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USE OF SELECTED FODDER SHRUBS IN THE RECLAMATION OF DEGRADED ARID RANGELANDS.

By

Trove Elizabeth Wilcock

Submitted in partial fulfilment of the requirements for the degree

M. Sc. Agriculture (Pasture Science)

Department of Plant Production and Soil Science
Faculty of Natural and Agricultural Sciences
University of Pretoria
Pretoria

Supervisor: Prof. N.F.G. Rethman

Co-Supervisor: Prof. W.A. van Niekerk

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Declaration

I, Trove Wilcock, declare that this dissertation, which I hereby submit for the degree M. Sc. (Agric) at the University of Pretoria, is my own work and has not previously been submitted by me for a degree at this or any other tertiary institution.

T.E. Wilcock

Pretoria

December 2009

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Table of Contents

Cover Page……………………………………………………………………I

Declaration……………………………………………………………………II

Acknowledgements…………………………………………………………III

Table of Contents……………………………………………………………IV

List of Tables…………………………………………………………………X

List of Figures………………………………………………………………XIV

List of Abbreviations………………………………………………………XVII

Summary……………………………………………………………………XIX

Chapter 1…………………………………………………………………**1**

1. Introduction…………………………………………………………………1

2. Literature survey…………………………………………………………… 2

2.1. Arid Rangelands……………………………………………………………2

- Rainfall………………………………………………………………… 5
- Temperature……………………………………………………………6

2.2. Degradation……………………………………………………………… 7

2.3. Desertification ……………………………………………………………8

2.4. Causes of Degradation and Desertification……………… ……..10

2.5. Results of Degradation and Desertification………………………… 14

2.6. Restoration and Rehabilitation………………………………………18

A. Restoration and Reclamation…………………………………18

B. Rehabilitation…………………………………………………………19

2.7. Species………………………………………………………………… 24

2.7.1. *Atriplex nummularia*…………………………………………………24

2.7.2. *Cassia sturtii*……………………………………………………… 25

2.7.3. *Salsola glabrescens*…………………………………………………26

2.7.4. *Sutherlandia microphylla* ……………………………………. 27

2.7.5. *Tripteris sinuatum*……………………………………………... 28

2.7.6. *Tetragonia calycina*……………………………………………30

2.8. Study Objective………………………………………………… 30

3. References………..……………………………………………. 30

Chapter 2a……………………………………………………..……. **50**

The influence of rumen digestion on the germination
of different fodder shrubs…………………………………..……...…. 50

- Abstract……………………………………………………………50
- Introduction……………………………………………………… 51
- Stratification……………………………………………………… 51
- Leaching…………………………………………………..…… 51
- Scarification……………………………………………………… 52
- Materials and Methods…………………………………………..53
- Results and Discussion……………………………………………55
- Conclusion…………………………………………………….. 59
- Acknowledgements……………………………..……………… 61
- References………………………………………………………. 61

Chapter 2b……………………………………………………..……. **64**

The effect of rumen digestion on the percentage and rate of
germination of *Salsola glabrescens*. ……………………………..……64

- Abstract……………………………………………………………64
- Introduction……………………………………………………… 65
- Materials and Methods…………………………………………..66
- Results and Discussion……………………………………………68
- Conclusion…………………………………………………….. 70
- Acknowledgements……………………………..……………… 71

- References…………………………………………………… 71

Chapter 3……………………………………………………..……...**75**

The use of *Atriplex nummularia* and *Cassia sturtti* to reclaim bare areas in arid areas of the Northern Cape Province, South Africa. …..…………………………………………..…… 75

- Abstract……………………………………………………75
- Introduction…………………………………………………… 76
- Materials and Methods………………………………………..77
- \- Study area…………………………………………………….. 77
- \- Pits/Furrows…….……………………………………………..78
- \- Species…………………………………………….………….. 79
- \- Seeds/Seedlings..…………………………………………….. 79
  - a) Untreated seed………………………………………80
  - b) Treated seed…………………………………………...80
  - c) Seedlings…………………………………….……81
- \- Protection…….……………………………………………..81
- \- Dates of Plantings……..…………………………………... 82
- Results and Discussion……………………………………83
  - a) September 2002….………………………………83
  - b) January 2003………………………………………...83
  - c) August 2003……………………………….……85
  - d) April 2003……….…………………………….. 87
- Conclusion……………………………………………….. 88
- Acknowledgements……………………………..…………… 89
- References…………………………………………………… 90

Chapter 4…………………………………………………………………... **93**

The selection of *Atriplex nummularia* shrubs for palatability………..……………………………………………..……….…93

- Abstract…………………………………………………………………93
- Introduction……………………………………………………………. 94
- Materials and Methods……………………………………………..96
- Study area…………………………………………………………….. 96
- Materials……………………………………………………………...97
- Method………………………………………………………………..97
- Results and Discussion…………………………………………..…98
- Conclusion……………………………………………………………101
- Acknowledgements……………………………..……………101
- References…………………………………………………….….102

Chapter 5……………………………………………………..……**104**

Dry matter production of three fodder shrubs used in re-vegetation of degraded rangelands………………..…………....104

- Abstract………………………………………………………….……104
- Introduction……………………………………………………………105
- Materials and Methods………………………………………….106
- Study area……………………………………………………………..106
- Method………………………………………………………………...107
- Results and Discussion……………………………………….110
- Total dry matter production…………………………………….110
- Edible material……………………..………………………………....114
- Conclusion…………………………………………………………117
- Acknowledgements……………………………..…………....118
- References…………………………………………………………118

Chapter 6……..……………………………………………………………**122**

Nutritive value of three fodder shrub species which may be used in the reclamation of degraded rangelands……..........……122

- Abstract………………………………………………………..122
- Introduction……………………………………………………123
- Materials and Methods…………………………………….…124
- Study area……………………………………………………..124
- Materials………………………………………………………124
- Method..………………………………………………………127
- Results and Discussion………………………………………128
- Percentage leaf material……………….……………………128
- Crude Protein..…………………..……………………………129
- *In vitro* digestible organic matter...…………………………133
- Macro minerals.……………….……………………………...134
  - Magnesium……………………………………………...134
  - Calcium……………………………………………..….135
  - Phosphorus…………………………………………..…136
- Trace minerals………………..………………………………139
  - Copper.…………………………………………………..…139
  - Manganese………………………………………..…141
  - Zinc……..…………………………………………………...141
- Conclusion……………………………………………………143
- Acknowledgements…………………………..……………143
- References……………………………………………………143

Chapter 7……………………………………………………………………**152**

The impact of stage of harvest on the re-growth of three fodder shrub species. ……………………………………………………152

- Abstract……………………………………………………………..152
- Introduction…………………………………………………………153
- Materials and Methods……………………………………………154
- Study area…………………………………………………………..154
- Materials……………………………………………………………155
- Method……………………………………………………………155
- Results and Discussion……………………………………………159
  - Percentage Survival……………………………………..…159
  - Healthiness…………………………………………………...160
  - Leafiness…………………………………………………..…161
  - Volume……………………………………………………..…163
  - Dry matter yields……………………………………………...164
- Conclusion…………………………………………………………166
- Acknowledgements………………………………………………167
- References…………………………………………………………167

Chapter 8……………………………………………………………………**170**

General Conclusions…………………………………………………..170

- References…………………………………………………………174

List of Tables

Chapter 1

Table 1 Classification of South Africa into aridity zones according to annual rainfall……………………………………………………………… .3

Chapter 2a

Table 1 The final % germination (LS mean) - a comparison of the different treatments within and between species………………………………………55

Chapter 2b

Table 1 The final germination percentage (LS mean) of the control and pepsin treatment in *Salsola glabrescens*. …………………………………68

Table 2 Treatment differences in percentage germination (LS mean), over time……………………………………………………………………69

Chapter 3

Table 1 Survival rating given to each plant according to the level of predation……………………………………………………………………84

Table 2 Survival ratings, as described in Table 1, of *A. nummularia* and *C. sturtii* (LS mean) with and without protection in the spring planting, assessed in January 2003 (4 months after planting)…………84

Table 3 Survival ratings, as described in Table 1, of *A. nummularia* and *C. sturtii* (LS mean) with and without protection in the spring planting assessed in August 2003 (11 months after planting)……….86

Table 4 Survival ratings, as described in Table 1, of *A. nummularia* and *C. sturtii* (LS mean) with and without protection in the autumn planting assessed in August 2003 (5 months after autumn planting)……........86

Chapter 4

Table 1 The chemical composition (%DM basis) of three different methods of feeding saltbush ("saltbush utilization") (Abou El Nasr, et al., 1996)……………………………………………………….95

Table 2 Ratings according to how much edible material has been removed…………………………………………………………………………98

Table 3. The percentage of shrubs rated as having been browsed to different degrees, described in Table 2, observed by three independent observers over eleven days……………………………….99

Chapter 5

Table 1 Harvest dates, after the initial 2 weeks establishment phase…....108

Table 2 Total DM production (g/plant) of *C. sturtii, S. microphylla* and *T. sinuatum* (LS mean), harvested at five different harvest dates..…...111

Table 3 The production of edible material (g/plant) of *C. sturtii, S. microphylla* and *T. sinuatum* (LS mean) harvested at five different dates. ……………………….............………………………………115

Table 4 Material (g/plant) of *C. sturtii* and *T. sinuatum* (LS mean) affected by frost during August/ September………..………………..…..…….117

Chapter 6

Table 1 Harvest dates, after the 2 weeks establishment phase..………….125

Table 2 Percentage of leaf material (LS mean) of *C. sturtii, S. microphylla* and *T. sinuatum* (LS mean), over time…………………….…………..129

Table 3 The crude protein concentration and organic matter *in vitro* digestibility (LS mean) of the different plant parts of *C. sturtii, S. microphylla* and *T. sinuatum*, over time..……………….…..……....130

Table 4 The percentage magnesium, calcium and phosphorus (LS mean) of the different plant parts of *C. sturtii, S. microphylla* and *T. sinuatum*, over time …………..…………………………..……..…135

Table 5 The calcium to phosphorus ratio (LS mean) in the different plant parts of *C. sturtii, S. microphylla* and *T. sinuatum*, over time.………138

Table 6 The copper, manganese and zinc concentration (mg/kg) (LS mean) in the different plant parts of *C. sturtii, S. microphylla* and *T. sinuatum,* over time ……………………………………………140

Chapter 7

Table 1 Approximate weeks and days of re-growth after the different harvests.……………………………………………...……………...156

Table 2 Rating of healthiness…….………………..…………..……………...156

Table 3 Rating of leafiness……………………...……………..……………...158

Table 4 Percentage survival (LS mean) of *C. sturtii, S. microphylla* and *T. sinuatum* shrubs*,* harvested at different stages of growth…....……..159

Table 5 The Mean Healthiness Rating (LS mean) of the re-growth of *C. sturtii, S. microphylla* and *T. sinuatum,* on a scale of 1-5, after different stages of harvest…..………..………..………………………161

Table 6 The Mean Leafiness Rating (LS mean) of the re-growth of *C. sturtii, S. microphylla* and *T. sinuatum,* on a scale of 1-5, after different stages of harvest………………...……………….……….162

Table 7 Mean volume (cm^3) of the re-growth (LS mean) of *C. sturtii, S. microphylla* and *T. sinuatum*, after different stages of harvest.…....164

Table 8 Dry matter yield (g/plant) of the re-growth LS mean) of *C. sturtii, S. microphylla* and *T. sinuatum*, after different stages of harvest …….165

List of Figures

Chapter 1

Figure 1 The four desert biomes of southern Africa (Lovegrove, 1993)…….4

Figure 2 *Cassia sturtii* in bloom, with an inset of the shape of this shrub….26

Figure 3 *Sutherlandia microphylla* can grow up to 1.5m in height and produces bunches of bright red flowers, when in bloom. ………..…...28

Figure 4 *Tripteris sinuatum* in bloom………………..…………...…………….29

Chapter 2a

Figure 1 Germination rate (average seeds germinated/period) of *Atriplex nummularia*……………………………………………………………....57

Figure 2 Germination rate (average seeds germinated/period) of *Cassia sturtii*……………………………………………………..…...……....…58

Figure 3 Germination rate (average seeds germinated/period) of *Sutherlandia microphylla*…………………………………………...….59

Chapter 2b

Figure 1 The germination rate (average seeds germinated/period) of *Salsola glabrescens*. …………………………………………………......69

Chapter 3

Figure 1 Furrows four metres in length were ripped into the bare patch at Pofadder in the Northern Cape. ………………....……………....79

Chapter 5

Figure 1 Field layout of trial to assess the growth and re-growth of *Cassia sturtii, Sutherlandia microphylla* and *Tripteris sinuatum*.. …109

Figure 2 *C. sturtii* seedling at Harvest 1, approximately eight weeks after planting……………………...…………………………………………...112

Figure 3 *S. microphylla* seedling 8 weeks after planting, at the first Harvest (H1)……...……………………………......……………………...113

Figure 4 Many of the *S. microphylla* shrubs had lost most of their leaves, with stem material predominating, towards the end of the trial (H5) ……………………………………………………………………113

Figure 5 *T. sinuatum* seedling 8 weeks after planting at the first harvest (H1) ………....…………………………………………………….…...114

Figure 6 Proportion of woody, edible and frosted material produced by *C. sturtii* at five different harvest dates. …………………………...115

Figure 7 Proportion of woody, edible and frosted material produced by *S. microphylla* at five different harvest dates…………………..…..116

Figure 8 Proportion of woody, edible and frosted material produced by *T. sinuatum* over five different harvest dates..…..……………………..117

Chapter 6

Figure 1 Field layout of trial to assess the growth and re-growth of *Cassia sturtii, Sutherlandia microphylla* and *Tripteris sinuatum*.…...126

Chapter 7

Figure 1 Field layout of trial to assess the growth and re-growth of *Cassia sturtii, Sutherlandia microphylla* and *Tripteris sinuatum.* 157

List of Abbreviations

ADL	- acid detergent lignin
Ca:P	- calcium: phosphorus
cm	- centimetre
cm^3	- cubic centimetre
CP	- crude protein
C4	- four carbon acids
DM	- dry matter
%DM	- percentage dry matter
E	- east
e.g.	- example
etc.	- etcetera
g	- grams
g/kg	- grams per kilogram
$g\ kg^{-1}$	- grams per kilogram
g/plant	- grams per plant
h	- height
ha	- hectare
HCl	- hydrochloric acid
H1	- harvest 1
H2	- harvest 2
H3	- harvest 3
H4	- harvest 4
H5	- harvest 5
IVDOM	- *in vitro* digestible organic matter
km^2	- kilometres squared
l	- litre
m	- metre
mg/kg	- milligram per kilogram
mm	- millimetre
N	- nitrogen
NPAA	- non-protein amino acid

N:P:K	- nitrogen: phosphorus: potassium
pers. comm.	- personal communication
pH	- H-ion concentration
r^2	- radius squared
S	- south
spp.	- species
sq km	- squared kilometres
V	- volume
%	- percentage
°	- degrees
℃	- degrees celsius

Summary

Use of selected fodder shrubs in the reclamation of degraded arid rangelands.

by

Trove Elizabeth Wilcock

Supervisor	**:**	**Prof. N.F.G. Rethman**
Co-Supervisor	**:**	**Prof. W.A. van Niekerk**
Department	**:**	**Plant Production and Soil Science**
		Faculty of Natural and Agricultural Sciences
		University of Pretoria
Degree	**:**	**M. Sc. (Agric) Pasture Science**

Aspects, which influence the choice of species for the rehabilitation of degraded arid areas, were studied. Although only one trial was established in the target area (transition area between the Succulent and Nama Karoo) seed of the indigenous species used was collected from this area.

In the initial trials the effect of rumen digestion on the germination of fodder shrubs was observed. Species included the exotic *Atriplex nummularia* and *Cassia sturtii*, and the indigenous *Sutherlandia microphylla*, *Tetragonia calycina*, *Tripteris sinuatum* and *Salsola glabrescens.* No seed of *T. calycina* germinated. In *T. sinuatum* and *S. glabrescens* rumen digestion prevented germination while in the other species percentage germination was reduced.

In the establishment trial with *A. nummularia* and *C. sturtti,* on a bare area on-farm, in the arid Northern Cape Province, no seed germinated. Observations

showed that, for both species, protection is essential, where the risk of herbivory is high. Of the two species, *C. sturtti* shrubs appeared to be more drought tolerant.

A further trial addressed the intra-species variation in the palatability of *A. nummularia.* Established shrubs of the F1 "elite" generation were browsed by sheep. The most palatable shrubs were identified and seed from these shrubs will be used to produce seedlings that will go into further selection trials.

The final section of this study was a comparison, in terms of quantity, quality and re-growth, of *C. sturtii, T. sinuatum* and *S. microphylla*, at, and subsequent to, five different harvest dates. In the first three harvests no significant differences were observed in the total plant material produced, between the three species. In Harvest 5 both indigenous species had produced more edible material (leaf and <3mm stem material) than *C. sturtii*. The edible material of Harvests 1, 3 and 5, was analysed for crude protein content, *in vitro* digestibility and mineral concentrations. All three species had sufficient crude protein as well as calcium, phosphorus and magnesium, to meet maintenance requirements of sheep. Trace minerals, manganese and copper, were present in adequate amounts and toxicity could be more of a concern. The concentrations of zinc in all three species, however, were only sufficient in material obtained in Harvests 1 and 3. Re-growth of all shrubs 21 weeks after Harvest 5 was assessed in terms of survival, healthiness, leafiness, volume and dry matter production. *C. sturtii* shrubs harvested at a later stage in the initial trial had the best survival. For most re-growth periods, *C. sturtii* shrubs also appeared healthier and leafier than the indigenous species. *S. microphylla* seedlings had, however, established in the *S. microphylla* plots, which was a plus for that species.

Chapter 1

1. Introduction

"It is a quirk of human nature that people only appreciate what they understand, and the deserts of southern Africa can be appreciated for many things." – (Seely, 1993).

The same can be said for the arid and semi-arid rangelands (Table 1) of South Africa, as these contain a rich and diverse range of fauna and flora (Lovegrove, 1993; Palmer & Ainslie, 2002). Understanding the effect of degradation and desertification occurring in these areas will, hopefully, lead to the appreciation of the importance of conservation and rehabilitation (Lovegrove, 1993; Seely, 1993).

Most farming systems found in these arid and semi-arid areas are focused on livestock production. Due to irrigation not being feasible (Dean & MacDonald, 1994) farmers are heavily reliant on the natural rangelands (Palmer & Ainslie, 2002). Over-utilization and degradation, however, has resulted in a decrease, and in some cases the endangerment, of a number of natural flora and fauna found within these areas (Lovegrove, 1993). The loss of natural vegetation has also led to a decreased carrying capacity of the land (Le Houérou, 1989, Dean & MacDonald, 1994).

Once severely degraded rest and natural processes are insufficient to restore the land. Some form of intervention is, therefore, necessary in order to rehabilitate the area to a productive state (Box, 1978; Esler & Kellner, 2001a).

Due to there being no definite guidelines to follow (Van Der Merwe & Kellner, 1999; Snyman, 2003) the objective of this study was to observe a number of different possible methods of rehabilitation. Trials focused on aspects such as germination, establishment, productivity and palatability of different exotic and indigenous drought tolerant fodder shrub species. Species used included *Atriplex nummularia, Cassia sturtii, Salsola glabrescens, Sutherlandia microphylla, Tripteris sinuatum* and *Tetragonia calycina*

The study focused on the Northern Cape Province, which, according to Palmer & Ainslie (2002), is one of the worst affected areas in South Africa. The target area was situated in the transition area between the Succulent and Nama Karoo. This area has a bimodal rainfall of approximately 130mm per annum (Sparks, 2003), with most of the rain falling in the later summer. Droughts are also frequent occurrences due to the extremely variable rainfall, low humidity and unfavourable geographical position (Bosch, 1999).

Although only one of the trials was established in the area itself, seed of most of the indigenous species used in this programme was collected from this area.

2. Literature survey

2.1. Arid Rangelands

Thompson (1975) defined aridity as the lack of adequate moisture and Hawkins (1988) defined a rangeland as a "large open stretch of grazing- or hunting-ground". According to Dean & MacDonald (1994), rangelands should be considered as arid when they have an average annual rainfall of below 300mm, coupled with high evaporation rates. Due to South Africa's mean annual rainfall being only 450mm, the country as a whole is considered semi-arid (Table 1). Within South Africa, however, the annual rainfall is highly variable between different regions, ranging from 3000mm (in the mountains of the south western Cape) to 50mm (in the Richtersveld on the border of Namibia) (Palmer & Ainslie, 2002). A number of areas within South Africa are, therefore, considered to be arid and hyper-arid (Table 1).

South Africa is bordered by the Indian Ocean on the southern and eastern side, by the Atlantic Ocean on its western coast and by the Republics of Namibia, Botswana, Zimbabwe and Mozambique, in the North. Excluding the kingdoms of Lesotho and Swaziland, South Africa's total land area is 1223 201 sq km (Palmer & Ainslie, 2002).

Table1 Classification of South Africa into aridity zones according to annual rainfall

Rainfall (mm)	Classification	Percentage of land surface
<200	Desert & Hyper-arid	22.8
201 – 400	Arid	24.6
401 – 600	Semi-arid	24.6
601 – 800	Sub-humid	18.5
801 – 1000	Humid	6.7
>1000	Super-humid	2.8

Source: Schulze 1997; Palmer & Ainslie, 2002.

Rutherford & Westfall (1986), cited by Palmer & Ainslie (2002), separated South Africa into six biomes, in terms of bio-climatic and growth form information, namely the Succulent Karoo, Nama-Karoo, Savanna, Grassland, Forest and Fynbos.

Lovegrove (1993), however, believed that the arid areas of southern Africa alone can be separated into four distinct and different biomes (Figure 1).

These are:

1. The Arid Savanna biome – which consists of woody trees or shrubs (phanerophytes and leafy hemicryptophytes) that make up more than 50% of the canopy cover.
2. The Desert biome – which is dominated by annuals (therophytes). In the Namib Desert these plants constitute 96% of the canopy cover.
3. The Succulent Karoo biome – Such areas rarely have trees or grasses and are dominated by dwarf shrubs (chaemaphytes), which can make up to 85% of the canopy cover.
4. The Nama Karoo biome – which is dominated by “dwarf shrubs” (chaemaphytes) and grasses (caespitose hemicryptophytes).

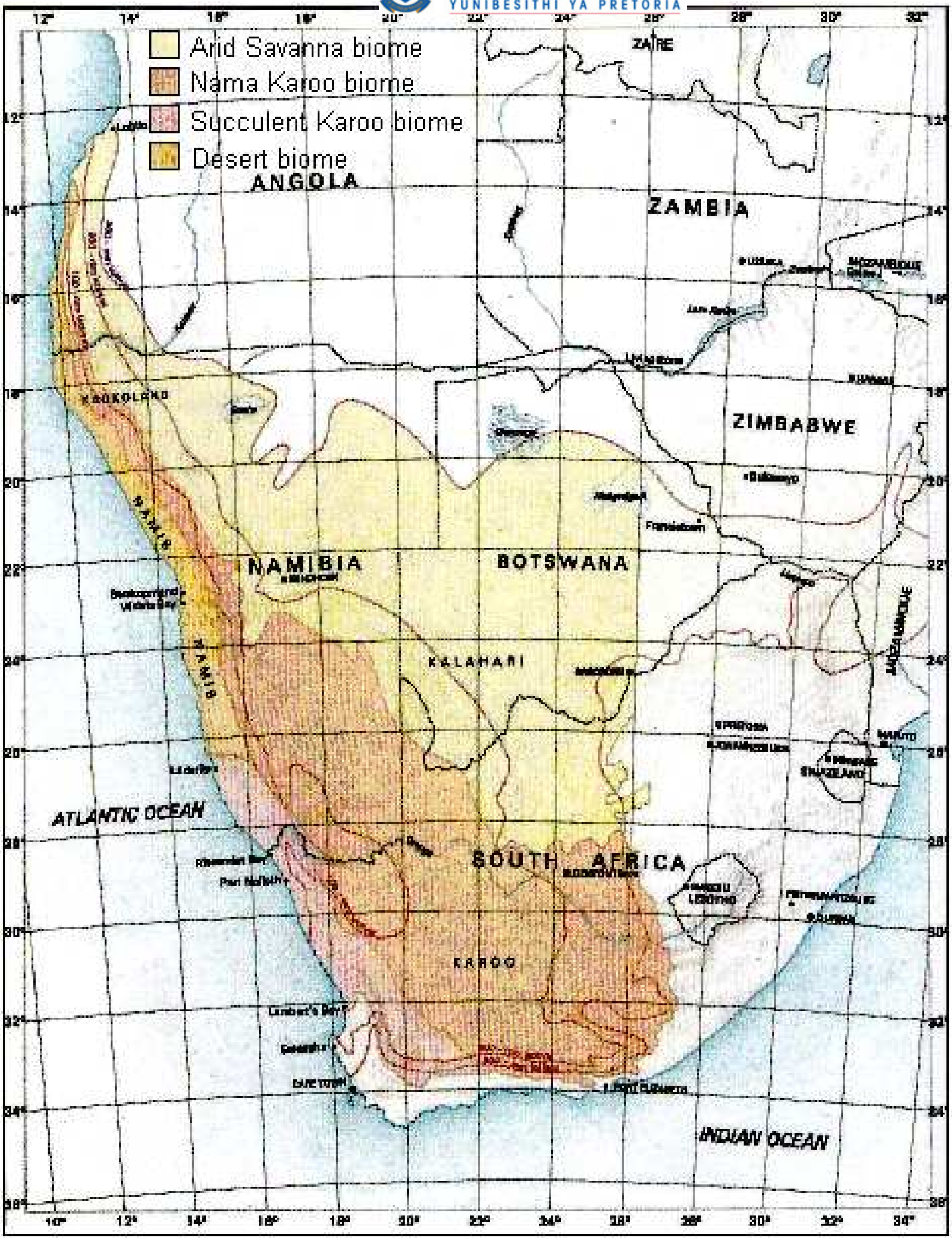

Figure 1 The four desert biomes of southern Africa (Lovegrove, 1993)

The word "Karoo" means 'dry' or 'barren' in the Khoikhoi language (Adamson, 1938; Cowling et al., 1997; Klopper, 2000), which gives an idea of how arid the Karoo biomes are. In the Karoo biomes the land is mostly flat with a few mountain ranges. One of the main characteristics of these biomes are, in fact, "Karoo koppies" (Karoo hills), which are scattered across the landscape. Although the great Orange River cuts through these biomes (Lovegrove, 1993), there is still a lack of available water, resulting in heterogenous, spatial and patchy vegetation, alternating with bare soil (Bertiller, 1998; De Villiers et al., 2001). The Karoo biomes have a rich and diverse biota (Cowling et al., 1999), with a wide range of fauna and flora. Both chaemaphytic dwarf shrubs and hemicryptophytic grasses dominate the flora (Lovegrove, 1993; Palmer & Ainslie, 2002). According to Lovegrove (1993), however, the grass component of these biomes is often not visible, due to overgrazing, and hence "Karoo" shrubs often dominate these areas.

The plant communities and "plant-soil systems" in arid rangelands are highly sensitive and extremely responsive to changes in climate and are mainly impacted on by rainfall, sunlight and humidity (MacMahon & Schimpf, 1981; Ayensu, 1985; Turner, 1990). Survival, in any rangeland, is, according to Warren & Agnew (1988), driven by energy acquired. The amount of food available is mainly dependent on the rainfall (Palmer & Ainslie, 2002). Arid areas are, therefore, as stated by Ali et al. (2000), "water-controlled".

- <u>Rainfall</u>

"Life on earth evolved in water and today no organism can live without it. In deserts water is the currency of life." – (Lovegrove, 1993). This is especially true for arid areas, which generally have a scarce, low, episodic and unpredictable rainfall that disappears quickly. This often results in insufficient, low quality forage production (Lovegrove, 1993). In terms of seasonal rainfall, according to Palmer & Ainslie (2002), there are three main zones within South Africa. The first is a winter rainfall region; the second is a bimodal rainfall region, with peak rainfall in autumn and spring and the third is a strong summer rainfall area.

The rainfall in the northwestern parts of South Africa varies from winter to bimodal rainfall. The rainfall in this area is a lot more unpredictable, erratic and variable than in the northeastern parts, with the highest unpredictability being in the Namib Desert. It is also important to note that two regions within a biome, which are stated to have the same mean annual rainfall, can be completely different in terms of the reliability and pattern of rainfall (Lovegrove, 1993). Rainfall in the northwestern parts of South Africa also varies greatly from year to year. Very often many years may pass without meaningful precipitation and then suddenly a number of storms may occur, with three times the average annual rainfall falling within hours (Lovegrove, 1993). Where there is no canopy cover this often results in erosion.

- <u>Temperature</u>

These arid areas also experience large extremes in temperature, ranging from 0-2° C, in the winter months, to 32-34° C, on summer days (Schulze & McGee, 1978; Palmer & Ainslie, 2002). According to Schulze & McGee (1978) the highest incoming thermal radiation can be found in the west of the country (27-28 mega joules/square meter/day) in summer. These high maximum temperatures are as a result of the low relative humidity (Lovegrove, 1993).

The west of South Africa gets dry air masses from the north, resulting in very little moisture in the skies. The relative humidity (amount of water vapour in the air) is, therefore, about a third in the west of what it is in the east of South Africa (20-30% mean monthly relative humidity). The low relative humidity not only results in high maximum temperatures but also low water vapour pressure, which is seen as an indicator of high evaporation rates (Lovegrove, 1993).

According to Ayensu (1985), more important than the low erratic rainfall in determining the amount of available water and thus the dry-matter production, is the ratio between the evapo-transpiration rate and annual rainfall.
In arid areas the immense power of the hot dry air strongly increases the rate of water loss, not only from the surface after rain, but also via animals transpiring and evapo-transpiration in plants (Warren & Agnew, 1988; Lovegrove, 1993).
Results from research show that the annual evaporation rates are twice as high in the western half of southern Africa (Lovegrove, 1993). Evapo-transpiration in these areas often exceeds the annual precipitation with ratios of up to 20:1

(Schulze, 1997; Palmer & Ainslie, 2002). This makes dew and fog, in arid areas important sources of water, which, according to Lovegrove (1993), are both more reliable than the rainfall. Regions, which have similar rainfall patterns and receive approximately the same quantity of annual rain, do not necessarily have the same amount of water available for plant production due to the differences in rates of evaporation.

In such extremely dry areas it is almost impossible to grow even the most drought-resistant crops without irrigation (Dean & MacDonald, 1994), which is rarely feasible. The farming systems, therefore, focus on livestock production, namely sheep, goats and, in come cases, ostriches. These systems are heavily dependent on the natural arid rangelands (Palmer & Ainslie, 2002).
Arid rangelands, however, are fragile ecosystems and due to the different pressures, such as population growth, local conflicts, economics, etc., the quantity, quality and condition of rangelands are not constant. The challenge, therefore, is for the farmer to utilize the land in a manner, which is most sustainable over time (Allsopp et al., 2003). Unfortunately this rarely happens. Over-utilization, due to cultivation and over-grazing of the natural resources has, according to Lovegrove (1993), resulted in the decrease and in some cases the endangerment, of a number of natural flora and fauna within these areas.

2.2. Degradation

"Man has always disturbed the land." - (Box, 1978)

Degradation, and the concept thereof, differs in different cultures and even different individuals within a culture. Box (1978) considered land as having been degraded if the native vegetation and animal communities have been removed and the soil altered. Warren & Agnew (1988) described land degradation as the loss of resilience within an area, and believe the measure of degradation should be equated to the cost of rehabilitation.

According to Conway (1984), cited by Warren & Agnew (1988), land degradation has two broad criteria by which it can be measured, namely:

1. Productivity – a decline, of economic importance, in production levels and rate, could be a sign of degradation.
2. Resilience – which is the ability of a resource to "bounce back" from some form of degradation, such as drought or overgrazing. It is considered to be what makes the use of a resource sustainable. The resilience of a resource varies from place to place and from time to time (due either to climatic changes or a change in land use).

Warren & Agnew (1988) believed, as do other researchers, that according to the severity of the damage, degradation can be classified as either acute or chronic. Acute degradation is the loss of only small areas of vegetation, which is short-lived (Aubreville, 1949; Hellden, 1978, 1984). Whereas chronic degradation is either the removal of almost all vegetation or the loss of natural resources, leading to a chronic decrease in productivity. According to Warren & Agnew (1988), it also affected much greater areas. Both, however, are serious and if not stopped, increase in severity, covering larger areas and may be followed by desertification (Warren & Agnew, 1988).

2.3. Desertification

Land degradation often includes the term desertification as its severest form (Warren & Agnew, 1988). According to Dregne & Tucker (1988), however, desertification is often diagnosed where the problem is degradation, due to the notion that existing deserts are expanding. It is, therefore, important to distinguish between degradation and desertification, especially in arid and semi-arid lands.

Degradation is not necessarily the same as the formation of more desert-like conditions, as it does not always result in the loss of vegetation (Sandford, 1983; Warren & Agnew, 1988). It may in fact result in an increase in vegetation cover.

At the same time, however, there is a change in species composition, from palatable to unpalatable species (Warren & Agnew, 1988; Smit & Rethman, 1999; Smit et al., 1999; Palmer & Ainslie, 2002; Snyman, 2003; Van Den Berg & Kellner, 2003). Similarly, desertification may occur where no degradation of the pastures has occurred (Warren & Agnew, 1988).

