . .	. . . . . .	.
Acacia robusta	. . . .	. . . . .	. . . .	. . . .	. . .	. . . .	. . . .	. . . . .	. . . .	. . . . . .	.
Oxygonum sinuatum	. . . .	. . . . .	. . . .	. . . .	. . .	. . . .	. . . .	. . . . .	. . . .	. . . . . .	.
Freesia laxa	. . . .	. . . . .	. . . .	. . . .	. . .	. . . .	. . . .	. . r . .	. . . .	. . . . . .	.
Mariscus rehmannianus	. . . .	. . . . .	. . . .	. . . .	. . .	. . . .	. . . .	. . . . .	. . . .	. . . . . .	.
Blepharis integrifolia	. . . .	. . . . .	. . . .	. . . .	. . .	. . . .	. . . .	. . . . .	. . . .	. . . . . .	.
Acacia caffra	. . . .	. . . . .	. 2	. . . .	. . .	. . . .	. . . .	. . . . .	. . . .	. . . . . .	.
Crabbea angustifolia	. . . .	. . . . .	. . . .	. . . .	. . .	. . . .	. . . .	. . + . .	. . . .	. . . . . .	.
Tephrosia longipes	. . . .	. . . . .	. . . .	. . . .	. . .	. . . .	. . . .	. . 1 . .	. . . .	. . . . . .	.
Hibiscus cannabinus	. . . . 2 . . .	. . . . .	. . . .	. r . .	. . .	. 1	. . . .	. . . . .	. . . .	. . . . . .	.
Haworthia species	. . . r	. . . . .	. . r	. . . .	. r .	. . . .	. . . .	. . . . .	. . . .	. . . . . .	.
Striga elegans	r	. . . . r	. . . .	. . . .	. . .	. . . .	. . . .	. . . . .	. . . .	. . . . . .	.
Hyptis species	. . . . +	. . . 2 .	. . . .	. . . .	. . .	. . . .	. . . .	. . . . .	. . . .	. . . . . .	.
Zinnia peruviana	. . . .	. . . 1 .	. . . .	. . . .	. . .	. . . .	. . . .	. . . . .	. . . .	. . . . . .	.
Acanthospermum species	r r	. . . . .	. . . .	. . . .	. . .	. . . .	. . . .	. . . . .	. . . .	. . . . . .	.

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              |          3               |
    2 .  3    |   3 .  1   |    3 .  2   |
              |            |             |
              |            |             |
              |            |             |
5 3 3 3 3 4 6 | 2 2 2 2 2 2 | 3 2 2 3 3 3 3 |
0 2 0 6 8 0 2 | 6 7 1 2 3 4 | 1 8 9 3 9 4 5 |
              |             |               |
              |             |               |

. . . . . . . | . . . . . . | . . . . . . . |

. . . . . . . | . . . . . . | . . . . . . . |

. . . . r . . | . . . + . . | . . . . . . . |
. . . . . . . | . . . . . . | r . . . . . . |
. . r . . . . | . . . . . . | . r . . . . . |
. . + . . . . | . . . . . . | . 1 . . . . . |
. + . . 1 . . | r . 1 . . . | . + . . . . . |

. . . . . . . | . . . . . . | . . . . . . . |
. . . . . . . | . . . . . . | . . . . . . . |
. . . . . . . | . . . . . . | . . . . . . . |
. . . . . . . | . . . . . . | . . . . . . . |
. . . . . . . | . . . . . . | . . . . . . . |

. . . . . . 2 | . . . . . . | . . . . . . . |

. . . . . . . | . . . . . . | . . . . . . . |

. . . . . . . | . . . . . . | . . . . . . . |
. . . . . . . | . . . . . . | . . . . . . . |

. . . . . . . | . . . . . . | . . . . . . . |
. . . . . . . | . . . . . . | . . . . . . . |
. . . . . . . | . . . . . . | . . . . . . . |
. . . . . . . | . . . . . . | . . . . . . . |

. . . . . . . | . . . . . . | . . . . . . . |
1 . . . . . . | . . . . . . | . . . . . . . |
. . . . . . . | . . . . . . | . . . . . . . |

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. . . . . . . | . . . . . . | . . . . . . . |
. . . . . . . | . . . . . . | . . . . . . . |

r . . . . . . | . . . . . . | . . . . . . . |

. . . . . . . | . . . . . . | . 2 . . . . . |
. r . . . . . | . . . . r . | . r . . . . . |
+ . . . . . . | . . + . . . | . . . r . . . |
. . r . . . . | . . . . . . | . . . . . . . |

. . . 2 . . . | . . . . . . | . + . . . . . |
. . . . . . . | . . . . . . | . . . . . . . |
. 1 . r . . . | . 2 . . . . | . . . . . . . |
. . . . . . . | . . . . . . | . . . . . . . |
. . . . . . . | . . . . . . | . . . . . . . |
. 1 2 . . . 1 | . . . . . . | . . . . . . . |
2 . . . . . . | . . . . . . | . . . . . . . |
. . . . + . . | . . . . . 1 | . . . . . + . |
. . . . . . . | . . . . . . | . . . 2 . . . |

+ . . . . . . | . . . . . . | . + . . . . . |
. . . . . . . | . . . . . . | . . . . . . . |
. . . . . . . | . . . . . 1 | . 2 . . . . . |
. . . . . . . | . . . . . . | . . . . . . . |
. . . . . . . | . . . . . . | . . . . . . . |
. . . . . . . | . . . . . + | . . . + . . . |
. . . . . . . | . . . . . . | . . . . . . . |
. . . . . . . | . . . . . . | . . . . . . . |
. . . . . . . | . . . . . . | . . . . . . . |
. . . . . . . | . . . . . . | . . . . . . . |
. . . . . . . | . . 1 . . . | . . . . . . . |

