SUSTAINABLE MANAGEMENT OF *Harpagophytum procumbens* AND THE EFFECT OF EFFECTIVE MICRO-ORGANISMS AND SULPHURIC ACID ON ITS SEED GERMINATION

A THESIS SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN BIODIVERSITY MANAGEMENT AND RESEARCH AT UNIVERSITY OF NAMIBIA AND HUMBOLDT-UNIVERSITAT ZU BERLIN

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Declaration

This thesis represents the original work of the author and has not been submitted in any form for any degree to another University. Where use has been made of the work of others, it has duly been acknowledged in the text.

Signature……..………………………………

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Abstract

Devil's claw (*Harpagophytum procumbens*) is a geophyte that occurs mainly in Central, East and South eastern Namibia where it was previously regarded as a nuisance due to its fruit-claws getting caught on sheep and other livestock. The species has been exploited due to its medicinal properties leading to concerns regarding its sustainability. Efforts to conserve it have been tried in order to understand conditions suitable for its management but there are still poor results in the germination of the species' seeds and an inconclusive debate about the resting period between harvests which would be considered to be sustainable for the plant. There is also little known about the influence of parent tuber size, and fencing on the plant's fruit and secondary tuber production. Moreover, the correlation between the number and length of *Harpagophytum procumbens* branches and

the number of its fruits have received less research attention. There is also a lack of knowledge on correlations between above-ground basal cover and below-ground root mass, below-ground root mass and tuber production in *Harpagophytum procumbens.*

A study was carried out at Ben-Hur and Vergenoeg farms in central eastern Namibia to investigate the above mentioned concerns.

The number and weight of secondary tubers were found to increase with parent tuber sizes even though fruit production was found not to be influenced by age. *Harpagophytum procumbens* plants that were protected from grazing produced more fruits, and more secondary tubers that were large in size. There was a positive correlation between above ground basal cover by other plants and below-ground root mass which negatively correlated with the number and weight of secondary tubers, suggesting that competition with specifically long-rooted shrubs is a threat to maximum tuber production in *Harpagophytum procumbens.*

Seeds pre-treated in Effective Microorganisms (EM) resulted in a germination rate of 32%, whilst those pretreated with H_2SO_4 germinated to 17% compared to 5.3 % that germinated from the control. The combination of EM and H_2SO_4 resulted in a lower germination percentage than as expected.

It is concluded that fruit production in *H.procumbens* is neither influenced by the period a plant is left without harvesting, nor by parent tuber size,but rather by protection of *H.procumbens* from grazing. The study therefore recommends fencing for stakeholders who wish to maximize fruit production of the species.

The study also concludes that five years of not harvesting *H.procumbens* produces more and large secondary tubers than two years. It is therefore recommended that

H.procumbens should not be harvested after every two years but rather after five years when the plant is able to produce more and larger secondary tubers. A shifting harvesting practice is therefore recommended for sustainable management of *H.procumbens.*

The study further concludes that protection of *H.procumbens* from grazing benefits the plant to produce more and lager secondary tubers which subsequently benefit involved stakeholders.

The study recommends fencing of *H.procumbens* during their active season and allowing animals to forage again when the plants are dormant.

The study also concludes that *H.procumbens* with larger parent tubers produce more and larger secondary tubers. The study recommends that even after not harvesting *H.procumbens* for five years whilst protecting the plants from grazing when they are active, parent tuber diameter must be what determines the choice of plants to be harvested.

It is also concluded that the presence of shrubs around *H. procumbens* is a threat because their long roots negatively correlate with the number and weight of secondary tubers. It is therefore recommended that shrubs be removed around *H.procumbens,* leaving grasses which were found to coexist wit *H.procumbens.*

Lastly, the study concludes that sulphuric acid and effective micro-organisms enhance germination in *H.procumbens.* It is therefore recommended that the two treatments be considered to *H.procumbens* stakeholders who have been struggling with germination of the species.

CHAPTER 1

INTRODUCTION

1.1 General introduction

Biodiversity refers to the variety of life forms on earth, their genetic variability, variety and abundance of species and complex ecological interrelationships between them (Spellerberg, 1996). Namibia forms part of the world's richest regions as far as biodiversity is concerned. Though it is an arid country, Namibia is biologically diverse from flora to fauna (Barnard, 1998). It is in fact one of the very few countries in Africa with internationally-recognised "biodiversity hotspots", areas of richness and uniqueness that they compare with great rainforests (Barnard *et al.,* undated).

This biodiversity is however threatened by many factors such as over-utilisation, mistrust of the aims of conservation, lack of scientific enquiry on our biodiversity (Barnard, 1998), poor management and many more leading to declines in this important resource. With the world's biodiversity concerns soaring, Namibia is also feeling the consequences at local level. This is because biodiversity in Namibia is usefully depended on for food, aesthetic reasons, medicine and timber, among other uses (Sandison *et al.,* 1999).

Harpagophytum procumbens, the devil's claw is one of the plants with medicinal values in Namibia.

This study recognises that commercially valuable plants like *H. procumbens* in Namibia are threatened by lack of sustainable management practices in areas where they occur naturally. Sustainable management of traditional medicinal plant resources is recognized to be important by Zietsman and Pelser (2004), considering the role they play in human lives. Another factor the study recognizes is that a complete knowledge of this plant and its environment is still a need to those concerned.

1.2 Purpose of the study

This study seeks to investigate, explain and understand environmental and human induced conditions that favour or threaten *H. procumbens* to produce fruits and secondary tubers required to benefit both local and international people.

The study further seeks to understand germination requirements of *H. procumbens* in order to overcome the problem of low germination rates currently experienced. The purpose of the study is based on the realisation that *H. procumbens* is under pressure to benefit both local and international communities while its sustainability is being overlooked. Another purpose is the realisation that *H. procumbens* has a constraint of poor germination rates, which threatens its future. The overall aim is therefore to promote biodiversity conservation, sustainability and management of a local resource, while improving income generation and contributing to the social wellbeing of the Namibian people.

1.3 Scope of study

The possibility of sustainably managing *H. procumbens* is investigated. The ability of *H. procumbens* to regenerate through its seeds is very important for the species future survival on one hand, whilst understanding factors such as plant age, protection from grazing and a resting period between harvests from *H. procumbens*, are also important on the other hand. As the basis on which sustainable management of *H. procumbens* rests, this study investigates the initial stages of the plant, germination, and the ultimate stages where proper sustainable management practices can ensure recurring benefits from the plant.

1.4 General literature review

1.4.1 Species importance

1.4.1.1 Species Description

Harpagophytum procumbens is a geophyte with a positively gravitropical tuberous main root, from which plagiotropical thick secondary roots develop. The genus *Harpagophytum* comprises of two species (*H. zeyheri* and *H. procumbens*) which are perennial herbs with creeping stems that sprout every year from the main root. Secondary root tubers, which can reach a length of 5 – 25 cm, grow from the main root (parent tuber). It is these secondary tubers that are harvested for medicinal purposes and contain active ingredients that have analgesic and anti-inflammatory properties (Cole & Strohbach, 2007).

The plant is called devil's claw because of the very sharp and hooked form of the fruit (Cole & Strohbach, 2007). The fruit comprise a flattened woody capsule with spiny appendages on each carpel (Hachfeld, 2003).

Recruitment rates are low with only a few seedlings surviving the first year. Despite these life history traits, *H. procumbens* is considered a pioneer or even weedy species and is often found growing in areas where the soil has been disturbed or where grazing pressure is high. In established plants, annual shoot growth from the perennial tuber begins after summer rain (usually October/November) and the shoots die back between April and June as a prelude to winter dormancy (Cole & Strohbach, 2007).

1.4.1.2 Species Geographical distribution

The genus *Harpagophytum* occurs between 15 degrees and 30 degrees latitude in the Southern hemisphere. *Harpagophytum procumbens* in particular, is found in Namibia, Botswana and South Africa (figure 1).

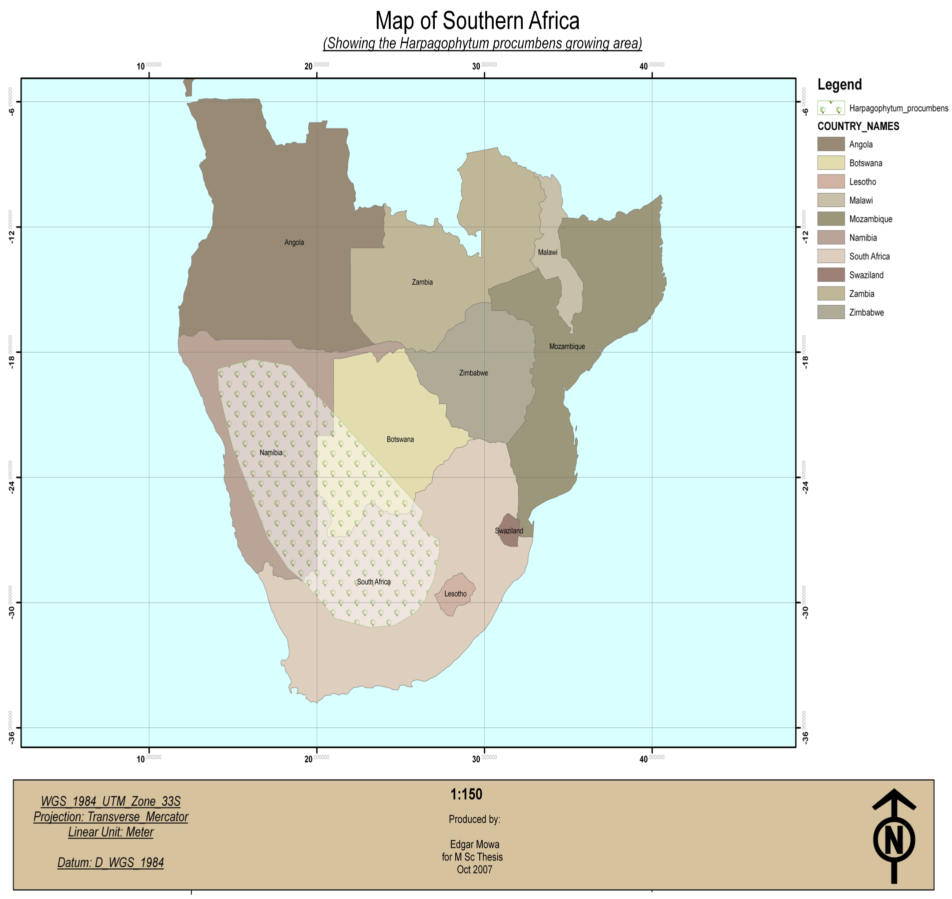

Figure1. Distribution of *H. procumbens* in Southern Africa. *H. procumbens* zone on the map adapted from CITES (unpublished).

1.4.1.3 Medicinal value

Indigenous people of Southern Africa have used *H. procumbens* medicinally for centuries, if not millennia. The tuber is traditionally used for fever relief, blood diseases, muscular aches and pains, and as an analgesic during pregnancy. In addition, pulverized root material is used as an ointment for sores, ulcers and boils, and for difficult births. Today there is widespread use of the plant by indigenous inhabitants of Namibia and other stakeholders (Grote, 2003).

Harpagophytum procumbens plants were first collected and described by European scientists in 1820 and the medicinal value was discovered in 1907 by G.H. Mehnert, in Namibia (Grote, 2003) for 'western medicine'. Some dried *H. procumbens* tubers were then exported to Germany, where they were studied by B. Zorn at the University of Jena in 1950, and in 1962 the Namibian company Harpago (Pty) Ltd started exporting *H. procumbens* in larger quantities.

This international demand resulted in additional pressure being exerted on the resource itself which in turn led to questions regarding its sustainability. In order to meet market demand and ensure sustainability, management measures have to be put in place so that the plant resource continues to provide these benefits over a prolonged period.