As with degradation, a number of definitions for desertification have been given over the years. Aubreville (1949), cited by Warren & Agnew (1988), defined desertification as the process whereby deserts increase and extend into the lands. Warren & Agnew (1988), however, believe this to be inaccurate, as it portrays the picture of sand dunes invading agricultural fields and burying crops. This impression, according to Warren & Agnew (1988), is given in the hope of catching the attention of funding organizations. The most severe cases of desertification, however, do not actually occur at the desert margins (UNCOD Plan of Action, 1977), which are in fact, inhabited by very few people. Very little cultivation or intensive grazing, therefore, occurs in these areas (Warren & Agnew, 1988). Although Warren & Agnew (1988) do believe that desertification should refer to the creation of desert-like conditions and not just to the degradation of pastures, they believe this definition to be too broad. Warren & Agnew (1988), therefore, defined desertification as an extreme form of land degradation, which results when the vegetation cover falls below 35% of the optimum.

According to Roux & Vorster (1983), cited by Cowling & Roux (1987), the desertification process has five distinct phases. It begins with “primary degradation” then “denudation”. This leads to the “re-vegetation” of the previously grass dominated vegetation with shrubby vegetation. This phase is followed by “secondary degradation” and finally ends in “desertification” (Darkoh, 2003a). Large areas of the Karoo biomes can, therefore, be considered to be in the third phase of degradation, due to the grass component of the vegetation having been removed and the vegetation being composed mostly of shrubs.

Some areas within these biomes, however, have been degraded further. A clear sign of this are the bare patches, which are visible in the land (Lovegrove, 1993).

According to Darkoh (2003a), if symptoms of desertification are left to continue they will result in irreversible damage, reducing the future production potential of the land (Fernàndez et al., 2002; Reynolds et al., 2003). Many believe that desertification, due to human influence, has already resulted in irreversible declines in forage production and long-term changes in the total diversity of semi-arid and arid areas (Dregne, 1983; Mabbutt, 1984; Grainger, 1990; Dean & MacDonald, 1994).

2.4. Causes of Degradation and Desertification

In the past few years' research has shown that degradation results from a combination of biophysical, socio-economical, environmental, climatic, historical and political factors (Palmer & Ainslie, 2002; Reynolds et al., 2003). Indirect causes, such as the increasing population pressure, dependency, inequality, ignorance, greed, and direct causes, such as drought, overutilization and overgrazing, combine in a number of different ways (Warren & Agnew, 1988). Identifying the factors that led to the degradation or desertification of an area will help in solving the problem.

Arid areas are already prone to degradation and desertification due to the infrequent, highly variable and unpredictable rainfall (UNEP, 1992; Lovegrove, 1993; Darkoh, 2003a), as well as the frequency of dry years (Warren & Agnew, 1988; Bezuidenhout, 2004). Climatic patterns, that affect water availability, and changes thereof, therefore, greatly impact on composition of the natural vegetation (Alcamo et al., 1996) as well as the lives of the animals and people within the area (Lovegrove, 1993).

Although climatic conditions are one of the direct causes of degradation, other factors also have an effect. According to Stokes (1994), cited by Gabriels et al.

(2003), reduced levels of moisture, along with an increase in levels of grazing, result in visible deterioration in the vegetation. Land use, therefore, also plays an important role and, according to Warren & Agnew (1988), should receive more attention.

Human activities have a direct impact on the land, its productivity as well as the diversity within the vegetation (Hoffman et al., 2003). These activities include, poor management practices, overstocking (which leads to overgrazing), harvesting of medicinal plants and fuel wood (the main source of energy in many rural households), replacing natural vegetation with extensive dry-land cropping systems, as well as mining and deforestation (Dregne, 1983; Van Den Berg & Kellner, 2003).

In arid areas light browsing/grazing at very low densities is, in most cases, the only form of land use possible (Ayensu, 1985). In the Northern Cape Province, according to Palmer & Ainslie (2002), due to its dry conditions, the rangeland is dominated by C_4 grasses and shrubs, limiting the farming industry to sheep and goat production. For a number of rural communities in these arid areas small stock production is their main source of meat and income (Noble, 1986; Khan, et al., 1999). These production systems rely heavily on the natural rangelands as a vital, and in some cases the only, source of forage (Bosch, 1999; Ali et al., 2000; Palmer & Ainslie, 2002; Reynolds et al., 2003).

Cowling & Roux (1987) believe that the introduction of domestic livestock into sensitive arid and semi-arid areas has played a major part in altering the vegetation composition. Previously, under natural circumstances, the wildlife were in balance with the resources available to them. This, however, is no longer the case once domestic livestock are introduced (Illius & O'Connor, 1999; Palmer & Ainslie, 2002). According to Botha (1981) sheep, as well as goats, are very selective and have preferences. This results in the seasonality, frequency and intensity of grazing being altered (Esler & Kellner, 2001a).

Large numbers of domestic livestock, in combination with the indigenous wildlife, therefore, result in the over-utilization of the rangelands (Illius & O'Connor, 1999; Palmer & Ainslie, 2002). For this reason livestock are considered to be one of the main causes of land degradation (Downing, 1978; Dean & MacDonald, 1994). At the same time conservative grazing practises are not implemented as farmers believe moderate stocking rates and rest periods to be impractical and costly (Düval & Scholtz, 1992; Milton, 1994). Stocking rates in the western arid areas of South Africa have, in the past, been reported to exceed the carrying capacity by about 30% (Roux, 1981; Bosch, 1999). According to Todd (1999), communal rangelands are often grazed at almost twice the recommended rate. When areas are fenced off it further increases the pressure on the land (Abou El Nasr et al., 1996).

Excessive stocking rates, according to Cowling & Roux (1987), results in the rate of removal of vegetation exceeding that of recovery, which would lead to the denudation of the land and an increase in the risk of erosion.

Overstocking also has a trampling effect (Todd, 1999) damaging the plant material, pulverizing the organic matter and compacting the soil. This results in increased risk of run-off and erosion. Such hoof action of livestock can also kill off the older shrubs, which provide protection for young seedlings (Gibson et al., 1987; Milton & Hoffman, 1994; Beukes & Cowling, 1999). This situation may be intensified by the removal of older woody plants for the use of firewood (Ayensu, 1985; Khan et al., 1999; Ali et al., 2000; Darkoh, 2003a; Reynolds et al., 2003; Sudhersan et al., 2003).

Research done by Ali et al. (2000) has shown that disturbances such as grazing alone, with no other significant changes in the abiotic environment, such as drought, having occurred, can lead to a reduction in plant diversity.

Trampling of plant material, overgrazing and selective grazing, in combination with natural causes such as drought, place the land under immense pressure and can have serious consequences (O'Connor, 1994; Snyman, 2003). It often leads to degradation and the development of bare patches (Roux, 1979, 1987; Dean, 1992; Kellner & Bosch, 1992; Dean & MacDonald, 1994; Van der Merwe & Kellner, 1999).

Dry land systems, according to Reynolds et al. (2003), are also impacted on by indirect factors, such as biophysical (population dynamics, etc.), social (cultures, attitudes, tenures, etc.) and economic factors (work force available, supply-demand, etc.). No one of these can be considered as the sole cause, but rather a combination of some, if not all (Reynolds, 2001; Reynolds et al., 2003).

Both Box (1978) and Darkoh (2003a) believed over-utilization of arid areas is linked to the continuously increasing population. According to Box (1978) having to provide food for the world's growing population is one of the main reasons why continuous land degradation takes place.

Today, both commercial and communal farmers are constantly increasing the size of land to be used in order to keep up with the demand, placing pressure on the natural resources. This often also leads to the use of areas, which are highly susceptible to degradation (Darkoh, 2003a).

Population increases are also linked to degradation by the fact that the land units to be used, or inherited, are becoming smaller, which also leads to further over-cropping and overgrazing (Darkoh, 2003a; 2003b; Smith & Koala, 2003).

Communal areas, according to Palmer & Ainslie (2002), are generally more degraded than commercial farming areas, due to the land tenure systems. Rural people are heavily dependent on the natural resources to supply energy, in the form of firewood, as well as forage for their livestock. In land tenure systems boundaries are often unclear and the rural farmer is "subsistence" orientated. This limits the introduction and adoption of new and improved management practices, which are more production orientated (Palmer & Ainslie, 2002).

2.5. Results of Degradation and Desertification

Overgrazing of arid areas has resulted in a large number of palatable perennial shrub species becoming very scarce or disappearing (Van Breda & Barnard, 1991; Dean & MacDonald, 1994).

According to Hoffman et al. (2003), one of the main ways in which perennial forage shrubs species are removed from the rangeland, is through the constant grazing/ browsing of "photosynthetically-active" plant material and, along with it, the removal of reproductive material. Studies conducted by both Milton (1994) and Todd & Hoffman (1999) have demonstrated that heavy grazing not only decreased the canopy size of the shrubs but also the flower and seed production. With very little seed set occurring, the soil-stored seed-bank becomes impoverished (Hoffman et al., 2003). Few, if any, shrub seedlings are, therefore, likely to re-establish in the area (O'Connor, 1991; Milton, 1994; Gabriels et al., 2003). The low success rate of seedling establishment in arid areas is, however, not only the result of too little seed being available (Louda, 1982; Milton, 1994), but also due to livestock grazing the young seedlings, before they are able to establish.

Milton (1994) found that when a drought (resulting in the death of heavily browsed palatable species) is followed by a rainy season, large scale, often radical, changes, in the species and their diversity, occur. Palatable perennial shrubs are usually replaced by unpalatable species (Roux & Vorster, 1983; Hoffman & Cowling, 1990; Dean & MacDonald, 1994; Milton, 1994; Gabriels et al., 2003). Palatable species, normally re-establish themselves after good rains. They are, however, unable to do so, and are often lost, due to being browsed before becoming well established (Cowling & Roux 1987; O'Connor, 1991; Milton, 1994; Todd, 1999; Hoffman et al*.,* 2003). Unpalatable species, however, are not browsed to the same extent, even with high grazing pressures (Meissner et al*.,* 1999). These species will, therefore, have a good seed set (Milton & Dean, 1990; Milton, 1994), and seedlings will not be browsed while establishing.

This results in the loss of a number of valuable and productive species from our rangelands (Lovegrove, 1993; Esler & Kellner, 2001a; Hoffman et al., 2003).

Any changes in the vegetation composition also result in changes in the diversity and abundance of wildlife communities (Roux & Voster, 1983; Hoffman & Cowling, 1990; Dean & MacDonald, 1994). The smaller fauna in the area are also affected (Hoffman et al., 2003), as the removal of vegetation cover can lead to an increase in the predation risk (Cassini & Galanthe, 1992; Eccard et al., 2000). Trials conducted by Eccard et al. (2000) found that although the height of vegetation did not differ greatly between grazed and un-grazed camps, there was a decrease in vegetation cover as well as the number of small mammals captured, in the grazed camp. Research has also shown there to be a decrease in the diversity of invertebrates and a shift in dominant species in degraded areas (Seymour & Dean, 1999; Hoffman et al., 2003).

In degraded areas not only are the fauna and flora impacted on but also the soil conditions. Where there is a decrease in vegetative cover the soil becomes exposed and disrupted. This results in the soils becoming unstable and even more susceptible to run-off and erosion (Evenari et al., 1983; Warren & Agnew, 1988; Shachak et al., 1998; Khan et al., 1999), especially in areas with sandy soils (Harper & Gilkes, 1994; Abadi Ghadim, 2000). The exposed soils form bare areas (Roux & Vorster, 1983; Komwihangilo et al., 1995), which are usually eroded to the lowest horizons of the soil profile (Kellner & Bosch, 1992; Van Der Merwe & Kellner, 1999).

In arid areas soil formation, from the weathering of rock, is extremely slow (Warren & Agnew, 1988). Lost soils are, therefore, either replaced by mobile sands, in which it is extremely difficult to re-establish plants (Hoffman et al., 2003), or form hard crusts (Adler, 1985; Van Oudtshoorn, 1992; Hoffman & Ashwell, 2001). Bare areas that form hard crusts are impenetrable to seed and rainfall (Snyman, 1999a; Snyman, 2003), resulting in a reduction in infiltration rates (Dean & MacDonald, 1994). Shachak et al. (1998) found runoff to be

significantly higher from crusted areas, with topsoil as well as rainfall (of between 30 and 50%) being lost (Snyman, 1999a; Snyman, 2003).
Low infiltration rates and the lack of “available” water also mean little removal of excess salts (through leaching), which might have accumulated (Warren & Agnew, 1988). The first few centimetres of the exposed soils of bare areas, down to approximately 30 centimetres, are also more susceptible to extreme daily temperature fluctuations, which occur due to the soil absorbing solar radiation during the day and losing it during the night (Kellner & Bosch, 1992; Lovegrove, 1993; Van Der Merwe & Kellner, 1999).

Along with the decrease in vegetation there is also a decrease in nutrients, in the form of organic matter, in the soil (Allsopp, 1999; Allsopp et al., 2000; Hoffman et al., 2003). Organic matter is not only an important source of nutrients, but it also promotes soil aggregation and root development as well as improving water infiltration and water-use efficiency (Allison, 1973; Du Preez & Snyman, 2003). The organic matter content of the soil, therefore, plays an important part in a well functioning ecosystem (Tate, 1995). When the distribution of nutrients is disrupted, plants only grow where higher soil organic matter and nitrogen concentrations can still be found, resulting in patchy plant cover (Allsopp et al., 2000; Hoffman et al., 2003). According to Shachak et al. (1998) the amount of shrub cover determines the amount of water, soil and nutrients the system is able to retain. It is important to remember that good soil conditions, and rich seed reserves within the soil, are the basic building blocks of improving the land. Therefore, when these vanish, little recovery can take place (Esler & Kellner, 2001a). In nutrient poor soils with high temperatures, it is almost impossible for successful germination and establishment of shrubs to occur (Mott et al., 1979; Van Der Merwe & Kellner, 1999; Snyman, 2003; Van Den Berg & Kellner, 2003). There is, therefore, little or no chance that bare areas will recover with rest alone (Snyman, 2003).

Degradation, whether it leads to an increase in unpalatable species or an increase in the formation of bare areas, results in a decrease in the carrying capacity of an area (Le Houérou, 1989). Rangelands, which have experienced deterioration in vegetation, both in quality and quantity, are no longer able to support the same numbers of livestock (Dean & MacDonald, 1994).

Hoffman (1997), cited by Palmer & Ainslie (2002), observed that in the last decade cattle, sheep and goat numbers have been at their lowest in 60 years.

According to Dean & MacDonald (1994), there has been a ±14.6% drop in domestic livestock numbers in South Africa. This differs between biomes, with arid areas being more seriously affected (Dean & MacDonald, 1994). Mabbutt (1984), believed one of the clear signs that there was desertification within an area were these lowered stocking rates, which resulted from the lowered carrying capacity (Le Houérou, 1989; Dean & MacDonald, 1994). The decrease in the number of livestock further impacted the land due to a decrease in the distribution of animal faeces, and hence less organic matter, over the rangeland (Dean & MacDonald, 1994). Another clear sign of a reduction in productivity of the land is a change in the domestic livestock production system, in terms of species (Dregne, 1983; Mabbutt, 1984; Geerling & De Bie, 1986; Geerling et al., 1986; Schofield & Bucher, 1986; Le Houérou, 1989; Friedel et al., 1990; Grainger, 1990; Tchernov & Horwitz, 1990; Van Keulen & Breman, 1990; Dean & MacDonald, 1994). Van Rooyen (2002) believed that such changes had also occurred in many arid areas of South Africa.

Although the true extent of degradation and desertification is not known, it is recognised to be a growing problem and authorities are in agreement that the degradation rate is greater today than that of yesteryear (Warren & Agnew, 1988; Stiles, 1995). Combating degradation has, therefore, become a priority in many parts of South Africa (Coetsee, 1992; Van Der Merwe & Kellner, 1999; Van Den Berg & Kellner, 2003). Livestock farming (commercial and communal), although one of the main factors impacting on, and increasing, land degradation, is essential to the future of South Africa and cannot be abandoned (Hoffman &

Ashwell, 2001; Palmer & Ainslie, 2002). Despite the importance of livestock production, as well as the natural rangelands these systems rely on, degraded areas are not being rehabilitated, as farmers don't consider it feasible (Danckwerts & Marais, 1989; Milton, 1994). But as Esler & Kellner (2001a) stated; "If an area is degraded to the point where it has little or no vegetative cover, it wouldn't contribute any grazing or fodder to the farming operation in any case – it is effectively lost to the farmer and produces zero income". At this point, Esler & Kellner (2001a) believe that any attempt to restore the land, no matter how limited, will benefit the land and the farmer, by improving its grazing potential.

2.6. Restoration and Rehabilitation

With the basic building blocks for improving the land removed, little recovery can take place. The notion, therefore, that the land will renew itself through rest and the natural restoration processes, without some form of intervention, is unrealistic (Box, 1978; Esler & Kellner, 2001a). In most cases it is necessary to intervene with a restoration project (Van Den Berg & Kellner, 2003), where mechanical inputs can be used to assist in restoring the area (Snyman, 2003). Where changes have taken place, restoring the rangeland will improve the biodiversity as well as increase its production potential (Esler & Kellner, 2001a).

A. Restoration and Reclamation

Restoration is defined as returning a site to the exact state, or as close as possible to the condition, that it was in before the disturbance occurred (Pastorok et al., 1997). Similarly, Box (1978) defined reclamation as improving a degraded area to a state where the original organisms present, will be able to re-inhabit the area at a similar composition and density. In many cases, however, it almost impossible to restore an area to its original state due to the natural resources having been diminished and the building blocks damaged (Box, 1978; Esler & Kellner, 2001a). According to Box (1978) an area should, therefore, only be restored if it has valuable archaeological and historical artefacts, which need to be preserved. In other cases rehabilitation measures are necessary in order to return seriously degraded areas to a point where they can be used in sustainable animal production systems (Snyman, 2003).

B. Rehabilitation

Pastorok et al. (1997) defined "rehabilitation" as improving system to a 'good working order'. Rehabilitation of disturbed sites, therefore, involves returning the site to some form of productivity, which, according to Box (1978), should be pre-planned. The aim should, according to Esler & Kellner (2001a), be to rehabilitate the land in such a way as to improve the condition as well as increase the land's production potential. Box (1978) believed that drastically degraded land could be rehabilitated in such a way that its new land use, although different, may be more productive. The new land use system should, according to Box (1978), be more beneficial to society than the previous system and at the same time be ecologically stable, even with use. The area must also be consistent or compatible with the surrounding environment (Box, 1978).

Rehabilitation of the rangeland is obtained, according to De Villiers et al. (2001), by improving the soil condition and seed bank. Along with the improved soil conditions, increasing water infiltration can also help improve conditions for rehabilitation (Davies et al., 1982; Snyman, 1999b). Water infiltration can be increased by decreasing runoff (Snyman, 1999a) as well as by improving the vegetation cover, density and overall composition (Snyman, 1998; O'Connor et al., 2001). Restoring the plant cover also protects the soil against high temperatures and provides nutrients in the form of organic matter to the soil (Van Rooyen, 2002). Creating a favourable microclimate and improving soil conditions will make conditions more favourable for plants to re-establish on bare patches (Snyman, 2003).

There are, however, no definite guidelines for rehabilitation to be followed (Van Der Merwe & Kellner, 1999; Snyman, 2003), no single tried and tested recipe.

There are only some principles, which have emerged from successful rehabilitation projects (Milton, 2001).
Where bare patches have formed a hard impenetrable compact crust, ripping will improve the penetration of seed, increase water infiltration (Van Der Merwe & Kellner, 1999; Snyman, 2003), improve soil aeration and ensure root penetration (Esler & Kellner, 2001a). There are many different mechanized cultivation methods (Griffith et al., 1984; Schlesinger, 1989). Hard soil crusts can either be shattered with a light toothed harrow (Viljoen, 1971) or by making pits where water, organic material and seed may gather (Snyman, 1999a; Van Der Merwe & Kellner, 1999; Tainton et al*.,* 2000; Snyman, 2003). Blankinship (2004) believed livestock could also play an important part in the process of breaking the hard crust formed on the land and making holes in the earth, thereby, improving the patchiness of the grass and the soil conditions. Additional organic material can also be provided in the form of animal dung (Van Den Berg & Kellner, 2003).

Another method of rehabilitating an area is through the establishment of palatable trees and shrubs, which according to Blankinship (2004), have been used in a number of environmental rehabilitation projects. According to Le Houérou (2000), the use of forage trees and shrubs in arid and semi-arid areas began after World War I, and was later expanded between the years 1950 and 1970. Trees and shrubs act as nutritive pumps, bringing nutrients that are deep down in the soil, up to the surface (Blankinship, 2004). They also provide a good perennial surface cover, which, according to Newman & Redente (2001), can help accelerate the stabilization of sites that are seriously at risk of eroding. Shachak et al*.* (1998) found shrubs can decrease runoff by approximately 75% and soil erosion by 50%. Trees, however, tend to deplete the soil reserves quickly and require more water than shrubs, thus lowering the water table further. Trees, therefore, rarely grow successfully in arid conditions and are, according to Armstrong & Gibbs (2000), considered “unsuitable” for such areas. Shrubs have a low canopy, and are able to provide protection against wind erosion, high temperatures and evapotranspiration. Shrubs are, therefore, preferred (Le

Houérou, 2000). Soil, water and nutrients, in the form of organic matter and animal excretions, also accumulate underneath shrubs. Patches of shrubs are, therefore, productive, diverse and able to promote vegetative growth, under their canopies (Weinstein, 1975; Noy-Meir, 1985; McAuliffe, 1988; Garner & Steinberger, 1989; West, 1989; Schlesinger et al., 1990; Allen, 1991; Boeken & Shachak, 1994; Milton, 1994; Zaady, et al*.,* 1996; Shachak & Lovett, 1998; Shachak et al., 1998). Researchers have observed that the establishment and survival of seedlings under the canopies of already established shrubs is greater than in open spaces. The microclimate, provided by the vegetative cover, therefore, plays an important role in the germination and establishment of seedlings (Cowling & Roux, 1987; De Villiers et al., 2001).

Establishing degraded rangelands with a self-sustaining shrub species can also improve the productivity of the land (Aronson et al., 1991; Arredondo et al., 1998) and, therefore, the provision of commodities in the area (Newman & Redente, 2001). In most arid areas the objective of re-vegetating an area is to make it, once again, available for livestock production (Palmer & Ainslie, 2002). According to Van Heerden et al. (2000) this can be done by establishing palatable, evergreen, perennial species. Although annual plants are capable of establishing in arid areas and, according to Hoffman et al. (2003), there is often an abundance of these plants found in degraded lands, they generally die off in drought periods. Using a perennial fodder species, which has a longer life expectancy is, therefore, more beneficial to rehabilitation projects (Abadi Ghadim, 2000). Perennial fodder species are also often thought to need longer to recover than annual grasses, after being utilized. Trials done by Donaldson (1989) on a number of shrubs, both indigenous and exotic, however, proved shrubs to have higher growth rates and dry matter production levels than most grasses. A number of browse shrub species are also able to maintain their greenness and nutritive value, including mineral levels, right through the year. Such species are an important forage supplement for livestock during the dry months. These shrubs ensure a stable intake of good quality forage when other forage species decline in quality (Devendra, 1990; Rafique et al., 1992; Kibon & Ørskov, 1993; Tolera et al., 1997; Khan et al., 1999; Abadi Ghadim, 2000; Palmer & Ainslie, 2002).

According to Komwihangilo et al. (1995) shrubs are able to contribute to agriculture both directly and indirectly. A number of different shrubs species can either provide a product, and thus a source of income, or decrease the need to purchase a certain product (Arredondo et al., 1998) and, in some cases, both. Multipurpose species is the term that has been given to tree, shrub, bush, palm, woody grass and bamboo species (woody perennial species) that have more than one use. Multipurpose species are preferred due to these shrubs being able to provide more than one product (Burley & Von Carlowitz, 1984; Wood & Burley, 1991; Palmer & Ainslie, 2002). Such species are often able to provide a source of forage as well as fuel/fire wood, shade, shelter, act as a windbreak or a hedge to prevent erosion, while some species even have medicinal value (Komwihangilo et al., 1995; El Hassan et al., 2000; Le Houérou, 2000). Once established, shrubs may also produce seed, which may reach other patches of bare soil. This will benefit rehabilitation projects by increasing the species richness and decreasing rehabilitation costs (De Villiers et al., 2001).

In arid areas plants undergo severe physiological drought and heat stress (Van Rooyen, 1999) and forage production may be limited. It is, therefore, important that the species used be hardy, adapted to the unpredictable environmental conditions (Palmer & Ainslie, 2002), able to establish quickly and be quite resistant to disturbances (Van Rooyen 1999; Beukes & Cowling, 1999). Drought tolerant shrubs generally have deep root systems and are able reach water resources, ensuring successful establishment. These evergreen shrubs supply an abundance of green forage (Le Houérou, 2000), which, according to Palmer and Ainslie (2002), can be utilized intensively. Due to their ability to survive dry conditions drought tolerant shrubs are preferred, in arid areas (Palmer & Ainslie, 2002).

According to Ayensu (1985) few indigenous "plant resources" can be depended on continuously throughout the year, in arid and semiarid zones. Thomas, et al. (1986), therefore, believes that in dry areas, or in times of drought, when the annual cover has died off and the indigenous perennial cover is under 5%, the use of exotic perennial shrubs should be considered. Keeping in mind the importance of using a species that is adapted to the harsh environmental conditions (McFarland et al., 1990) and is not invasive. The conservation and production, however, of the indigenous species, also plays an important role in the rehabilitation of an area (AboEl-Nil, 1997; Sudhersan et al., 2003). According to Sudhersan et al. (2003), by using native plants the natural biological diversity of both the fauna and flora of the area can be conserved. This also provides aesthetic value to the environment. Native species are adapted to the local environmental and climatic conditions, such as harsh droughts, high salinity levels and high temperatures (Peacock et al., 2003). According to Esler & Kellner (2001a), this makes indigenous shrubs ideal for rehabilitation of the area. At the same time native shrubs often require less water, care and maintenance than introduced exotic species (Sudhersan et al., 2003). Another major constraint of re-vegetation is the availability and cost of seeds or seedlings (Palmer & Ainslie, 2002). Indigenous species seed can be collected from the area, which will also help reduce rehabilitation costs (Esler & Kellner, 2001b). Holmes & Richardson (1999) believe that, in order to ensure adaptability, it is best to collect seed from an "environmentally-matched nearby site".

According to Goodin & Northington (1985) a third of the earth's land surface is comprised of dry areas. It is, therefore, important that plant species indigenous to semi-arid and arid areas are assessed in terms of potential food, forage, fibre, fuel and medicinal uses. Sudhersan et al. (2003), believe that there are many species, indigenous to arid areas, which have the potential of being a source of livestock forage, as well as providing shelter and preventing erosion.

2.7. Species to be used in reclamation and rehabilitation

In this study a number of different drought tolerant fodder shrub species, both exotic and indigenous, that have shown potential or are already being used in the rehabilitation of degraded arid areas, were used. These species included *Atriplex nummularia, Cassia sturtii, Salsola glabrescens, Sutherlandia microphylla, Tripteris sinuatum* and *Tetragonia calycina*

2.7.1. *Atriplex nummularia*

Atriplex nummularia, commonly known as "Oldman's Saltbush" (Malan, 2000), belongs to the *Chenopodiaceae* family. Although indigenous to Australia, this species can be found in North and South America as well as North and South Africa (Malan & Rethman, 1997; Quershi & Barrett-Lennard, 1998). These shrubs reach a height of ±2m and can be up to 2.4m wide (Abou El Nasr et al., 1996; Aganga et al., 2003). *A. nummularia* thrives in an annual rainfall area exceeding 150-200mm. It can, however, according to Palmer & Ainslie (2002), survive for approximately a year when the rainfall falls to only 50mm. It is also capable of withstanding temperatures below –10º Celsius (Palmer & Ainslie, 2002). The *Atriplex* species are halophytes (salt tolerant) and are, therefore, able to grow under saline and alkaline soil conditions (Hill, 1999; Armstrong & Gibbs, 2000). This tolerance to salt is partly due to the presence of a dense mat of grey microscopic glands (trichomes) on the leaves, where they store salt, giving the leaves a grey-green colour (Quershi & Barrett-Lennard, 1998). *A.nummularia* is a dioecious species. It is, therefore, important that the correct ratio of male shrubs is planted in the optimum proximity to the female shrubs to ensure seed production in a self-propagating population (Barrett-Lennard & Malcolm, 1995; Quershi & Barrett-Lennard, 1998). Seedlings obtained through vegetative propagation (e.g. cuttings), are, therefore, often preferred. Due to the high nitrogen concentrations in this species and its ability to produce approximately 5-6 tonnes/ha/year of plant material (once established), it is regularly used as maintenance feed during drought conditions (Quershi &

Barrett-Lennard, 1998; Aganga et al., 2003). The crude protein concentration of *A. nummularia* ranges from 10.9% to 21% (Jacob, 1977; Jacobs & Smit, 1977; Hassan, 1986). According to Williams & Lazarides (1985), *A. nummularia* also has a relatively high potassium, sodium and chloride content. Farmers, therefore, often establish this shrub species to use as a forage source during dry periods (Barnard, 1986; Malan & Rethman, 1997).

2.7.2. *Cassia sturtii*

Cassia sturtii is a fast growing, exotic, drought tolerant fodder shrub (Chopra & Bhatia, 1987), which belongs to the *Fabaceae* family. This evergreen shrub, which is originally from southern Australia, grows up to 1.8 m high and 1.8 m wide (Faucon, 2001; Sparks, 2003). Although *C. sturtii* grow best on loamy soils, this species is able to grow in a variety of soils (NAS, 1975; Sparks, 2003). According to Faucon (2001), cited by Sparks (2003), these shrubs can survive in full sun with infrequent watering. *C. sturtii* shrubs are, according to NAS (1975), cited by Sparks (2003), able to survive in areas with a rainfall as low as 200-500mm. These shrubs are however, susceptible to severe frost. In a rainfall area of 200mm, shrubs are able to produce a dry matter yield of approximately one tonne/ha annually (Mabbutt, 1979; Richmond, 1980; Pasternak et al., 1986; Chopra & Bhatia, 1987; Sparks, 2003). *C. sturtii* has a crude protein concentration of ±12 % in its leaves (Mabbutt, 1979; Chopra & Bhatia, 1987). *C. sturtii* is also low in fibre, which is an indication of good digestibility, (Sharp et al., 2000, Sparks, 2003). Richmond (1980), cited by Sparks (2003), found *C. sturtii* to have a better year round palatability, when compared with other shrubs being researched in the Negev desert. Although this species is readily grazed by livestock and may be completely defoliated, researchers have found that, with controlled browsing, shrubs have good browsing resistance (Benjamin et al., 1995). Sparks (2003), believes that *C. sturtii*, could, with mineral supplementation, be used as a replacement for *Atriplex sp.*, due to it having sufficient crude protein and a good digestibility.

C. sturtii produces numerous yellow flowers (Figure 2), when in blossom, and can be propagated by the dark hard coated seeds that are located in the seedpods (Faucon, 2001; Sparks, 2003).

Figure 2 *Cassia sturtii* in full bloom, with an inset of the shape of this shrub

2.7.3. *Salsola glabrescens*

Salsola glabrescens, commonly known as "Rivierganna", is indigenous to South Africa. This species can grow up to 1.5m high and 1.5m wide. It is generally found in depressions, riparian rangelands and, in some cases, on plains (Le Roux, et al., 1994). The woody branches are scattered with leafy shoots and buds. New shoots are hairless and red in colour (Le Roux et al., 1994), a trait only found in this species (pers. comm. from W.A. van Niekerk, 2007)[1].

As with many *Salsola* species, *S. glabrescens* have densely packed, small, sessile, alternate bluish green leaves, which cover the shoots (Solereder, 1908; Dyer, 1975; Hobson & Jessop, 1975; Le Roux et al., 1994).

[1] Professor W.A. van Niekerk, Department of Animal and Wildlife Sciences, University of Pretoria, Pretoria, 0002, South Africa.

When in bloom small yellow-greenish flowers on scattered spikes, which are grouped into panicles, appear on the shoots (Le Roux et al., 1994). The fruits are round in shape with a "crown of translucent wings" (Henrici, 1945).

This species, which is readily browsed by sheep and goats (Henrici, 1945), is considered to be relatively palatable (Hobson & Jessop, 1975; Vorster, 1986; Klopper, 2000). Fresh *S. glabrescens* has a protein concentration of 16.5%, a crude fibre content of 25.2% and an ash content of 13.2% (Henrici, 1945). According to Van Der Heyden & Stock (1999) *Salsola* spp. may also accumulate sodium sulphate, which may affect the palatability of this species. *S. glabrescens* is extremely drought tolerant (Hobson & Jessop, 1975; Vorster, 1986; Klopper, 2000) and very often it is the only greenery present in times of drought (Le Roux et al., 1994).