5 4 5 2 4 4 + | . . . . . . | . . . . . . . |
2 . r 2 2 . . | . . + . . . | . . . + . . . ||
. r . . . . 2 | . . + . . . | . . . . . . . |

. . 2 . . . . | + 1 + + + . | . . . . . . . |
. 2 . . + . . | 1 r 2 2 2 2 | . . . + r . . |
. . + . + . + | . + 2 2 2 . | + . . . . . . |

. . . . . 1 . | . . + . . . | 3 1 . 1 . + . |

. + . . . . . | + 2 . 2 + 1 | . 2 2 r . . r |

+ . + 2 . 1 . | . 2 . . + . | + . . 2 1 . 2 |
4 4 3 4 4 3 . | . 1 4 3 . 4 | 4 4 . 4 . 4 . |
2 1 1 2 2 2 2 | . 2 3 3 . 1 | + 1 r 2 3 1 1 |
. 1 2 1 . . r | 1 . 2 3 1 2 | . 2 2 1 . . r |
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. . 2 .  2 1 + |  1 1 + . .  + |  1 .  1 + +  1 1 |
.  2 2 .  2 . . | . .  +  2 .  1 | .  2 + . .  3 . |
 2 2 . .  1 . . | r  1 .  2 .  2 |  1 1 1 .  + . . |
. . . . r . . | . .  + + + + |  2 r  .  1 .  1 . |
 2 . . . .  + . | .  + . . . . | . . .  1 . . . |
 1 +  2 1 .  + . | + +  1 1 1 1 | + +  1 + + + + |
 1 2 + . .  1 . | + .  3 2 1 3 |  4 r  .  2 3 . . |
.  2 1 . . .  + | .  1 .  r .  r | .  1 2 r . .  r |
. . . . . . . | . .  1 1 2 1 | + + . . . . . |

 1 2 2 .  3 2 . | . .  2 2 1 . |  2 .  2 2 .  1 . |
.  1 2 .  r  +  1 |  2 2 2 2 1 1 | r  2 2 .  1 +  2 |
.  2 1 1 2 2 . |  2 2 2 +  2 2 | .  2 2 2 2 . . |
 1 2 1 2 2 2 1 |  1 2 + . .  1 |  2 +  2 2 2 2 . |
 2 + . .  + .  2 |  3 1 2 .  +  1 |  1 .  +  1 1 .  + |
.  2 2 3 3 2 + | . . . . . . |  2 1 .  2 2 3 3 |
 1 2 .  2 + .  2 | . .  r  2 1 2 | . . .  1 . .  1 |
.  1 2 . . . . | .  + .  2 2 2 |  1 1 .  + . . . |
 1 . .  1 .  1 . | . . .  + .  + |  2 2 1 . .  3 2 |
.  + +  1 + .  2 | . . . . . . | . . .  + .  r  . |
.  1 2 +  2 1 . | .  +  r  + . . | r  1 .  2 .  1 + |
+  1 .  1 . .  + | . .  1 2 .  1 |  1 2 . . . . . |
.  2 .  1 3 1 r |  1 1 +  1 .  + |  1 + .  1 +  1 + |
. . . .  1 . . | r  .  r  1 1 . | . . . . . . . |
+  1 . .  1 . . |  1 1 2 . . . | .  2 . . . . . |
.  + . . . . . |  1 .  1 1 . . | . . . . . . . |
. . . . . .  r | . . . . .  2 | . .  3 2 . .  + |
.  r  . . .  1 . | . .  1 2 .  3 | r  . . . . . . |
 1 . . . .  + . | . . . . . . | . . .  1 . . . |
. .  1 + . .  1 | . . . .  1 . | .  1 . .  + . . |
.  +  2 +  1 . . | . . . . .  + | . . . . . . . |
. . . . . . . | r  .  r  . .  1 | .  r  . .  r  . . |


. . . . . . . | . . . . . . | . . . . . . . |
r . . . . .  r | . . . .  r  . | . . . . . . . |
r . .  1 . . . | . . . . . . | .  3 . . . . . |
. . . . . . . | . . . . . . | . . . . . . . |
. .  r  . .  + . | . . . . .  r | .  + .  + . . . |
. .  + . . . . | . . . . . . | . . . . .  r  r |
. . . .  r  . . | . . . .  + . | . . . . . . . |
. . .  1 . . . | . . . . . . | . . . . . . . |
. . . . . . . | . . . . . . | . . . . . . . |
. . . . . . . | . . . . . . | . . . . . . . |
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. . . . . . . | . . . . . . | . . . . . . . |
. . . . . . . | . . . . . . | . . . . . . . |
. . . . . . . | . . . 1 . . | . . . . . . . |
. + . . . . . | . . . . . . | . . . . . . . |
. . . . . . . | . . 2 . + . | . . . . . . . |
. . . . . . . | . . . 2 . . | . . . . . . . |
. . . . . . . | . . . . . . | . 3 . . . . . |
. . . . . . . | . . . . . . | . + . . . . . |
. . . . 1 . . | . . . . . . | + . . . . . . |
. . . . . . . | . . . . . . | . . . r . . . |
. . . . 3 . . | . . . . . . | . . . . 1 1 . |
. . . . . . . | . . . . . . | . . . . . . . |
r . . . . . . | . . . . . . | . . . . . . . |
r . . . . . . | . . . . . . | . . . . . . . |
. . . . . . . | . . . . . . | . . . . . . . |
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