1.4.1.4 Market and export value

Recent years have seen indigenous inhabitants of Namibia, Botswana and South Africa harvest and sell more of the plant's dried secondary tubers for their livelihoods (Grote, 2003). Namibia is the world's largest producer of *H. procumbens* on the international trade market (Raimondo and Donaldson, 2002).

Of the total 6 269 297 kg exported from 1992 – 2006 (table 1), 95 % of exports originate from Namibia, 3 % from Botswana, and 2 % from South Africa (Cole & Bennett, 2007). The demand for *H. procumbens* on the international market is unpredictable because it depends much on importing companies. Some years they demand more whereas other years they only demand and buy less. As the lead supplier, Namibia has the potential to affect the world market price for Devil's Claw (Cole & Bennett, 2007). Though demand may be unpredictable, consistent availability of supply has to be maintained at all times, so that benefits continue sustainably.

Table 1: Unprocessed Devil's Claw exports, 1992-2006. Table adopted from Cole and Bennett (2007).

DEVIL'S CLAW EXPORTS (kilograms)				
Year	**Botswana**	**South Africa**	**Namibia**	**TOTAL**
1992	10 719	No data	96 000	**106 719**
1993	3 278	No data	66 000	**69 278**
1994	24 437	No data	158 000	**182 437**
1995	45 633	No data	284 409	**330 042**
1996	No data	No data	313 652	**313 652**
1997	5 493	No data	251 091	**256 584**
1998	501	No data	613 336	**613 837**
1999	2 050	6 936	604 335	**613 321**
2000	No data	341	379 740	**380 081**
2001	33 506	31 112	726 333	**790 951**
2002	27 950	20 619	851 016	**899 585**
2003	3 084	4 500	592 387	**599 971**
2004	42 025	14 000	331 466	**387 491**
2005	540	27 000	336 713	**364 253**
2006	2 249	No data	358 846	**361 095**
TOTAL	**201 465**	**104 508**	**5 963 324**	**6 269 297**

There is however, a lack of quality control within Namibia on *H. procumbens* and minimal local value adding opportunities (Gruenwald, 2003). Researches have found that between 60-80% of *H. procumbens* from Namibia go to international buyers who only clean, grade, and pre-process and re-pack it (Lombard, 2003).

The main importing countries of Namibian *H. procumbens* are Germany, France, Italy and Britain (Lombard, 2003). Germany leads among the four (4) above – mentioned countries, for example, one (1) German company (with branches in France, Spain, Italy and Poland) purchased 41%, 44% and 23% of Namibia's exports in 2002, 2003 and 2004 respectively. From 2003 to 2005, nine companies (five German, two French, one Spanish and one South African) purchased more than a container load of Devil's Claw in a single year (Cole & Bennett, 2007).

It is estimated that the annual global retail sales of Devil's Claw products amounted to 38 million per annum, of which the producing states received €1, 4 million and harvesters €414 000 or 1.1%. This inequity, combined with the open-access nature of the product and the extreme poverty of the harvesters, lies at the heart of the industry's problems (Cole & Bennet, 2007). With improvement to the financial sharing which is unfair at the moment, it is clear to note that Namibia could benefit maximally from conserving this plant species.

1.4.2 Legislative Management

1.4.2.1 Policies

In 1977 devil's claw was listed as a protected species in Namibia under the Nature Conservation Ordinance of 1975 (Cole & Bennett, 2007). In terms of this ordinance, permits are required to harvest and export devil's claw. It is also protected through similar legislation in both Botswana and South Africa (Cole & Strohbach, 2007).

1.4.3 Management of *H. procumbens* through Domestication

1.4.3.1 Cultivation trials

In order to have *H. procumbens* in abundance, cultivation was repeatedly suggested but efforts to carry it out were limited because of the following reasons:

- Cultivation may become so commercialized that the communities at present earning an income from the harvest may no longer be considered.
- Experience has shown that the improvement of germination rates by various treatments of seeds (i.e. abrasion and hormone treatments) result in relatively weak seedlings, which have a low establishment rate.
- Propagation from cuttings, micro-propagation techniques, or even secondary tubers result in the formation of secondary tubers only – which means that a plant can be harvested only once (Strohbach, 2003).

Finally, after a cultivation proposal by Strohbach in April 2003 and von Willert in October 2003, cultivation trials began but have been constrained by the lack of constant seedling supply that resulted from poor seed germination.

Some cultivation projects are still in their implementation phases and have not produced reports so far, since they need three-five (3-5) years to start producing secondary tubers. Some cultivation trials at irrigated plantations yielded high tuber mass, but relatively low concentrations of the active ingredients (Von Willert *et al.,* 2003).

There has also been cultivation trials on *H. procumbens* in South Africa. This was done through cuttings and depended much on artificial fertilizers and extensive irrigation. Secondary tubers harvested from this project were massive in size but had less medicinal ingredients due to high water content. A follow-up cultivation trial using cuttings was therefore done but with less expensive resources. The follow-up produced tubers like those in the wild in terms of medicinal ingredients (Stewart & Cole, 2005).

1.5 Statement of the problem

The management of *H. procumbens* is still not sustainable because there is lack of complete understanding of the many factors which can limit the plant's maximum tuber and fruit production. This study intends to look at some factors that may limit such production.

The period *H. procumbens* is left without harvesting can have an influence on how much each plant produces in terms of tuber and fruit production. Harvesting a plant twice in a space of five years may produce less products compared to harvesting it only once at the end of that period. Currently, plants are harvested twice in a space of four (4) years (Cole & Strohbach, 2007), not knowing how much such a plant would be able to produce after a longer period without being harvested.

There is still a lack of knowledge with regards to the influence of *H. procumbens* size of its main tuber on its secondary tuber and fruit production.

It is not known as to whether protection from grazing of *H. procumbens* will have a positive or negative influence on the number and fresh weight of secondary tubers, number and length of branches and the number of fruits a plant can produce.

The type of plants growing close to *H. procumbens* could also influence the number of secondary tubers, tuber weight and the number of fruits produced per plant. It is not known as to which plant types have a negative or positive relationship with the production of tubers and fruits by *H. procumbens.*

There are roots from other plants in soil layers where *H. procumbens* extends its roots. The correlation between these roots and the presence or absence of plants found growing close to *H. procumbens* above ground is not known. Once established, this correlation can help to determine below-ground root density based on above-ground basal cover by other plants growing around *H. procumbens*.

The density of roots from other species may be a negative factor, since nutrients and water available for absorption by *H. procumbens* will be competed for with the roots of such species. This can therefore lead to fewer and smaller secondary tubers formed by *H. procumbens*.

According to Cole (pers.comm., 2005) local harvesters can sometimes tell which plant to harvest by its above-ground cover (number of branches and branch length). There is still a lack of knowledge on the possible correlation between above-ground biomass of *H.*

procumbens and its underground secondary tubers. Therefore knowledge of the correlation between these factors could help in confidently identifying which plants to harvest based on their above-ground biomass. There has also been little attention given to an understanding of a correlation between branches of *H. procumbens* and the number of fruits *H. procumbens* can produce.

Some of the factors mentioned above may have a strong influence on the number of fruits, secondary tubers and the fresh weight of secondary tubers that *H. procumbens* can produce, whilst some may not have such influence at all. Therefore, this study intends to investigate these factors.

Since *H. procumbens* is in demand, there is a need to have consistent supply of seedlings to stakeholders. At the moment this supply of seedlings is hampered by poor germination rates. Enhancing germination rates will help both commercial stakeholders and local inhabitants to have localized population-enrichment planting.

Effective Microorganisms (EM) and sulphuric acid (H_2SO_4) have enhanced seed germination in other plants. There has however, been no germination studies using EM done on *H. procumbens.* Even though there has been an experiment on *H. procumbens* germination using 100% sulphuric acid (H_2SO_4), it resulted in no germination at all (Ernst *et al.,* 1988). Doubts arise as to whether the 100% concentrate used for that particular experiment was the cause of seeds not germinating. Germinating them at a concentrate less than 100% could improve germination as in other species.

1.5.1 Study Objectives

1.5.1.1 General objectives

a. To understand environmental and human induced conditions that favor or threaten *H. procumbens* to produce fruits and secondary tubers required to benefit both local and international people.

b. To understand germination requirements of *H. procumbens* in order to overcome the problem of low germination rates currently experienced.

1.5.1.2 Specific objectives

a. To determine fruit production in *H. procumbens* over two different resting periods from harvesting.

b. To determine secondary tuber production in *H. procumbens* over two different resting periods from harvesting, with economic and conservation implications of each resting period.

c. To determine the relationship between *H. procumbens* parent tuber size and its fruit production.

d. To determine the relationship between *H. procumbens* parent tuber size and its secondary tuber production.

e. To investigate the influence of protection from grazing on branches and fruit production of *H. procumbens.*

f. To investigate the influence of protection from grazing on secondary tuber production of *H. procumbens.*
g. To establish the correlation between the number and length of *H. procumbens* branches and the number of fruits.
h. To determine the influence of the presence of other plant types/species around *H. procumbens* on its secondary tubers production.
i. To investigate the influence of germination stimulants on seed germination of *H. procumbens*.

1.5.2 Key questions

This study asks and intends to answer the following key questions:

a. Is there a difference in the number of fruits between plants that were rested from harvesting for two years compared to those which were rested from harvested for five years?
b. Is there a difference in the number of secondary tubers and secondary tuber weight between plants that were rested from harvesting for two years compared to those that were rested from harvesting for five years and what are the economic and conservation implications of each harvest.
c. What correlation exists between *H. procumbens* parent tuber size and the number of its fruit?

d. What correlation exists between *H. procumbens* parent tuber size and the numbers of its secondary tubers and secondary tuber weight?

e. Is there a difference in the length of branches, number of branches and number of fruits between *H. procumbens* protected from grazing and *H. procumbens* without any protection from grazing?

f. Is there a difference in the number of secondary tubers and secondary tuber weight between *H. procumbens* protected from grazing and *H. procumbens* with no protection from grazing?

g. What correlation exists between the number of *H. procumbens* fruits and the number and length of branches on the same plants?

h. What correlation exists between above-ground basal cover (by other plant type/species), below-ground root density from other species found around *H. procumbens* and the number and weight of secondary tubers it can produce.

i. Which germination stimulant (H_2SO_4 or EM) enhances germination of *H. procumbens*?