2.7.4. *Sutherlandia microphylla*

Sutherlandia microphylla is indigenous to South Africa and is commonly known as "Grootkeurtjie" or "Kanker bos" (Le Roux et al., 1994). *S. microphylla*, which belongs to the *Leguminosae* family, can grow up to 1.5m in height and 0.6m in diameter. Although it prefers to grow in disturbed gravel soils, this species can be established practically anywhere. This species is, however, according to Le Roux et al. (1994), not long-lived. In blossom *S. microphylla* is covered in bright red, typical pea flowers, which can be found in small bunches in between the leaves (Figure 3). This shrub is easily established by broadcasting the small dark brown "lense shaped" seeds, onto the land. Seeds can be found, in large numbers, inside "inflated" papery seedpods (Le Roux et al., 1994). According to Le Roux et al. (1994), *S. microphylla* is highly nutritious and palatable, resulting in it often being heavily browsed, with only the bare stems remaining.

Figure 3 *Sutherlandia microphylla* can grow up to 1.5m in height and produces bunches of bright red flowers, when in bloom

S. microphylla is also considered to have many different medicinal uses. The Khoi and Nama people use this species for numerous ailments, such as stomachache, fever relief, to wash wounds, etc. *S. microphylla* tea is also used for treating internal cancers (Roberts, 1990; Van Wyk et al., 1997; Snyman, 2002).

2.7.5. *Tripteris sinuatum*

Tripteris sinuatum, previously known as *Osteospermum sinuatum*, is part of the *Asteraceae* family. It is commonly known as “Geelbietou”. This woody shrub, which Wands et al. (2001), refer to as drought-deciduous, is indigenous to South Africa and can be found growing over most of the Karoo area, in colonies (Le Roux et al., 1994). It has a prostate growth form (Figure 4) and only grows to a height of 0,5m (Milton, 1994), but can grow up to 1m in diameter (Le Roux et al., 1994).

T. sinuatum produces bright yellow daisy head flowers, which are selectively browsed by livestock, resulting in a lower seed production (Milton & Dean, 1990; Todd, 1999). The seeds are light brown, "spindle-shaped" and winged, (O'Connor, 1991; Todd, 1999), making them easily dispersed. These shrubs are, therefore, often used to reinforce the rangelands in the winter rainfall areas (Le Roux et al., 1994; Van Heerden et al., 2000). According to Donaldson (1989), however, this species is susceptible to frost damage.

T. sinuatum is considered to be highly productive and very palatable (Le Roux et al., 1994). According to Todd (1999), it is an important species in livestock systems in arid areas, as it reacts "promptly to rain after drought" (Le Roux et al., 1994). This species has, however, become scarce, especially in communal rangelands (Todd & Hoffman, 1999), due to heavy grazing impacting on the persistence and reproductive output (Todd, 1999).

Figure 4 *Tripteris sinuatum* in bloom

2.7.6. *Tetragonia calycina*

Tetragonia calycina is a woody shrub indigenous to South Africa. This shrub, commonly known as "Klappiesbrak", grows up to a metre high. It is often only seen along roadsides as it is often browsed "to the ground" in the rangeland (Le Roux et al., 1994). Although considered a very palatable shrub, with a high production, it is, according to Le Roux et al. (1994), difficult to germinate.

2.8. Study Objective

The objective of this study was to look at a number of different aspects of reclaiming arid rangelands, including species, germination, establishment, productivity and palatability. All of which influence the success of the rehabilitation of degraded areas, such as in the Northern Cape Province.

Trials, which assessed the following aspects, were included in this study.

- The influence of rumen digestion on the germination of a number of different fodder shrub species, both exotic and indigenous, including a separate trial conducted with seed of *S. glabrescens.*
- The use of *A. nummularia* and *C. sturtti* to reclaim bare areas in the arid areas of the Northern Cape Province, South Africa.
- Selecting more palatable plants of the well-known, drought tolerant *A. nummularia* fodder shrub.
- A comparison, in terms of quantity, quality and re-growth, of the exotic species *C. sturtii,* and two indigenous species, *T. sinuatum* and *S. microphylla.*

Results from these trials were represented in article form according to the guidelines of the Journal of Arid Environments.

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Chapter 2a

The influence of rumen digestion on the germination of different fodder shrubs. *

T.E. Wilcock[1], N.F.G. Rethman[1], W.A. van Niekerk[2] and R.J. Coertze[2]

[1] Department of Plant Production and Soil Science, University of Pretoria, Pretoria, 0002, South Africa.
[2] Department of Animal and Wildlife Sciences, University of Pretoria, Pretoria, 0002, South Africa.

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Abstract

In nature seed germination and establishment are affected by many different factors. Seeds generally undergo a dormancy phase, which may be broken by scarification, stratification, etc. In some seeds dormancy is broken after having passed through the digestive tract of an animal. Predation may, however, damage the seed coat and prevent germination altogether. In this trial the effect of rumen digestion on the percentage and rate of germination of five different fodder shrub species, used in reclamation trials, was studied. These included *Atriplex nummularia, Cassia sturtii, Sutherlandia microphylla, Tetragonia calycina* and *Tripteris sinuatum. T. calycina* seed (including the control) did not germinate. For all other species, with the exception of *T. sinuatum*, passing through the rumen did not inhibit germination. For *C. sturtti* and *S. microphylla*, although different effects were observed for the different treatments, the final percentage germination was greater in the control. *A. nummularia* percentage germination was overall low, with no significant difference observed between the different treatments.

Keywords: seeds, *Atriplex nummularia, Cassia sturtii, Sutherlandia microphylla, Tetragonia calycina, Tripteris sinuatum,*

Introduction

Seriously degraded arid areas are often re-vegetated with palatable, nutritious perennial shrubs. These shrubs improve the available forage source, decrease erosion and prevent further degradation (Kibon & Ørskov, 1993). Perennial shrubs are also able to improve soil conditions to a point that it is favourable for the germination and the establishment of indigenous seedlings. In order for the re-vegetation to be successful, however, the species must be able to persist, be able to colonize and spread to other areas, via seed dispersal (McIvor & Gardener, 1986). Colonization of a species is, therefore, very dependent on seed germination (Van Rooyen, 1999).

In order for seed to germinate imbibtion of water is required, which may be prevented when the seeds are dormant. Seeds often remain in this dormant stage until optimum conditions for establishment occur. Most dormancy mechanisms are opportunistic and react according to the environment becoming favourable for germination (Van Rooyen, 1999). The initiation of germination is, therefore, dependent on the interplay of a number of different internal and external factors. Dormancy, due to either mechanical or physiological elements (Stern, 1994), may be broken through stratification, leaching or scarification.

<u>Stratification</u>

Some seeds require germination stimulators to be present. These develop during periods of wet weather and/or with cold temperatures, for approximately four to six weeks. This can be simulated by placing seed in the refrigerator for a similar length of time, which is known as “stratification” (Stern, 1994).

<u>Leaching</u>

In some species water controls when seed germinate. In many desert plants dormancy is induced by growth-inhibiting substances (Stern, 1994), which are water soluble and water-leachable (Van Rooyen, 1999). In order to break such dormancies the seeds need to be soaked in water, which will leach out the inhibitors (Stern, 1994).

Scarification

Dormancy may also be due to physical characteristics of the seed. A number of seeds, such as those from the *Leguminosae* (*Fabaceae*) family, have hard, thick seed coats that are impermeable to water and oxygen (Stern, 1994). In order for imbibition of water to take place, the seed coat needs to be broken down, either by chemical or mechanical scarification. Mechanical scarification is achieved using abrasive materials, such as rough surfaces of soil, mastication of teeth, etc. Chemical scarification, on the other hand, is through the process of chemicals that "eat" away at, and break down, the seed coat. Factors such as soil conditions, micro-organisms, rainfall, alternating temperatures and predation may all play a role in breaking down such seed coats (Carvalho & Nakagawa, 1988; Araújo Neto & Aguiar, 2000).
When seed is eaten seed coats may not only be broken down via the mastication of teeth, but also by the acidic juices of the digestive tract. These digestive juices weaken the seed coat and improve water imbibition, thus allowing germination to take place (Barnes et al., 1998; El-Shatnawi & Ereifej, 2001). At the same time rumen micro-organisms may also help in the process.

For seeds that are able to survive the digestive tract, long distance dispersal through animal excreta is possible. According to McIvor & Gardener (1986) this is an important method of long distance dispersal and colonization for a number of different species. Animals are, therefore, instrumental in maintaining and spreading certain shrub species (Janzen, 1983; McIvor & Gardener, 1986; Holmes & Richardson, 1999; El-Shatnawi & Ereifej, 2001).

Mastication and digestion can, however, also have a negative effect and destroy the seed (Thill et al., 1986; El-Shatnawi & Ereifej, 2001). Seeds that do not survive the passage through the digestive tract of a ruminant will not germinate and no new seedlings will be able to establish. According to Hoffman et al. (2003) a number of perennial species disappear from the ecosystem due to a decrease in reproductive material. Such shrub species generally have highly nutritious flowers, which domestic livestock readily consume. Along with the flowers, the livestock consume seeds (Hoffman et al., 2003).

Predation affects the germination of different species in a number of different ways. This makes it important to determine whether passing through the digestive tract of a ruminant is relevant to the use of a certain shrub species in rehabilitation projects. It is also important to determine whether a species can be spread to other areas through animals.

The objective of this trial was, therefore, to determine the effect of rumen digestion on the seed viability of a number of different fodder shrubs.

Two exotic and three indigenous shrub species, which have been selected for reclamation of degraded areas in the Northern Cape Province were used in this trial. Species included *Atriplex nummularia, Cassia sturtti, Sutherlandia microphylla, Tetragonia calycina* and *Tripteris sinuatum.*

Materials and Methods

Seed of all the species was stored in the seed store (at ± 5ºC) on the Hatfield Experimental Farm of the University of Pretoria, situated in Pretoria. Seed of the indigenous species was originally harvested near Pofadder, in the Northern Cape. Seed of the exotic species was collected from plantings on the experimental farm. Approximately twenty to thirty seeds of *A. nummularia, C. sturtii, T. calycina* and *T. sinuatum* were placed in each dacron bag. If a seedpod of some form was present, this was removed. As the very small seeds of *S. microphylla* made it difficult to get the correct number of seed out of the dacron bag, slightly more seeds were used.

In total sixty dacron bags were placed in the rumens of two canulated sheep (5 species × 3 Rumen treatments × 4 replications = 60 dacron bags). Four bags of each species were removed at different intervals. The first set of bags was removed after twelve hours, the next set after twenty-four hours and the third after thirty-six hours. The canulated sheep were kept on a diet of lucerne (*Medicago sativa*) during this period.

Once removed from the rumen, seed was rinsed in distilled water and then separated into two sets. One set was left "as is" and the other was placed in test tubes with a solution of 1g pepsin /ℓ of 0.01 N HCl, which simulates the digestive process of the stomach where proteins and amino acids are broken down. This set underwent a three-hour soak in the solution, which was kept at 39°C. The test tubes were shaken approximately every half an hour, simulating abomasum digestion.

These seeds were, once more, rinsed in distilled water. All seeds were then placed in petri dishes on filter paper, which had been moistened with distilled water. Each replication of each treatment was placed in a separate petri dish, which was sealed with plastic film (Baskin et al., 1998). These petri dishes were placed in a growth chamber for the following twelve days to allow for germination of seed. The growth chamber was set to have twelve hours daylight and twelve hours darkness, and maintained at a temperature of 26ºC. A control of each species was also kept. The percentages and rate of germination were recorded.

Treatments were:

1. Control (seed not treated)
2. Seed kept in rumen fluid for 12 hours
3. Seed kept in rumen fluid for 12 hours and then for three hours in 1g pepsin /ℓ of 0.01 N HCl at 39°C
4. Seed kept in rumen fluid for 24 hours
5. Seed kept in rumen fluid for 24 hours and then for three hours in 1g pepsin /ℓ of 0.01 N HCl at 39°C
6. Seed kept in rumen fluid for 36 hours
7. Seed kept in rumen fluid for 36 hours and then for three hours in 1g pepsin /ℓ of 0.01 N HCl at 39°C

Analysis of variance using the GLM model (Statistical Analysis Systems, 2001) was used in order to determine the significance between the different species treatments and period effects for the unbalanced data. Least square means and standard errors (SE) were calculated. The significance of difference (5%) between means was determined by using Bonferroni test (Samuels, 1989).

Results and Discussion

In the case of *T. calycina*, none of the rumen treatments were effective in breaking dormancy and almost no seeds germinated in this species. In fact only two seed germinated in total, one after twenty four hours in the rumen, with no pepsin treatment, and the other after thirty six hours in the rumen, with a three hour soaking in pepsin solution. No seed germinated in the control.

In *T. sinuatum*, approximately 40% of the control germinated. None of the *T. sinuatum* seed, which had been placed in the rumen, with or without the pepsin solution, germinated.

Due to little or no seed germinating in *T. calycina* and *T. sinuatum,* these species were not considered in the statistical analysis. In the remaining three species the rumen treatments had different effects on the different species (Table 1).

Table 1 The final % germination (LS mean) - a comparison of the different treatments within and between species

Treatment	*A. nummularia*	*C. sturtti*	*S. microphylla*
Control	7.2 $^{a}_{2}$ (±11.60)*	92.2 $^{a}_{1}$ (±11.60)*	87.6 $^{a}_{1}$ (±11.60)*
12 hours, no pepsin	7.5 $^{a}_{2}$ (±8.09)	12.5 $^{b}_{2}$ (±8.09)	61.5 $^{ab}_{1}$ (±8.09)
12 hours + pepsin	5.5 $^{a}_{2}$ (±8.09)	10.0 $^{b}_{2}$ (±8.09)	43.5 $^{bc}_{1}$ (±8.09)
24 hours, no pepsin	7.1 $^{a}_{2}$ (±8.09)	10.0 $^{b}_{2}$ (±8.09)	68.8 $^{a}_{1}$ (±8.09)
24 hours + pepsin	10.3 $^{a}_{1}$ (±8.09)	13.1 $^{b}_{1}$ (±8.09)	24.8 $^{cd}_{1}$ (±9.40)
36 hours, no pepsin	2.5 $^{a}_{12}$ (±8.09)	0.0 $^{b}_{2}$ (±8.09)	25.0 $^{cd}_{1}$ (±8.09)
36 hours + pepsin	5.3 $^{a}_{1}$ (±8.09)	15.0 $^{b}_{1}$ (±8.09)	5.8 $^{d}_{1}$ (±8.09)

^{ab} Column LS means with common superscripts do not differ significantly (P>0.05)

$_{12}$ Row LS means with common subscripts do not differ significantly (P>0.05)

* Values in brackets represent standard error

A. nummularia had a very low percentage germination for all treatments, including the control, with no significant differences (P>0.05) between the different treatments and the control (Table 1).

The percentage germination of seed in the control of *C. sturtti* and *S. microphylla* was significantly (P<0.05) higher than that of *A. nummularia*, but not significantly (P>0.05) different from each other.

When comparing the rumen treatments between the different species, significantly more (P<0.05) *S. microphylla* seed, that had spent 12-24 hours in the rumen without pepsin treatment, germinated than any other species. This was also true for *S. microphylla* seed that had spent 12 hours in the rumen followed by the pepsin treatment. The increasing duration in the rumen, however, decreased the percentage germination of this species. No significant differences (P>0.05) were observed between the three species when undergoing 36 hours in the rumen followed by the pepsin treatment.

S. microphylla seed that had spent 36 hours in the rumen had a significantly (P<0.05) lower percentage germination than the control. The three hours in the pepsin solution, after the twelve, twenty-four and thirty six hours rumen treatment, further depressed (not always significantly) the percentage germination of *S. microphylla* (Table 1).

In *C. sturtti* the highest (P<0.05) percentage germination was in the control treatment (Table 1). Time spent in the rumen, whether twelve, twenty-four or thirty-six hours (with or without the pepsin treatment), drastically lowered the percentage germination in *C. sturtti* seed. No significant differences (P>0.05) were observed between the different rumen treatments (Table 1).

In terms of the rate of germination, differences were found between the different periods, which consisted of four days each, Period 1 = day 1-4, Period 2 = 5-8 and Period 3 = 9-12 days.

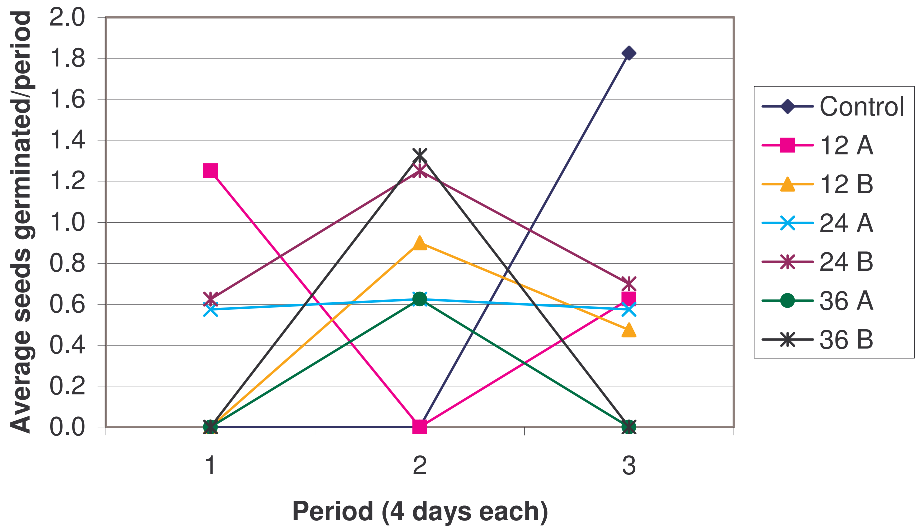

Figure 1 Germination rate (average seeds germinated/period) of *Atriplex nummularia*

Where:

- Control = Seed not treated at all
- 12 A = 12 hours in the rumen with no pepsin treatment
- 12 B = 12 hours in the rumen with 3 hours 1g pepsin /ℓ of 0.01 N HCl at 39°C treatment
- 24 A = 24 hours in the rumen with no pepsin treatment
- 24 B = 24 hours in the rumen with 3 hours 1g pepsin / ℓ of 0.01 N HCl at 39°C treatment
- 36 A = 36 hours in the rumen with no pepsin treatment
- 36 B = 36 hours in the rumen with 3 hours 1g pepsin /ℓ of 0.01 N HCl at 39°C treatment

In *A. nummularia* seed, with the exception of the 24 hour in the rumen (without the pepsin soak) treatment, most of the seed in the rumen treatments had germinated by day eight. No seed in the control germinated in Period 1 or 2 (Figure 1). In Period 3 (day 9-12), however, an average of 1.8 seeds/day germinated. By Period 3 the control had reached a final percentage germination similar to that of the highest rumen treatment (Table 1). The rumen treatments, therefore, increased the germination rate in Period 1 and 2 (Figure 1), but did not affect the final percentage germination (Table 1).

In *A. nummularia,* however, according to Osman & Ghassali (1997), the salts, which keep the seed dormant, need to be leached out of the bracts of the seed before germination can occur. Seed would 'normally', therefore, be soaked for forty-eight hours in distilled water. The high germination rate in

Period 3 could, therefore, have been due to the addition of distilled water that was added to the petri dishes that had become dry, over time.

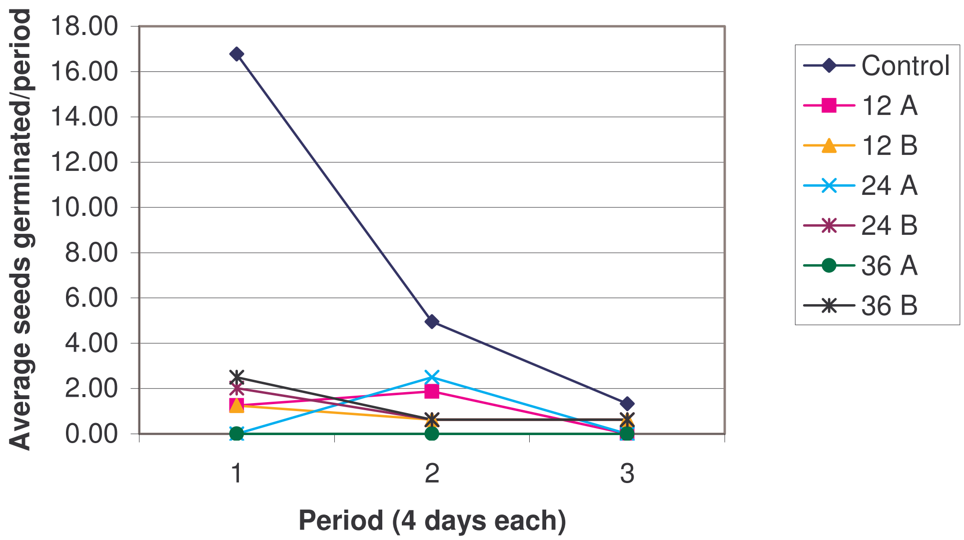

Figure 2 Germination rate (average seeds germinated/period) of *Cassia sturtii*

Seed in the *C. sturtti* control started to germinate within twenty four to forty eight hours, with an average of 16.8 seeds/day germinating in the first period. Most of the seed in the control had germinated by the end of the first period (days 1-4) and only an average of 5.0 seeds/day and 1.3 seeds/day germinated in Periods 2 and 3 respectively. In all rumen treatments, with or without the three-hour pepsin treatment, *C. sturtii* seed had a lower germination rate than the control, throughout the monitoring period (Figure 2). Very little seed germinated in all treatments in Period 3 (9-12 days).

Seed of *S. microphylla*, placed in the rumen for twelve to twenty four hours, seemed to have an increased germination rate, with most seeds having germinated within the first few days (Period 1) when compared to the control. Most of the *S. microphylla* seed in the control germinated in Period 2 (days 5-8), with an average of 11.9 seeds/day. In Period 3 almost no seed germinated in the different rumen treatments and an average of only 6.7 seed/day germinated in the control (Figure 3).

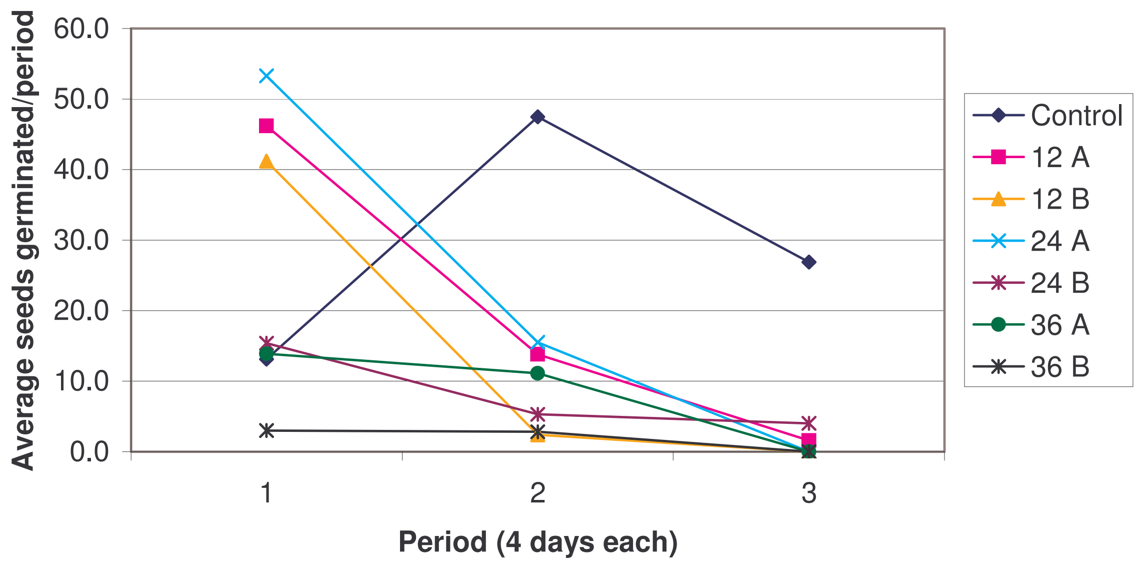

Figure 3 Germination rate (average seeds germinated/period) of *Sutherlandia microphylla*

The percentage and rate of germination of rumen treated seed generally decreased when the amount of time spent in the rumen increased (Figure 3). Seed that had been in the rumen for thirty-six hours not only had the lowest percentage germination but also had the lowest germination rate.

Seeds that were in the rumen for twelve, twenty four and thirty six hours, without the three-hour pepsin treatment (12A, 24A and 36A), had higher germination rates than the twelve, twenty four and thirty six hour rumen treatment, which included the pepsin treatment (Figure 3).

Conclusion

The rumen treatments had no significant detrimental effect on the final germination percentage of *A. nummularia* and had, in fact, increased the germination rate marginally. This exotic shrub species should be able to re-establish itself and could, therefore, be used in the reclamation of overgrazed areas. Care should, however, be taken to ensure it does not become invasive.

C. sturtii and *S. microphylla* on the other hand exhibited a decrease in the final germination percentage obtained from all the rumen treatments, in comparison with the control. Extremely low germination percentages were observed for all seed of *C. sturtii* that passed through the rumen. *S. microphylla* seed, however, that had spent up to twenty four hours in the rumen still had a germination above 60%. This species' seed is small and it would be highly likely that seed would not spend more than twenty-four hours in the rumen. Percentage germination was, however, decreased dramatically by the pepsin treatment. Seed of these species, which had passed through the digestive tract of a ruminant, would, therefore, stand less chance of germinating. It is unlikely that sufficient seed would germinate in order for these species to re-establish themselves. It is, therefore, suggested that camps of both *C. sturtii* and *S. microphylla* should be managed in such a way as to allow rest periods to ensure they are not overgrazed and to allow time for re-establishment.

T. sinuatum was the only specie, which did not germinate at all after rumen treatments. It can, therefore, be concluded that seed, which has passed through the digestive system of a ruminant will not germinate. According to De Villiers et al. (2001), seedling establishment would be more successful underneath shrub canopies in comparison to out in the open, due to the other species providing protection against high temperatures (Vetaas, 1992), high irradiance, high transpiration rates and predation (Turner et al., 1966; Nobel, 1980; Noy-Meir, 1980; McAuliffe, 1988; Franco & Nobel, 1989; Yeaton & Esler, 1990; Valiente-Banuet & Ezcurra, 1991; Keeley, 1992; Moro et al., 1997; De Villiers et al., 2001). The winged seeds of *T. sinuatum* would most likely be blown and collect under larger shrubs and thus be protected against predation. In heavily grazed areas, however, it is suggested that farmers harvest seed in order to reseed areas with this species where necessary.

According to Le Roux et al. (1994), *T. calycina* seed is difficult to germinate. The seed of this species might benefit from being left for a longer duration in the rumen and/or perhaps in the pepsin solution. Seed could also be fed to sheep allowing seed to pass through the entire digestive tract. *T. calycina* has also got winged seed and perhaps when blown across a rough soil surface the seed coat undergoes a form of scarification. Mastication by the teeth may also have the same result.

Once re-vegetated, areas should be protected from herbivore predation, in order to allow the seedlings to become well established before being browsed. Rest periods, during times when shrubs are producing seed, should also be incorporated into the management practices, to allow shrubs species to colonize and spread to other areas (McIvor & Gardener, 1986).

Acknowledgements

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Chapter 2b

The effect of rumen digestion on the percentage and rate of germination of *Salsola glabrescens*.

T.E. Wilcock[1], N.F.G. Rethman[1], W.A. van Niekerk[2] and R.J. Coertze[2]

[1] Department of Plant Production and Soil Science, University of Pretoria, Pretoria, 0002, South Africa.
[2] Department of Animal and Wildlife Sciences, University of Pretoria, Pretoria, 0002, South Africa.

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Abstract

Livestock in the arid and semi-arid rangelands of the Northern Cape, South Africa, rely on shrubs as their main source of fodder. Many shrub species have disappeared from rangeland through overgrazing, and are often unsuccessful in reclamation projects, if they are unable to self-propagate. Shrubs are unable to re-establish in the land due to being browsed in the seedling phase, or before seed production can occur. In some cases the seeds are consumed. Seeds that are consumed may be destroyed, but may also remain viable after passing through the digestive tract.

The objective of this trial was to determine the effect of the digestive tract of a ruminant on *Salsola glabrescens*. Seed was placed in the rumen of fistulated sheep for six, twelve and twenty four hour periods. To simulate the abomasum, some seed was also placed in a 1g pepsin /ℓ of 0.01 N HCl solution for three hours at 39°C.

Seed of *S. glabrescens* that had been in the rumen, whether for six or twenty four hours, was no longer viable. Seed treated with only the pepsin solution, however, still germinated and had a higher germination percentage than that of the control.

Keywords: fodder shrub, reclamation, seed viability, self-propagate

Introduction

One of the most arid areas in South Africa is the Karoo, which covers approximately 35% of South Africa's surface area, ± 430 000km^2 (Cowling, 1986; Rutherford & Westfall, 1994). The word Karoo is in fact the Khoikhoi word for 'dry' or 'barren' (Adamson, 1938; Cowling et al., 1997; Klopper, 2000). The Karoo does, however, have a "rich floristic diversity", consisting of up to 7000 different species (White, 1983; Cowling, 1986; Hilton-Taylor, 1987; Cowling & Hilton-Taylor, 1999). Although annual grasses and succulents dominate in some areas, the Karoo is mainly described as bare soil with Karoo shrubs "dotted" throughout the area (White, 1983; Anon, 1986; Bosch, 1987; Acocks, 1988; Bosch, 1999; Klopper, 2000). These shrubs can, in fact, be found over approximately one third of South Africa (Le Roux et al., 1994), mainly in the semi-arid and arid areas. These shrubs are adapted, in a number of different ways, to minimise water loss and tolerate low water content within the plant, while maintaining a positive carbon balance in times when there is very little water available (Van Der Heyden & Stock, 1999). Many of these drought tolerant species play an important role in the livestock nutrition of the small stock production systems, which are the main form of agriculture in these arid areas. Such species may also play an important role in stabilizing soil, thus preventing erosion (Botschantzev, 1969; Bromilow, 1995; Klopper, 2000).

Of the numerous species found in the Karoo, researchers have found a number of *Salsola* species that are considered palatable and readily utilized by livestock and wildlife in the area (Burtt Davy, 1926; Bruce et al, 1951; Watt & Breywijk, 1962; Hobson & Jessop, 1975; Botha et al., 1983a, 1983b; Du Toit Van Der Merwe, 1986; Vorster, 1986; Bosch, 1987; Kellerman et al., 1988; Morgenthal, 1988; Botha et al., 1994; Milton et al., 1999).

In a number of overgrazed lands, however, many species, including *Salsola* species have disappeared from the rangeland. This may be due to the reproductive material, including seeds, being consumed along with the leaf material, during grazing (Hoffman et al., 2003).

The digestive tract of a ruminant has different effects on the seed of different species. In some species the acidic juices of the digestive tract weaken the seed coat and improve water imbibition, thus allowing germination to take place (Barnes et al., 1998; El-Shatnawi & Ereifej, 2001). For such species animals are an important method of dispersal and colonization. Seeds can be dispersed over long distances through animal excreta (McIvor & Gardener, 1986). In other species, however, the opposite occurs; the seed is destroyed through mastication and/or digestion (Thill et al., 1986; El-Shatnawi & Ereifej, 2001). If seeds are unable to survive the passage through the digestive tract, the species is unable to self-propagate, and will, if not managed correctly, disappear from the rangeland.

This trial investigated the effect of rumen fluid on *S. glabrescens* seeds and whether germination would still take place once the seeds had passed through the digestive system of a ruminant.

Materials and Methods

This trial was conducted on the Hatfield Experimental Farm of the University of Pretoria, in July 2003. Seed was originally harvested at Fraserburg, in the Northern Cape Province.

Approximately sixty *S. glabrescens* seeds were placed in each dacron bag. No seedpods were present. The dacron bags were placed in the rumen of fistulated sheep for different lengths of time. During this period the fistulated sheep were kept on a diet of lucerne (*Medicago sativa*).

In the first rumen trial, which included seed of *Atriplex nummularia, Cassia sturtii, Sutherlandia microphylla, Tetragonia calycina* and *Tripteris sinuatum,* seed was placed in the rumen for twelve, twenty four and thirty six hours (Wilcock et al., 2009). The *S. glabrescens* seed was very small and would, theoretically, pass through the rumen more rapidly. These seed were, therefore, placed in the rumen for shorter periods of time, namely; six, twelve and twenty four hours. The first four bags were packed in the rumen twenty four hours before they would be removed, the next set twelve hours before all the bags would be removed. The six hour treatment was packed in the rumen when the others were removed. Twelve dacron bags in total were used (1 species × 3 Rumen treatments × 4 replications = 12).

Once removed from the rumen the seeds were rinsed in distilled water and separated into two sets. One set was left “as is”, while the other was placed into test tubes to undergo a three hour soak in 1g pepsin /ℓ of 0.01 N HCl. The test tubes were placed in a warm bath at 39°C and were shaken by hand every half an hour, simulating abomasum digestion. A control, as well as seed that only underwent a three hour soaking in 1g pepsin /ℓ of 0.01 N HCl at 39°C, were also included in this trial.

Seed that underwent the pepsin treatment was, once again, rinsed in distilled water. All seeds were then placed in petri dishes on wet filter paper, including the control and pepsin solution only treatment. The petri dishes were sealed with plastic film (Baskin et al., 1998) and placed in a growth chamber to germinate. The growth chamber was set to have twelve hours daylight and twelve hours darkness, and maintained at a temperature of 26ºC.

Treatments were:

1. Seed not treated (control)
2. Seed treated for three hours in 1g pepsin /ℓof 0.01 N HCl at 39°C
3. Seed kept in rumen fluid for 6 hours
4. Seed kept in rumen fluid for 6 hours and then for three hours in1g pepsin /ℓ of 0.01 N HCl at 39°C
5. Seed kept in rumen fluid for 12 hours
6. Seed kept in rumen fluid for 12 hours and then for three hours in1g pepsin /ℓ of 0.01 N HCl at 39°C
7. Seed kept in rumen fluid for 24 hours
8. Seed kept in rumen fluid for 24 hours and then for three hours in 1g pepsin /ℓ of 0.01 N HCl at 39°C

The percentage germination and rate were recorded over the following sixteen days, starting three days after seed had been placed in the growth chamber.

Analysis of variance using the GLM model (Statistical Analysis Systems, 2001) was used in order to determine the significance between the different treatments and period effects for the unbalanced data. Least square means and standard errors (SE) were calculated. The significance of difference (5%) between means was determined by using Bonferroni's test (Samuels, 1989).

Results and Discussion

No seed germinated in any of the rumen treatments. These treatments were, therefore, not considered in the statistical analysis. Seed of the control and pepsin treatment had, however, germinated.

No significant difference (P>0.05) was found between the percentage germination of the seed in the control and seed that had been soaked in 1g pepsin /ℓ of 0.01 N HCl at 39°C, for three hours. Germination was overall low (Table 1).

Table 1 The final germination percentage (LS mean) of the control and pepsin treatment in *Salsola glabrescens*

Treatment	Germination %
Control	39. 5 ^{a} (±5.53)*
Pepsin trt	39.8 ^{a} (±5.53)*

^{ab} Column LS means with common superscripts do not differ (P>0.05)

* Values in brackets represent standard error

A significantly (P<0.05) higher percentage germination was observed in the first few days (Period 1) for both the control and the pepsin treatment, than any other period (Table 2). These periods each consisted of four days, Period 1 = days 1-4, Period 2 = days 5-8 Period 3 = days 9-12 and Period 4 = days 13-16.

Table 2 Treatment differences in percentage germination (LS mean), overtime

Treatment	Period 1	Period 2	Period 3	Period 4
Control	31.2 $^{a}_{1}$ (±7.10)*	5.2 $^{a}_{2}$ (±0.84)*	2.1 $^{a}_{3}$ (±0.86)*	1.0 $^{a}_{3}$ (±0.71)*
Pepsin	38.1 $^{a}_{1}$ (±7.10)	1.7 $^{a}_{2}$ (±0.84)	0.0 $^{a}_{2}$ (±0.86)	0.0 $^{a}_{2}$ (±0.71)

^{ab} Column LS means with common superscripts do not differ (P>0.05)

$_{12}$ Row LS means with common subscripts do not differ significantly (P>0.05)

* Values in brackets represent standard error

There were no significant differences (P>0.05) in the number of seeds that germinated in the pepsin treatment and control within the different periods. In Periods 3 and 4 very little seed germinated in the control, which was significantly (P<0.05) less than the amount of seed that had germinated in Period 2. A very low germination percentage was observed for the pepsin treatment in Period 2, which was not significantly (P>0.05) different to Periods 3 and 4. No seed germinated in the pepsin treatment in Periods 3 and 4 (Table 2).

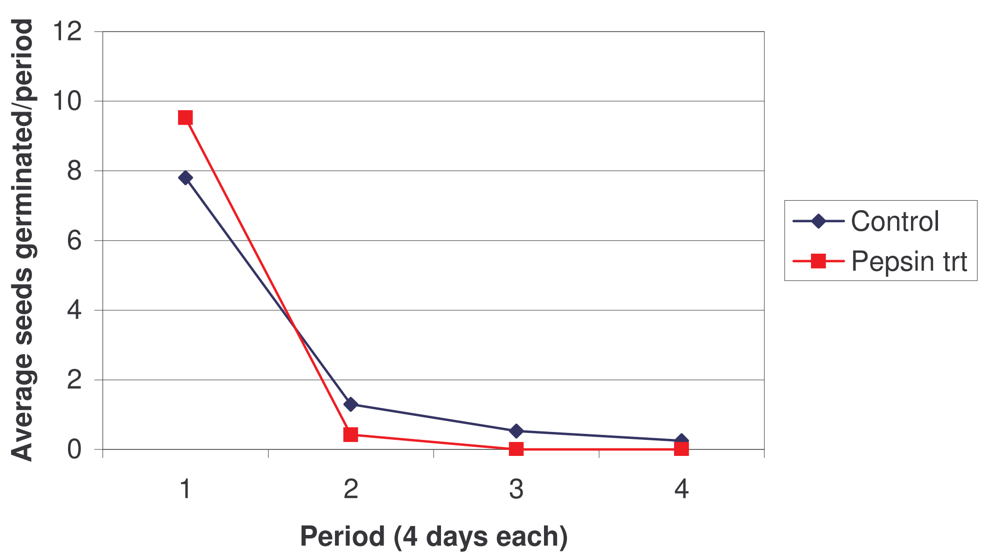

Figure 1 The germination rate (average seeds germinated/period) of *Salsola glabrescens*.

The pepsin treatment appeared to increase the rate of germination, marginally but not statistically, of *S. glabrescens* (Figure 1).

Within the first day of observation an average of 8.8 seeds/day of the pepsin treatment had germinated whereas only an average of 4.3 seeds/day germinated in the control. In Period 1 an average of 9.5 seeds/day had germinated in the pepsin treatment in comparison to an average of 7.8 seeds/day in the control (Figure 1). In Period 2, on average, less than 0.5 seeds/day germinated in the pepsin treatment and 1.3 seeds/day in the control. No seed germinated in the pepsin treatment in Period 3 and 4, but in the control an average of 0.5 and 0.25 seeds/day germinated respectively.

Conclusion

Salsola glabrescens, which is located in many of the arid to semi-arid areas of South Africa (Arnold & De Wet, 1993, Klopper, 2000), is considered to play an important part in supplying forage in small stock production systems in these areas (Vorster, 1986; Klopper, 2000). Seed of this species, however, that had been exposed to the digestion process in the rumen, did not germinate at all. Suggesting that during times of seed production *S. glabrescens* shrubs would need to be protected in order to ensure self-propagation.

S. glabrescens seed, however, that had only been treated with the pepsin treatment, to simulate digestion in the abomasum, was still viable. The seed of this species is very small and it is very likely that it could pass through the rumen much quicker. A trial in which the seed is left in the rumen for one to three hours, or a trial where seed is fed straight to the sheep, as it is possible that these small seeds would pass straight though to the abomasum, might show that seed remains viable. If not, it is suggested that farmers harvest seed in order to reseed areas, where this species has disappeared.

Pure stands of this species should, according to Le Roux et al. (1994), only be grown as a source of seed, to re-establish the species in the natural rangeland, as this species is browsed to a lesser extent when grown in pure stands.

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Chapter 3

The use of *Atriplex nummularia* and *Cassia sturtti* to reclaim bare areas in arid areas of the Northern Cape Province, South Africa. *

T.E. Wilcock[1], N.F.G. Rethman[1], W.A. van Niekerk[2] and R.J. Coertze[2]

[1] Department of Plant Production and Soil Science, University of Pretoria, Pretoria, 0002, South Africa.

[2] Department of Animal and Wildlife Sciences, University of Pretoria, Pretoria, 0002, South Africa.

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Abstract

In Africa millions of hectares of rangeland have been degraded, making them less productive and of less value. Research, therefore needs to be focused on ways of preventing further degradation as well as improving the productivity of such land. The objective of this trial was to determine the feasibility of using drought tolerant fodder shrubs, such as *Atriplex nummularia* and *Cassia sturtti*, in the rehabilitation of bare patches in arid rangelands of the Northern Cape Province, South Africa. Treatments focused on the success of establishment of these fodder shrubs on bare areas and the effects of herbivore predation. Seedlings, treated seed and untreated seed were placed in furrows, which had been ripped into the bare soil. Protection, using thorny branches, was placed over randomly selected furrows.

Although no seed of the shrubs species germinated, there was definite evidence that using a form of protection against herbivore predation benefited the establishment of shrub seedlings.

Key Words: arid rangelands, drought, fodder shrubs, reclamation

Introduction

Many arid rangelands are over-utilized to such an extent that little, if any vegetative cover remains. Where there is no vegetative cover remaining, the soil often becomes unstable and valuable topsoils are lost. At the same time, there is a decrease in infiltration rates (Dean, 1992), resulting in increased run-off and erosion, two factors linked to degradation and desertification (Warren & Agnew, 1988).

With little or no topsoil remaining, bare patches form. These bare patches have very little organic matter in the soil (Allsopp, 1999; Allsopp, et al., 2000; Hoffman et al., 2003), which, according to Tate (1995), is essential in a well functioning ecosystem. Seedlings are, therefore, even under "normal" rainfall conditions, often unable to establish in such soils. Such severely degraded areas are of little value to the commercial, or communal, farmer, as they are unable to provide the desperately needed grazing or fodder reserves (Esler & Kellner, 2001), which support many livestock production systems in arid lands. In such situations rest and natural succession is insufficient for the recovery. It is necessary, therefore, to intervene with some form of rehabilitation (Van Den Berg & Kellner, 2003). Khan et al. (1999) believed that, in addition to having the correct stocking rates, the land can be reseeded in order to improve the forage production. The establishment of palatable shrubs in such degraded areas will not only improve the grazing capacity of the area (Van Heerden et al., 2000), but also prevent further erosion and degradation (Abou El Nasr et al., 1996). This not only provides landholders with forage for sheep, but also a return on their investment in reclaiming degraded lands (Salerian et al., 1987; Barrett-Lennard et al., 1990; Bathgate et al., 1992).

A number of factors influence the success of establishing shrubs in arid areas, including: species; whether to use seedlings or seed; whether seed is treated to break dormancy or not; when they are sown or planted and whether they should be protected from herbivory.

Farmers are rarely willing to invest in systems with a high risk. The most "economically feasible fail-safe method", for a specific area or ecosystem, should, therefore, be determined and implemented (Esler & Kellner, 2001).

The objective of this trial was to determine the feasibility of using *Atriplex nummularia* and *Cassia sturtti* to reclaim bare patches in the arid areas of the Northern Cape Province, South Africa. Treatments focused on the effect of herbivore predation and the success of establishment of these fodder shrubs on bare areas using seedlings or seed.

Material and methods

- **Study area**

This trial was planted on the farm 'Lovedale', which is approximately forty kilometres South East of Pofadder, a small town in the Kenhardt district. Kenhardt is situated in the Northern Cape Province at an altitude of 1015m (coordinates 019º44'0.57" E, 29º18'58.8" S.) (Sparks, 2003). This area has a bimodal rainfall with peaks in late summer/autumn. Milton & Dean (1996) described the bimodal rainfall in this area to consist of a combination of "spring drizzle and autumn thunderstorms". The rainfall, which is approximately 130mm per annum (Sparks, 2003), is very erratic and highly variable in amount and distribution both within and between years. According to Sparks (2003) the annual rainfall can be as low as 35mm. Average daily temperatures range from 11.6º C to 28.4º C. Temperatures of up to 40º C can, however, be reached (Sparks, 2003). The soils in this area are very shallow, only reaching a depth of approximately 300mm. A soil analysis by Sparks (2003) showed the soils to be calcareous sandy, with a low clay content (<10%). These soils belong to the Hutton form (MacVicar et al., 1977). Due to the dry hot conditions, shallow sandy soils and low rainfall, the land is susceptible to degradation. There are, therefore, a large number of bare patches present in the landscape. The trial was laid out on such a bare patch located on the farm. The area had a slight slope (<2%) with a southerly aspect.

- **Pits/Furrows**

Shachak et al. (1998) found that, in arid areas of Israel, water leakage could be reduced and water storage (in the form of soil moisture) increased by constructing "sink patches" (pits/ furrows) in the landscape. "Sink patches" according to Shachak et al. (1998) are "resource-enriched man-made" patches. These are similar to shrub patches that were destroyed during the desertification process. "Sink patches" are mini-catchment areas that encourage the infiltration of water and the entrapment of organic matter as well as numerous wind dispersed seeds. Such "sink patches" / furrows can prevent further soil loss as well as increase nutrient content of the soil (Shachak et al., 1998), thus improving the microclimate in the area. Research done by Schachak et al. (1998) showed that plant numbers established in man-made pits were much greater. This was not only because of the improved water retention, but also due to the soil crust having been disturbed, allowing penetration of seed into the soil.

The number, size and distribution of pits/ "sink patches" depends on the area. According to Shachak et al. (1998) "sink patches" must be constructed in such a way that they collect and store just a few runoff pulses, enough to support vegetation growth during the long dry periods. In Pofadder, however, there is very little rainfall (130mm/annum). "Sink patches" / furrows were, therefore, constructed in such a manner (generally on down slope) that maximum runoff, organic matter and soil could be collected.

Rows of shallow furrows (15-20cm in depth) were ripped into the selected area using a double-wing tine implement. The furrows were four metres in length (with four metres between each furrow) and alternate in each row (Figure 1). Rows were three metres apart (Figure 1).

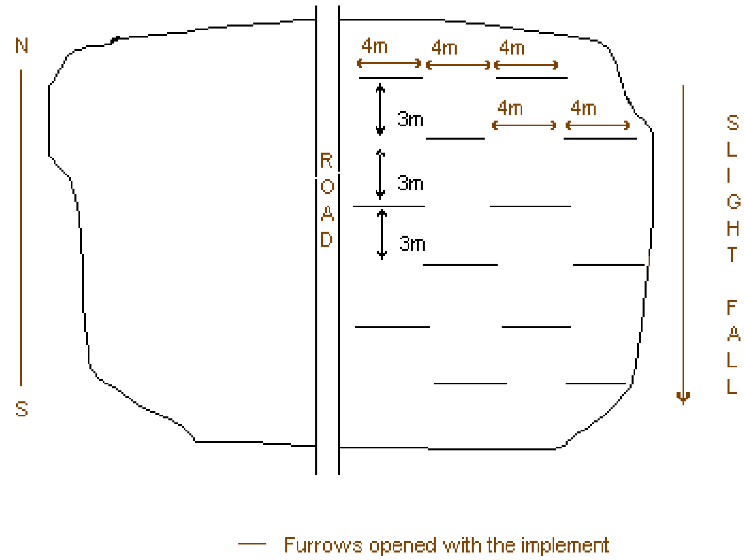

Figure 1 Furrows four metres in length were ripped into the bare patch at Pofadder in the Northern Cape

- **Species**

Both species used in this trial, *A. nummularia* and *C. sturtti*, are exotic drought tolerant fodder shrub species, originating from Australia.

- **Seeds/Seedlings**

Wallace (1896) found that getting the plant started was the most difficult phase and that once established the "dangers" to survival decreased. There are a number of ways of getting shrubs established, either by direct seeding, natural regeneration or by planting nursery-raised seedlings. When selecting which method, however, there are a few considerations, such as the site characteristics, the climate, the financial situation (Barrett-Lennard & Malcolm, 1995) as well as the risks involved.

Seed as well as seedlings were used in this trial.
Treatments included:

a) Untreated seed – 40 seeds were sown per furrow
b) Treated seed – 20 seeds were sown per furrow

c) Seedlings – four seedlings were planted per furrow

Double the number of untreated seed was sown than treated. This was done in order to give plots sown with untreated seed a fair chance of establishment. Plots / furrows, with numerous seedlings, established with seed, would be thinned to only four seedlings per plot.

a) Untreated seed

Broadcasting seed onto the land is a lot less labour intensive than planting seedlings. When sowing seed, however, it is important that they be covered with some soil. This is done to ensure germination and establishment (Packer & Aldon, 1978), as well as to prevent them being blown away by wind.

The soil surface on the selected bare patch was, however, hard and impenetrable to seed. Seed was, therefore, sown into the furrows and covered with a fine layer of soil.

b) Treated seed

A number of seeds undergo a period of dormancy. This prevents imbibition of water, thus delaying germination until climatic conditions are more ideal (Osman & Ghassali, 1997).

Seed of both, *A. nummularia* and *C. sturtii,* require some form of treatment to break dormancy and allow for imbibition. In *A. nummularia*, the leaching of salts found on the bracts of the seed is necessary for germination to occur (Osman & Ghassali, 1997). *A. nummualria* seed was, therefore soaked in distilled water for 48 hours. The water was changed every twelve hours.

C. sturtti has a hard outer seed coat, which needs to be scarified (broken down) before imbibition can take place. *C. sturtti* seeds were, therefore, placed in hydro-chloric acid (32%) for ten minutes and then rinsed in distilled water. All seed was then placed on tissue paper to dry and later stored in separate paper bags until planting. Seeds were stored in the seed store (± 5ºC) on the Hatfield Experimental Farm of the University of Pretoria, situated in Pretoria, South Africa. All seed was originally harvested from plantings located on the experimental farm.

c) Seedlings

The transition from germinating seed to established seedling is a crucial time. In this time period shrubs must adjust to the change from the moist dark soil to the drier, illuminated terrestrial environment (Osman & Ghassali, 1997). Packer & Aldon (1978) believe that relying on seed germination and establishment is too risky and that more success is obtained from planting "nursery-grown" seedlings. According to Packer & Aldon (1978) hardening-off of seedlings for several weeks before planting allows the seedling to acclimatise to the extreme conditions (dry winds and extreme temperatures) experienced in the area.

Four seedlings of either *A. nummularia* or *C. sturtii* were planted in the randomly selected furrows at a spacing of one metre between the shrubs. All seedlings used were germinated from seed harvested on the University of Pretoria's Hatfield Experimental Farm, and allowed to harden in plastic bags before being transported to the Northern Cape experimental site.

Each seedling received approximately three to four litres of water at planting, for both the spring and autumn planting, and a second watering a few days later. Further irrigation was limited to only preventing mortality under extreme drought conditions. No water was given to furrows that were sown with seed, whether treated or untreated.

- **Protection**

Herbivore predation is another reason for failure in reclaiming bare patches. Wildlife as well as livestock (if not removed) seek out the young green seedlings, which do not easily recover, from being browsed. Protection from herbivore predation is, therefore, important. A study conducted by Todd (1999) showed that in heavily grazed areas, palatable shrubs growing underneath older, thorny shrub species were protected from predation. According to Esler & Kellner (2001), using branches of a thorny species to cover the establishing seedlings provides the necessary protection, keeping in mind that the brush packing should not be so thick as to inhibit germination (Esler & Kellner, 2001).

In this trial the efficiency of protection against herbivore predation using thorn branches was evaluated. Thorn branches, cut from local shrubs, were packed over randomly selected plots/furrows. Furrows of all three different types of treatments, for both species, were covered.

a) Three-thorn protection
b) No protection

- **Dates of Plantings**

The time of seeding, according to Packer & Aldon (1978), is very important, and should be done just before the "longest period of favourable growing conditions" so that seedlings will be well established before the winter. Planting in late fall, however, will ensure that losses, due to small herbivores, are low as they generally hibernate during this time (Plummer et al., 1968; Packer & Aldon, 1978). A spring planting at the end of September 2002 and an autumn planting at the end of March 2003 were, therefore, evaluated.

Species (*C. sturtii* & *A. nummularia*) x seedlings/seed (untreated seed, treated seed & seedlings) x protection (protected furrows & unprotected furrows) = twelve furrows. Each treatment was replicated three times, thirty six plots in total were, therefore, used in the spring planting. Only half the numbers of plots were used in the autumn (March 2003) planting due to the unprotected treatment being eliminated.

Data was collected in terms of

a) A comparison between the two species
b) A comparison between sown untreated seeds, treated seeds or planted seedlings
c) A comparison between protected and unprotected furrows
d) A comparison between Spring and Autumn plantings

Observations were made in September 2002, January 2003, August 2003 and April 2005. Observations in September 2002 and January 2003 were limited to the spring planting. Observations in August 2003 and April 2005 were conducted on both the spring and autumn plantings (March 2003).

Statistical analyses were done on the observations done in January 2003 and August 2003. Analysis of variance using the GLM model (Statistical Analysis Systems, 2001) was used in order to determine the significance between the different species and treatments. Least square means and standard errors (SE) were calculated. The significance of difference (5%) between means was determined by using Bonferroni's test (Samuels, 1989).

Results and Discussion

a) September 2002

Within days after planting it was observed that all unprotected seedlings, of both species, had already been browsed, a number of them down to ground level. Two unprotected *A. nummularia* seedlings had been uprooted, perhaps by animals in search of water in these dry conditions. These two uprooted shrubs were re-planted. In the protected plots, seedling branches that protruded through the protective thorn branches had also been browsed. This was true for both species.

No seed, treated or not, had germinated. This was to be expected at this time of the year, as the Northern Cape has a late summer/autumn rainfall pattern.

b) January 2003

No seed for any treatment had germinated and analysis was, therefore, done only on the seedlings.

Due to the strong winds experienced, some branches had blown off the furrows, leaving the shrubs exposed. Shrubs were, therefore, analysed according to whether they were protected, not protected or had lost their protection.

Each shrub was given a survival rating according to the extent of predation (Table 1).

Table 1 Survival rating given to each plant according to the level of predation

Rating	Level of Predation
1	No remnants
2	Severely eaten – survival doubtful
3	Severely eaten – but surviving
4	Good survival (where protection still present)

Significantly (P<0.05) more shrubs that had been packed with thorn branches for protection, of both *A. nummularia* and *C. sturtii,* survived than those that had lost the protection or were not protected. *A. nummularia,* which had not been protected fared significantly better (P<0.05) than *C. sturtii* that had not been protected. No significant differences (P<0.05) were observed between *A. nummularia* and *C. sturtii* shrubs that were protected or had lost the protection.

Table 2 Survival ratings, as described in Table 1, of *A. nummularia* and *C. sturtii* (LS mean) with and without protection in the spring planting, assessed in January 2003 (4 months after planting)

Species	Treatment		
	Protected	**Lost Protection**	**Not Protected**
A. nummularia	4.0 $^{a}_{1}$ (±0.14)*	2.0 $^{a}_{2}$ (±0.17)*	1.8 $^{a}_{2}$ (±0.11)*
C. sturtii	4.0 $^{a}_{1}$ (±0.12)	1.5 $^{a}_{2}$ (±0.27)	1.0 $^{b}_{2}$ (±0.11)

^{ab} Column means with common superscripts do not differ (P>0.05)

$_{12}$ Rows means with common subscripts do not differ (P>0.05)

* Values in brackets represent standard error

It was doubtful whether any of the *A. nummularia* seedlings, which were unprotected or had lost the protective branches, would survive. Shrubs, which had remained protected, although exposed branches had been browsed, were all doing well (Table 2). All of the unprotected *C. sturtii* shrubs had been severely browsed and did not survive (Table 2). Of the protected shrubs two had lost the protective cover and it was doubtful whether these shrubs would survive. The other protected shrubs were doing well, but as in the case of the *A. nummularia* shrubs, the exposed branches had been browsed.

All protection that had blown off was repacked.

c) August 2003

No seed of either species, whether treated or not, or protected or not, had germinated. This was true for both the spring and autumn plantings.

Analysis was, therefore, only done on the planted seedlings.

Observations made in January 2003 showed that although protection was successful, not only was it easily blown off, but all branches of seedlings protruding above the brush pack were also browsed. It was, therefore, decided, in April 2003 (a month after the autumn planting), to fence off this area to exclude both livestock and small wildlife species.

In August 2003 it was observed that there were no significant ($P>0.05$) differences between the two species, in the September 2002 planting (Table 3). *A. nummularia* and *C. sturtii* shrubs that had been protected had been severely browsed and survival was doubtful (Table 3). The protected shrubs had, however, fared significantly ($P<0.05$) better than the shrubs that had lost the protection or were not protected. The shrubs, of both species, which had lost, or had no protection were either browsed down to the ground, and were dead, or no remnants could be found (Table 3).

There had been significant ($P<0.05$) deterioration in the shrubs of the spring planting between January 2003 and August 2003 (Tables 2 and 3). Even these shrubs that had been protected had now been heavily browsed.

In March 2003 a second planting, in autumn, was done. Results from the spring planting had demonstrated that protection, for both species, was definitely necessary.

Table 3 Survival ratings, as described in Table 1, of *A. nummularia* and *C. sturtii* (LS mean) with and without protection in the spring planting assessed in August 2003 (11 months after planting)

Species	Treatment		
	Protected	Lost Protection	Not Protected
A. nummularia	2.4 $^{a}_{1}$ (±0.23)*	1.2 $^{a}_{2}$ (±0.27)*	1.3 $^{a}_{2}$ (±0.17)*
C. sturtii	2.4 $^{a}_{1}$ (±0.19)	1.0 $^{a}_{2}$ (±0.42)	1.0 $^{a}_{2}$ (±0.17)

^{ab} Column means with common superscripts do not differ (P>0.05)

$_{12}$ Rows means with common subscripts do not differ (P>0.05)

* Values in brackets represent standard error

All plots/furrows were, therefore, protected with thorn branches in this autumn planting. Due to all shrubs having been packed with thorn branches, shrubs were now analysed on whether they were protected or had lost the protection (Table 4). Shrubs were, once again, given a rating from one to four, according to the degree of predation.

Table 4 Survival ratings, as described in Table 1, of *A. nummularia* and *C. sturtii* (LS mean) with and without protection in the autumn planting assessed in August 2003 (5 months after autumn planting)

Species	Treatment	
	Protected	Lost Protection
Atriplex nummularia	4.0 $^{a}_{1}$ (±0.72)*	3.7 $^{a}_{1}$ (±0.32)*
Cassia sturtii	2.8 $^{a}_{1}$ (±0.45)	1.4 $^{b}_{2}$ (±0.38)

^{ab} Column means with common superscripts do not differ (P>0.05)

$_{12}$ Rows means with common subscripts do not differ (P>0.05)

* Values in brackets represent standard error

A. nummularia seedlings, that had lost the protection were in better (P<0.05) condition than the *C. sturtii* seedlings that had lost the protection. There were, in fact, no remnants of the *C. sturtii* seedlings that had lost their protection (Table 4). Although not significantly (P>0.05) different, protected *A.*

nummularia seedlings appeared to be in better condition than protected *C. sturtii* seedlings, which, even with protection, had been severely browsed.

Unprotected *A. nummularia* seedlings planted in September, and then analysed in January (approximately four months after planting) did not appear to do as well as shrubs planted in March and analysed in August (approximately five months after being planted). Although cooler conditions, experienced in the autumn planting, should have improved the chances of survival, it must be kept in mind that shrubs were fenced off in April 2003. Shrubs that had been planted in March (in the autumn planting) had, therefore, a greater chance of survival, as loss of protection was less of a factor. In *C. sturtii*, however, some herbivore predation had already taken place before the fencing was completed.

In the case of *C. sturtii* both protected shrubs and shrubs that had lost their protection, which were planted in March and analysed in August (approximately five months after being planted), did not do as well as those planted in September and analysed in January (approximately four months after being planted). By August protected *C. sturtii* seedlings from the autumn planting were observed to be only slightly better off than those of the spring planting (Tables 3 and 4).

d) <u>April 2005</u>

In April 2005, approximately two and a half years after the first planting had taken place, final field observations were made. Even at this final stage none of the seed, which had been sown in the furrows, had germinated. Observations were, therefore, focused on the survival of the shrubs that had been planted. Most brush-covered furrows had lost some, if not all, protection. The area had, however, been enclosed with animal proof fencing shortly after the autumn planting.

Only a few shrubs were, however, still present and of these very few were still alive. Although some of the *A. nummularia* shrubs that had been protected were still visible, all had died from drought stress. All of the shrubs that were still alive were *C. sturtii* seedlings that had been planted in protected furrows. A total ten of the original thirty six *C. sturtii* shrubs that had been planted had survived, even though in earlier observations most of these shrubs had been heavily browsed.

Indigenous seed and organic matter had, over time, been blown into and accumulated in some of the furrows. In April 2005 it was observed that indigenous species' had become established in a number of these furrows. This included some of the extra furrows that had been made and not used in the trial. Annual ephemerals and grasses were found to be growing in the furrows, whether protected or not. Of the sixty eight furrows observed grasses had established in twenty two furrows. This varied from very little to an abundance of grass. Only twelve of the furrows were observed to contain annual ephemerals.

Under such severe drought conditions the establishment of any plant life was quite remarkable. It might be ascribed to the harvesting of water and organic matter, which was made possible by the furrows, as well as the disturbance of the soil crust, that allowed seed to penetrate.

Conclusion

No seed that was sown in this trial, whether protected or not, whether treated to break dormancy or not, germinated. According to Khan et al. (1999) reseeding is only possible where the natural conditions are favourable. In a number of arid areas, as with Pofadder, the conditions are rarely favourable and planting seedlings proved to be a better option.

Both species were heavily browsed, suggesting that both species could be considered a good source of forage. It was, however, clear that shrub seedlings needed to be protected. Brush packing, although successful, was often lost in strong winds. Another difficulty was that shrub's branches that had grown past the protection of the brush packing were heavily browsed. This trial's findings coincide with those of Butler (1986), that areas to be re-vegetated should be fenced off, or all livestock should be removed from the paddock, in order to ensure success.

C. sturtii seedlings that survived being browsed appeared to survive the drought conditions reasonably well. *A. nummularia* seedlings, however, had not survived the severe drought conditions. This was partly due to herbivore predation, but mainly due to the stress of the dry hot conditions with very little to no rainfall experienced, in the last few years. Packer & Aldon (1978) found that the survival of shrubs planted in degradable containers was much greater than that of bare-root shrub plantings. This might allow for shrubs to become better established before having to survive with very little water (Packer & Aldon 1978).

In this trial supplementary irrigation was kept to a minimum. This was done because watering was labour intensive it was decided to determine how well these species survive extremely dry conditions. During the two and a half years over which the trial was monitored, surviving shrubs were only watered in severe drought conditions and then only when possible, which was 2 to 3 times a year. By April, at the end of the 2004/2005 season, surviving shrubs had last been watered six months previously. For the first time in several years, however, there had been an effective rain shower in the autumn of 2004/2005, which explained the germination and establishment of grass and ephemeral annuals in at least some of the furrows.

Research conducted by Shachak et al. (1998) demonstrated that "sink patches"/ furrows would act as mini-catchment areas that encourage the infiltration of water and the entrapment of organic matter as well as numerous wind dispersed indigenous seed. This was also found to be true of the furrows made in the bare patches at Lovedale. Hopefully the establishment of indigenous species in the furrows will, in time, improve the microclimate in the area, as suggested by Shachak et al. (1998), and thus increase the chance of successfully establishing fodder shrub species in the area.

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Chapter 4

The selection of *Atriplex nummularia* shrubs for palatability. *

T.E. Wilcock[1], N.F.G. Rethman[1], W.A. van Niekerk[2] and R.J. Coertze[2]

[1]. Department of Plant Production and Soil Science, University of Pretoria, Pretoria, 0002, South Africa.
[2]. Department of Animal and Wildlife Sciences, University of Pretoria, Pretoria, 0002, South Africa.

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Abstract

In many degraded arid areas the carrying capacity of the natural rangelands has decreased. Many farmers, therefore, rely on plantings of the exotic drought tolerant fodder shrub, *Atriplex nummularia* to maintain livestock during drought periods. There is, however, intra-species variation in the palatability of this shrub. Researchers believe this might be due to the great genetic variability within this open pollinated species.

In this ongoing programme the objective was to select plants, which were more palatable to sheep. There has been recurrent selection of these shrubs over time. In this trial a further selection process was conducted to determine which plants of the F1 "elite" generation of *A. nummularia* shrubs were more palatable. Seedlings of shrubs identified as palatable will be produced from seed and further selection work will be conducted on this next generation of shrubs.

Keywords: drought tolerant, fodder shrubs, nutritive value

Introduction

In arid and semi-arid areas of South Africa livestock production is the main form of agriculture, with the focus being on browsing animals such as sheep, goats and, in some cases, ostriches (Palmer & Ainslie, 2002). Farmers rely heavily on the natural rangelands as a source of forage for livestock. Drought and poor management practices have, however, led to the degradation and, in severe cases, desertification of many arid rangelands, resulting in a shortage of feed (Abou El Nasr *et al*., 1996). In such areas research has shown that the establishment of palatable evergreen drought tolerant fodder shrubs can improve the carrying capacity of the rangeland (Abou El Nasr *et al*., 1996; Adugna *et al*., 1997; Hill, 1999; Kinet *et al*., 1998; Van Heerden *et al*., 2000; Sparks, 2003).

Many arid areas also have saline soil conditions, a result of low precipitation, and high evaporation, which retards the leaching of salts. Over time salts, therefore, accumulate (Knight, 1991). Knight (1991) believes that many arid areas are also often shaped in such a way they have a "land-locked topography". Water from the surrounding "uplands" are, therefore, deposited in the enclosed low lying areas, resulting in further salt accumulation.

The ability of *Atriplex spp*. to not only grow in drought stress areas, but also under saline and alkaline soil conditions, has made it an important species in the rehabilitation of arid rangelands. This species is also a valuable source of forage in areas where the quantity and quality of the natural rangeland is low (Hill, 1999; Armstrong & Gibbs, 2000).

The *Atriplex* genus contains 42 species. Of these, *A. nummularia* is considered to be one of the most wide spread fodder shrubs (Williams & Lazarides, 1985). In the semi-arid and arid areas of South Africa, this shrub is a well-known drought tolerant fodder shrub (Malan, 2000). Farmers, both communal and commercial, often keep a fodder bank of this species, to use in dry periods (Ostyina *et al*., 1984; Barnard, 1986; Malan, 2000). These shrubs also provide firewood and shelter (Armstrong & Gibbs, 2000).