1.5.3 Research hypotheses

The following are the research hypothesis for this study:

a. ***Harpagophytum procumbens* will produce more fruits when rested from harvesting for five years than when rested from harvesting for only two (2) years.** Since a plant reproduces more under favorable conditions without many stressors, it is assumed that *H. procumbens* will produce more fruits when there is no harvesting stressor to these plants. In this case, the harvesting stressor is absent to plants that have not been harvested for five years and therefore, provided there is adequate water (rainfall) and other resources like soil nutrients (also available to the harvested plants), fruit production will be higher on these plants.

b. ***Harpagophytum procumbens* will produce more and larger secondary tubers when rested from harvesting for five years than when rested from harvesting for only two years. This will result in harvesters benefiting more whilst conserving the species.** The absence of the harvesting stressor could favor more secondary tubers to be produced and with five years of no harvest, such secondary tubers will become larger compared to when they are just given two years before they get harvested. *Harpagophytum procumbens* will be able to produce more and large secondary tubers when rested from harvesting for five (5) years, harvesters will benefit more from fewer plants whilst they give more time to other plants for future harvests.

c. ***Harpagophytum procumbens* parent tuber size has a positive correlation with the numbers of fruits on the same plants.** Fruit reproduction in plants increases with age. It is therefore expected that the larger the size of the main-tuber (plant age) in *H. procumbens*, the more fruits will be found on such plants.

d. **There is a positive correlation between the numbers and weights of secondary tubers and *H. procumbens* size.** Reproduction in plants increases with age. It is expected that the larger the size of the main-tuber, the more secondary tubers and the larger the secondary tubers produced by *H. procumbens.*

e. ***H. procumbens* within plots protected from grazing will have long and more branches and more fruits than those from unfenced plots.** Even if other conditions are uniform, protection from grazing and trampling by animals will provide opportunity for development of fruits and seeds without disturbance.

f. ***Harpagophytum procumbens* within plots protected from grazing will have more and larger secondary tubers than those from plots unprotected from grazing.** Undisturbed plants may also have the ability to produce more tubers than those whose above-ground biomass gets disturbed.

g. **There is a positive correlation between the number of fruits on *H. procumbens* and the number and length of branches found on the same plants.** The number of branches determines the number of fruits in some species and therefore, it is expected that *H. procumbens* with more branches will have more fruits on them. Branch length is also known to determine the number of fruits on a plant in some species, since the longer the branch, the more nodes on which fruits will ultimately develop. It is therefore expected that more fruits will be found on plants with longer branches than on plants with short branches.

h. **The presence of plant types like shrubs and other deep rooted species positively correlates with below-ground root density which in turn negatively influences the number of secondary tubers and secondary tuber weight in *H. procumbens* plants.** Shrubs and trees are known to have both deep and lateral root systems which are expected to out-compete grasses, other herbs and forbs where they occur. Furthermore, due to the fact that below-ground competition for nutrients and water results in these resources being scarce, *H. procumbens* will not have enough of these resources necessary to them to produce more fruits, more and larger secondary tubers

i. **Sulphuric acid and Effective Micro-organisms (EM) enhance germination of *H. procumbens* seeds.** Since sulphuric acid is corrosive, it will damage the hard seed coat of *H. procumbens,* exposing the seed to light, water, germination substrate and other factors required for germination. Since microbes in EM are known to positively influence seed germination (Bhat *et al.,* 1994), it is expected that they will enhance germination of *H. procumbens* seeds. This is because microbes in EM are known to protect seeds from other fungal species that may affect them negatively (Higa, 1999). Even weakened seeds may survive to produce normal plantlets (Siqueira *et al., undated*) due to such protection.

CHAPTER 2

DESCRIPTION OF THE STUDY AREA

For the first part, the study area falls within the Omaheke region of eastern Namibia, which is often referred to as the Sandveld.

The study sites for the first part of the study were the Tjaka/Ben Hur Communal Development Center and Vergenoeg Post 1 (figure 2), which are part of the larger group of communal farms in eastern Namibia. Tjaka/Ben Hur is about 50 km south of Gobabis whilst Vergenoeg post 1 is about 140 km North-East of Gobabis. These study sites are part of the study carried out by Strohbach and Cole (2007) for the "Population Dynamics and Sustainable Harvesting of the Medicinal Plant *H. procumbens* (SHDC) in Namibia".

2.1 Study plots

It must be noted that this study builds on previous research and uses four existing research plots at two study sites.

Each study site consisted of two monitoring plots, each measuring 10 m x 30 m. One plot was fenced with diamond mesh to exclude all grazers. The unfenced plot was situated parallel to the fenced one. Each pair of sites had a rainfall gauge from which daily rainfall figures were recorded by local community members throughout the rainfall season.

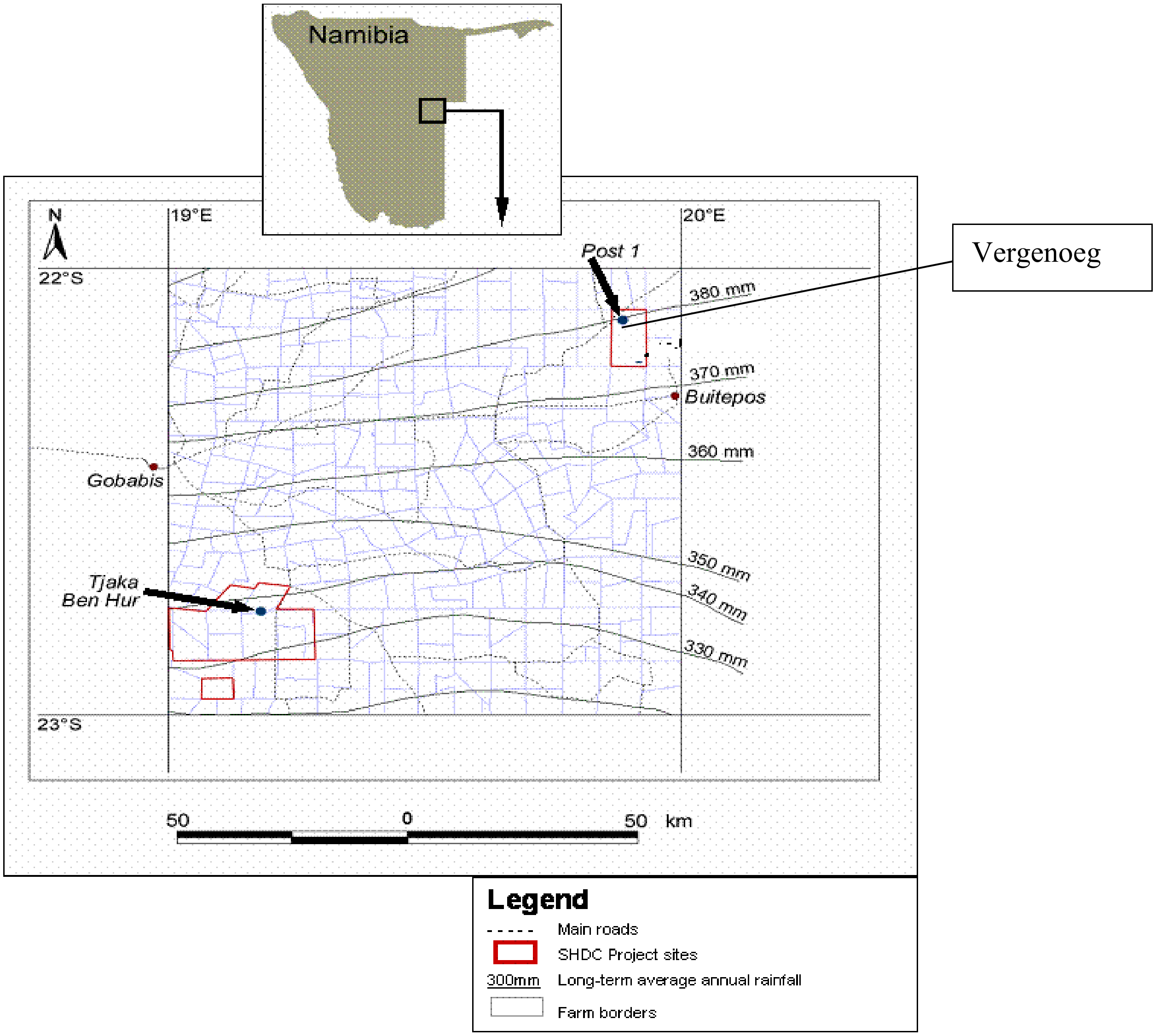

Figure 2. The two (2) study sites: Vergenoeg and Tjaka Ben Hur Communal Development Center. GIS files adapted from NARIS (AEZ, 2001)

2.2 Rainfall

The long-term (2000/2001 – 2004/2005) average annual rainfall is from about 340 mm per year at Ben Hur and Tjaka to 380 mm at Vergenoeg Post 1. The rainfall events occur predominantly in summer (October – May) with occasional early rains in October and November (Cole & Strohbach, 2007). Most of the rainfall is between December and March, and occasional as late as May. Considerable inter-annual differences in rainfall patterns (figure 3 a & 3b) are common (Cole & Strohbach, 2007).

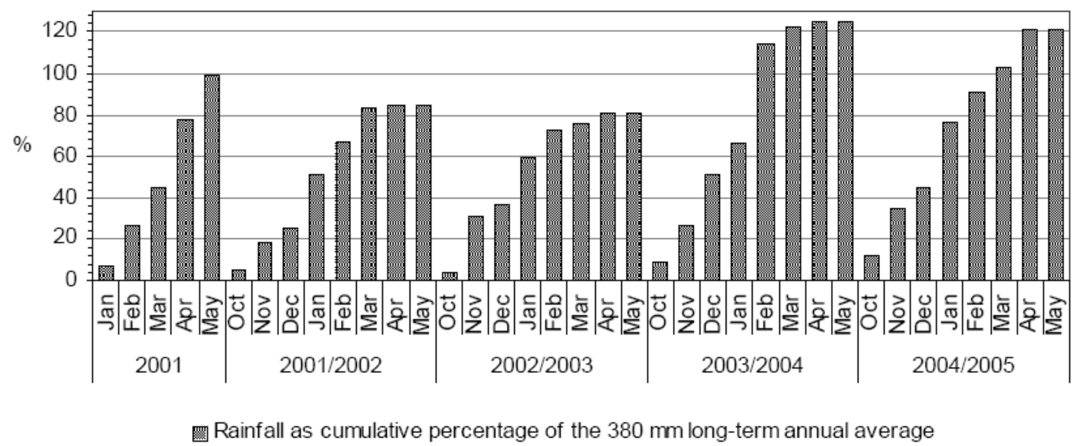

Figure 3 (a) Annual cumulative rainfall for each season at Ben Hur (Cole & Strohbach, 2007).

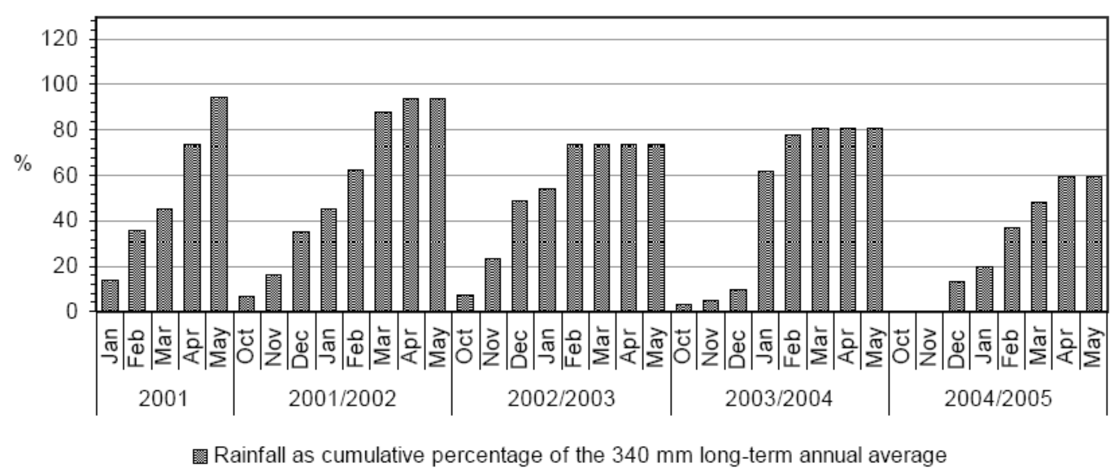

Figure 3 (b) Annual cumulative rainfalls for each season at Vergenoeg (Cole & Strohbach, 2007).

2.3 Vegetation

The vegetation at Ben Hur is dominated by short *Acacia erioloba* trees, as well as *Acacia hebeclada* subsp *hebeclada* shrubs.