Qureshi & Barrett-Lennard (1998) believed that one of the main reasons saltbush is regularly used as a fodder bank is due to the high nitrogen concentrations, which typify the species. The chemical composition of saltbush, however, differed according to the form in which it is fed (Table 1). According to Abou El Nasr *et al*. (1996), the fibre content was lowest and the crude protein content highest when it was fed fresh.

Table 1 The chemical composition (%DM basis) of three different methods of feeding saltbush ("saltbush utilization") (Abou El Nasr *et al* ., 1996)

	fresh saltbush	**saltbush hay**	**saltbush silage**
Dry matter	38.6	87.2	33.1
Crude protein	12.7	9.1	11.8
Crude fibre	28.7	29.3	20.4
Ether extract	3.4	2.2	4.0
Ash	24.9	26.5	22.5
Hemicellulose	22.6	24.6	21.7
Cellulose	27.5	28.3	29.9
NFE	30.3	32.9	41.3
Neutral detergent fibre	59.4	63.8	60.1
Acid detergent fibre	36.8	39.2	38.4
ADL	9.3	10.9	8.46

Along with high levels of protein, however, these shrubs also have high salt concentrations. This has a number of disadvantages, namely, a decrease in digestibility and palatability as well as a decrease in the available energy (Qureshi & Barrett-Lennard, 1998). Energy may be lost in three different ways; firstly, due to animals needing to drink more water than normal (due to the high salt content of the leaves), resulting in forage being flushed rapidly through the digestive tract. As a result there is less time available for digestion and absorption and less energy is, therefore, available. Secondly the higher levels of salt results in animals requiring more energy to fuel salt excretion from the kidneys. Thirdly, animals need to walk to the watering points more frequently (Quershi & Barrett-Lennard, 1998).

According to Van Der Heyden & Stock (1999), there is a strong relation between the chemical composition of the plant and its palatability. Many researchers believe that the high levels of sodium chloride in *A. nummularia*, together with its low digestibility, result in a low palatability (Jones & Hodginson, 1969; Hoon *et al*., 1991; Casson *et al*., 1996; Quershi & Barrett-Lennard, 1998; Snyman, 2006). There is, however, variation in palatability between *A. nummularia* shrubs, which is due to genetic variation within the species (Quershi & Barrett-Lennard, 1998; Malan, 2000). A more palatable *A. nummularia* cultivar may, therefore, be selected for (Armstrong & Gibbs, 2000). Once identified the more palatable shrubs can be multiplied by cloning via cuttings or tissue culture (Quershi & Barrett-Lennard, 1998; Malan, 2000).

A palatability trial was, therefore, conducted on the F1 generation of *A. nummularia* cv. "Elite". In this ongoing programme the objective is to select shrubs, which are considered more palatable to sheep. This trial started with *Atriplex nummularia* shrubs of the F1 generation. Shrubs were originally selected from the De Kock Selection from Grootfontein Agricultural College in Middleburg, Eastern Cape Province. These selected shrubs were propagated using tissue culture (Malan, 2000), and planted out on the Hatfield Experimental Farm of the University of Pretoria. In this trial a further selection process was conducted to determine which plants of this F1 "Elite" generation were the most palatable. The selection of more palatable shrubs has also been underway in older fodder shrub plantations in Israel and now in younger introduction sites in South Africa (Malan, 2000).

Materials and Methods

- **Study Area**

This trial was conducted on the Hatfield Experimental Farm of the University of Pretoria, in Pretoria (co-ordinates 025º 15'28.9" E, 25º45'03.6"S at an altitude of 1360m) (Sparks, 2003), South Africa.

The area experiences maximum temperatures, which reach above 30ºC and minimum temperatures above 15ºC, in the summer months. Winter temperatures vary between 22ºC and 8ºC, although it can be much lower. Frost also occurs quite frequently in the winter months (Sparks, 2003; Weather S.A., 2007). Pretoria has a mostly summer rainfall of 650mm with 50% falling during November to January (Sparks, 2003). Winter rainfall, from

June to July, is only seven to fifteen millimetres. Shrubs were, however, irrigated regularly, during establishment.

- **Materials**

A. nummularia shrubs of the F1 generation from shrubs, which had been propagated using tissue culture (Malan, 2000), were kept under bird netting during the seed harvesting period. This was done for protection against predation by birds, thus ensuring a successful seed production. Seed, harvested from these "elite" saltbushes, was germinated and seedlings then hardened under shade netting before being planted on the Hatfield Experimental Farm, Pretoria, in May 2002. Shrubs were planted 1.5 metres apart, between and within rows. Of the seedlings originally planted 99% survived.

- **Method**

Shrubs were given time to become well established. Once they had reached a height, at which they would survive being browsed, the camp was cleaned of most of the grasses and weeds found between the saltbush shrubs. Three water troughs were then placed in the camp, one at either end and one in the middle. Twenty-seven sheep were placed into the camp, daily for a week. Sheep were herded into the camp in the morning at approximately 08:00 and removed back to the pen at approximately 15:00, every afternoon. Every second afternoon, after the sheep had been removed, each shrub was visually rated. This assessment was based on the amount of leaf and stem material that had been removed (Table 2). Three independent observers did the ratings to ensure there was no bias.

Once the initial browsing trial was completed, all shrubs were cut back to approximately 40cm, irrigated and given time to re-grow. The process was then repeated. In the second browsing ten sheep were used to identify the most palatable plants. For the following eleven days sheep were, once again, placed in the camp in the morning and taken back to their pen in the afternoon.

Table 2 Ratings according to how much edible material had been removed

Rating	Browsed
1	0% browsed – no leaf material had been removed from the plant
2	25% browsed – the plant had been lightly browsed
3	50% browsed – 50% of the plant's leaf and soft stem material had been removed and is considered moderately browsed
4	75% browsed – the plant had been heavily browsed
5	99% browsed – the plant had been severely browsed and only woody material remains

The plants were, as previously, assessed according to the amount of leaf and stem material that had been removed, by using the same ratings as in Table 2. Using these ratings the most palatable shrubs in the camp were identified. The intention was that the less palatable plants would be discarded and the more palatable plants used to produce F2 seed (Hatfield Select).

Results and Discussion

During the first browsing area selection, rather than plant selection, predominated. There could be a number of reasons for this:

- the number of sheep was too high;
- the sheep preferred to remain close to the gate and did not utilize the whole camp and/or
- the saltbush was quite dense and the sheep avoided such dense bush, only moving to the next row once the first row had been well utilized.

Due to these results a second browsing trial was conducted. The density and height of the bushes was less in this trial, making it easier for sheep to move between the shrubs. Although there was still a degree of area selection, there was definite preference for certain shrubs, demonstrating that some shrubs were more palatable than others.

Ratings did vary between the three observers, but overall the longer the sheep spent in the camp the more shrubs were browsed (Table 3).

Table 3 The percentage of shrubs rated as having been browsed to different degrees, described in Table 2, observed by three independent observers over eleven days

Day	Observer	Rating				
		1	2	3	4	5
1	1	80.97	19.03	0.00	0.00	0.00
	2	91.42	8.58	0.00	0.00	0.00
	3	92.16	7.84	0.00	0.00	0.00
3	1	53.74	38.81	5.59	1.86	0.00
	2	73.50	23.14	3.36	0.00	0.00
	3	73.22	18.28	6.64	1.86	0.00
5	1	13.81	60.44	17.91	7.84	0.00
	2	44.40	30.97	17.17	7.09	0.37
	3	44.40	23.51	21.64	9.70	0.75
7	1	9.70	54.11	25.75	10.44	0.00
	2	23.51	35.08	26.49	13.80	1.12
	3	26.87	27.24	27.98	16.42	1.49
9	1	0.00	18.28	50.00	28.73	2.99
	2	7.84	12.32	38.06	35.44	6.34
	3	6.72	10.07	42.53	32.47	8.21
11	1	0.00	2.24	2.98	51.87	42.91
	2	0.75	1.87	42.16	52.23	2.99
	3	1.12	0.75	15.30	77.98	4.85

After Day 1 only a few shrubs had been "tasted" and were rated as lightly browsed. By Day 3, however, according to the observers, 30% to 50% of the shrubs had been browsed to some degree. Only one or two shrubs had been heavily browsed. Such shrubs were noted as being more palatable. Observers 2 and 3 appeared to be more conservative when estimating the degree of browsing. By Day 5 these two observers still considered approximately 40% of shrubs as not having being browsed. Observer 1, however, considered approximately 86% of all shrubs to have been browsed to some extent, with 60% being lightly browsed. At the same time (Day 5), Observers 1 and 2 considered just over 7% of all shrubs to have been heavily browsed. Observer 3 reported approximately 9% of all shrubs to be heavily browsed, with one or two shrubs as having been completely defoliated (Table 3).

On Day 7, although there were variations between the specific proportions, all observers reported approximately 75% or more of all shrubs to have been at least lightly browsed. Of these shrubs 25% or more had been moderately browsed. No more than ±17% of all shrubs had, however, been heavily browsed by Day 7. Specific amounts varied between the three observers (Table 3).

By Day 9, according to Observer 1, ±3% of all shrubs had been completely defoliated and only woody material remained. Observers 2 and 3, however, estimated this percentage to be 6% - 8%. Observers 2 and 3 also reported that approximately 7% of all shrubs had not yet been browsed.

On Day 11 only one or two shrubs were considered unutilised by Observers 2 and 3. According to Observer 1, however, only ±6 shrubs had been lightly browsed, with all other shrubs having been moderately to heavily defoliated (Table 3).

Throughout the trial certain shrubs had been identified. These included shrubs that had been browsed from an earlier date and more continuously than other shrubs. These shrubs were considered to be more palatable than the shrubs that were not as heavily browsed and those that were left until the last. From the observations made in the browsing trials, the more palatable shrubs were identified and retained, while the less palatable shrubs were removed. A total of seventy seven shrubs were kept. These shrubs will be used to produce F2 seed (Hatfield Select).

Reasons for preferences by livestock could include the chemical composition of the shrubs, the amount of salt on the leaves, the leaf to stem ratio or the gender of the plants, as *A. nummularia* is dioecious (the male and female are separate shrubs). These are only a few of a number of possible reasons, for differences in palatability.

Before “unpalatable” shrubs were removed from the camp, Snyman (2006) conducted further investigations and assessed the shrubs in terms of the chemical composition. Snyman (2006) did a further selection trial using both boer-goats and sheep. Snyman (2006) differentiated the shrubs into three groups, “most-palatable”, “less-palatable” and “least-palatable”, which he then sampled and analysed separately in terms of crude protein, digestibility, and minerals. Snyman (2006) observed that shrubs, which were in the "most-palatable" group had a significantly higher crude protein, phosphorus and magnesium concentration than the other groups. Snyman (2006) also found that as the fibre content increased, palatability decreased. The "most-palatable" group also had higher concentrations of calcium, potassium, sodium and chlorine, than the "least-palatable" shrubs, but the differences were not significant. Snyman (2006) found that at this site the salt concentration was generally low, with no significant effects on palatability. The salt concentration is, in most cases, given as the main reason for low palatability in *Atriplex* (Jones & Hodginson, 1969; Hoon *et al*., 1991; Casson, *et al*., 1996; Snyman, 2006). In this trial, however, salt levels may have been low due these plants being offspring of plants which were previously selected for in terms of palatability (Malan, 2000), or due to the low salt concentration of the soil on the experimental site.

Conclusion

Of the shrubs established 21% were identified as more palatable. All other shrubs were removed from the camp. The remaining shrubs, which are considered palatable, will be allowed to re-grow under bird netting in order to obtain seed. Seed will be germinated and used for further recurrent palatability trials. Selecting a more palatable *A. nummularia* cultivar will also, hopefully, result in a shrub that is higher in crude protein, phosphorus and magnesium content.

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Chapter 5

Dry matter production of three fodder shrubs used in re-vegetation of degraded rangelands. *

T.E. Wilcock[1], N.F.G. Rethman[1], W.A. van Niekerk[2] and R.J. Coertze[2]

[1] Department of Plant Production and Soil Science, University of Pretoria, Pretoria, 0002, South Africa.
[2] Department of Animal and Wildlife Sciences, University of Pretoria, Pretoria, 0002, South Africa.

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Abstract

Where rangelands have been degraded farmers often establish fodder shrubs, to improve the grazing capacity of the land and ensure there is sufficient forage available for livestock. Many farmers use exotic species, which have been declared potentially invasive. The objective of this trial was to assess the dry matter production of two indigenous (*Sutherlandia microphylla* and *Tripteris sinuatum*) and one exotic (*Cassia sturtii*) fodder species, over time, in terms of growth and availability of forage. Different plots of these shrubs were harvested at different harvest dates, six weeks apart. Plant material was separated into edible and woody material. All three species produced significantly ($P<0.05$) more total, and edible, plant material in Harvest 5 than Harvest 1. In Harvest 4 *S. microphylla* had produced more ($P<0.05$) plant material than *C. sturtii*. In Harvest 5 *S. microphylla* had produced the most ($P<0.05$) plant material of the three species. Both indigenous species had produced significantly ($P<0.05$) more edible plant material in Harvest 5 than *C. sturtii*. In Harvests 2 and 3 *T. sinuatum* and *C. sturtii* were affected by frost. A larger ($P<0.05$) proportion of *T. sinuatum* plant material was damaged by frost.

Keywords: availability, growth, *Cassia sturtii, Sutherlandia microphylla, Tripteris sinuatum,*

Introduction

In South Africa alone sixty five percent of the natural pastures are situated in arid and semi-arid areas (De Kock, 1980; Sparks, 2003). Due to the extremely dry conditions in these areas farming systems focus mainly on livestock production from browsing animals such as goats and sheep (Dean & MacDonald, 1994; Palmer & Ainslie, 2002). In rural arid areas these are often the main source of meat and income (Noble, 1986; Khan et al., 1999). The livestock graze on forbs and grasses, if and when these are available. In dry periods, however, livestock rely heavily on drought tolerant fodder shrubs, which dominate many of South Africa's semi-arid and arid areas (Clark, 1980; Sparks, 2003).

The shrub populations in a number of these areas have been damaged or eliminated through overgrazing and/or the removal of woody plants for firewood (Sudhersan et al., 2003). Where severe degradation has occurred the density and cover of the vegetation does not recover with rest alone (Snyman, 1999; Hoffman & Aswell, 2001; Snyman, 2003) and large bare patches may develop (Kellner & Bosch, 1992; Van Der Merwe & Kellner, 1999). Once degraded to such an extent additional inputs are necessary for the re-establishment of vegetation in these areas (Snyman, 2003).

Many farmers, both commercial and communal, establish stands of well-known exotic species as a source of fodder, firewood and shelter (Armstrong & Gibbs, 2000). These palatable evergreen fodder shrubs provide sufficient green feed during the dry months, when the quality and quantity of the natural rangelands has deteriorated. With the improved grazing capacity further overgrazing can also be prevented (Abou El Nasr et al., 1996; Adugna et al., 1997; Kinet et al., 1998; Van Heerden et al., 2000; Sparks, 2003). In 2001, however, a number of these exotic, multipurpose tree and shrub species were declared weeds and invader plants. Most of these declared species are only allowed to be planted under specified conditions, if at all (Armstrong & Gibbs, 2000).

There have been many discussions on whether multipurpose trees or shrubs used should be exotic or indigenous. According to Wood & Burley (1991), the most important factor is that the species is the best choice for the farmer and the site. Wood & Burley (1991) also believe that there has been too much emphasis on exotic species, due to the belief that these species are easier to establish and manage. Products of exotic species have also been considered more marketable, than those of indigenous species (Wood & Burley, 1991). Goodin & Northington (1985), however, believe that with such large areas being, and more becoming, arid, it is important that indigenous plant species from arid and semi-arid areas be assessed in terms of potential food, forage, fibre, fuel and medicinal uses.

The objective of this trial was to compare the production of two indigenous and one exotic species, over time, in terms of growth and availability of forage. *Cassia sturtii*, an exotic fodder shrubs species, *Sutherlandia microphylla* and *Tripteris sinuatum* (previously known as *Osteospermum sinuatum*), two indigenous drought tolerant species, were evaluated. Locally the indigenous shrubs are known as "Karoo bossies" (Karoo shrubs/bushes) (Le Roux et al., 1994). The word "Karoo", meaning "dry" or "barren" in the Khoikhoi language (Adamson, 1938; Cowling et al., 1997; Klopper, 2000).
These three species have been used in "On-Farm" trials, in the Northern Cape.

Materials and Method

- **Study Area**

This trial was conducted on the Hatfield Experimental Farm of the University of Pretoria in Pretoria (co-ordinates 025º 15'28.9" E, 25º45'03.6"S at an altitude of 1360m) (Sparks, 2003), South Africa. The area experiences maximum temperatures, which reach above 30ºC and minimum temperatures above 15ºC in the summer months. Winter temperatures range between 8ºC and 22ºC. These can, however, be much lower, with frost occurring quite frequently in the winter months (Sparks, 2003; Weather S.A., 2007). Pretoria has an average annual summer rainfall of 650mm with 50% falling during November to January (Sparks, 2003). Winter rainfall, from June to July, is only seven to fifteen millimetres. Shrubs were, however, irrigated to eliminate moisture stress as a limiting factor. Shrubs were watered in the first and second week after planting and every four weeks thereafter. Shrubs were also fertilized at planting with each seedling receiving a small amount of 2:3:4 (N: P: K – starter mix) in each planting hole.

The soil was a well-drained Hutton form with 35% clay (MacVicar et al., 1977). A representative sample of the topsoil (± 30cm) from the experimental site was analysed in March 2005. These results showed the soil to be slightly acidic with a $pH_{(H2O)}$ of 5.6. The status of phosphorus, calcium, potassium, magnesium and sodium were 14.8mg/kg, 764mg/kg, 141mg/kg, 213mg/kg and 16mg/kg, respectively.

- **Method**

Seeds of both indigenous species were originally collected from the farm "Lovedale", near Pofadder, in the Northern Cape Province, where these two species occur naturally. *C. sturtii* seed was obtained from a plantation of these shrubs located on the Hatfield Experimental Farm. All seed had been stored in the seed store at ± 5ºC, in paper bags. Seeds were germinated in seed trays with hygromix. Seedlings were planted out in plastic bags and kept under shade cloth to harden off until reaching a height of 15 - 20cm before planting out in the field. Seedlings were planted out in randomly allocated plots in a field (35m X 100m). The field contained sixty plots. Each plot contained five seedlings of the same species, which were planted at a spacing of 1 meter apart within the plots. Due to the possible influence of the leguminous species (*C. sturtii* and *S. microphylla*) on the non-leguminous specie (*T. sinuatum*), plots were five metres apart, within and between rows. Available space was, however, limited and the layout, as shown in Figure 1, was therefore used. Once planted (9th May 2003) shrubs were left to establish for approximately two weeks before the trial was initiated. Five different harvests, which were six weeks apart, were taken (Table 1).

Table 1 Harvest dates, after the initial 2 weeks establishment phase

Harvest	Time of harvesting	Dates
H1	6 weeks	7 July
H2	12 weeks	18 August
H3	18 weeks	29 September
H4	24 weeks	10 November
H5	30 weeks	22 December

The first harvest was on the 7th of July 2003. Four replicates/plots per species were harvested (at 20cm above ground level) at each harvest date (H1, H2, H3, H4, H5) (Figure 1). Plots were harvested cumulatively and not as separate shrubs.

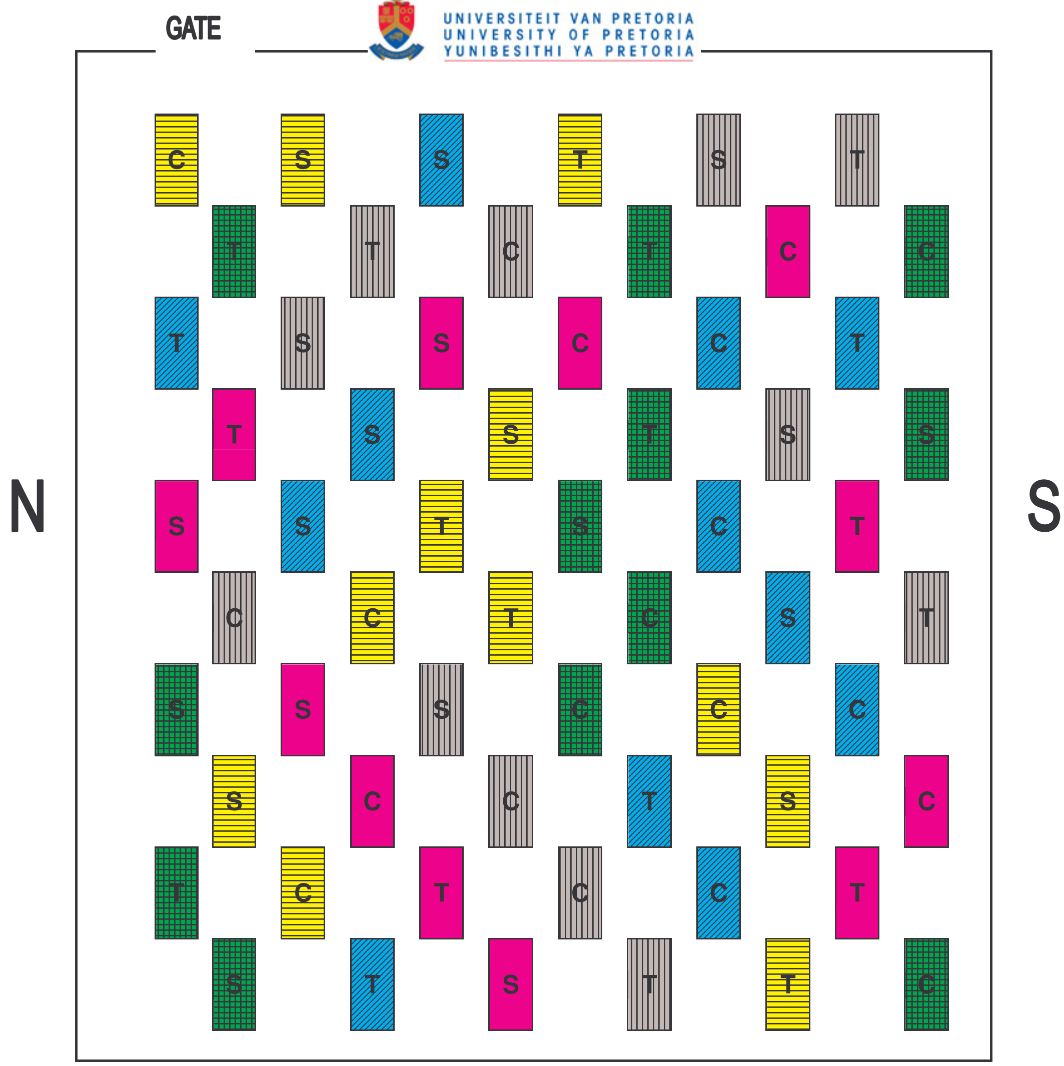

Figure 1 Field layout of trial to assess the growth and re-growth of *C. sturtii, S. microphylla* and *T. sinuatum*

Where:
C = *Cassia sturtii*
S = *Sutherlandia microphylla*
T = *Tripteris sinuatum*

Represents the plots harvested after 6 weeks (H1) of growth (post establishment)

Represents the plots harvested after 12 weeks (H2) of growth (post establishment)

Represents the plots harvested after 18 weeks (H3) of growth (post establishment)

Represents the plots harvested after 24 weeks (H4) of growth (post establishment)

Represents the plots harvested after 30 weeks (H5) of growth (post establishment)

Data collected included:

1. **Total dry matter production**. Shrubs were harvested at twenty centimetres above ground level. Branches of *T. sinuatum*, which has a prostate growth form, were lifted up and cut off at twenty centimetres above the ground. All material was then packed into separate brown paper bags and dried in a forced draught oven at 60°C for twenty-four hours. Plant material was then removed and allowed to cool before being weighed.
2. **Total edible material** produced on a dry matter basis, included leaves, flowers, seeds/seedpods and stem material less than three millimetres in diameter. All plant material was separated into the different plant components, which were weighed separately.
3. **Total woody material** on a dry matter basis, consisted of stem material >3mm in diameter. This material was considered woody and inedible.
4. **Frosted material** on a dry matter basis. During the period July to September some of the material that was harvested from *C. sturtii* and *T. sinuatum* had been damaged by frost. This material was separated from the rest of the plant material and weighed separately in order to determine to what extent the frost had affected these species.

Analysis of variance using the GLM model (Statistical Analysis Systems, 2001) was used in order to determine the significance between the different species and plant components at different stages of maturity. Means and standard deviations (SD) were calculated. The significance of difference (5%) between means was determined by using Bonferroni's test (Samuels, 1989).

Results and Discussion

- **Total dry matter production**

T. sinuatum and *C. sturtii* produced significantly ($P<0.05$) more material in the final harvest than the in first three harvests (Table 2).

Table 2 Total DM production (g/plant) of *C. sturtii, S. microphylla* and *T. sinuatum* (LS mean), harvested at five different harvest dates

Treatment	*C. sturtii*	*S. microphylla*	*T. sinuatum*
Harvest 1	5.4 $^{b}_{1}$ (±1.68)*	3.5 $^{c}_{1}$ (±2.57)*	17.7 $^{b}_{1}$ (±5.59)*
Harvest 2	4.9 $^{b}_{1}$ (±0.78)	21.9 $^{c}_{1}$ (±9.52)	50.6 $^{b}_{1}$ (±18.85)
Harvest 3	7.3 $^{b}_{1}$ (±2.48)	54.3 $^{c}_{1}$ (±12.74)	81.8 $^{b}_{1}$ (±30.35)
Harvest 4	42.1 $^{ab}_{2}$ (±8.83)	158.5 $^{b}_{1}$ (±39.19)	91.6 $^{ab}_{12}$ (±97.65)
Harvest 5	102.6 $^{a}_{2}$ (±82.30)	337.0 $^{a}_{1}$ (±116.58)	171.6 $^{a}_{2}$ (±128.21)

^{ab} Column means with common superscripts do not differ significantly (P>0.05)

$_{12}$ Row means with common subscripts do not differ significantly (P>0.05)

* Values in brackets represent standard deviation

S. microphylla produced significantly (P<0.05) more material in Harvest 4 than in the first three harvests. At the final harvest (Harvest 5) *S. microphylla* also produced significantly (P<0.05) more plant material than in Harvest 4 (Table 2). This yield was also more (P<0.05) than that of *T. sinuatum* and *C. sturtii* produced in Harvest 5 (Table 2). Although *T. sinuatum* appeared to have produced more dry matter than *C. sturtii* (Table 2), no significant (P>0.05) differences were observed between these two species, in any of the harvests (Table 2).

In trials conducted by Donaldson (1989), in Middleburg in the Eastern Cape Province, in which some shrub and grasses were compared in terms of survival and production, it was also noted that *S. microphylla* produced more dry matter than *T. sinuatum*. In this trial, however, it was only in the final harvest (Harvest 5) that *S. microphylla* produced more (P<0.05) than *T. sinuatum*. The production values obtained by Donaldson (1989) were lower than the values obtained in Harvest 5 of this trial, for both *S. microphylla* and *T. sinuatum*. This was most likely due to the fact that while observations by Donaldson (1989) were under rain fed conditions, in this trial shrubs were irrigated regularly.

Although *C. sturtii* had not produced much material in the first and second harvest, most of the material was edible (Figure 2). In Harvest 3 production had only increased to 7.3 g/plant. This was probably due to the effect of cold temperatures, experienced in the winter months, on this species. From Harvest 3 (at the end of September) onwards, however, production started to increase and had increased to 42.1 g/plant by the beginning of November. By Harvest 5, which was on the 22 December 2003, production had increased to 102.6 g/plant (Table 2).

Figure 2 *C. sturtii* seedling at Harvest 1, approximately eight weeks after planting

At the first harvest *S. microphylla* also had a low yield with an average of only 3.5 g/plant being harvested (Table 2) (Figure 3). From the first harvest onwards, however, *S. microphylla* appeared to have experienced no setbacks with yields increasing from harvest to harvest (Table 2). By Harvest 2 production had increased to 21.9 g/plant and at the final harvest (Harvest 5) yields had increased to 337.0 g/plant.

Figure 3 *S. microphylla* seedling 8 weeks after planting, at the first harvest (H1)

By Harvest 5, however, many of the *S. microphylla* shrubs appeared to have more stem material than leaf material (Figure 4). On average only 61.5% of the material harvested at this stage was considered to be edible. In other trials on the Hatfield Experimental Farm, where this species was being evaluated, this was not the case, and it was speculated at the time whether shrubs had possibly suffered insect damage, although this was not visually evident.

Figure 4 Many of the *S. microphylla* shrubs had lost most of their leaves, with stem material predominating, towards the end of the trial (H5)

T. sinuatum produced much more (17.7 g/plant) material than *C. sturtii* by the first harvest, but this was not significant (Figure 5). Yields of *T. sinuatum* increased to 50.6 g/plant in Harvest 2, in August 2003 and by the end of September (Harvest 3), production had increased to 81.8 g/plant. This was surprising as during the winter months this species was affected, quite badly, by frost . In the following six weeks (Harvests 3 to 4), however, there was very little increase in yield (91.6 g/plant) (Table 2). From November to December, however, yields improved immensely, although not significantly, with an increase to 171.6 g/plant being observed (Table 2).

Figure 5 *T. sinuatum* seedling 8 weeks after planting, at the first harvest (H1)

- **Edible material**

T. sinuatum and *S. microphylla* yielded significantly ($P<0.05$) more edible material in Harvest 5 than in any other harvest. *C. sturtii* produced significantly ($P<0.05$) more edible material at Harvest 5 than the first three harvests but not significantly ($P>0.05$) more than at Harvest 4 (Table 3).

In Harvests 1 to 4 no significant differences were observed between the three different species. At Harvest 5, however, both indigenous species yielded significantly ($P<0.05$) more edible plant material than the exotic species, *C. sturtii.*

Although *C. sturtii* did not produce large amounts of material, it was predominantly edible (Figure 6). The proportion of edible material remained high throughout with the percentage of coarse material still being as low as 12.6% in the final harvest (Harvest 5).

Table 3 The production of edible material (g/plant) of *C. sturtii, S. microphylla* and *T. sinuatum* (LS mean) harvested at five different dates

Treatment	*C. sturtii*	*S. microphylla*	*T. sinuatum*
Harvest 1	5.3^{b}_{1} (±1.56)*	3.2^{c}_{1} (±2.15)*	15.2^{c}_{1} (±4.50)*
Harvest 2	4.1^{b}_{1} (±0.85)	19.1^{bc}_{1} (±8.53)	12.1^{c}_{1} (±3.27)
Harvest 3	5.3^{b}_{1} (±3.13)	47.2^{bc}_{1} (±11.25)	35.8^{bc}_{1} (±26.66)
Harvest 4	38.1^{ab}_{1} (±7.41)	83.9^{b}_{1} (±14.40)	91.2^{b}_{1} (±96.97)
Harvest 5	89.7^{a}_{2} (±71.40)	207.5^{a}_{1} (±59.27)	166.3^{a}_{1} (±126.13)

^{ab} Column means with common superscripts do not differ significantly (P>0.05)

$_{12}$ Row means with common subscripts do not differ significantly (P>0.05)

* Values in brackets represent standard deviation

In *C. sturtii,* of the total material produced, 87.4% was considered edible in the final harvest (Harvest 5) (Figure 6), whereas only 61.6 % of *S. microphylla* material was edible (Figure 7), and 96.9%of *T. sinuatum* in the final harvest was edible (Figure 8).

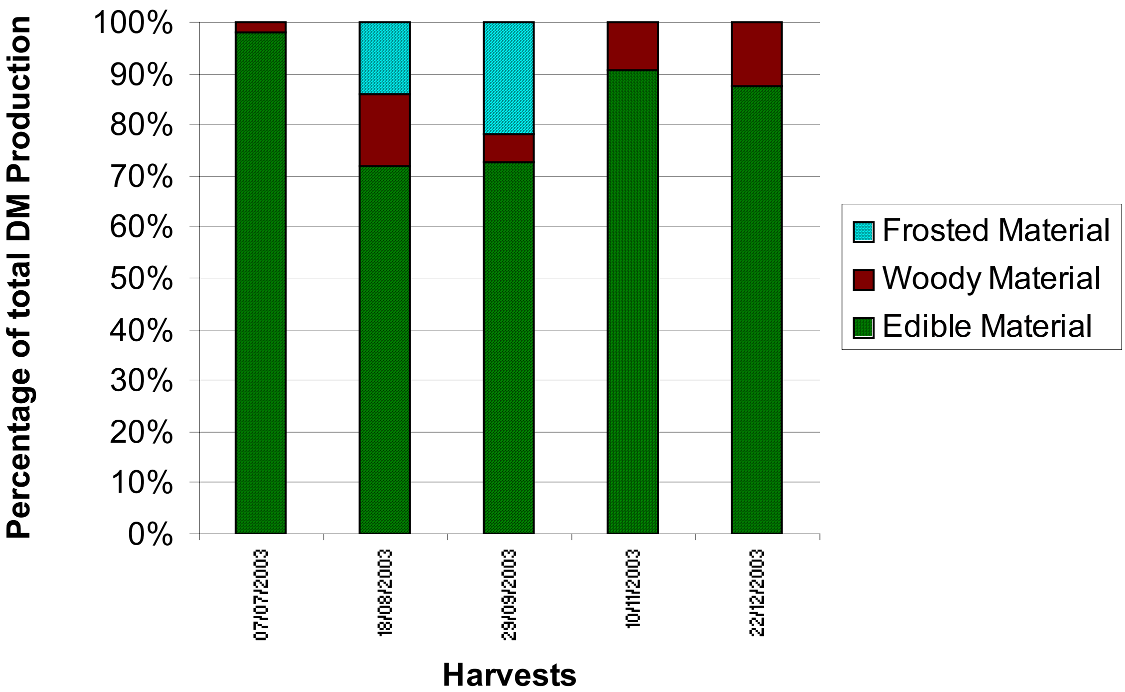

Figure 6 Proportion of woody, edible and frosted material produced by *C. sturtii* at five different harvest dates

Although *S. microphylla* had produced very little plant material (±3.5 g/plant) in the first harvest, 91.4% was considered edible (Figure 7). In the following two harvests (Harvests 2 and 3) the percentage woody material remained low.

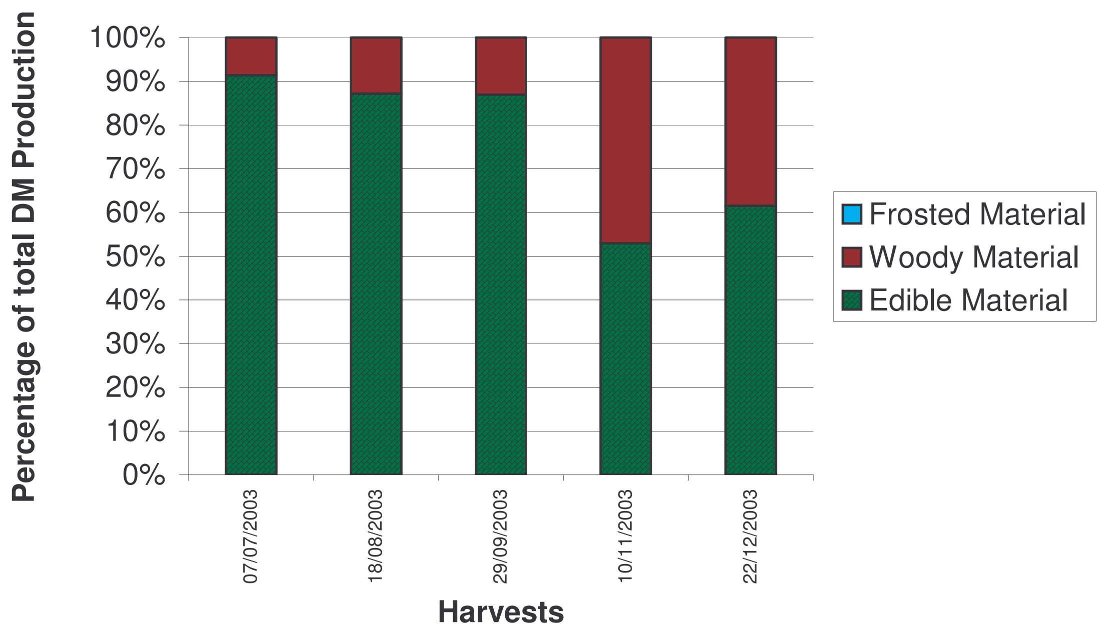

Figure 7 Proportion of woody, edible and frosted material produced by *S. microphylla* at five different harvest dates

In Harvests 4 and 5, however, *S. microphylla* had produced much larger ($P<0.05$) amounts of plant material than in the first three harvests. As the amount of plant material produced increased, however, so did the proportion of woody material. By the final harvest 38.4% of the material produced was woody and inedible (Figure 7). *S. microphylla* still, however, produced significantly ($P<0.05$) more edible material than *C. sturtii*, in the final harvest (Table 3).

The fact that *T. sinuatum* is susceptible to frost damage (Donaldson, 1989), is clearly seen in Figure 8. Although only 36.0 g/plant and 42.2 g/plant was damaged by frost in Harvests 2 and 3 respectively (Table 4), it made up a large percentage of the material that was available in these two harvests. By Harvest 4, however, shrubs had recovered well and by the final harvest (Harvest 5) very little material harvested was considered inedible (Figure 8).

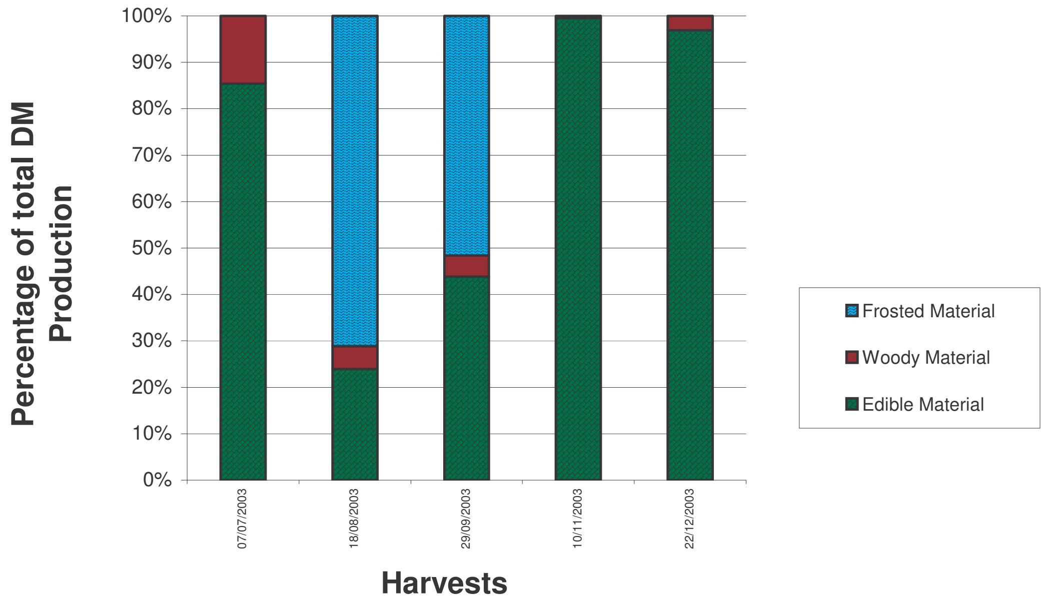

Figure 8. Proportion of woody, edible and frosted material produced by *T. sinuatum* over five different harvest dates

Both *C. sturtii* and *T. sinuatum* were affected by frost during the winter months. *T. sinuatum* was affected significantly (P<0.05) more so than *C. sturtii* (Table 4), with 71.1% and 51.7% of *T. sinuatum* total plant material produced having been damaged in Harvests 2 and 3 respectively. In *C. sturtii* *o*nly 14% and 21.9% of was affected in Harvests 2 and 3 respectively.

Table 4 Material (g/plant) of *C. sturtii* and *T. sinuatum* (LS mean) affected by frost during August/ September

Treatment	*C. sturtii*	*T. sinuatum*
Harvest 2	0.8 $^{a}_{2}$ (±0.79)	36.0 $^{a}_{1}$ (±18.71)
Harvest 3	1.6 $^{a}_{2}$ (±1.76)	42.2 $^{a}_{1}$ (±9.22)

^{ab} Column means with common superscripts do not differ significantly (P>0.05)

$_{12}$ Row means with common subscripts do not differ significantly (P>0.05)

* Values in brackets represent the standard deviation

Conclusion

Although *S. microphylla* had produced significantly (P<0.05) more total plant material in the fifth and final harvest, a larger percentage of the total plant material produced by *T. sinuatum* was considered edible. At Harvest 5 both indigenous species (*S. microphylla* and *T. sinuatum*) had significantly (P<0.05) more edible plant material than the exotic species, *C. sturtii*. Of the total material produced by *C. sturtii* a large percentage was, however, considered edible. This species was also not as badly affected by the frost as *T. sinuatum.*

In terms of production all three species appear to be promising fodder shrubs that could be used for the rehabilitation of degraded arid areas of South Africa. These species cannot, however, be considered feasible fodder shrub species until their nutrient content is known. Research was, therefore, extended to include the determination of quality of these three species.

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Chapter 6

Nutritive value of three fodder shrub species which may be used in the reclamation of degraded rangelands *

T.E. Wilcock[1], N.F.G. Rethman[1], W.A. van Niekerk[2] and R.J. Coertze[2]

[1] Department of Plant Production and Soil Science, University of Pretoria, Pretoria, 0002, South Africa.

[2] Department of Animal and Wildlife Sciences, University of Pretoria, Pretoria, 0002, South Africa.

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Abstract

In degraded arid and semi-arid rangelands farmers often rely on stands of well-known fodder shrub species to supply forage during the dry seasons and in times of drought. Most shrub species used are exotic, due to lack of information on the potential of indigenous species. In this trial two indigenous species, *Sutherlandia microphylla, Tripteris sinuatum* and one exotic specie, *Cassia sturtii*, were compared in terms of nutritive value. Leaf and edible stem material (<3mm in diameter) were analysed, over time, in terms of crude protein, organic matter digestibility and mineral concentrations (calcium, phosphorus, magnesium, copper, manganese and zinc). Both indigenous species had higher ($P<0.05$) organic matter digestibility and crude protein concentrations in the leaf material than *C. sturtii. S. microphylla* leaf material contains L-canavanine, a non-protein amino acid, which may adversely effect intake and, if consumed, animal performance. Only in Harvest 3 was the crude protein concentration in the stem material of *S. microphylla* higher ($P<0.05$) than *C. sturtii*. With the exception of zinc all three species provided sufficient macro and trace minerals to fulfil in the nutrient requirements of sheep for maintenance. Toxicity was in fact more of a concern in some minerals, for certain species. In older *T. sinuatum* plant material ratios between calcium and phosphorus were not ideal.

Keywords: crude protein, digestibility, minerals, *Cassia sturtii, Sutherlandia microphylla, Tripteris sinuatum,*

Introduction

Arid and semi-arid rangelands that have been degraded are characterized by a decrease in vegetation quality and quantity. This leads to a decrease in the carrying capacity of the rangeland (Dean & McDonald, 1994). Farmers are, therefore, forced to decrease livestock numbers. Researchers have found that over the past sixty years in South Africa cattle, sheep and goat numbers have been at the lowest in the last decade (Hoffman, 1997; Palmer & Ainslie, 2002). This is problematic, as in many arid and semi-arid areas livestock production is the main form of agriculture, and in many cases the main form of meat and income (Noble, 1986).

Palatable, evergreen fodder shrubs are often established in degraded rangelands to improve the grazing capacity (Abou El Nasr et al., 1996; Adugna et al., 1997; Kinet et al., 1998; Van Heerden et al., 2000; Sparks, 2003). In many instances farmers rely on stands of exotic shrub species as a source of fodder, firewood and shelter (Armstrong & Gibbs, 2000). According to Whalley et al. (1978), this is mainly due to farmers being unaware of the potential of indigenous species. Robinson & Whalley (1986) believed that a lack of comparisons between indigenous and well-known introduced species, under the same environmental conditions, was the reason for this.

When evaluating shrub species as possible fodder species for arid areas, drought tolerance, productivity, palatability and ability to recover from being browsed should all be assessed (Hassan, 1986). Shrubs also, however, need to be assessed in terms of nutritive quality. According to Meissner et al. (1999), nutritive value, along with feed intake, are two of the main factors that determine animal performance. The nutritive value is determined mainly by the digestibility and chemical composition. Lipids, soluble carbohydrates, starch, organic acids, cellulose and hemi-cellulose are considered the energy constituent of forage. Proteins, minerals and vitamins, in the correct balance, however, are also necessary for the animal to perform satisfactorily (Meissner et al., 1999).

The objective of this trial was to compare the nutritive value of two indigenous and one exotic species, in terms of crude protein, organic matter *in vitro* digestibility and minerals (calcium, phosphorus, magnesium, copper, manganese and zinc), over time, using sequential harvesting. The trial included *Cassia sturtii*, an exotic fodder shrub specie, native to Australia, and two indigenous species, *Sutherlandia microphylla* and *Tripteris sinuatum* (previously known as *Osteospermum sinuatum*). Both indigenous species are known locally as "Karoo bossies" (Karoo shrubs/bushes) (Le Roux et al., 1994).

Materials and Method

- **Study Area**

The shrubs were planted on the Hatfield Experimental Farm of the University of Pretoria in Pretoria (co-ordinates 025º 15'28.9" E, 25º45'03.6"S at an altitude of 1360m) (Sparks, 2003), Gauteng, South Africa. Maximum temperatures in Pretoria often reach above 30ºC and minimum temperatures above 15ºC, in the summer months. In winter, temperatures are between 22ºC and 8ºC but can be much lower. Frost also occurs quite frequently in the winter (Sparks, 2003; Weather S.A., 2007). Pretoria has a summer rainfall of 650mm with 50% of the precipitation being recorded during November to January (Sparks, 2003). Only seven to fifteen millimetres of rain falls in the winter months, from June to July. Shrubs were, however, irrigated to eliminate moisture stress as a limiting factor. After transplanting, shrubs were watered in the first and second week and every four weeks thereafter. Shrubs were also fertilized at planting (in each planting hole), with a planting mixture of 2:3:4 (N: P: K). The soil was a well-drained Hutton form with 35% clay (MacVicar et al., 1977). A representative sample of the topsoil (± 30cm) from the site was analysed in March 2005. Lab results showed the soil to be slightly acidic with a $pH_{(H2O)}$ of 5.6 and a nutrient status for phosphorus, calcium, potassium, magnesium and sodium of 14.8 mg/kg, 764 mg/kg,
141 mg/kg, 213 mg/kg and 16 mg/kg, respectively.

- **Materials**

S. microphylla and *T. sinuatum* seedlings were propagated from seed harvested on the farm "Lovedale", which is situated near Pofadder, Northern Cape Province. Seeds of *C. sturtii* were obtained from a plantation located on the experimental farm in Pretoria. All seed had been stored in paper bags in a seed store at ± 5ºC. Hardened off seedlings, of between fifteen to twenty centimetres in height, were planted out in randomly allocated plots in a field (35m X 100m). The layout consisted of sixty plots, which were five metres apart between and within rows. This was done to prevent any possible influence the leguminous species (*C. sturtii* and *S. microphylla*) might have had on the non-leguminous species (*T. sinuatum*). Available space was limited, however, and the layout shown in Figure 1 was, therefore, used. Each plot contained five plants of the same species. Seedlings were planted at a spacing of 1meter apart within the plots.

Once planted (9th May 2003) shrubs were given approximately two weeks to establish before the trial was initiated. Five different harvests, which were six weeks apart, were taken (Table 1).

Table 1 Harvest dates, after the 2 weeks establishment phase

Harvest	Time of harvesting	Dates
H1	6 weeks	7 July
H2	12 weeks	18 August
H3	18 weeks	29 September
H4	24 weeks	10 November
H5	30 weeks	22 December

Harvest 1 was taken on the 7th of July 2003, 8 weeks (2 weeks to establish and then 6 weeks till harvest date) from when shrubs were planted. The final, fifth harvest was taken on the 22nd of December 2003, approximately 30 weeks from the day the trial had started (32 weeks after planting).

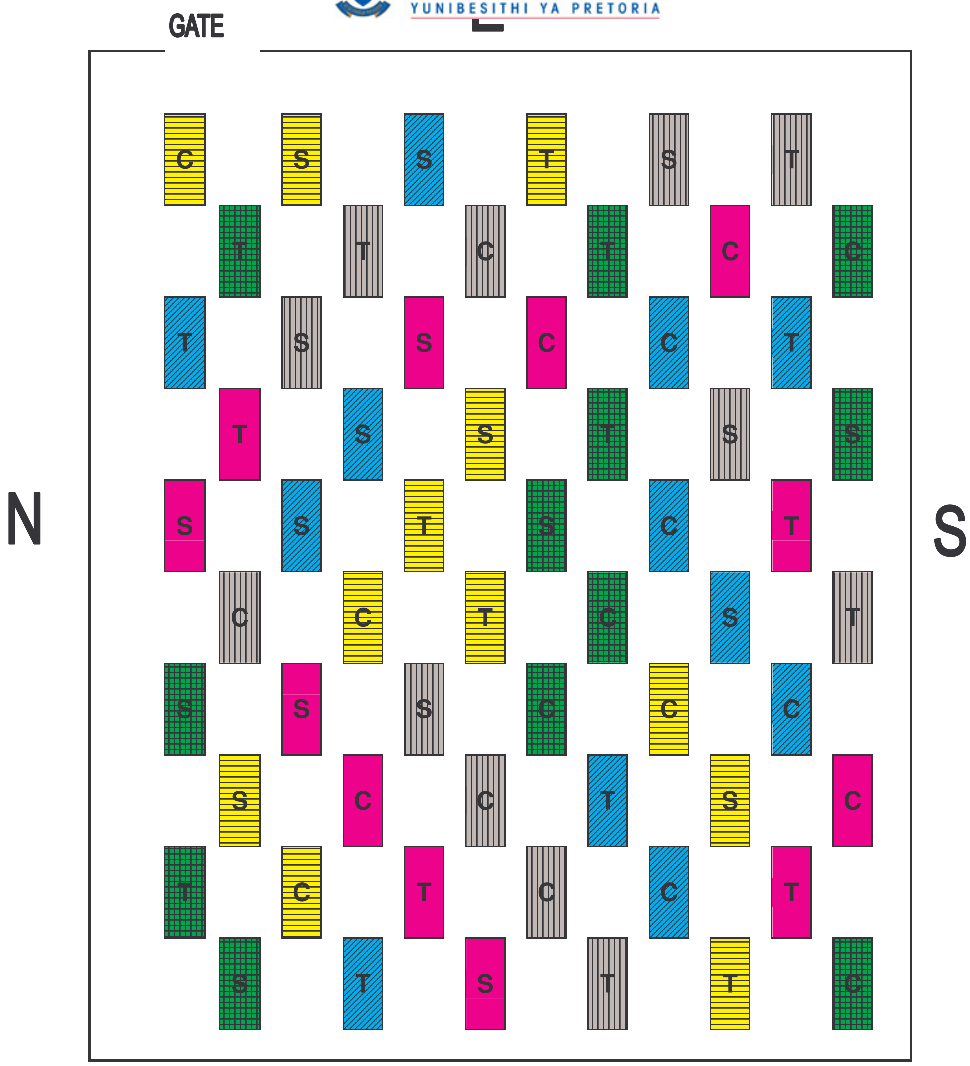

Figure 1 Field layout of trial to assess the growth and re-growth of *Cassia sturtii, Sutherlandia microphylla* and *Tripteris sinuatum*

Where:
C = *Cassia sturtii*
S = *Sutherlandia microphylla*
T = *Tripteris sinuatum*

Represents the plots harvested 6 weeks (H1) after the establishment phase.

Represents the plots harvested 12 weeks (H2) after the establishment phase..

Represents the plots harvested 18 weeks (H3) after the establishment phase..

Represents the plots harvested 24 weeks (H4) after the establishment phase..

Represents the plots harvested 30 weeks (H5) after the establishment phase..

At each harvest date four randomly selected plots (replicates) of each species were harvested (Figure 1). Shrubs were harvested at approximately twenty centimetres above ground level. Due to the prostate growth form of *T. sinuatum*, the branches of this species were gathered up and cut at twenty centimetres above ground level. Plots were harvested cumulatively and not as separate shrubs.

- **Method**

Selected shrubs were harvested twenty centimetres above ground level. Branches of *T. sinuatum*, which has a prostate growth form, were lifted up and cut off at twenty centimetres above the ground. Initially all material that had been harvested was placed in paper bags and dried in a forced draught oven at 60° C for twenty-four hours. Plant material was then removed and allowed to cool before being weighed. Material was separated into leaf, woody stem (>3mm in diameter) and edible stem (<3mm in diameter) material. All material was weighed separately to determine the amount of edible and inedible material produced. Woody stem material larger than 3mm in diameter was considered inedible and was, therefore, not analysed in terms of nutritive value. During the months of July to September some of the plant material that was harvested from *C. sturtii* and *T. sinuatum* had been damaged by frost. In order to determine to what extent the frost had affected these species, this material was separated from the rest of the plant material and weighed separately. This material was not, however, analysed.

The dried plant components were milled and representative samples of the leaf and edible stem material (<3mm in diameter) were analysed for ash, crude protein, *in vitro* digestible organic matter (IVDOM%) and a number of macro and micro-minerals (including calcium, phosphorus, magnesium, copper, manganese and zinc).

The percentage ash was determined by dividing the mass of material that had been ashed in an oven at 600ºC for five hours, by the mass of the same sample that had been previously dried in an oven at 105ºC overnight [% Ash = (Ash mass / oven dried material mass) X100)] (AOAC, 2000).

Crude protein (CP) was determined, using the Dumas method (AOAC, 2000), where $\%N \times 6.25 = \%CP$ (crude protein).

The *in vitro* digestible organic matter (IVDOM%) was determined using the Tilley & Terry method (Tilley & Terry, 1963), as modified by Engels & Van Der Merwe (1976).

This adaptation of the two-phase technique included a 48-hour fermentation by rumen microoganisms in a buffer solution followed by a 48-hour pepsin digestion after acidifying with hydrochloric acid (Tilley & Terry, 1963; Engels & Van Der Merwe, 1976).

Minerals analysed included calcium, magnesium, phosphorus, manganese, copper and zinc. All minerals, except for phosphorus, were analysed using the atomic absorption spectrophotometer (AOAC, 2000). Phosphorus content was determined using an Auto Analyser (AOAC, 2000).

Only material from Harvests 1, 3 and 5 was analysed, with leaf and edible stem material being analysed separately.

Analysis of variance using the GLM model (Statistical Analysis Systems, 2001) was used in order to determine the significance between the different species and plant parts at different stages of maturity. Least square means and standard deviations (SD) were calculated. The significance of difference (5%) between means was determined using the Bonferroni's test (Samuels, 1989).

Results and Discussion

- **Percentage leaf material**

The percentage of leaf material in all three species decreased with age, with significantly ($P<0.05$) more leaf material in Harvest 1 than in Harvest 3 or Harvest 5. In Harvest 5 *C. sturtii* had significantly more leaf material than the other species (Table 2). Both indigenous species were characterized by low percentages of leaf material by Harvest 5. *S. microphylla* had significantly ($P<0.05$) less leaf material in Harvest 5 than in Harvest 3 (Table 2). Although *S. microphylla* shrubs in this trial had very little leaf material present, in an adjacent camp the same species appeared to be much leafier. No explanation for this is evident although it is possible, that some type of insect damage was responsible.

Nutritive value is directly linked to leafiness. The quality of the forage is, therefore, influenced by changes in the proportions of leaf and stem material available. This makes it important that the percentage leaf is known. Although the proportion of edible stems that will be grazed is unknown (Wilson, 1977; Watson et al., 1987; Sparks, 2003) in arid areas, where forage is often scarce, the consumption of edible stem material is probably relatively high.

Table 2 Percentage of leaf material (LS mean) of *C. sturtii, S. microphylla* and *T. sinuatum*, over time

Treatment	*C. sturtii*	*S. microphylla*	*T. sinuatum*
Harvest 1	61.9 $^{a}_{1}$ (±4.39)*	55.5 $^{a}_{1}$ (±14.40)*	55.6 $^{a}_{1}$ (±5.10)*
Harvest 3	49.9 $^{b}_{1}$ (±8.39)	44.2 $^{b}_{1}$ (±5.66)	41.6 $^{b}_{1}$ (±12.92)
Harvest 5	47.7 $^{b}_{1}$ (±4.89)	26.3 $^{c}_{2}$ (±5.17)	34.2 $^{b}_{2}$ (±2.70)

^{ab} Column means with common superscripts do not differ significantly (P>0.05)

$_{12}$ Row means with common subscripts do not differ significantly (P>0.05)

* Values in brackets represent standard deviations

- **Crude Protein**

In all three species the stem material had significantly (P<0.05) less crude protein than the leaf material, in all harvests analysed. Of the three species, *C. sturtii* had the lowest (P<0.05) crude protein concentration in the leaf material, in all harvests. It was only in Harvest 1 that *S. microphylla* had higher (P<0.05) leaf crude protein levels than *T. sinuatum*. Except for Harvest 3, no significant (P>0.05) differences were observed in the crude protein concentration of the stem material, for all three species. In Harvest 3, *S. microphylla* had significantly (P<0.05) higher crude protein concentrations in the stem material than *C. sturtii* (Table 3).

Leaf and stem material of *S. microphylla* had similar crude protein concentrations in Harvests 1 and 3, both of which were significantly (P<0.05) higher than in Harvest 5. The leaf material of *T. sinuatum* had higher (P<0.05) crude protein concentrations in Harvest 3 than in either Harvests 1 or 5. The crude protein concentrations of the leaf material of *T. sinuatum* were also higher (P<0.05) in Harvest 1 than in Harvest 5.

No significant (P>0.05) differences were observed in the stem samples of this species from different harvests. This was also true for the leaf samples of *C. sturtii.* In the stem material of *C. sturtii*, however, the crude protein concentration appeared to decrease with age and a significantly (P<0.05) lower crude protein concentration was observed in Harvest 5 than Harvest 1 (Table 3). The crude protein concentrations in the leaf samples of *C. sturtii* in Harvests 1 and 5 were similar to those reported by Sparks (2003) (14.7%).

Table 3 The crude protein concentration and organic matter *in vitro* digestibility (LS mean) of the different plant parts of *C. sturtii, S. microphylla*, and *T. sinuatum,* over time

Treatment	Plant part	Species	Crude Protein	*In vitro* organic matter digestibility
Harvest 1	Leaves	*C. sturtii*	15.7^{a}_{3} (±0.70)*	59.4^{ab}_{2} (±7.31)*
		S. microphylla	29.8^{a}_{1} (±0.68)	78.5^{a}_{1} (±0.88)
		T. sinuatum	26.6^{b}_{2} (±1.17)	75.3^{a}_{1} (±2.62)
	Stems	*C. sturtii*	11.7^{b}_{4} (±0.40)	55.2^{b}_{23} (±0.93)
		S. microphylla	12.6^{c}_{4} (±0.49)	54.7^{c}_{23} (±4.05)
		T. sinuatum	12.1^{d}_{4} (±0.62)	52.6^{c}_{3} (±5.13)
Harvest 3	Leaves	*C. sturtii*	17.7^{a}_{2} (±1.34)	62.6^{a}_{2} (±0.42)
		S. microphylla	29.4^{a}_{1} (±1.50)	71.7^{b}_{1} (±1.65)
		T. sinuatum	29.4^{a}_{1} (±1.19)	70.3^{ab}_{1} (±3.57)
	Stems	*C. sturtii*	9.4^{bc}_{4} (±0.49)	48.6^{c}_{34} (±2.28)
		S. microphylla	13.6^{c}_{3} (±1.08)	49.6^{c}_{3} (±1.40)
		T. sinuatum	11.8^{d}_{34} (±1.08)	43.2^{d}_{4} (±8.88)
Harvest 5	Leaves	*C. sturtii*	15.5^{a}_{2} (±1.14)	58.1^{ab}_{2} (±2.77)
		S. microphylla	24.2^{b}_{1} (±2.03)	70.1^{b}_{1} (±3.53)
		T. sinuatum	23.4^{c}_{1} (±5.06)	68.3^{b}_{1} (±2.83)
	Stems	*C. sturtii*	8.0^{c}_{3} (±1.08)	41.6^{d}_{3} (±1.52)
		S. microphylla	9.2^{d}_{3} (±0.96)	41.8^{d}_{3} (±3.36)
		T. sinuatum	10.3^{d}_{3} (±0.81)	40.9^{d}_{3} (±5.42)

^{ab} Column means with common superscripts, within a species, do not differ significantly (P>0.05)

$_{12}$ Column means with common subscripts, within a harvest, do not differ significantly (P>0.05)

* Values in brackets represent standard deviations

In Harvest 3 the crude protein concentration was slightly higher (17.7%). This was, however, much higher than those reported by Chopra & Bhatia (1987) for *C. sturtii* (±12%) in western Rajasthan, India, for all harvests.

When animals are solely reliant on the rangeland, protein is, in many cases, the limiting factor in terms of performance (Meissner et al., 1999). Digestion of organic matter, especially that of poor quality fibrous feed, is dependent on a supply of sufficient nitrogen to the micro-organisms, in order for microbial fermentation to take place in the rumen. Sufficient protein in the diet, therefore, ensures that poor quality feed passes through the digestive system at a rate that allows animals to continue to consume sufficient feed (Romney et al., 1996; Snyman 2006). According to Minson (1990), cited by Snyman (2006), a crude protein concentration of at least 62g/kg dry matter is necessary to prevent fibre digestion from being inhibited. The amount of crude protein in the forage is, however, only an indication of whether protein supplementation might be necessary. This value does not distinguish between non-protein nitrogen (NPN), protein available to the microflora or how much is absorbed in the lower digestive tract. No information on the origin and quality of the protein is given. In forages where a large percentage of the protein is non-protein nitrogen (such as grass fertilized with N), supplementation may be necessary to improve the animal's performance (Meissner et al., 1999). It is important to also keep in mind that age, as well as physiological condition, will affect the protein requirements of animals (Meissner et al., 1999).

Although all three species were able to fulfil the nutrient requirements for maintenance of sheep (9.5-15%) and goats (10-15%), (NRC, 1981, 1985; AFRC, 1998), the indigenous species were better than *C. sturtii* in this regard. Sharp et al., (2000), cited by Sparks (2003), however, believes that although *C sturtii*'s protein levels are low for a leguminous species, it could still be used to substitute expensive concentrates.
When compared to the well-known *Medicago sativa* (lucerne), which has 20.4%-22.5% crude protein (Bredon et al., 1987; Meissner et al., 1999), *S. microphylla* had similar levels of protein in the leaf material.

The leaf material of this species, however, contains the non-protein amino acid (NPAA), L-canavanine (pers. comm. from J. Els, 2008)[1]. L-canavanine, which is present at levels of 2-3mg/ g dry *Sutherlandia* leaf material (Yamamoto, et al., 1980; Rosenthal, 1997; Miersch, et al., 2000; Sia, 2004), plays a defensive role against predation (Makkar & Becker, 1999; Siddhuraju & Becker, 2001; Thomson, 2002).

[1] Jaquelene Els, MSc. student in the Department of Animal and Wildlife Sciences, University of Pretoria, Pretoria, 0002, South Africa.

This non-protein amino acid can, in fact, be found in 350 species of the subfamily Papilionoideae of Leguminosae (Bell, 1960; Birdsong, et al., 1960; Bell et al., 1978; Enneking, 1994; Bell, 2003). In most other species, however, L-canavanine is located mainly in the seeds (Rosenthal & Bell, 1979; Bell, 2003). The presence of this non-protein amino acid may result in animals not consuming this plant material or, if consumed, may have adverse effects on the animals (Thomson, 2002). L-canavanine ($H_2N–C(= NH)–NH–O–CH – CH_2 – CH (NH_2) CO_2H$) is the guanidinoxy structural analogue of arginine (Rosenthal, 1970; Rosenthal, 1977a; Kammer, et al., 1978) and, when consumed, is incorporated into proteins in the place of arginine (Prete, 1985a; Prete, 1985b; Mills, et al., 2005). Proteins that are formed from L-canavanine have a dysfunctional structure (Nilsen, et al., 2000) and often act as antimetabolites in many of the biological systems (Rosenthal, 1977; Rosenthal, 1982; Bell, 2003). L-canavanine containing proteins result in the disturbance of protein synthesis and the RNA and DNA metabolic pathways (Sia, 2004). Research done by Thomas & Rosenthal (1987a), cited by Enneking (1994), showed that rats fed 2g kg^{-1} L-canavanine experienced alopecia, appetite loss and weight loss. Prete (1985a; 1985b, cited by Mills et al., 2005) believed that long term consumption would result in autoimmunity.

Ruminants, however, appear to be less affected by the toxic effects of this non-protein amino acid than monogastric animals (Dominguez & Stewart, 1990; Thomson, 2002). According to Dominguez-Bello (1996), microbial detoxification occurs in the rumen, which makes ruminants more capable of tolerating poisonous plants. Rumen fermentation results in the modification of a number of anti-nutritional factors, making them less toxic to mammalian metabolism (James, et al., 1975; Hume, 1984; Dixon & Hosking, 1992).

Dominguez-Bello & Stewart (1990), observed there to be no adverse affects to sheep fed L-canavanine containing *Canavalia ensiformis*. Dominguez-Bello & Stewart (1990), believed this to be due to sufficient amounts of L-canavanine being broken down by canavanine-degrading bacteria in the rumen.

Dominguez-Bello & Stewart (1990) also observed an increase in the proportion of Gram-negative bacteria in the rumen as well as a decrease in ammonia and valerate concentrations, when sheep were fed on L-canavanine containing diets. Although ruminants appear not to be affected by L-canavanine, Enneking (1994) believes these animals may well experience toxic effects of canaline, which, in some cases, is one of the breakdown products of this non-protein amino acid. This may explain the occasional poisoning of cattle by L-canavanine containing plants that has been observed by some researchers (Claughton & Claughton, 1955; Shone, 1961; Enneking 1994). Other researchers, however, believe non-protein amino acids have a toxic effect on micro-organisms resulting in a decrease in microbial growth as well as a decrease in the rate of rumen fermentation, especially in fibrous material (Dixon, et al., 1983; Dixon & Hosking, 1992). Mora et al. (1989), cited by Dixon & Hosking (1992), found that, although metabolism still occurs in the rumen in the presence of non-protein amino acids, it is at a slower rate than with protein amino acids. Tschiersch (1962), cited by Enneking (1994), discovered that the toxic effects of L-canavanine could be alleviated by the supplementation of arginine, fed at ten times the dose of L-canavanine, simultaneously. Due to the presence of this non-protein amino acid, L-canavanine, *S. microphylla* may also prove to be disappointing as a leguminous species.