During 2000, the site had a good layer of the perennial grass *Stipagrostis uniplumis*. Although canopy cover of this grass was up to 60%, basal cover was much less, enabling devil's claw to easily expand between the grass tufts. Gradually this grass layer became decimated by animals, especially during low rainfall seasons (2001/2002 and 2002/2003). The grass layer was initially followed by a very dense layer of creepers, mainly *Acanthosicyos naudinianus* and *Ipomoea* species, which were strong but short-lived competitors of devil's claw. However, this layer was also decimated, leaving only a sparse herb layer towards the end of 2005 of the study (Cole & Strohbach, 2007).

Vegetation at Vergenoeg Post 1 is dominated by very low to 3 m high shrubs, mostly *Acacia luederitzii*, *A. mellifera* subsp *detinens* and *Dichrostachys cinerea*. An increase of these shrubs from an initial 15% in 2000 to almost 40% in 2004 was observed during the study by Strohbach and Cole (2007), which necessitated clearing of the monitoring sites in 2004 and 2005 to enable monitoring of devil's claw to continue. The herb layer is sparse and highly variable. Dominant grasses include *Eragrostis porosa* (annual) and *Aristida congesta* (weak perennial). On the fenced site the highly palatable perennial grasses

Antephora pubescens, *Brachiaria nigropedata* and *Stipagrostis uniplumis* managed to get re-established after 2 – 3 years during the course of the study by Cole & Strohbach, (2007) which started in 2000 and ended in 2005.

2.4 Soil

The study area is characterized to a large extent by the loose, weakly structured to unstructured aeolian sands of the Kalahari, which cover an underlying calcic horizon to varying depths (Cole & Strohbach, 2007).

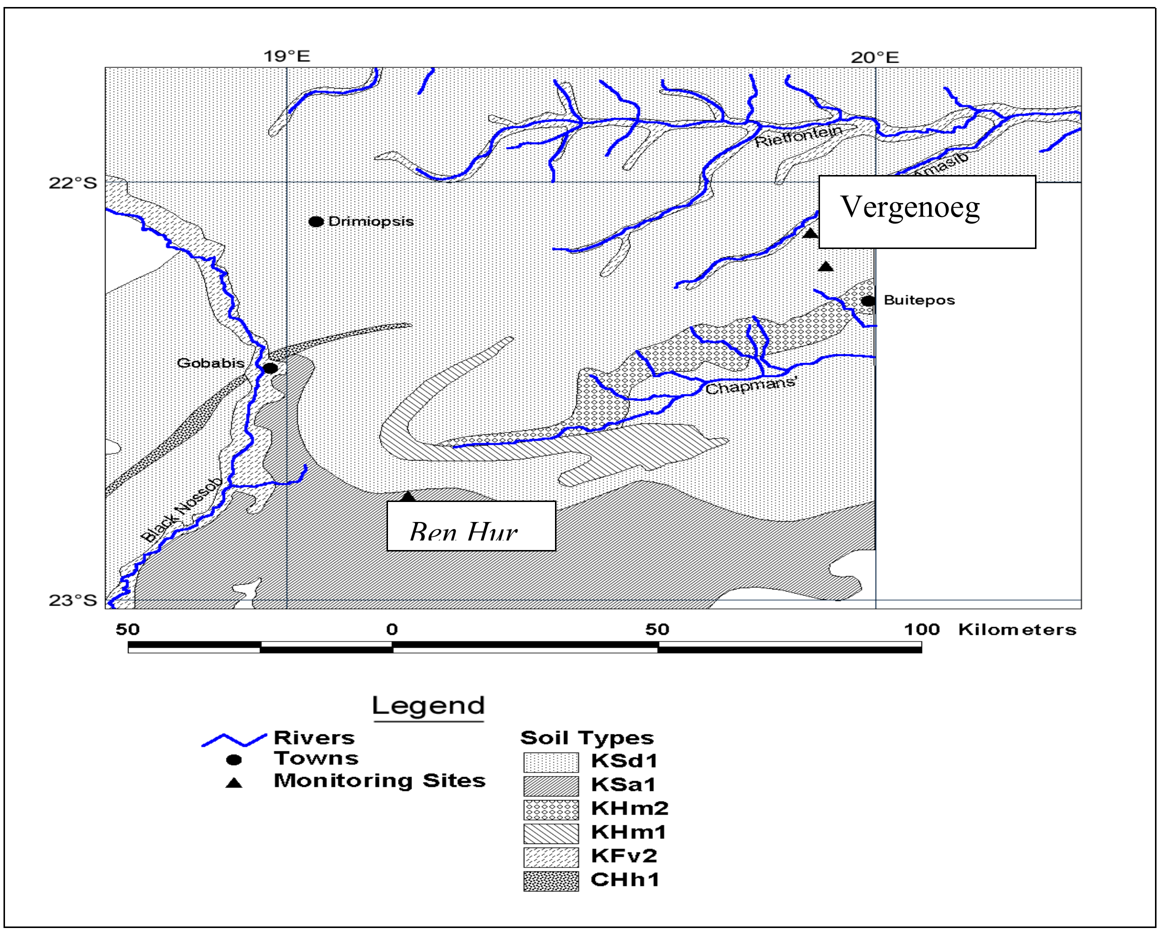

Figure 4 Soil types of the study area: CHh1 = rock outcrops, KFv2 = omuramba and river valleys with arenic Fluvisols and ferralic Arenosols association, KHm1 = relict meanders with ferralic Arenosols, KHm2 = relict meanders with arenic-leptic Regosols, KSa1 = sand deposits and aligned dunes with ferralic Arenosols, KSd1 = sand plains with ferralic Arenosols. Map adapted from the NARIS GIS files (AEZ, 2001)

At Ben Hur the soils are predominantly shallower and finer-grained reddish ferralic Arenosols of the Namibia soil type KSa1 (Figure 2, AEZ 2001). The finer particle size ensures a slightly higher water retention capacity than at Vergenoeg Post 1, but soils are still excessively drained. Ben-Hur took were in the sand deposits that are aligned dunes with ferralic Arenosols.

At Vergenoeg the soils are predominantly deep yellow to brown coarse ferralic Arenosols of the Namibian soil type KSd1 (Figure 2). These sands are excessively drained, and very limited runoff occurs only in areas surrounding small depressions or *omuramba* systems within the sandy plains. Vergenoeg Post 1 is a typical site on a raised sandy plain as opposed to other areas in depressions. Depressions often have a more favourable water retention capacity, which makes moisture available to plants for a slightly longer period after sufficient rains. In addition, mineral and nutrient content is usually higher in the depressions as these accumulate from surrounding areas (Cole & Strohbach, 2007).

CHAPTER 3

INFLUENCE OF RESTING PERIOD ON FRUITS AND SECONDARY TUBERS

3.1 Introduction

As described in chapter 1, *H. procumbens* has a tuberous rootstock consisting of central (parent) and laterally developing (secondary storage) tubers which humans harvest for various uses. The plant occurs to a large extent on communal areas (and resettlement farms) in Namibia where marginalized and poor local people harvest secondary tubers for income augmentation. The plants have been harvested with intervals of two (2) years between harvests and this chapter presents an investigation of possibilities on maximizing these harvests given a period longer than the two years practiced by locals, given the economic and sustainable management implications.

3.2 Literature review

3.2.1 Sustainability of harvesting

When the medicinal value of *H. procumbens* became known in Namibia, exploitation was done through harvesting and selling of tubers to international buyers. Consequently, there were concerns about the sustainability of harvesting of *H. procumbens*. This led to policies being made to better manage this resource; therefore a permit system for harvesting and transporting *H. procumbens* was introduced in 1977 but failed. In 1999 the Ministry of Environment and Tourism reintroduced a permit system in response to concerns about over-exploitation (Cole & du Plessis, 2001).

Currently, there have been applications of better harvesting techniques in Namibia, modified from traditional and other unsustainable techniques based on findings by the Sustainably Harvested Devil's Claw project (Cole & Strohbach, 2007). All harvesters are now required to use the prescribed guidelines provided by NASSP (2004) to harvest *H. procumbens* sustainably. Traditional techniques involved uprooting the whole plant, whereas sustainable harvesting techniques involve the harvesting of secondary tubers only living the main (parent) tuber to re-stock more secondary tubers for the next harvest.

In line with sustainable harvesting techniques, when harvesting, care is taken to space the plants widely enough to prevent any confusion of below-surface secondary tubers (Cole & Strohbach, 2007). *Harpagophytum procumbens* plants growing close to each other can have their secondary tubers confused by the harvester, if they don't space the holes around the harvested plant wide enough.

3.2.2 Harvesting and resting period

The study on harvesting and the resting period by Strohbach and Cole for the Population Dynamics and Sustainable Harvesting of the Medicinal Plant *H. procumbens* in Namibia project has been done on two plots at Ben Hur/ Tjaka and at Vergenoeg posts 1, east of Namibia from 2001 – 2005. This study found that after four (4) years, plants which were rested from harvesting for such a period produced more and larger secondary tubers than those rested from harvesting for two (2) years, the later was initially thought to be a period long-enough.

The current study which investigates the resting period uses some of the baseline data gathered by Cole and Strohbach (2007) in their study.

3.3 Materials and methods

3.3.1 Data collection

In order to determine fruit and secondary tuber production in *H. procumbens* over two different periods of resting from harvesting, plants were observed at Ben Hur and Vergenoeg post 1.

From the Vergenoeg post 1, eighteen (18) *H. procumbens* plants were harvested in April 2006 (appendix 1: table 1a). These were old reproductive plants in a fenced plot and were not harvested since it was set-up in 2001 and are hence hereby referred to as five (5) year rested plants. Furthermore, there were nine (9) old reproductive plants that were harvested from a fenced plot twice in five years (2001-2006) with a two-year resting period between the harvests, hence hereby referred to as two (2) year rested plants or plants harvested twice in five years (appendix 1: table 1a). Their harvested records were brought in from the SHDC study by Strohbach and Cole.

Old reproductive plants were selected because they are believed to produce more fruits and secondary tubers.

For each plant, all fruits were counted, secondary tubers harvested, weighed and recorded. Secondary tubers were harvested at depths between thirty (30) and hundred and twenty (120) centimeters. Counting of fruits and harvesting of secondary tubers were done to investigate whether the resting period influenced the potential of *H. procumbens* to produce secondary tubers and fruits.

The same procedure was followed at Ben Hur where twenty (20) plants belonging to the five (5) year rested group were used, whilst from the two (2)-year rested group, thirteen

(13) plants were found and observed in the same way as at Vergenoeg (appendix 1: table 6 a). These were also plants in the old reproductive age state and fenced as the ones described at Ben Hur.

After weighing the secondary tubers at each site, they were all sliced into 7mm pieces. These pieces were then spread on a net raised 1.5cm above ground to be sun-dried at each study site. The size of slices was done according to experienced local harvesters who confirmed the size they usually slice up pieces to be dried at each yearly harvest.
This was done in order to determine how many plants the harvesters need in order to get the amount valued for a kilogram of dried tubers. This would link the economic needs of harvesters with conservation or sustainable management of *H. procumbens* populations.

Rainfall data was recorded using a rain gauge at Ben-Hur for the 2005/2006 rainfall season. It was not possible to do so at Vergenoeg hence rainfall data from that site was collected from the Namibia Meteorological Service.

3.3.2 Data analysis

In order to analyze the statistical significance of the difference in the number of fruits, secondary tubers and secondary tuber weight per plant between the two plant-harvest resting groups, data was tested for normality using the Kolmogorov-Smirnov normality test (Townend, 2002) in Statistical Program for Social Sciences (SPSS) (appendix 1:

table 2 & 7). Throughout the chapters where the Kolmogorov-Smirnov normality test was used, it was preferred over histograms in testing normality because histograms are subjective and open to abuse, whereas this study sought for an objective test.