- ***In vitro* digestible organic matter**

In the indigenous species, as with leaf percentage and crude protein content, digestibility had a tendency to decrease with age (Table 3). In both indigenous species the leaf and stem material digestibility in Harvest 1 was higher ($P<0.05$) than the digestibility values obtained for Harvest 5. The same was also true for the stem material of *C. sturtii* (Table 3). This decrease in digestibility could suggest that fibre content of this plant material increased with age. The digestibility of the leaf material of both indigenous species was significantly better ($P<0.05$) than that of *C. sturtii*, in all harvests. The exotic species, *C. sturtii*, however, had a much higher proportion of leaf material.

The digestibility of the stem material was similar in the three species for Harvests 1 and 5. In Harvest 3, however, the stem material of *T. sinuatum* had a significantly lower ($P<0.05$) digestibility than *S. microphylla* (Table 3). The presence of L-canavanine in *S. microphylla*, however, will affect the true organic matter digestibility of this species, as it may occur at a slower rate due to the presence of these non-protein amino acids, as discussed earlier.

Except for *C. sturtii* in Harvest 1, leaf material had a higher digestibility ($P<0.05$) than stem material (Table 3), in all species, in all harvests.

Values for *C. sturtii* leaf material, observed in this trial, were slightly higher than the values reported by Sparks (2003), for *C. sturtii* (57.4%). In this trial *C. sturtii* only had a lower stem digestibility than the values reported by Sparks (2003) for *C. sturtii* (46.0%) in samples of Harvest 5 (at approximately thirty-two weeks of age).

- **Macro Minerals**
  - **Magnesium**

Except for *S. microphylla* in Harvest 1, both indigenous species had higher (P<0.05) magnesium concentrations in the leaf material than in the stem material (Table 4). Only in Harvest 5 was this also true for *C. sturtii*. Stem and leaf material of *T. sinuatum* had significantly (P<0.05) higher concentrations of magnesium than the other species, in all harvests. Except for the leaf material in Harvest 1, there was no significant (P>0.05) difference observed between the leaf or stem material of *C. sturtii* and *S. microphylla* (Table 4). The magnesium concentration in *T. sinuatum* leaf material appeared to increase with age. In this species concentrations in Harvest 1 were significantly (P<0.05) lower than those in Harvest 5, for both the leaf and stem material. In the stem material of *T. sinuatum* concentrations of magnesium in Harvests 1 and 3 were similar (Table 4). Between the different harvests no significant (P>0.05) differences were observed in either the leaf or stem material of *S. microphylla*. This was also true for the stem material of *C. sturtii*. In the leaf material of *C. sturtii* Harvest 1 had a lower (P<0.05) magnesium concentration than in Harvest 5 (Table 4). Values for *C. sturtii* and *S. microphylla* were similar to the magnesium concentrations reported by Sparks (2003) for *C. sturtii* leaf (0.20%) and stem material (0.12%) in Harvests 3 and 5.
For all harvests, all species were able to meet the maintenance requirements of sheep and goats (0.04%-0.08%) (NRC, 1976, 1985).

Table 4 The percentage magnesium, calcium and phosphorus (LS mean) in the different plant parts of *C. sturtii, S. microphylla*, and *T. sinuatum*, over time

Treatment	Plant part	Species	Magnesium	Calcium	Phosphorus
Harvest 1	Leaves	*C. sturtii*	0.10^{b}_{4} (±0.00)*	0.7^{c}_{3} (±0.05)*	0.25^{bd}_{2} (±0.58)*
		S. microphylla	0.20^{a}_{23} (±0.00)	1.4^{b}_{2} (±0.17)	0.43^{a}_{1} (±0.06)
		T. sinuatum	0.65^{b}_{1} (±0.06)	3.1^{c}_{1} (±0.21)	0.38^{a}_{1} (±0.10)
	Stems	*C. sturtii*	0.10^{b}_{4} (±0.00)	0.7^{c}_{34} (±0.05)	0.35^{a}_{1} (±0.06)
		S. microphylla	0.17^{ab}_{34} (±0.12)	0.4^{c}_{4} (±0.10)	0.43^{a}_{1} (±0.12)
		T. sinuatum	0.28^{d}_{2} (±0.05)	0.7^{e}_{3} (±0.00)	0.20^{bc}_{2} (±0.00)
Harvest 3	Leaves	*C. sturtii*	0.20^{ab}_{24} (±0.00)	1.2^{b}_{3} (±0.14)	0.25^{abc}_{12} (±0.07)
		S. microphylla	0.20^{a}_{23} (±0.00)	2.1^{a}_{2} (±0.22)	0.30^{b}_{1} (±0.08)
		T. sinuatum	0.78^{a}_{1} (±0.10)	4.5^{a}_{1} (±0.26)	0.33^{a}_{1} (±0.05)
	Stems	*C. sturtii*	0.10^{ab}_{34} (±0.00)	0.7^{c}_{4} (±0.14)	0.35^{ab}_{1} (±0.21)
		S. microphylla	0.10^{b}_{4} (±0.00)	0.4^{c}_{5} (±0.05)	0.25^{b}_{1} (±0.06)
		T. sinuatum	0.25^{d}_{2} (±0.06)	0.8^{e}_{4} (±0.06)	0.15^{bc}_{2} (±0.06)
Harvest 5	Leaves	*C. sturtii*	0.20^{a}_{3} (±0.00)	1.8^{a}_{2} (±0.34)	0.20^{cd}_{123} (±0.00)
		S. microphylla	0.20^{a}_{3} (±0.00)	1.3^{b}_{3} (±0.08)	0.25^{b}_{1} (±0.06)
		T. sinuatum	0.85^{a}_{1} (±0.17)	4.2^{b}_{1} (±0.29)	0.23^{b}_{12} (±0.05)
	Stems	*C. sturtii*	0.10^{b}_{4} (±0.00)	1.3^{b}_{3} (±0.10)	0.15^{c}_{24} (±0.06)
		S. microphylla	0.10^{b}_{4} (±0.00)	0.3^{c}_{4} (±0.00)	0.10^{c}_{4} (±0.00)
		T. sinuatum	0.55^{c}_{2} (±0.10)	1.5^{d}_{3} (±0.32)	0.13^{c}_{34} (±0.05)

^{ab} Column means with common superscripts, within a species, do not differ significantly (P>0.05)

$_{12}$ Column means with common subscripts, within a harvest, do not differ significantly (P>0.05)

* Values in brackets represent standard deviations

- **Calcium**

Except for *C. sturtii* in Harvest 1, calcium concentrations were higher (P<0.05) in the leaf material than in the stem material, in all three species (Table 4). Of the three species *T. sinuatum* had the highest (P<0.05) concentrations of calcium in the leaf material, in all harvests. In Harvests 1 and 3, *S. microphylla* had significantly more (P<0.05) calcium in the leaf material than did *C. sturtii*. With age, however, the calcium concentration in the leaf material of *C. sturtii* increased significantly (P<0.05). By Harvest 5 the leaves of this species had significantly (P<0.05) higher calcium concentrations than leaves of *S microphylla*. The calcium concentration in the stem material of *S. microphylla* remained low throughout all harvests and was significantly (P<0.05) lower than that of *T. sinuatum*.

With the exception of Harvest 1, the calcium concentration in the stem material of *S. microphylla* was also lower (P<0.05) than *C. sturtii* (Table 4). The calcium concentration in the stem material of *C. sturtii* remained similar in Harvests 1 and 3 but increased significantly (P<0.05) in Harvest 5. In the stem material of *T. sinuatum* calcium concentrations increased with age and in Harvest 5 were significantly (P<0.05) higher than in Harvests 1 and 3.

Both indigenous species had higher (P<0.05) calcium concentrations in their leaf material in Harvest 3 than in Harvests 1 or 5. In the case of *T. sinuatum* leaf material in Harvest 5 this had significantly (P<0.05) more calcium than in Harvest 1. The calcium values reported by Sparks (2003) for the leaf (1.55%) and stem (0.83%) material of *C. sturtii* were intermediate between those obtained in Harvests 1/ 3 and Harvest 5.

According to many researchers leguminous crops are good sources of calcium (Van Der Merwe, 1974; N.A.S., 1975; McDonald et al., 1996; Sparks, 2003). In this trial, however, both leguminous shrubs (*C. sturtii* and *S. microphylla*) had lower concentrations of calcium than the non-leguminous species (*T. sinuatum*). All three were, however, able to meet the nutritional nutrient requirements of sheep (0.21-0.52%) and goats (0.138%)(NRC 1981, 1985).

- **Phosphorus**

Except for Harvest 1, no significant (P>0.05) differences were observed in the concentrations of phosphorus in the leaf material, between the three species, in all harvests. In Harvest 1 both indigenous species had higher (P<0.05) concentrations of phosphorus in the leaf material than *C. sturtii* (Table 4). In the stem samples of Harvests 1 and 3 both *S. microphylla* and *C. sturtii* had significantly (P<0.05) higher concentrations of phosphorus than *T. sinuatum*. In Harvest 5 no significant (P>0.05) differences were observed in the phosphorus concentrations in the stem material. In *S. microphylla* the phosphorus concentrations in the stem material decreased (P<0.05) with age. The phosphorus concentrations in the leaf material of this species tended to decrease with age as well, with concentrations in Harvest 1 being higher (P<0.05) than in Harvests 3 and 5. Although the phosphorus concentrations of *T. sinuatum* also tended to decrease with age, in this species the phosphorus concentration in the leaves was significantly ($P<0.05$) higher in Harvests 1 and 3 than in Harvest 5. No significant differences ($P>0.05$) were observed in the phosphorus concentration in the stem material of *T. sinuatum* or the leaf material of *C. sturtii* (Table 4), in all harvests. In the stem material of *C. sturtii* phosphorus concentrations in Harvests 1 and 3 were similar and both were significantly ($P<0.05$) higher than in Harvest 5.

Except for the stem sample of Harvest 5, phosphorus concentrations in *C. sturtii,* in this trial, were much higher than those reported by Sparks (2003), for both leaf (0.152%) and stem material (0.194%), in all harvests.

In South Africa, phosphorus is generally deficient in a number of forages (Meissner et al., 1999). This is further aggravated by, nutrients such as nitrogen and phosphorus needing to be dissolved in water in order for them to be taken up by plants. With water being scarce in arid and semi-arid areas, such nutrients become even more limiting (Lovegrove, 1993). In this trial, however, only the stem material of all three species in Harvest 5 and the stem material of *T. sinuatum* in Harvest 3 were unable to meet the phosphorus nutrient requirements (0.16-0.37%) of sheep. The shrub as a whole, however, would fulfil sheep maintenance requirements.

For the metabolism of calcium and phosphorus to take place it is important that these two minerals be supplied in the correct ratio. A Ca: P ratio of between 1:1 or 2:1 of calcium: phosphorus is considered to be an ideal ratio, to ensure good growth and bone formation (McDonald, et al., 2002). Higher or lower levels of either mineral may lead to poor utilisation of the other mineral.

Research, however, has shown that, where there is adequate dietary levels of each mineral and a sufficient supply of vitamin D, ruminants are able to tolerate much wider calcium: phosphorus ratios (McDonald, et al., 2002). A number of researchers believe that ruminants are capable of tolerating calcium: phosphorus ratios of up to 7:1 and even 9:1 (Wise, et al., 1963; Young, et al., 1966; Call, et al., 1978; McDonald, et al., 2002). Calcium: phosphorus ratios, however, that are higher than 7:1 or lower than 1:1 (e.g. 0.5:1) result in poor nutrient conversion, reduced growth and poor performance (Wise, et al., 1963; Young, et al., 1966; McDonald, et al., 2002).

Table 5 The calcium to phosphorus ratio (LS mean) in the different plant parts of *C. sturtti, S. microphylla* and *T. sinuatum*, over time

Treatment	Plant part	*C. sturtii*	*S. microphylla*	*T. sinuatum*
Harvest 1	Leaves	3.0:1 $^{b}_{2}$ (±0.86)*	3.3:1 $^{bc}_{2}$ (±0.81)*	8.8:1 $^{c}_{1}$ (±2.42)*
	Stems	2.0:1 $^{b}_{1}$ (±0.24)	0.9:1 $^{c}_{1}$ (±0.12)	3.5:1 $^{d}_{1}$ (±0.00)
Harvest 3	Leaves	4.9:1 $^{b}_{2}$ (±0.85)	7.5:1 $^{a}_{2}$ (±2.39)	14.2:1 $^{b}_{1}$ (±2.26)
	Stems	2.6:1 $^{b}_{12}$ (±1.98)	1.5:1 $^{c}_{2}$ (±0.33)	5.6:1 $^{cd}_{1}$ (±2.21)
Harvest 5	Leaves	9.0:1 $^{a}_{2}$ (±1.68)	5.4:1 $^{ab}_{3}$ (±1.04)	18.9:1 $^{a}_{1}$ (±3.05)
	Stems	9.9:1 $^{a}_{2}$ (±3.71)	3.0:1 $^{bc}_{3}$ (±0.00)	13.3:1 $^{b}_{1}$ (±5.50)

^{ab} Column means with common superscripts do not differ significantly (P>0.05)

$_{12}$ Row means with common subscripts do not differ significantly (P>0.05)

* Values in brackets represent standard deviations

With the exception of the stem material of *C. sturtti* in Harvests 1 and 3, *T. sinuatum* had the highest (P<0.05) Ca:P ratios, for both the leaf and stem material, of all three species, throughout the experimental period. In Harvest 5 *C. sturtti* had higher (P<0.05) Ca:P ratios in both the leaf and stem material than *S. microphylla* (Table 5). In *T. sinuatum* the leaf material had higher (P<0.05) ratios than the stem material. In the leaf material of *T. sinuatum* the ratio of calcium to phosphorus increased (P<0.05) with age (Table 5). Although this also appeared true for the stem material, no significant (P>0.05) differences were observed between Harvests 1 and 3. The Ca:P ratio in Harvest 5, however, was significantly (P<0.05) higher than either of the earlier harvests. In the leaf material of *S. microphylla* significantly higher (P<0.05) Ca:P ratios were observed in Harvest 3 than Harvest 1 (Table 5). Only in Harvest 3 had the leaf material of this species higher (P<0.05) Ca:P ratios than the stem material. No significant (P>0.05) differences were observed in the calcium to phosphorus ratios between the leaf and stem material of *C. sturtii* (Table 5). The Ca:P ratios in both the leaf and stem material of *C. sturtii* increased significantly (P<0.05) from Harvest 3 to Harvest 5 (Table 5). The Ca:P ratios of the leaf and stem material of *C. sturtii* were significantly (P<0.05) better in Harvests 1 and 3 than the ratios observed in Harvest 5 (Table 5). In Harvest 5 both the leaf and stem material of *C. sturtii* had Ca:P ratios that would be considered too high for the proper utilization of these two minerals in ruminants (Wise, et al., 1963; Young, et al., 1966; Call, et al., 1978; McDonald, et al., 2002). The calcium: phosphorus ratio in the leaf material of *T. sinuatum* was high in all harvests and it was, therefore, doubtful whether these minerals would be well utilized in this plant material. The stem material of *T. sinuatum* was lower in the earlier harvests. By Harvest 5, however, the Ca:P ratio in stem material of *T. sinuatum* was higher than the recommended ratios of calcium: phosphorus, for ruminants (Wise, et al., 1963; Young, et al., 1966; Call, et al., 1978; McDonald, et al., 2002). Only in Harvest 3 did the Ca:P ratios in the leaf material of *S. microphylla* reach levels that might result in these minerals not being optimally utilized (Table 5). With phosphorus levels that decreased with age, supplementing phosphorus should be considered in order to decrease the ratio of calcium: phosphorus, which increased as the phosphorus levels decreased, in older plant material of both *C. sturtii* and *T. sinuatum*.

- **Trace Minerals**
  - **Copper**

Two abnormally high concentrations of copper were found in Harvest 1, in the leaf material of *C. sturtii* and the stem material of *S. microphylla* (Table 6). This may have been due to too little plant material being available for the analysis or too few surviving plants being harvested. These two values were, therefore, not taken into consideration.

No significant (P>0.05) differences were observed between the plant parts or species, in all other samples. In both indigenous species the copper concentration in the leaf material had a tendency to decrease with age, although this was not significant. This also appeared to be true for the stem material of *T. sinuatum* (not significant) (Table 6).

Copper concentrations in *C. sturtii* reported by Sparks (2003), which were 14.0mg/kg and 13.0mg/kg for leaf and stem material respectively, coincided with the concentrations found in Harvest 1 in the *C. sturtii* stem samples. In Harvests 3 and 5, however, concentrations were lower in both the leaf and stem material, especially in Harvest 3. In all harvests, all species fulfilled the maintenance requirements of sheep (5mg/kg) (NRC 1985) and possible toxicity was of more concern. Although dangerous levels are only reached at about 1000mg/kg fat-free DM, researchers have found that fodder supplying as little as 20mg/kg copper on a regular basis can lead to the accumulation of this mineral in the liver.

Table 6 The copper, manganese and zinc concentrations (mg/kg) (LS mean) in the different plant parts of *C. sturtti, S. microphylla* and *T. sinuatum*, over time

Treatment	Plant part	Species	Copper	Manganese	Zinc
Harvest 1	Leaves	*C. sturtii*	-	82.3^{a}_{3} (±18.13)*	48.9^{a}_{23} (±13.31)*
		S. microphylla	16.5^{b}_{3} (±3.21)	299.2^{a}_{2} (±87.77)	124.3^{a}_{1} (±28.65)
		T. sinuatum	26.4^{a}_{23} (±15.27)	569.2^{a}_{1} (±170.44)	131.0^{a}_{1} (±40.02)
	Stems	*C. sturtii*	13.9^{b}_{3} (±10.29)	45.2^{a}_{3} (±35.67)	38.1^{a}_{3} (±27.00)
		S. microphylla	-	63.6^{cd}_{3} (±24.81)	100.3^{ab}_{12} (±53.88)
		T. sinuatum	15.4^{a}_{3} (±5.68)	256.3^{b}_{2} (±31.81)	76.7^{ab}_{13} (±29.48)
Harvest 3	Leaves	*C. sturtii*	6.1^{b}_{1} (±1.06)	47.8^{a}_{2} (±29.34)	37.1^{a}_{2} (±2.05)
		S. microphylla	12.8^{b}_{1} (±2.15)	176.9^{b}_{1} (±56.83)	126.0^{a}_{1} (±138.01)
		T. sinuatum	17.5^{a}_{1} (±2.00)	210.0^{b}_{1} (±37.06)	60.6^{b}_{2} (±7.51)
	Stems	*C. sturtii*	6.0^{b}_{1} (±0.07)	21.2^{a}_{2} (±4.17)	30.4^{a}_{2} (±5.30)
		S. microphylla	9.4^{b}_{1} (±1.27)	28.8^{d}_{2} (±7.93)	39.5^{bc}_{2} (±17.29)
		T. sinuatum	14.5^{a}_{1} (±0.70)	53.8^{c}_{2} (±12.26)	31.8^{b}_{2} (±5.03)
Harvest 5	Leaves	*C. sturtii*	10.0^{b}_{1} (±2.86)	38.8^{a}_{3} (±5.93)	21.4^{a}_{1} (±8.75)
		S. microphylla	9.3^{b}_{1} (±3.73)	134.3^{bc}_{2} (±35.08)	31.8^{c}_{1} (±4.60)
		T. sinuatum	15.4^{a}_{1} (±1.04)	225.0^{b}_{1} (±47.45)	68.0^{b}_{1} (±9.02)
	Stems	*C. sturtii*	10.3^{b}_{1} (±4.47)	15.6^{a}_{3} (±2.18)	28.9^{a}_{1} (±19.03)
		S. microphylla	13.1^{b}_{1} (±4.48)	32.1^{d}_{3} (±2.29)	26.0^{c}_{1} (±9.00)
		T. sinuatum	11.1^{a}_{1} (±1.24)	84.7^{c}_{23} (±12.05)	33.2^{b}_{1} (±6.89)

^{ab} Column means with common superscripts, within a species, do not differ significantly (P>0.05)

$_{12}$ Column means with common subscripts, within a harvest, do not differ significantly (P>0.05)

* Values in brackets represent standard deviations

Once accumulate copper has reached dangerous levels, it could lead to chronic copper poisoning (Van Der Merwe, 1974; McDonald et al., 1996; Sparks, 2003). In situations where copper poisoning might occur McDonald et al. (1996), cited by Sparks (2003), suggested that molybdenum or sulphate should be administered to treat the poisoning.

Although used in the treatment of copper poisoning, according to the N.R.C. (1985), the "Food and Drug Administration" consider molybdenum unsafe and the addition of molybdenum to feed, unless prescribed by a veterinarian, is prohibited. Where poisoning, due to copper accumulation, is a common occurrence, however, the storage of copper in the liver can be reduced by high dietary concentrations of zinc (100mg/kg on a DM basis) (Pope, 1971; McDonald et al., 1996).

- **Manganese**

The leaf material of both indigenous species contained significantly (P<0.05) more manganese than *C. sturtii* in all harvests. In Harvest 1 *T. sinuatum* had the highest (P<0.05) concentrations of manganese in both leaf and stem material. No significant (P>0.05) differences were, however, observed in manganese concentration in the stem material of all three species in Harvests 3 and 5. Manganese concentrations in the leaf material of *S. microphylla*, had a tendency to decrease with age. In the leaf material of this species, higher (P<0.05) concentrations of manganese were observed in Harvest 1 than in Harvests 3 and 5. This was also true for the leaf and stem material of *T. sinuatum.* In *T. sinuatum*, however, manganese concentrations, in both the leaf and stem material, had not decreased with age and appeared lower (not significant) in Harvest 3 than Harvest 5. In all harvests both indigenous species had higher (P<0.05) concentrations of manganese in the leaf material than in the stem material (Table 6). In *C. sturtii* no significant (P>0.05) differences were observed between the plant parts or harvests. In Harvests 1 and 3 manganese concentrations in *C. sturtii* were higher than those reported by Sparks (2003), in both leaf (37.0 mg/kg) and stem material (14.0 mg/kg). In Harvest 5, however, concentrations were similar to those reported by Sparks (2003).

All species were able to meet the nutrient requirements of sheep (20-40 mg/kg) (NRC, 1985). According to the N.R.C. (1985) 1000mg/kg is the maximum level of manganese that sheep are able to tolerate.

- **Zinc**

In Harvest 1 both indigenous species had higher (P<0.05) zinc concentrations in the leaf material than *C. sturtii*. Only *S. microphylla* had significantly higher zinc concentrations in the stem material than *C. sturtii* in Harvest 1. Except for *S. microphylla* leaf material in Harvest 3, no significant (P>0.05) differences were

observed within and between the different species, for leaf and stem samples of Harvests 3 and 5 (Table 6). In Harvest 3 leaf samples of *S. microphylla* had significantly (P<0.05) higher zinc concentrations than either of the other species. *S. microphylla* had lower (P<0.05) zinc concentrations in Harvest 5, in both leaf and stem material, than Harvest 1. The zinc concentrations in the stem material of *S. microphylla* had a tendency to decrease with age and significantly (P<0.05) lower concentrations of zinc were observed in Harvest 5 than Harvest 1. No significant (P>0.05) differences were observed in the stem material of *T. sinuatum,* as well as in the leaf and stem material of *C. sturtii*. In the leaf material of *T. sinuatum* zinc concentrations in Harvests 3 and 5 were significantly (P<0.05) lower than in Harvest 1. When compared to values reported by Sparks (2003) for leaf (22mg/kg) and stem (24mg/kg) material of *C. sturtii*, only the zinc concentration of *C. sturtii* leaves in Harvest 5 were lower.
In both indigenous species only shrubs harvested in Harvests 1 and 3, at approximately eight and twenty weeks of age, were able to supply sufficient zinc to fulfil the maintenance requirements of sheep (35-50 mg/kg) (NRC 1981, 1985). *C. sturtii* only had adequate zinc concentrations in Harvest 1. In Harvest 5, at approximately seven months of age (thirty-two weeks) only *T. sinuatum* leaf material had adequate (68.0mg/kg) concentrations of zinc. When considering the low proportion of leaf material (34.2%) in this species, however, this too may be insufficient for livestock. Taking into account the levels of copper observed in all three species, it might be necessary to supplement animal diets with zinc. Not only to ensure that they receive sufficient levels of zinc, but also to reduce the accumulation of copper in the animal's liver and thus prevent chronic copper poisoning (Pope, 1971; McDonald et al., 1996).

With the exception of zinc all three species were able to supply sufficient levels of macro and trace minerals to fulfil the nutrient requirements of sheep and, in the case of copper, was even close to having toxic effects, where accumulation of this element may occur.

Conclusion

The findings of this trial, coinciding with those of Sparks (2003), confirm that *C. sturtii*, *T. sinuatum* and *S. microphylla*, could, with appropriate mineral supplementation, be used as replacements for *Atriplex spp*., due to them having sufficient crude protein, a good digestibility and, in young growth, a high percentage of leaf. *S. microphylla*, however, although containing similar concentrations of crude protein as *M. sativa* (lucerne) (Bredon et al., 1987; Meissner et al., 1999), in the leaf material, also contains the non-protein amino acid, L-canavanine. When consumed L-canavanine may have toxic effects on the micro-organisms in the rumen resulting in a decrease in the rate of rumen fermentation (Dixon, et al., 1983; Dixon & Hosking, 1992). Animals may also be affected by toxic effects of canaline, one of the breakdown products of L-canavanine (Enneking, 1994).
Lailhacar-Kind, (1986) believed that using a number of different species is more advantageous than a pure stand of a single species, as this will prevent nutrient deficiencies and reduce the risk of toxicity. Randomly establishing a combination of these shrubs in the natural rangeland might, therefore, be an option.

In terms of nutritive value all three species could be potential fodder shrub species. It is, however, also important to know whether shrubs are able to recover from utilization. A further trial was, therefore, conducted to determine the ability of the plants that were harvested at different harvest dates to re-grow.

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Chapter 7

The impact of stage of harvest on the re-growth of three fodder shrub species *

T.E. Wilcock[1], N.F.G. Rethman[1], W.A. van Niekerk[2] and R.J. Coertze[2]

[1] Department of Plant Production and Soil Science, University of Pretoria, Pretoria, 0002, South Africa.
[2] Department of Animal and Wildlife Sciences, University of Pretoria, Pretoria, 0002, South Africa.

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Abstract

In degraded rangelands farmers often establish fodder shrubs to improve the grazing capacity. When selecting a species, production, nutritive value, palatability, as well as the species' tolerance to defoliation and ability to recover, must be determined. The objective of this trial was to determine the effect of stage of harvest on re-growth of three species namely, *Cassia sturtii* (an exotic fodder species), and two indigenous species, *Sutherlandia microphylla* and *Tripteris sinuatum*.

In this trial *C. sturtii, S. microphylla* and *T. sinuatum* had an average percentage survival of ± 69%, ±49% and ±25%, respectively. After Harvests 4 and 5 significantly ($P<0.05$) more *C. sturtii* shrubs survived than either of the other species. The surviving shrubs of both indigenous species were also less ($P<0.05$) healthy and leafy after these harvests. Although *S. microphylla* shrubs, with a re-growth period of 39 to 45 weeks, were the largest ($P<0.05$) in volume, this species produced the least ($P<0.05$) dry matter. *C. sturtii*, after 39 to 45 weeks of re-growth produced more ($P<0.05$) material than after only 21 to 27 weeks of re-growth. *C. sturtii'* shrubs with 39 to 45 weeks re-growth produced a bushy shrub with a DM yield of approximately one kilogram.

Keywords: production, survival, *Cassia sturtii, Sutherlandia microphylla, Tripteris sinuatum,*

Introduction

In many of the arid and semi-arid areas South Africa the vegetation is dominated by drought tolerant, woody, shrubs (Le Roux et al., 1994). These are classified as such because of the ability to survive long droughts and continue to produce edible plant material under low rainfall conditions (De Kock, 1980; Sparks, 2003). These shrubs provide a vital source of forage and play an important role in the nutrition of livestock (Le Roux et al., 1994; Bosch, 1999), especially in times of drought (Donaldson & Vorster, 1989; Meissner et al., 1999; Vorster, 1999). Overgrazing and poor management, which leads to too intense or too frequent browsing, has, however, led to the degradation and desertification of a number of arid and semi-arid areas in South Africa (Acocks, 1988; Bosch, 1999). According to Esler & Phillips (1994), poor management practices are mainly due to a lack of knowledge about such drought tolerant shrubs and the browsing management required to ensure sustainable production.

Early studies, to determine the effect of defoliation on the growth and the physiology of plants, were concentrated on grasses. The results were incorrectly assumed to be applicable to shrubs. Livestock management strategies were often based on such information. This is perhaps the reason for much of the degradation that has taken place in arid and semi-arid areas of South Africa (Van Der Heyden & Stock, 1999). Recent studies, however, have shown that shrubs differ from grasses, in a number of ways. Shrubs, when producing new foliage, rely more heavily on carbohydrate reserves and for a more extended period than grasses (Van Der Heyden & Stock, 1999). Secondly, shrubs have a higher concentration of micronutrients, as well as less variable crude protein and phosphorus contents (Beukes, 1976; Meissner et al., 1999). Thirdly, unlike grasses, shrubs are rarely able to re-establish themselves vegetatively following heavy browsing (O'Connor & Pickett, 1992). Browsing is, therefore, more detrimental to the "demography" of shrubs than grazing is to grass (Milton, 1992; Van Der Heyden & Stock, 1999).

Van Der Heyden & Stock (1999) believed that meristematic factors were the main determinants in the rate of re-growth. Unlike grasses, shrubs grow from the meristematic centres at the tips of branches. Due to this location of the meristematic zones, shrubs are more susceptible to defoliation (Van Der Heyden & Stock, 1999). Although meristematic zones can also be found in the axillary buds ("epicomic" buds) located along the stems, the apical buds at the tips of branches exert apical dominance over the axillary buds. When shrubs are pruned, browsed or burnt, the terminal apical meristems are removed and apical dominance lost. Once apical dominance is decreased/lost, new shoots sprout from dormant and "epicomic" buds located in the lower stem and root collar regions (Kramer & Kozlowski, 1979), resulting in a "bushy" shape. These dormant buds vary in number and distribution among different shrubs species (Zimmerman & Brown, 1969), resulting in varying re-growth capacities (Hobson & Sykes, 1980; Vorster et al., 1983; Van Der Heyden & Stock, 1995; Van Der Heyden & Stock, 1999).

The objective of this trial was, therefore, to determine the effect of stage of harvest on re-growth. Three species namely, *Cassia sturtii* (an exotic fodder shrub species), and two indigenous shrub species, *Sutherlandia microphylla* and *Tripteris sinuatum* were studied.
These three species were also used in "On Farm" trials, in the Northern Cape, as part of a project, which involved evaluating forage shrubs for use in rangeland reclamation.

Materials and Method

- **Study Area**

This trial was conducted on the Hatfield Experimental Farm of the University of in Pretoria (co-ordinates 025º 15'28.9" E, 25º45'03.6"S) at an altitude of 1360m (Sparks, 2003). The area experiences maximum temperatures, which reach above 30ºC and minimum temperatures above 15ºC in the summer months and winter temperatures of between 8ºC and 22ºC. Winter temperatures can, however, be much lower and frost occurs quite frequently in the winter months (Sparks, 2003; Weather S.A., 2007). Pretoria receives a summer rainfall of 650mm with 50% falling during the November to January period (Sparks, 2003). Shrubs were, however, irrigated to eliminate moisture stress as a limiting factor.

The soil was a well-drained Hutton form with 35% clay (MacVicar et al., 1977). A representative sample of the topsoil (± 30cm) was analysed. Results showed the soil to be slightly acidic, with a $pH_{(H2O)}$ of 5.6, and a nutrient status for phosphorus, calcium, potassium, magnesium and sodium of 14.8mg/kg, 764mg/kg, 141mg/kg, 213mg/kg and 16mg/kg, respectively.

- **Materials**

An experimental paddock of *C. sturtii*, *S. microphylla* and *T. sinuatum* shrubs, which had previously been established on the University Experimental Farm in Pretoria, was used in this trial. The camp had initially been established for trials in which the quantity and quality of the plant material of these three species, harvested at different stages of growth, was determined (Wilcock, et al., 2009a, b). Due to the possible influence of the leguminous species (*C. sturtii* and *S. microphylla*) on the non-leguminous specie (*T. sinuatum*), plots were established with wide spacing between and within rows. Available space was, however, limited. The layout shown in Figure 1 was, therefore, used to allow more plots within the area available.

- **Method**

Initially four replicates (plots) of each species were harvested on each of five different harvest dates. These harvest dates were six weeks apart (Figure 1). After the initial trial had been completed a period of time was allowed for re-growth to occur (22 December 2003 to 23 May 2004) when all shrubs were harvested (on the same day) and analysed in terms of re-growth.