The number of secondary tubers at the Vergenoeg site was found to be normally distributed (appendix 1: table 2) and hence was analyzed using the Independent-Samples T-Test from SPSS to establish whether overall means collected from the study's two (2) independent samples (*H. procumbens* not harvested for five years and *H. procumbens* not harvested for two years) differed significantly. The *R* value was also calculated from the T-test results in order to show how important the effect measured by this study on a particular variable is. In order to get the *r* value from the T-test, the following formulae was employed:

$$\boldsymbol{r = \sqrt{(t^2/t^2 + df)}}$$

Where *t* is the value of *t*-statistic and *df* are the degrees of freedom. *R* value is constrained to lie between 0 (no effect) and 1(a perfect effect). Secondary tuber weight and the number of fruits at the Vergenoeg site were found to be non-normally distributed (appendix 1: table 2) and were therefore analyzed using the Mann-Whitney U test (Townend, 2002) in SPSS to test for mean differences. Notice in Appendix 1: table 2 that the two significance levels for secondary tuber weight and for the number of fruits are both significant non-significant. The Mann-Whitney U test, a non-parametric test, was chosen because one of the variables was not normally distributed (Field, 2005) for each in this context. Furthermore the Mann-Whitney U test is a non-parametric equivalent of the independent T-Test (Field, 2005), hence being used on this study's data which is comparing independent samples.

At the Ben-Hur site, the number of secondary tubers, secondary tuber weight and the number of fruits were all found to be not normally distributed (Appendix 1: table 7). They were therefore analyzed using the Mann-Whitney U test (Townend, 2002) in SPSS to test for mean differences.

3.4 Results and Discussion

3.4.1 Rainfall

The annual rainfall recorded at Ben Hur for the 2005/2006 rainfall season was 578.5 mm. As cumulative percentage of the 340 mm long-term annual average, the 2005/2006 annual rainfall is a record of 170 %.

The annual rainfall recorded at Vergenoeg for the 2005/2006 rainfall season was 428 mm. The cumulative percentage of the 380 mm long-term annual average for the 2005/2006 season for Vergenoeg was 113 %.

3.4.2 Influence of resting from harvesting for five (5) years on the number of fruits per plant

The Mann-Whitney U test results (appendix 1: table 3 & 8) for Vergenoeg and Ben-Hur respectively, show an unexpected result considering the hypothesis that there was going to be more fruits on *H. procumbens* plants that were rested from harvesting for five (5) years compared to plants harvested twice within the same period (appendix 1: table 3).

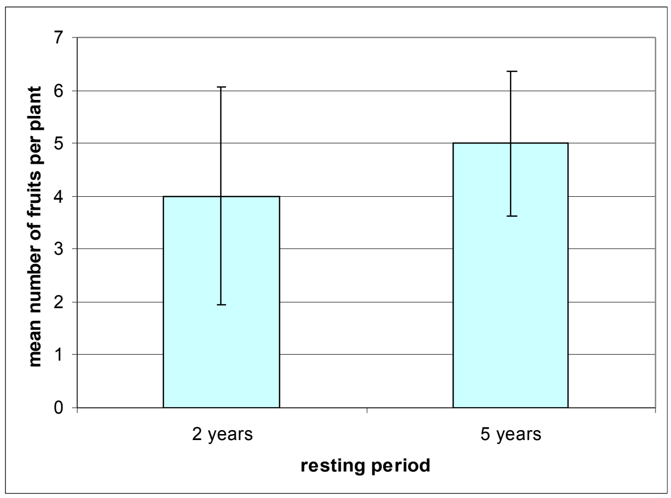

Figure 5 (a) Difference in the number of fruits per plant between plants rested from harvesting for two (2) years and plants that not harvested for five (5) years at Vergenoeg Post 1.

On average there were four (4) fruits per plant on *H. procumbens* rested from harvesting for two (2) years compared to five fruits per plant on *H. procumbens* rested from harvesting for five (5) years (Figure 5 a). The result show that there was no statistically significant difference in the number of fruits between plants rested from harvesting for two (2) years and plants rested from harvesting for five years at Vergenoeg (P = 0. 375) (appendix 1: table 3).

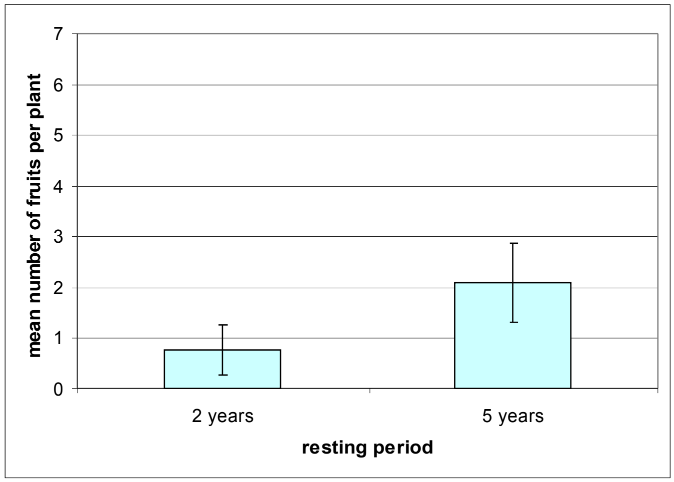

Figure 5 (b) Difference in the number of fruits per plant between plants rested from harvesting for two (2) years and plants that not harvested for five (5) years at Ben Hur.

There was also no statistically significant difference in the number of fruits produced per plant between plants that were rested from harvesting for two (2) years and those that were rested from harvesting for five (5) years at Ben Hur (P = 0.131) (appendix 1: table 8). The results from Ben-Hur and Vergenoeg therefore leads to the rejection of the study's hypothesis that *H. procumbens* rested from harvesting for five years produce more fruits than those rested from harvesting for two years only.

The implications of the results of the current study at Ben-Hur and Vergenoeg are that the ability of producing fruits by *H. procumbens* does not depend on how long it is left without harvesting. According to Hachfeld (2003), fruit-set depends on climatic conditions i.e. fruits tend to grow slower under dry conditions with many aborting before ripening. This and possibly other factors like rainfall could influence fruiting over a period of time and not the resting period since it is evident from these results that plants are able to produce the same number of fruits regardless of the resting period. Rainfall, for example, has been found in particular to positively influence production of flowers and shoots in *H. procumbens*.

3.4.3 Influence of resting from harvesting for five (5) years on the number and weight of secondary tubers.

Vergenoeg site

On average there were more secondary tubers (*mean*: 18.78, *SE*=2.40) on *H. procumbens* rested from harvesting for five years, than (*mean*: 6.78, *SE*=1.97) on *H. procumbens* rested from harvesting for two years only (appendix 1: table 4).

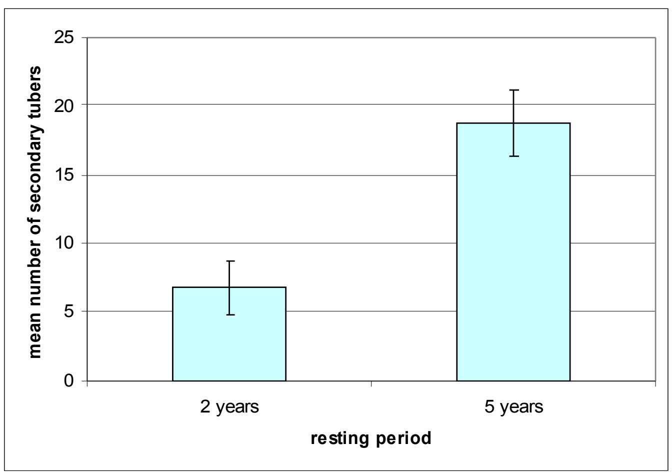

Figure 6 (a) Difference in the number of secondary tubers per plant between plants rested from harvesting for two years and plants rested from harvesting for five years at Vergenoeg.

Figure 6 (a) above displays that there were more secondary tubers on plants rested from harvesting for five (5) years than on plants rested from harvesting for two (2) years at Vergenoeg. The difference shown in figure 4 (a) found conclusive evidence when tested statistically (P = 0.003) (appendix 1: table 4). Furthermore, the difference in the number of secondary tubers between the two harvesting years does represent a large sized effect $r = 0.54$.

Ben-Hur site

On average, there were more (*mean rank:* 17.13, *sum of ranks*: 342.50) secondary tubers on *H. procumbens* rested from harvesting for five (5) years than (*mean rank:* 16.81, *sum of ranks*: 218.50) on *H. procumbens* rested from harvesting two (2) years (appendix 1: table 8).

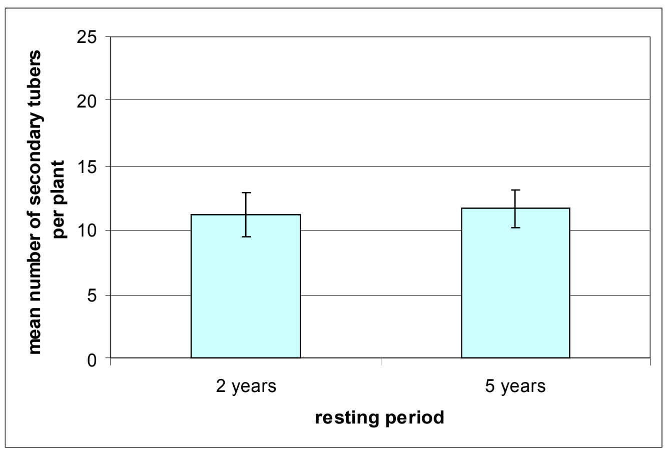

Figure 6 (b) Difference in the number of secondary tubers per plant between plants rested from harvesting for two years and plants that not harvested for five years at Ben Hur.

Statistical analysis is however evident that there was no difference ($P = 0.928$) in the number of secondary tubers on *H. procumbens* rested from harvesting for five (5) years compared to *H. procumbens* rested from harvesting for two (2) years (appendix 1: table 8).

Vergenoeg site

On average, there were larger (*mean rank:* 16.89, *sum of ranks*: 304.00) secondary tubers on *H. procumbens* rested from harvesting for five (5) years than (*mean rank:* 8.22, *sum of ranks*: 74.00) on *H. procumbens* rested from harvesting for two (2) years (Appendix 1: table 5).

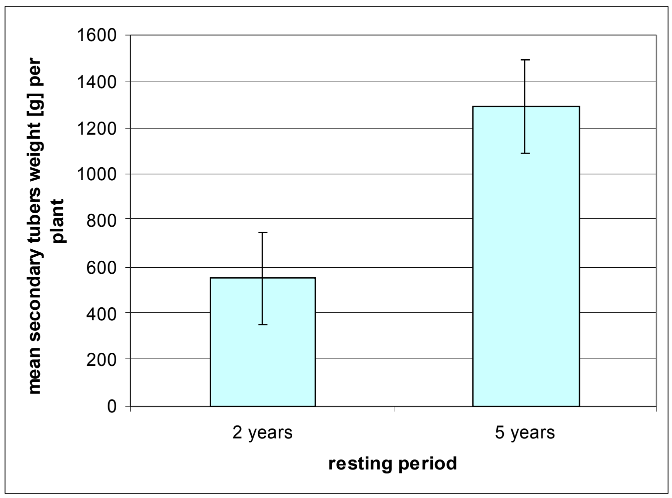

Figure 7 (a) Difference in secondary tuber weight between plants rested from harvesting for two(2) years and plants rested from harvesting for five (5) years at Vergenoeg.

Figure 7 (a) displays that there were larger secondary tubers on *H. procumbens* rested from harvesting for five (5) years than on *H. procumbens* rested from harvesting for two (2) years. This difference was found to be highly-significant (P = 0.006) (appendix 1: table 5).

Ben-Hur site

On average, there were larger (*mean rank*: 20.30, *Sum of ranks*: 406.00) secondary tubers on *H. procumbens* rested from harvesting for five (5) years than (*mean rank:* 11.92, *sum* *of ranks*: 155.00) on *H. procumbens* rested from harvesting for two (2) years (Appendix 1: table 8).