In the initial trial the first harvest (Harvest 1) was on the 7th of July 2003 and the final harvest (Harvest 5) on the 22nd of December 2003. The harvest of the re-growth material was, therefore, approximately 45 weeks after Harvest 1 and 21 weeks after the fifth and final production harvest (Table 1).

Table 1 Approximate weeks and days of re-growth after the different harvests

Harvest	Weeks of re-growth	Actual days of re-growth
Harvest 1	45 weeks	318 days
Harvest 2	39 weeks	268 days
Harvest 3	33 weeks	236 days
Harvest 4	27 weeks	194 days
Harvest 5	21 weeks	152 days

Before re-growth was harvested the percentage survival was determined and shrubs were rated according to leafiness and healthiness. At the same time the volume of the surviving shrubs was determined. Once these data had been gathered, *C. sturtii* and *S. microphylla* shrubs were harvested at twenty centimetres above ground level. Due to the prostate growth form of *T. sinuatum*, its branches were gathered up and cut off at twenty centimetres above ground level.

Data collected included:

1. **Percentage survival** The number of surviving shrubs per plot was determined in order to calculate the percentage survival on each treatment.

2. **Healthiness** - Each plant was given a rating of healthiness (Table 2) by four independent observers to ensure there was no bias.

Table 2 Rating of healthiness

Rating	Healthiness
1	Very healthy
2	Healthy
3	Alive but not doing well
4	Alive but just
5	Dead

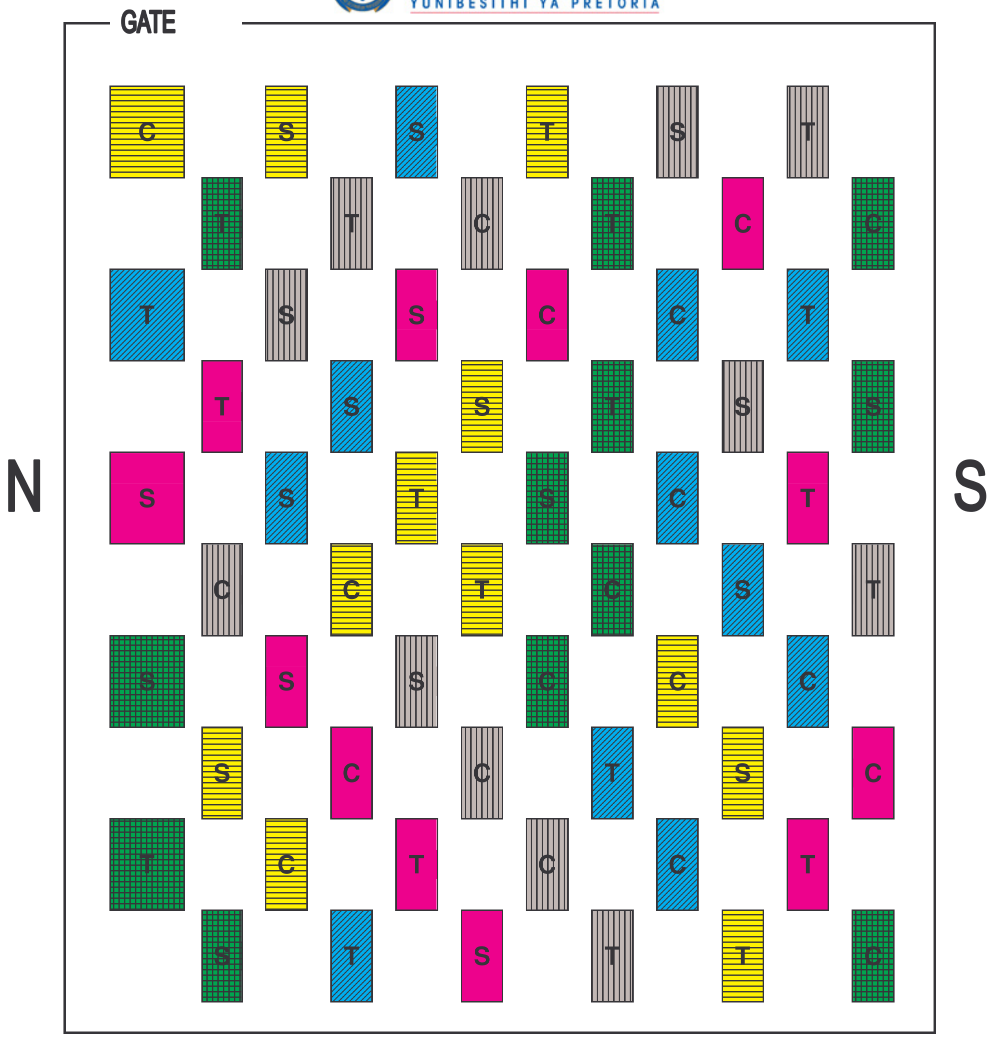

Figure 1 Field layout of trial to assess the growth and re-growth of *Cassia sturtii, Sutherlandia microphylla* and *Tripteris sinuatum*

Where:
C = *Cassia sturtii*
S = *Sutherlandia microphylla*
T = *Tripteris sinuatum*

Represents the plots harvested 6 weeks (H1) after the establishment phase.

Represents the plots harvested 12 weeks (H2) after the establishment phase.

Represents the plots harvested 18 weeks (H3) after the establishment phase.

Represents the plots harvested 24 weeks (H4) after the establishment phase.

Represents the plots harvested 30 weeks (H5) after the establishment phase.

3. **Leafiness -** According to Watson et al. (1987), cited by Sparks (2003), leafiness and nutritive value are directly linked, and leafiness is an indication of the quality of the forage. At the same time as the "Healthiness ratings" were made each plant was also given a rating of leafiness (Table 3). Four independent observers also did these ratings to ensure there was no bias.

Table 3 Rating of leafiness

Rating	Leafiness
1	Very leafy (80-100% leaf cover)
2	Slightly less but still quite leafy (50-80% leaf cover)
3	Below average amount of leaves (30-50% leaf cover)
4	Very few leaves present (10-30% leaf cover)
5	No leaves present

4. **Occurrence of flowering -** At the same time as the foregoing ratings were being done, a simple yes or no was used to record whether the shrubs were in flower or not. Whether any seedlings had established around the shrubs was also noted.

5. **Volume -** The height and width of each shrub was used to determine the volume of the shrubs according to a cylindrical shape. ($V=\pi r^2 h$).

6. **Dry Matter yield -** After all this data had been collected (healthiness, leafiness, volume and flowering), all surviving shrubs were harvested at 20 cm above ground level. Plant material was then air dried and weighed.

For all of the above observations results were averaged per plant, according to the number of surviving shrubs, within the plot. Analysis of variance using the GLM model (Statistical Analysis Systems, 2001) was used in order to determine the significance between the different species and plant parts after different periods of re-growth. LS Means and standard deviations (SD) were calculated. The significance of difference (5%) between means was determined by using Bonferroni's test (Samuels, 1989).

Results and Discussion

- **Percentage survival**

Over all harvest treatments *C. sturtii* tended to exhibit the best persistence (Table 4). Except for Harvest 3, *C. sturtii* had a higher (P<0.05) percentage survival than *T. sinuatum* in all harvests. In Harvests 4 and 5, where shrubs were harvested at approximately twenty six and thirty two weeks after the establishment, the percentage survival of *C. sturtii* was also significantly (P<0.05) higher than that of *S. microphylla* (Table 4). The percentage survival of *C. sturtii* in the different harvests remained relatively high, with the exception of Harvest 3, which had a significantly (P<0.05) lower percentage survival than Harvest 2. This species is susceptible to frost and in the initial production trial a substantial proportion of the plant material harvested in Harvest 3 had been damaged by frost (Wilcock et al., 2009a). The low percentage survival was most likely a combined effect of time of harvest and the impact of the frost, to which this species is particularly susceptible.

Table 4 Percentage survival (LS mean) of *C. sturtii*, *S. microphylla* and *T. sinuatum* shrubs, harvested at different stages of growth

Treatment	*C. sturtii*	*S. microphylla*	*T. sinuatum*
Harvest 1	75.0^{ab}_{1} (±10.00)*	85.0^{a}_{1} (±19.15)*	30.0^{a}_{2} (±11.55)*
Harvest 2	85.0^{a}_{1} (±10.00)	55.0^{ab}_{12} (±44.35)	20.0^{a}_{2} (±16.33)
Harvest 3	40.0^{b}_{1} (±23.09)	50.0^{ab}_{1} (±38.30)	40.0^{a}_{1} (±28.28)
Harvest 4	75.0^{ab}_{1} (±19.15)	25.0^{b}_{2} (±25.17)	10.0^{a}_{2} (±11.55)
Harvest 5	70.0^{ab}_{1} (±34.64)	30.0^{b}_{2} (±25.82)	25.0^{a}_{2} (±19.15)

^{ab} Column means with common superscripts do not differ (P>0.05)

$_{12}$ Row means with common subscripts do not differ (P>0.05)

* Values in brackets represent the standard deviation

Survival in *S. microphylla* tended to decrease as the age at the initial harvest increased (Table 4). *S. microphylla* shrubs that had been harvested at approximately eight weeks after establishment, had a significantly (P<0.05) higher survival rate than those harvested in Harvests 4 and 5, at approximately twenty six to thirty two weeks after establishment (Table 4). It was most likely that the older shrubs had most of the meristematic growth points removed and were, therefore, unable to survive and re-grow, when harvested at 20cm above the soil. When initially harvested at approximately 8 weeks after establishment (Harvest 1), significantly more (P<0.05) *S. microphylla* and *C. sturtii* shrubs survived than *T. sinuatum*. Except for Harvests 3 and 4 *T. sinuatum* had the lowest (P<0.05) percentage survival of the species, with initial growth stage, or length of re-growth period, appearing to have no clear effect (Table 4). No more than 40% of all *T. sinuatum* shrubs survived in any of the different harvests (Table 4). Over the entire trial *C. sturtii, S. microphylla* and *T. sinuatum* had average survival rates of ± 69%, ±49% and ±25%, respectively.

- **Healthiness**

Keeping in mind that a rating of 5 was the equivalent of dead and 1 very healthy (Table 2), *C. sturtii* shrubs, harvested in the 3rd harvest (29th September 2003) were significantly (P<0.05) less healthy than those in any other harvest, having been given a rating of "alive but not doing well" (Table 5). This was most likely a combined effect of the impact of frost and time of defoliation. In all other harvest's *C. sturtii* shrubs were rated either healthy or very healthy. No significant (P>0.05) differences were observed between the three species in Harvest 3 (with thirty three weeks of re-growth). *T. sinuatum* shrubs in Harvest 3 were significantly (P<0.05) healthier than in any of the other harvests. In Harvest 5 (twenty one weeks of re-growth) both *S. microphylla* and *T. sinuatum* shrubs were observed to be barely alive (Table 5). For all other harvests (Harvests 1, 2 and 4) *T. sinuatum* was rated as significantly (P<0.05) less healthy than either of the other species. As with the survival rate, *T. sinuatum* shrubs did not appear to be doing well, irrespective of when they were initially harvested, or the length of the re-growth period. All *T. sinuatum* shrubs were rated between a 3 and a 4, which "alive but not doing well" or "alive, but only just" (Table 5). In the case of *S. microphylla*, which was not as sensitive to frost, general healthiness, as with survival rate, appeared to decrease with the increase in age at initial harvest (Table 5).

Table 5 The Mean Healthiness Rating (LS mean) of the re-growth of *C. sturtii, S. microphylla* and *T. sinuatum*, on a scale of 1-5, after different stages of harvest

Treatment	*C. sturtii*	*S. microphylla*	*T. sinuatum*
Harvest 1 (45 weeks re-growth)	2.1 (±0.36)* $^{bc}{}_{2}$	2.2 (±0.30)* $^{c}{}_{2}$	3.8 (±0.43)* $^{b}{}_{1}$
Harvest 2 (39 weeks re-growth)	1.7 (±0.29)$^{c}{}_{3}$	3.0(±1.18)$^{b}{}_{2}$	4.1 (±0.31)$^{b}{}_{1}$
Harvest 3 (33 weeks re-growth)	3.3 (±0.98)$^{a}{}_{1}$	3.4 (±0.72)$^{b}{}_{1}$	3.1 (±0.51)$^{c}{}_{1}$
Harvest 4 (27 weeks re-growth)	2.2 (±0.72)$^{b}{}_{3}$	4.0 (±0.66)$^{a}{}_{2}$	4.6 (±0.26)$^{a}{}_{1}$
Harvest 5 (21 weeks re-growth)	2.5 (±1.22)$^{b}{}_{2}$	4.1 (±0.79)$^{a}{}_{1}$	3.8 (±0.80)$^{b}{}_{1}$

^{ab} Column means with common superscripts do not differ (P>0.05)

$_{12}$ Row means with common subscripts do not differ (P>0.05)

* Values in brackets represent standard deviations

S. microphylla shrubs from Harvest 1 (forty five weeks of re-growth) were significantly (P<0.05) healthier than in any of the other harvests. Shrubs from Harvests 2 and 3 (with thirty nine and thirty three weeks of re-growth, respectively) were also doing significantly (P<0.05) better than shrubs from Harvests 4 and 5 (with twenty seven and twenty one weeks of re-growth, respectively). Shrubs, which had had twenty one to twenty seven weeks (Harvests 4 and 5) to re-grow, were given a rating of "alive but just".

- **Leafiness**

As with healthiness, shrubs were given a rating of 1 to 5, where 1 was equal to "very leafy (80-100%)" and 5 was equal to "No leaves present". For both *C. sturtii* and *T. sinuatum* the leafiness and healthiness appeared highly correlated. As with the healthiness, *C. sturtii* experienced a significant (P<0.05) decrease in leafiness in shrubs that had a re-growth of thirty-three weeks after a winter defoliation. This was, once again, assumed to be a combined effect of harvesting and the effect of frost on this species. With the exception of Harvest 3 (with thirty three weeks of re-growth) *C. sturtii* had significantly (P<0.05) more leaf material than either of the other two species (Table 6).

Table 6 The Mean Leafiness Rating (LS mean) of the re-growth of *C. sturtii, S. microphylla* and *T. sinuatum*, on a scale of 1-5, after different stages of harvest

Treatment	*C. sturtii*	*S. microphylla*	*T. sinuatum*
Harvest 1 (45 weeks re-growth)	2.1^{bc}_{3} (±0.41)*	3.0^{b}_{2} (±0.45)*	3.7^{b}_{1} (±0.47)*
Harvest 2 (39 weeks re-growth)	1.7^{c}_{2} (±0.33)	3.7^{a}_{1} (±0.85)	4.1^{b}_{1} (±0.32)
Harvest 3 (33 weeks re-growth)	3.3^{a}_{1} (±1.00)	3.6^{a}_{1} (±0.75)	3.2^{c}_{1} (±0.52)
Harvest 4 (27 weeks re-growth)	2.1^{bc}_{3} (±0.74)	3.8^{a}_{2} (±0.77)	4.7^{a}_{1} (±0.25)
Harvest 5 (21 weeks re-growth)	2.3^{b}_{2} (±1.23)	3.7^{a}_{1} (±0.87)	3.8^{b}_{1} (±0.77)

^{ab} Column means with common superscripts do not differ (P>0.05)

$_{12}$ Row means with common subscripts do not differ (P>0.05)

* Values in brackets represent the standard deviation

S. microphylla shrubs in Harvest 1 (with 45 weeks of re-growth) had significantly (P<0.05) more leaf material than any of the other harvests.

Although this species started with a lot of leaf material, this decreased with time and at the time of the re-growth trial the leafiness of these shrubs was and remained poorer than average. For *S. microphylla* the correlation between health and leafiness was not strong. Whether the shrubs were healthy or not, all had been rated as between "Under average amount of leaves (30-50%) and "Very few leaves present (10-30%).

T. sinuatum generally appeared to have the poorest (not always significant) leaf cover (Table 6). As with healthiness in this species, shrubs in Harvest 3 (with thirty three weeks of re-growth) were significantly (P<0.05) leafier than shrubs in any of the other harvests. *T. sinuatum* shrubs in Harvest 4 (with twenty seven weeks of re-growth) had the lowest (P<0.05) leafiness rating of the different harvests (Table 6). This was also significantly (P<0.05) poorer than either of the other species.

While ratings were being conducted and volumes determined, a simple yes or no was used to determine whether the shrubs were in flower or not.

For *S. microphylla* no shrubs were flowering at the time of the re-growth trial (May 2004). These shrubs had, however, flowered during the production trial (2003) and flowers and seed were harvested, along with the plant material, during the months August to November. Throughout both trials, the production trial (July-December 2003) and the re-growth trial (May 2004), there were *T. sinuatum* shrubs in flower. Seeds were also harvested along with flowers, in the production trial. *C. sturtii* did not produce any flowers throughout the production trial. In the re-growth trial only shrubs that had been harvested early on and had, at least thirty three weeks to re-grow were flowering. Shrubs from the first and second initial harvests, as well as some of the shrubs from the third harvest, were in bloom. This did not coincide with observations by Sharp et al. (2000), cited by Sparks (2003), however, where *C. sturtii* flowered in the June to August period with no defoliation treatment.

- **Volume**

S. microphylla shrubs were significantly ($P<0.05$) bigger, in terms of volume, when compared to *C. sturtii*, in Harvests 1 and 2, and *T. sinuatum* in Harvests 1, 2 and 3. No significant differences ($P>0.05$) were observed between the three species in Harvests 4 and 5 (Table 7). For *S. microphylla* the longer the shrubs had to re-grow the larger the volume of the shrubs tended to be, with *S. microphylla* shrubs from Harvests 1, 2 and 3 having significantly ($P<0.05$) larger re-growth volumes, than shrubs from Harvests 4 and 5 (with only twenty seven and twenty one weeks re-growth, respectively) (Table 7). *C. sturtii* also tended to be smaller in volume when given less time to re-grow (Table 7) with shrubs in Harvests 1 and 2 (with forty five and thirty nine weeks of re-growth, respectively) being significantly ($P<0.05$) larger in volume than shrubs from Harvest 5 (with only twenty one weeks of re-growth). Although *C. sturtii* shrubs only reached a volume of approximately $740cm^3$, in Harvest 2, they had a rounder shape to, which was assumed to be due to the removal of the meristematic buds. *C. sturtii* shrubs in Harvest 3 did not appear to be as affected by the frost, in terms of volume, as they had been in terms of healthiness and leafiness.

Table 7 Mean Volume (cm^3) of the re-growth (LS mean) of *C. sturtii, S. microphylla* and *T. sinuatum,* after different stages of harvest

Treatment	*C. sturtii*	*S. microphylla*	*T. sinuatum*
Harvest 1 (45 weeks re-growth)	683.5 $^{a}_{2}$ (±103.11)*	1092.3 $^{a}_{1}$ (±228.72)*	309.7 $^{a}_{2}$ (±127.09)*
Harvest 2 (39 weeks re-growth)	736.5 $^{a}_{2}$ (±58.13)	1196.3 $^{a}_{1}$ (±541.91)	341.5 $^{a}_{2}$ (±10.89)
Harvest 3 (33 weeks re-growth)	514.4 $^{ab}_{12}$ (±199.84)	866.0 $^{a}_{1}$ (±696.48)	322.3 $^{a}_{2}$ (±88.84)
Harvest 4 (27 weeks re-growth)	457.4 $^{ab}_{1}$ (±208.17)	300.5 $^{b}_{1}$ (±422.40)	244.2 $^{a}_{1}$ (±126.71)
Harvest 5 (21 weeks re-growth)	253.8 $^{b}_{1}$ (±95.45)	220.9 $^{b}_{1}$ (±32.17)	194.7 $^{a}_{1}$ (±90.87)

^{ab} Column means with common superscripts do not differ (P>0.05)

$_{12}$ Row means with common subscripts do not differ (P>0.05)

* Values in brackets represent standard deviation

T. sinuatum did not follow the same trend as the other two species. Shrubs from different treatments were very similar in terms of volume (Table 7) with no significant (P>0.05) differences being observed between the different harvests (Table 7). This was most probably due to fewer meristematic buds being removed than in the other two species, due to its more prostrate growth form. Shrubs with forty five weeks of re-growth were, however, not much bigger, in terms of height, than those that had shorter periods of re-growth (Table 7).

- **Dry matter yields**

Re-growth of *C. sturtii, S. microphylla* and *T. sinuatum* after harvesting at six, twelve, eighteen, twenty four and thirty weeks after planting, corresponded with forty five, thirty nine, thirty three, twenty seven and twenty one weeks of re-growth respectively. Although both indigenous species appeared to have slight increases in dry matter yield with longer re-growth periods (Table 8), there were no significant (P>0.05) differences between the different harvests (Table 8). In *C.sturtii* the longer the re-growth period, after being harvested, the more dry matter the shrubs produced (Table 8). *C. sturtii* shrubs that had, had twenty seven to forty five weeks to re-grow produced significantly (P<0.05) more dry matter than shrubs which had only had twenty one weeks to re-grow.

Table 8. Dry Matter yield (g/plant) of the re-growth (LS mean) of *C. sturtii, S. microphylla* and *T. sinuatum,* after different stages of harvest

Treatment	*C. sturtii*	*S. microphylla*	*T. sinuatum*
Harvest 1 (45 weeks re-growth)	$1030.4^{ab}{}_{1}$ (±322.99)*	$322.8^{a}{}_{2}$ (±158.40)*	$719.8^{a}{}_{1}$ (±202.49)*
Harvest 2 (39 weeks re-growth)	$1151.3^{a}{}_{1}$ (±114.73)	$365.1^{a}{}_{2}$ (±189.04)	$825.0^{a}{}_{1}$ (±162.63)
Harvest 3 (33 weeks re-growth)	$785.7^{bc}{}_{1}$ (±386.30)	$200.7^{a}{}_{2}$ (±209.48)	$639.6^{a}{}_{1}$ (±260.18)
Harvest 4 (27 weeks re-growth)	$641.5^{c}{}_{1}$ (±303.70)	$146.6^{a}{}_{2}$ (±173.13)	$380.0^{a}{}_{12}$ (±141.42)
Harvest 5 (21 weeks re-growth)	$298.9^{d}{}_{1}$ (±118.67)	$67.8^{a}{}_{1}$ (±63.71)	$433.6^{a}{}_{1}$ (±66.70)

^{ab} Column means with common superscripts do not differ (P>0.05)

$_{12}$ Row means with common subscripts do not differ (P>0.05)

* Values in brackets represent standard deviation

Except for Harvest 5 (with only twenty one weeks of re-growth) *C. sturtii* had significantly (P<0.05) larger re-growth yields than *S. micropylla*. In most of the re-growth periods this species was also healthier and leafier than the other species. *C. sturtii*'s volume was well correlated with dry matter production. This species produced a well rounded "bush" shaped shrub with up to a kilogram of dry matter on shrubs that were initially harvested at eight or fourteen weeks after establishment (Harvests 1 and 2).

Although in most of the harvests *S. micropylla* shrubs were larger in volume than the other two species. The re-growth material of Harvests 1, 2 and 3, had significantly less (P<0.05) dry matter, with most of the material being woody stems (Table 8). This was also observed in the previous trial where the percentage leaf of *S. micropylla* decreased significantly (P<0.05) with age and by Harvest 5 (the final harvest in the previous trial) *S. micropylla* had an average percentage leaf of only 26.3% (Wilcock et al., 2009b). In all three species, shrubs that had been harvested originally at approximately 8 weeks after planting (Harvest 1), appeared not to have recovered as well as those that had been harvested 6 weeks later (with thirty nine weeks of re-growth) in Harvest 2, although this was not significant (Table 8). Although *S. microphylla* produced very little dry matter in the re-growth, with very little leaf material, it had, however, proved capable of self-propagation. By the end the trial there were numerous *S. microphylla* seedlings established in the field.

Conclusion

Results of the re-growth trial suggested that shrubs of all species should be given at least twelve weeks to establish before being harvested. The longer the rest period the better the re-growth tended to be, for all species. The re-growth of shrubs harvested in Harvest 2 of the initial trial, appeared to have fared better than shrubs that were harvested in Harvest 1, six weeks after the trial commenced and eight weeks after shrubs had been planted. Of the three species *C. sturtii* appeared superior with an average percentage survival of 69%. It also had an average leafiness and healthiness of 2.36 and 2.30, respectively, which, according to the ratings, are healthy shrubs with 50-80% leaf coverage. Although this species had not produced as much plant material as the indigenous species in the production trial (Wilcock et al., 2009a), in the re-growth trial it produced larger amounts of dry matter than the other species. Harvesting, at twenty centimetres above ground, did not appear to have any detrimental affect on this species. Findings in this trial, therefore, coincide with the findings of Benjamin et al. (1995) that even if *C. sturtii* shrubs are browsed until completely defoliated, they are able to recover their initial standing biomass. Initial harvesting had also given all shrubs a well-rounded “bushy” shape.

Of the two indigenous species, in terms of percentage survival (49% versus 25%), healthiness (3.34 versus 3.88) and leafiness (3.56 versus 3.90), *S. microphylla* appeared to have fared better than *T. sinuatum*. *S. microphylla* shrubs were also larger in volume, with a re-growth period of thirty three weeks or more. In terms of dry matter yield, however, *T. sinuatum* produced significantly ($P<0.05$) more material than *S. microphylla* for three of the five harvests. In the re-growth trial new *S. microphylla* seedlings, some almost as high as the shrubs that had been harvested in Harvest 5, had become established in and around the *S. microphylla* plots. This species could, therefore, be successful if used as a short-lived pioneer.

In these trials, shrubs were irrigated regularly and extrapolation to arid conditions should, therefore, be treated with caution. In arid conditions it is important to remember that the re-growth rate of shrubs would only be good, when there is sufficient available water present and this is dependent on episodic rainfall events. The amount and timing of the rainfall are, therefore, very important in determining the rate of re-growth. For this reason it is believed that browsing management decisions should be event-orientated, e.g. allowing time of browsing to be rainfall driven rather than at a fixed time of the year. This would prevent over-utilization of the shrubs, with sufficient water being present for re-growth (Westoby, 1980; Hoffman, 1988; Van Der Heyden & Stock, 1999).

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Chapter 8

General Conclusions

The objective of this study was to examine a number of different aspects, which determine the potential of shrub species for use in the re-vegetation of degraded arid and semi-arid rangelands.

Initial trials were conducted to determine the effect of rumen digestion on the germination of seed of certain species. In the case of *A. nummularia* rumen digestion had no significant (P>0.05) effects on germination, which was on average low. In *C. sturtii*, and *S. microphylla*, however, rumen digestion decreased the percentage germination. Seed of the indigenous species, *T. sinuatum* that had been in the rumen, for any length of time, was no longer viable. The same was true for seed of *S. glabrescens*, even when the period of time in the rumen was reduced to six hours. *S. glabrescens* seed, however, which had only been soaked for three hours in a pepsin solution, remained viable with a similar percentage germination (39.8%) to the control (39.5%). Due to the seed of this species being very small, it is very likely that it could pass through the rumen much quicker. A trial in which the seed is left in the rumen for only one to three hours, or where seed is fed straight to the sheep might ensure minimal effects on seed viability as it is possible that such small seeds would pass straight though to the abomasum. If not, it is suggested that farmers harvest seed in order to reseed areas, from which this species has disappeared. For all other species it was concluded that shrubs should be protected during times of seed production and seedling establishment, or seed should be harvested and stored in order to re-seed where necessary.

The two drought tolerant exotic species, *A. nummularia* and *C. sturtti*, from Australia, have been used in the rehabilitation of degraded arid rangelands. Seed and seedlings of these species were, therefore, used in degraded areas of the Northern Cape Province to determine how successful these shrubs would be in rehabilitating bare areas in arid rangelands of South Africa. Throughout the observation period, which extended over a two and a half year period from the first planting, no seed of either species germinated, whether treated to break dormancy or not. The seedlings that were planted out in each furrow, did not survive without protection and even then all branches protruding above the brush pack were browsed. These findings coincide with those of Butler (1986), that areas to be re-vegetated should be fenced off, or all livestock should be removed from the paddock, in order to ensure success. Of the two species *C. sturtii* appeared to be more drought tolerant with a 28% survival rate. All of the *A. nummularia* seedlings that had been planted eventually died due to the stress of the dry hot conditions. Of the sixty eight furrows that had been ripped in the bare area for this trial, grass species had established in twenty two, and twelve had annual ephemerals present. These furrows, as was reported by Shachak et al. (1998), acted as mini-catchment areas, which improved the microclimate in the areas, and thus increased the success rate of establishing perennial fodder shrubs.

According to a number of researchers there is a large intra-species variation in the palatability of *A. nummularia* shrubs (Malan, 2000). An ongoing palatability study, to select more palatable *A. nummularia* is, therefore, being conducted. In this trial palatable shrubs of the F1 "Elite" generation, originally from the De Kock Selection, were selected. Shrubs that the sheep selected more regularly, earlier in the grazing period, and which had been defoliated more than the other shrubs, were identified as being more palatable. These shrubs were kept, and will be used to produce F2 seed (Hatfield Select). All other shrubs were removed from the camp.

The major component of this study was a comparison between *C. sturtii* (an exotic species), *S. microphylla* and *T. sinuatum* (two indigenous species), in terms of productivity, nutritive value and the effect of defoliation on survival, leafiness and re-growth. Except for Harvest 5, there were no significant ($P>0.05$) differences observed in the amount of edible material produced by the three species, throughout the different production harvests. In Harvest 5 *C. sturtii* produced significantly ($P<0.05$) less edible material (89.7g/plant) than *S. microphylla* and *T. sinuatum*, which had produced 207.5g/plant and 166.3g/plant respectively. Both *C. sturtii* and *T. sinuatum* were detrimentally affected by frost in the winter months, with *T. sinuatum* being affected to a greater (P<0.05) extent.

All species were able to meet the crude protein maintenance requirements of sheep. The leaf material of both indigenous species, however, had a higher (P<0.05) crude protein concentration and organic matter digestibility than *C. sturtii*. The *in vitro* organic matter digestibility of both leaf and stem material of the two indigenous species tended to decrease with age, suggesting an increase in the fibre content with age. The concentration of macro-minerals, calcium, phosphorus and magnesium in all species met the maintenance requirements of sheep. Ratios between calcium and phosphorus were, however, high in all three species. It may, therefore, be necessary to supplement phosphorus in order to bring the ratio closer to 1:1 or 2:1 of calcium: phosphorus, which is the recommended ratio to ensure sufficient levels of these minerals are metabolised (McDonald, et al., 2002). The concentrations of the trace minerals, manganese and copper, in all species were able to fulfil the maintenance requirements of sheep. In the young plant material, however, copper, which may accumulate in the liver, was close to toxic levels. In all three species zinc levels were low and when taking into account the relatively high levels of copper observed, zinc supplementation in animal diets may be necessary. The supplementation of zinc would not only ensure that livestock receive sufficient zinc, but would also decrease the accumulation of copper in the animal's liver, thus reducing the risk of chronic copper poisoning (Pope, 1971; McDonald et al., 1996).

In the re-growth trial both *S. microphylla* and *T. sinuatum,* did not appear to be as healthy or as leafy as *C. sturtii*, for most of the re-growth periods. In Harvests 4 and 5 *C. sturtii* also had a higher (P<0.05) percentage survival than both indigenous species. Survival in *S. microphylla* tended to decrease with an increase in age at initial harvest. No more than 40% of the *T. sinuatum* shrubs survived in any of the different harvests. Initial growth stage before harvest and length of re-growth period appeared to have had no effect on this species.

When given thirty nine to forty five weeks to re-grow, *S. microphylla* plants were observed to be much larger (P<0.05) than either of the other species in terms of volume. This species, however, produced the least (P<0.05) plant material, most of which was woody stem material. Both *T. sinuatum* and *C. sturtii*, when given thirty three weeks to re-grow, produced 639.6g/plant and 785.7g/plant respectively, suggesting that under favourable moisture conditions and given sufficient time for re-growth, these shrubs could be browsed repeatedly. In all species the re-growth of shrubs harvested in Harvest 2 of the initial trial appeared to have fared better than shrubs that were harvested in Harvest 1, six weeks earlier. In the re-growth trial only *C. sturtii* was observed to be in flower, whereas *T. sinuatum* produced flowers and seed in the initial production trial as well. *S. microphylla* only produced flowers and seed in the initial production trial.

All three fodder species, with corrective mineral supplementation and the correct management, could be used to re-vegetate degraded areas. *C. sturtii* appeared to be better in terms of re-growth and percentage leaf material than either of the indigenous species. When given at least thirty nine weeks to recover from initial harvesting, this species produced a bushy shrub with approximately a kilogram of plant material per plant. *C. sturtii* also proved better able to survive severe drought conditions, than *A. nummularia*.

The indigenous species, however, had higher (P<0.05) crude protein levels and *in vitro* digestibility in the leaf material than *C. sturtii*. *S. microphylla* and *T. sinuatum* also produced large amounts of seed and although they are both relatively short-lived pioneer species (Le Roux et al., 1994), with the correct management they could easily re-establish in the area. It was observed, in the re-growth trial, that *S. micophylla*, is capable of self-propagation, with numerous seedlings having established in the field. Due to the large amount of seed that can be harvested from these indigenous species farmers could, in the interim, use these species to improve the conditions in the area. This would increase the chance of successful establishment of other species. Shrubs in this final trial were, however, irrigated regularly and extrapolation to arid areas should, therefore, only be recommended after extensive field (on farm) trials.

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