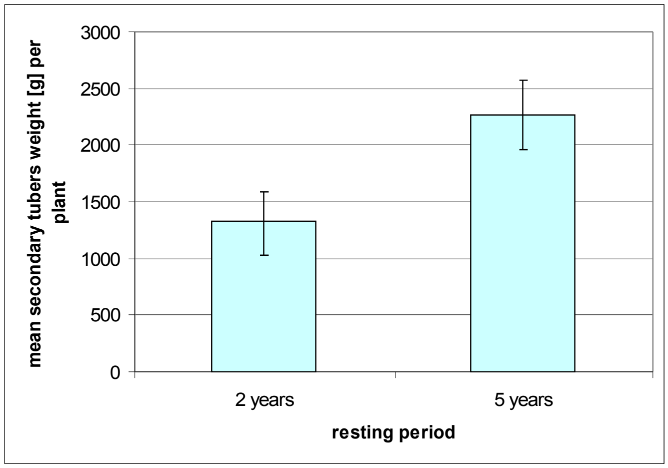

Figure 7 (b) Difference in secondary tuber weight per plant between plants rested from harvesting for two years and plants rested from harvesting for five years at Ben Hur.

As shown in figure 7 (b) above, plants rested from harvesting for five (5) years produced larger secondary tubers compared to plants rested from harvesting for two (2) years, statistical analysis of these differences show that there was a significant difference (P = 0.014) (appendix 1: table 8).

Differences in weight between fresh secondary tubers and sliced, dried secondary tubers

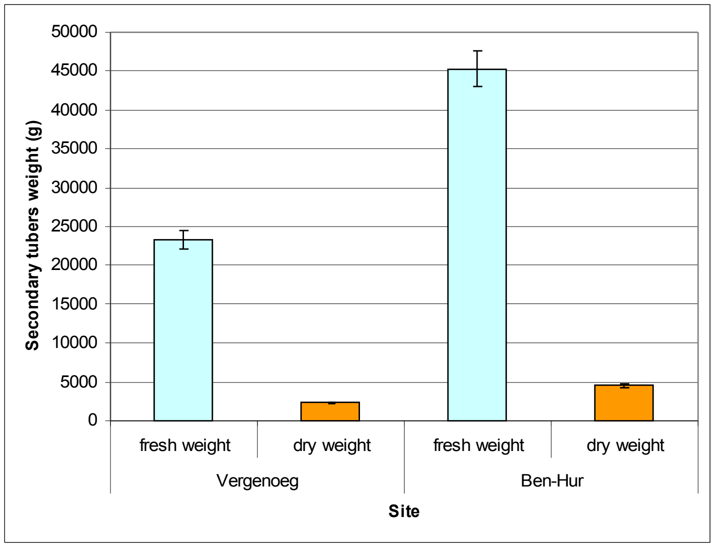

Figure 7 (c) Difference in secondary tuber weight between fresh tubers and dry slices of the same tubers at the two study sites.

Figure 7 (c) shows that secondary tubers lose 90% of their initial fresh weight when they get sliced and dry-up. This gives an idea of how much local community members around the study sites will have to collect to get profit from their labour costs.

The result that there was no difference in the number of secondary tubers between plants not harvested for two (2) years and those not harvested for five (5) years at Ben-Hur could be attributed to the soil type. In this area, the brown coarse ferralic Aren-osols (figure 2 (b)) can retain water long enough to allow *H. procumbens*, to develop superficial roots to absorb water each year which will be used in development of secondary tubers. For this reason, the resting period may be less important.

The average annual long-term rainfall has been observed to be 340mm (figures 3 a & 3 b), though it was an exceptional in 2005/2006 rainfall season. Rainfall has been found by

Strohbach & Cole (2007) to trigger growth in *H. procumbens*. With the results of the current study and consideration of the influence of rainfall on *H. procumbens*, the implication made here is that given favourable rains, *H. procumbens* is able to produce more secondary tubers with the current study's soil type and period the plants are left without harvesting.

At Vergenoeg, a different result was found where plants that were rested from harvesting for five (5) years produced significantly more secondary tubers than plants that were rested from harvesting for two years. At Vergenoeg there are sandy plains with ferralic Arenosols (figure 2 (b)) that allows quick water drainage. Plants that have not been harvested for five (5) years have enough time to develop superficial roots to absorb enough water even within a short period that it is present before draining downwards. The plants rested from harvesting for five (5) years were observed to have also developed deeper roots (personal observation) compared to plants at Ben Hur. According to Strohbach & Cole (2007), these deeper roots take years to reach beyond one (1) meter to absorb water when superficial roots have no more water around to absorb. *H. procumbens* not harvested for two years on the other hand would have less time to develop superficial roots to absorb water which drains quickly when it rains. Because of fewer superficial roots that may be developed on plants not harvested for two years, water absorption in these plants may be limited to amounts enough to enable the plant to produce few secondary tubers.

Based on figures 6(a) & 7 (a) which indicate that a single plant rested from harvesting for two years produced seven (6.77) secondary tubers that weighed 551.1 grams compared to nineteen (18.77) secondary tubers weighing 1292.556 grams produced by a single plant which was not harvested for five years.

Considering that the final product (sliced-dried tubers) lose 90% of the initial fresh weight (figure 7 c), the results from the current study implicates that a harvester would need to harvest nineteen (19) plants to get one (1) kilogram of dried tubers if such plants were rested from harvesting for the past two years, whereas a harvester would only need to harvest eight (8) plants to get one (1) kilogram of dried secondary tubers if such plants were rested from harvesting for five (5) years.

According to Cole & Bennett (2007), one (1) kilogram of secondary tubers is currently costing N$20.00 and considering that the final product (sliced-dried tubers) for harvesters loses 90% of the initial fresh weight, more plants need to be harvested for each harvester if they are to be harvesting every after two years from the same plants compared to when they would harvest after five years.

Therefore, harvesters from Vergenoeg would benefit more when they do not harvest such plants for five years whilst managing their own resource sustainably.

Even though rainfall at Vergenoeg has been 40 mm higher than Ben Hur for the period under study, the fact that Ben -Hur’s soil type retains water for longer periods giving time for absorption by all plants, explains why the two-year rested from harvesting plants can produce as many secondary tubers as the five-year rested from harvesting plants at Ben Hur.

The reason why there was no significant difference in the number of secondary tubers and yet there was a significance difference in weight at Ben Hur is because secondary tubers produced by the two-year rested from harvesting plants were smaller in size compared to those produced by the five-year rested from harvesting plants. Based on figure 6 (b) & 7 (b) an average tuber from plants rested from harvesting for five years weighed 193.65 grams, compared to 116.92 grams from plants rested from harvesting for two years only within that same period of time. This means that secondary tubers from the five-year rested from harvesting plants would be increasing in size in each of the five years they have not harvested, whereas for the two-year rested from harvesting plants, the increase would only be from the two years they are not harvested. The difference of more than seventy-six (76.8) grams(g) in weight per secondary tuber is the profit harvesters would benefit at Ben-Hur for not harvesting a plant twice in a space of five years. This translates into 2265.8g of secondary tubers fresh weight per plant in contrast to 1309.615g from plants not harvested for two years only.

Therefore, in order for a harvester at Ben-Hur to get one (1) kilogram of dried tubers, they only need to harvest five (5) plants if such plants were not harvested for the past five (5) years, compared to eight (8) plants they would harvest if such plants were not harvested for the past two years only.

The same reasons given for the difference in the number of secondary tubers above are attributed to why the same pattern still exists in secondary tuber weight for Vergenoeg.

Considering the economic situation of local harvesters, conservation of *H. procumbens* and the benefits of not harvesting for five years, sustainable harvesting quotas equally devided between the numbers of harvesters per area would help in this regard. Harvesters would devide their *H. procumbens* production area into five parts allowing themselves to harvest from one of the parts per year allowing them to harvest from each part only after five years. A similar approach has been done by some harvesters who divided their production area into two parts which allowed them to harvest from each part after two (2) years (Cole, 2005). It was evidently beneficial to the harvesters involved and if done on a large scale of involving all harvesters, it would benefit all involved.

This holistic approach would link conservation with economic satisfication for local harvesters who would become managers of their own resource. It has been established that such management systems workout successfully by Jones (2003). These systems have been found successful because they encourage community members to seek economic benefit from the managed exploitation of their resource (Jones, 2003).

3.5 Conclusion

The ability of producing fruits by *H. procumbens* does not depend on how long it is left without harvesting but possibly on other conditions like soil type, age of a plant and rainfall conditions found by previous researchers. This therefore, implies that *H. procumbens* in the wild can regenerate well with its fruits even when it is being harvested on. Local harvesters can therefore, still have *H. procumbens* continuing to recruit future plants for them to harvest in their production areas with sustainable harvesting techniques that leave the main tuber undisturbed after harvesting.

Because of the ability to retain water by the Ben Hur soils, *H. procumbens* can produce the same number of secondary tubers whether not harvested for two years or five years. This however, does not give enough reason for locals to harvest *H. procumbens* after two years only rather than after five (5) years because return on labor is important for maximization on their profit. The bigger the size of secondary tubers, the more dried slices will be sold and hence the more money for the harvesters who spend much effort and time to dig-up these tubers. Therefore, since the number of secondary tubers was equal but different in weight, it is recommendable to rest these plants for five (5) years at a site such as Ben Hur.

At Vergenoeg, the sandy plains with ferralic Arenosols allow quick water drainage. In order to absorb much of this quick-draining water when it rains, *H. procumbens* must develop superficial roots to absorb enough water. It is evident from the results of this study that, two-year rested from harvesting plants would not have as many of these superficial roots to absorb enough water helping the plant to produce more secondary tubers. Five years of resting on the other hand was evident to have enough deeper superficial roots, which helped absorb water enough to produce more secondary tubers that were bigger in size.

Considering the economic needs of harvesters, conservation concerns for *H. procumbens* and a higher profit for harvesters resulting from five (5) years of not harvesting these plants, a holistic management approach (rotational harvesting) is required to benefit stakeholders involved over a sustained period of time. Local harvesters would themselves manage who harvests which plants each particular year, maintaining that each plant gets harvested only after five (5) years. This management approach would give local harvesters control over their own resource linking conservation with economic satisfication, where many locals would in the end be benefiting from this resource, as opposed to when few individuals get to harvest many plants after every two years.

CHAPTER 4

CORRELATIONS BETWEEN PARENT TUBER SIZE AND FRUITS AND SECONDARY TUBERS

4.1 Introduction

In the previous chapter sustainable harvesting techniques have been mentioned to be practiced by local harvesters. These techniques have been applied on plants whose selection has been based on the parent tuber derived age. This correlation between parent tuber size and secondary tubers or fruits produced by *H. procumbens* has been given little scientific research. This chapter therefore serves to investigate this correlation.

4.2 Literature review

Local harvesters have been relying on parent tuber size to determine the plants to be harvested. They have been relying on experienced local community harvesters who would confirm that selections are large enough (Cole & Strohbach, 2007).

GATSUK *et al.* (1980) have demonstrated that in population studies, better predictive results are obtained by using plant size – related to age state or biological age – rather than actual age, which is difficult to determine for long-lived plants, especially perennial herbs.

Cole and Strohbach (2007) have therefore defined age states based on the diameter of the main tuber of *H. procumbens.* This was based on observations on reproductive capability of plants, main tuber diameter and rates of increase in main tuber diameter. In addition, they looked at the production of below-ground storage tubers to determine when a plant should have sufficient accumulated reserves to enable harvesting.

The mortalities recorded during the second tuber diameter survey on all sites three years later, showed that plants with an initial tuber diameter of less than 2.3 cm had the highest tuber diameter increase. When looking at reproductive ability, it was found that the plants with an original tuber size of less than 1.5 cm had not produced any fruit, and had probably also only produced very few flowers, if any. When all marked plants on each site were harvested, it was mainly those with a tuber diameter larger than 2.4 cm that were found to be capable of producing such minimum harvestable quantities of storage tuber. As this size coincided with the high mortality rates of plants with a tuber diameter < 2.3 cm, it was assumed that the latter plants would probably re-invest most of their assimilates in main tuber growth rather than produce an extensive system of secondary storage tubers. Based on these observations, age states were defined as follows:

Table 2 Definitions of age states for *H. procumbens* (from Cole & Strohbach, in preparation)

G1	Young reproductive plant	Calendar age estimated to be 2-5 years, main tuber diameter 1.5-2.3 cm. Flowering and fruiting is limited, but shoot growth very strong. Assimilates are still used mainly for main tuber growth, but secondary storage tubers are

		being formed, the latter mostly smaller than 1 cm in diameter and weighing less than 100 g.
G2	Mature reproductive plant	Calendar age estimated at 3-10 years, but may be much younger under very favorable conditions (e.g. dry land cultivation). Main tuber diameter 2.4 to 3.4 cm. Shoot production, flowering and fruiting rates at their optimal level. Assimilates are first used for the production of large amounts of flowers and the development of fruit. As the fruit ripens, assimilates are replenished and added to the storage tubers. The latter is very variable, but most plants are capable of producing at least 400-500 g under favorable conditions. The increase in main tuber diameter becomes much slower compared to the smaller age states.
G3	Old reproductive plant	Calendar age estimated to be from 5 or 6 years and older. Tuber diameter 3.5 cm and more. Tuber diameters of up to 6.5 cm were observed, but in general plants with a main tuber diameter above 5 cm are very rare. Shoot production, flowering and fruiting levels are optimal. Assimilates are first used for the production of flowers and fruit, then replenished and accumulated in the storage tubers. Plants that are harvested for the first time often have a storage tuber yield above 1kg, while healthy plants are generally able to regenerate at least 400 g of new storage tubers over a period of 4 years after harvesting. Many of these tubers are gnarled and woody to some extent.

4.3 Materials and methods

4.3.1 Data collection

Parent tuber diameter was used as a determinant in selecting *H. procumbens* plants to be classified into age groups to be observed in April-June 2006 (table 2).

The Ben Hur study site was used where twenty (20) plants within the fenced plot were observed (appendix 1: table 9). All the plants used in this regard were not harvested for five years. The plots at Vergenoeg could not be used in this regard because there were not enough plants available in plots at Vergenoeg which could be observed. Most plants in these plots were either harvested before or were observed in this study for other objectives presented in other chapters.

There were not enough plants from the unfenced plot at Ben Hur so that impacts of interactions between the two factors (protection from grazing and age) on *H. procumbens* could also be studied.

For each of the observed plants, the number of fruits, secondary tubers and secondary tuber weight were recorded.

4.3.2 Data analysis

In order to analyze the statistical significance of the correlations between parent tuber diameter and the number of fruits, the number of secondary tubers and secondary tuber weight, data was tested for normality using the Kolmogorov-Smirnov normality test (Townend, 2002) in the Statistical Program for Social Scientists (SPSS) (appendix 1: table 10).

The number of secondary tubers and secondary tuber weight variables were found to be normally distributed hence they were correlated using the Pearson's correlation test. The

Pearson's correlation test is a bivariate correlation test that is used when correlating two variables that are normally distributed (Field, 2005).

The number of fruits variable was found to be not normally distributed and hence the Spearman's correlation test was employed. The Spearman's correlation test is a non-parametric correlation test that is used for bivariate correlations on non-normal data (Field, 2005).

Both The Spearman's & Pearson correlation tests use correlation coefficient as a measure of the strength of relationship between two variables.

It measures from -1 to 1 as the inter-relationship between two variables. A correlation of 1 implies that each variable is completely determined by the other one, and that both increase and decrease together. A correlation of -1 again implies that they are determined by each other but that one decreases while the other increases. A correlation of 0 implies that there is no relationship between the variables.

4.4 Results and Discussion

After collecting and analyzing the data from the field, the following results were found.

4.4.1 Correlations between parent tuber size and the number of fruits per plant

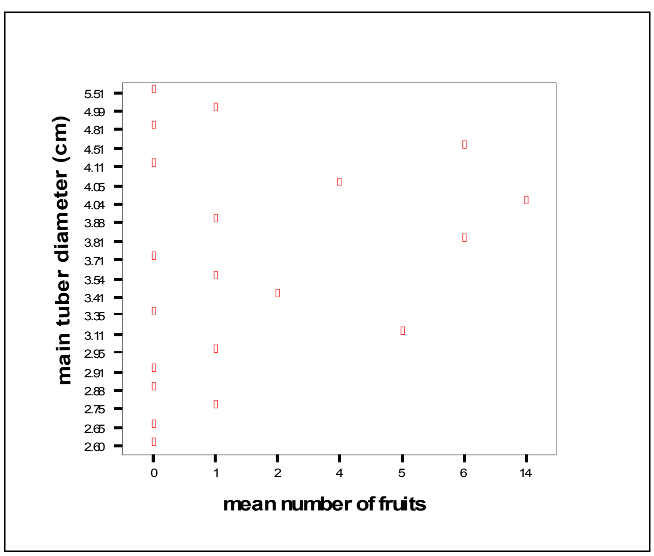

Figure 8 Correlation between parent tuber size and the number of fruits per plant

Figure 8 shows that there was no clear correlation between parent tuber size and the number of fruits per plant. As parent tuber size increase, the number of fruits remained the same for most observations in the graph. It was only in five (5) observations out of twenty (20) where the larger the parent tuber size, the more the fruits there was per plant. The Spearman's correlation test shows that there was no significant correlation between parent tuber size and the number of fruits per plant ($P = 0.337$) (appendix 1: table 11).

The result that shows that there was no significant correlation between parent tuber size and the number of fruits per plant implies that fruit production in *H. procumbens* does not depend on parent tuber size which determines the plant's age. Contrary to findings by Burghouts (1985) that the number of fruits produced by *H. procumbens* increase with the increase in parent tuber diameter. This study's results do not support conclusions reached by Burghouts (1985).

The difference in results can be attributed to the fact that Burghouts (1985) made comparisons even with young plants whose parent tuber size (1.5-2.3cm) were not observed in the current study. The current study did not also observe senescent plants but rather focused on plants in the mature and old reproductive life stages (main tuber diameter = 2.4 – 6.5cm). Therefore the current study can only provide evidence that regardless of parent tuber size when *H. procumbens* is at the mature and old reproductive age state, the species can produce the same number of fruits.

4.4.2 Correlations between parent tuber size and the number of secondary tubers and secondary tuber weight per plant

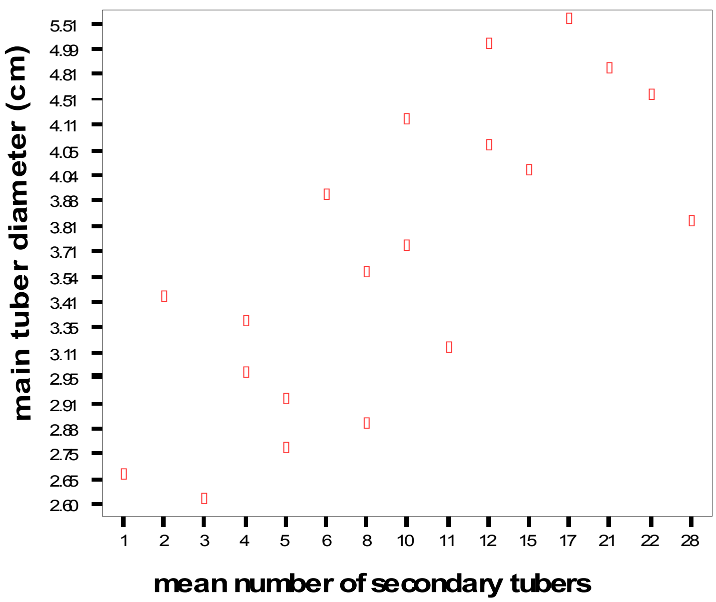

Figure 9 Correlations between parent tuber size and the number of secondary tubers.

Figure 9 shows a clear linear relationship between parent tuber size and the number of secondary tubers produced by *H. procumbens.* The larger the main tuber got, the more secondary tuber there was. For every 1cm increase in parent tuber size, there was corresponding increase of five (5) secondary tubers.

Pearson's correlation test provides evidence that there was a significant positive correlation between parent tuber size and the number of secondary tubers per plant (P = 0.001) (appendix 1: table 12).

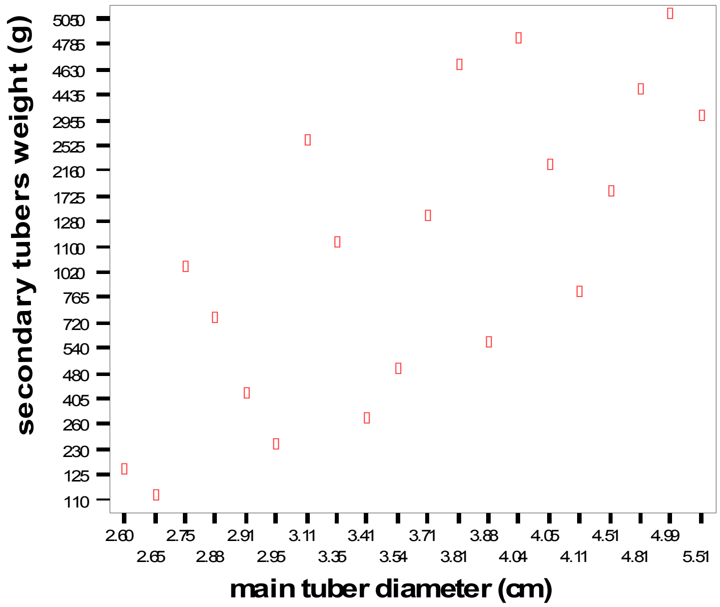

Figure 10 Correlations between parent tuber size and secondary tuber weights per plant

Figure 10 shows a clear linear relationship between parent tuber size and the fresh weight of secondary tubers produced by *H. procumbens.* The larger the parent tuber increased, the larger the size of its secondary tubers also. For every 1cm increase in parent tuber diameter, there was corresponding increase of 400g fresh weight of secondary tubers.

According to Burghouts (1985) *H. procumbens* is at its prime in producing secondary tubers in the old reproductive age. Results from this study support these findings. Hulzebos (1987) also found that production of secondary tubers in *H. procumbens* was based on parent-tuber diameter (age), in that old plants produce more. This is because mature plants would have less superficial roots than old plants to help them bear as many secondary tubers. Old plants would have secondary tubers when mature plants start producing their first secondary tubers. This subsequently leads to the secondary tuber weight following the same pattern.

Though these plants were harvested at the same time, the difference in parent tuber size suggests that plants with smaller parent tubers would still need to extend more superficial roots that are already on plants with bigger parent tubers.

According to Veenendaal (1984) secondary tuber weight increased with age (parent tuber diameter size). This is displayed in figure 8 above. This is because for the past five years, the tubers which were on old plants had been increasing in size every year, whereas secondary tubers on mature plants had to develop and gain weight which is still less than that of old plants.

4.5 Conclusion

Fruit production in *H. procumbens* does not depend on parent tuber diameter but rather on factors like protection from grazing (chapter 5).

The larger the parent tuber gets, the more secondary tubers can be produced by such a plant. Parent tuber size also determines the size of secondary tubers it has, provided that such a plant has not been harvested for five (5) years. This is useful to *H. procumbens* local harvesters in order to maximize benefits from *H. procumbens* while sustaining the plant populations. Since plants with smaller parent tubers will be given the opportunity to also produce more secondary tubers until they reach the size of those with larger parent tubers.

CHAPTER 5

INFLUENCE OF PROTECTION FROM GRAZING ON BRANCHES, FRUITS AND SECONDARY TUBERS

5.1 Introduction

Apart from concerns of a resting period between harvests and knowledge of a rational age state to harvest *H. procumbens*, grazing and trampling of shoots and other parts of *H. procumbens* is yet another that hinder the sustainable management of *H. procumbens*.

This chapter presents an investigation of the influence of protection from grazing on the length and number of branches, number of fruits, number of secondary tubers and weight of secondary tubers by *H. procumbens.* This chapter also investigates the correlation between branches and fruits of *H. procumbens.*

For the purposes of this study, protection refers to plants that were fenced off all grazing and trampling for a period of five years, whilst no protection refers to plants which were not fenced for the same period of time..

5.2 Literature review

The grazing threat to *H. procumbens* exist, especially in years with low rainfall and little other fodder for livestock, as well as through antelopes like duiker depending on the underground storage organs as a water resource. Newly emerged shoots which are grazed by antelopes and livestock are avoided once the clawed fruits begin to form (CITES, unpublished**)**. This suggests a high loss of above-ground *H. procumbens* plant parts when the plant is not protected from grazing. These above-ground parts of any plant are important much that without them plants will not produce any fruits that contribute to the maintenance of the species population. It was established by Allcock & Hik, (2004) that individual plants whose above-ground plant parts remain un-grazed are more likely to flower and therefore contribute to the maintenance of the population.
Moreover, above-ground parts help in performing photosynthesis for the plant, without which a plant dies.

Protection from grazing meanwhile, has been found to promote and increase cover and diversity of plant species (Choudhury *et al.,* 2005), especially grazing-intolerant plants (Hartley & Mitchell, 2005) in areas where it has been applied.

The impacts that grazing and trempling have on branch, tuber and fruit production of *H. procumbens* is however not known that is why a study needs to be carried out using protection from grazing as the treatment.

5.3 Materials and methods

5.3.1 Data collection

Both the Ben-Hur and Vergenoeg study sites described in chapter 2 were used for data collection in this regard. Both the fenced (protected from grazing) and the unfenced (not protected from grazing) plots were set-up in 2001 and *H. procumbens* plants to be observed have been in these plots since then. Plants were selected from both the fenced and unfenced plots at each site.

From the Ben Hur study site, eleven (11) *H. procumbens* plants were randomly selected from the fenced plot whereas seven (7) were selected from the unfenced plot (appendix 1 table 14a). All these were plants that had not been harvested since 2001 in the fenced and unfenced plots where they were found to be in the old reproductive stage during the year 2006. Old plants were selected because it is believed that *H. procumbens* produces more fruits and secondary tubers when in the old stage of its lifecycle (Burghouts, 1985). In both cases a random number table was used to select the plants.

The same procedure was followed at Vergenoeg where fourteen (14) old plants from the fenced plot whilst ten (10) old plants from the unfenced plot were found and observed in the same way as at Ben Hur (appendix 1: table 20 a).

From each of the plants described above at both study sites, the numbers of branches were counted and their lengths were measured using a measuring tape in order to determine the influence of protection from grazing on the number and length of branches. This data and the data on the correlation between branches and fruits would then be useful in explaining the difference in the number of fruits between plots with protection and plots without.

In order to determine the influence of protection from grazing on the number of fruits produced by *H. procumbens,* all fruits on the selected plants from all plots at both the study sites were recorded. This difference was additionally sought by correlating the numbers of branches and length of branches to the numbers of fruits found on plants in plots protected from grazing in contrast to plots not protected from grazing.

Secondary tubers from the same plants observed above were also harvested and recorded from both sites to determine the influence of protection from grazing on the amount and weight of *H. procumbens* secondary tubers.

5.3.2 Data analysis

The total number of fruits, secondary tubers and secondary tuber weight for plants from the fenced plots was summed and averaged by the number of observations (number of plants) to get the average number of fruits per plant from each site (fenced/un-fenced) for graphic presentation of results.

In order to perform statistical analysis on collected data, the test for normality using the Kolmogorov-Smirnov normality test in Statistical Program for Social Scientists (SPSS) was used on data from the study sites (appendix 1: tables 14 b & 20 b).

In order to determine the relationship between branch length and the number of fruits *H. procumbens* bear and the relationship between the number of branches and the number of fruits, a Spearman's correlation test was used for data from the Vergenoeg study site. Spearman's correlation test was used because data in this regard was found to be not normally distributed (appendix 1: table 24).

Data from the Ben-Hur study site was found to be normally distributed and hence the Pearson's correlation test was employed (appendix 1: tables 16 & 17)

Furthermore, the Independent Samples T-Test (Townend, 2002) from SPSS was employed in order to determine the influence of protection from grazing on the number of branches and their lengths at Ben-Hur (appendix 1: table 18).

The T-Test was employed because data for the number of branches and branch length was found to be normally distributed at both study sites and this data was assessing whether means of two groups are statistically different from each other.

The number of fruits variable was found not normally distributed at both sites and was therefore analyzed using the Mann-Whitney U test from SPSS. This analysis was done in order to determine the influence of protection from grazing on the number of fruits by *H. procumbens.*

The number of secondary tubers variable at Vergenoeg was found to be normally distributed hence was analyzed using the Independent Samples T-Test for mean differences (Townend, 2002) from SPSS. Secondary tuber weight were found not normally distributed hence they were analyzed using the Mann-Whitney U test which is a non-parametric test equivalent to the T-Test (Townend, 2002) from SPSS. From Ben Hur, the number and fresh weight of secondary tubers variables were found normally distributed and analyzed using the Independent Samples T-Test from SPSS for mean differences.

5.4 Results and Discussion

This section presents results and their implications thereof.

5.4.1 Influence of protection from grazing on the number and length of branches

Ben-Hur site

As can be seen in figure 11 (a) below, there were eight (8) branches on average on *H. procumbens* with protection whereas there were only three (3) branches on average found on *H. procumbens* without protection. The T-Test provides evidence that this difference was significant at 95% confidence intervals (P = 0.008) (appendix 1: table 18).

There were also longer branches (mean = 53.57cm) on plants with protection compared to (*mean* = 12cm) plants without protection (figure 11 a). This difference was statistically found to be highly significant (P = 0.0001) (appendix 1: table 18).

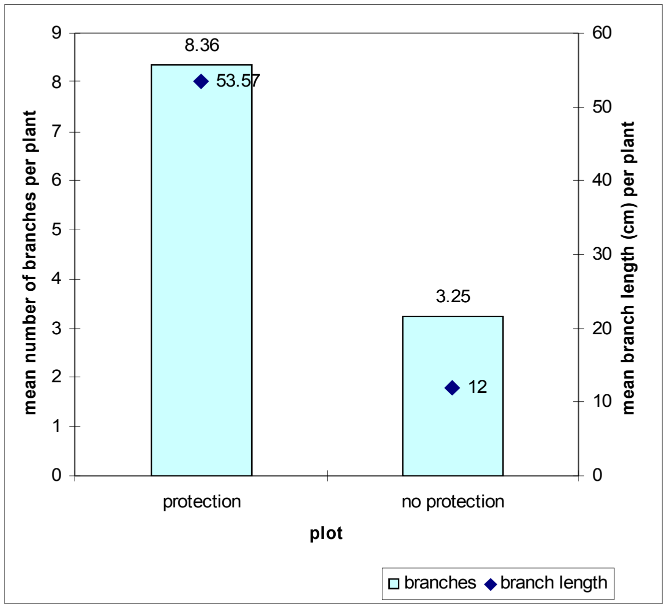

Figure 11 (a) Difference in *H. procumbens* above-ground biomass between plants with protection and plants without protection.

These branches were found to extend through spaces between tufts of grasses and also between bases of shrubs and other plants. They were found to be longer in cases where the distance to the nearest neighbor was big between other plants. They were however found to be short in cases where the distance to the nearest neighbor was small between other plants.

Vergenoeg site

There were thirteen (13) branches on average found on *H. procumbens* with protection compared to the average of five (5) branches found on *H. procumbens* without protection (figure 11 b). This difference was statistically found to be highly significant at 95% confidence intervals (P = 0.0001) (appendix 1: table 23).

There were also longer branches (mean = 64.2cm) on plants with protection compared to (*mean* = 14.3cm) plants without protection (figure 11 b). This difference was statistically found to be highly significant (P = 0.0001) (appendix 1: table 24).

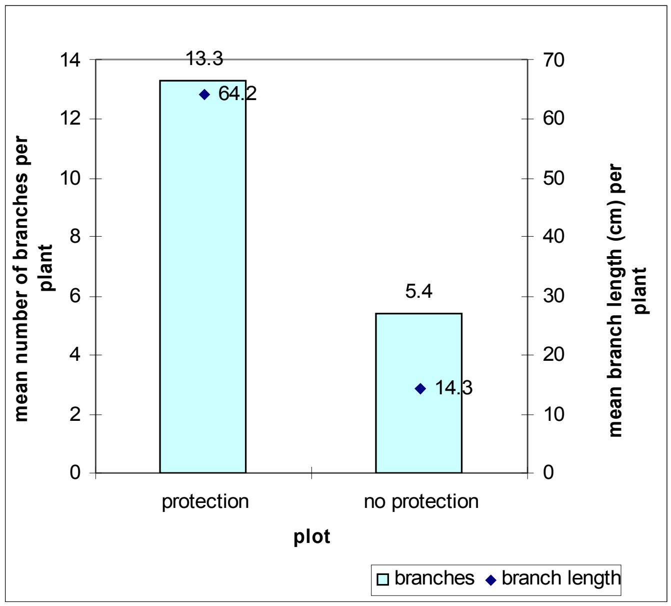

Figure 11 (b) Difference in *H. procumbens* above-ground biomass between plants with protection and plants without protection.

Like at Ben-Hur, *H. procumbens* plants were also found to extend their branches through tufts and bases of other plants around *H. procumbens* plants at Vergenoeg.

5.4.2 Correlations between *H. procumbens* branches and its fruits

Ben-Hur site

Figure 12 below shows a highly positive relationship between the number of fruits and branch length. This means that the longer the branch the more fruits there will be on it.

When tested statistically, this positive correlation was found to be significant (r = 0.894) (P = 0.001) (appendix 1: table 16).

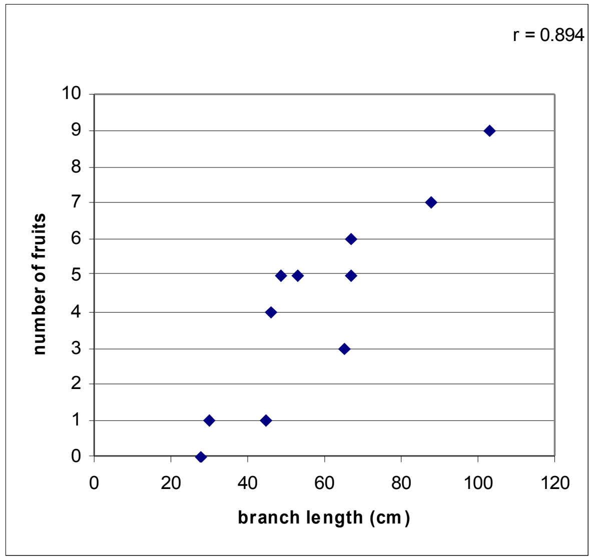

Figure 12 Correlation between the number of fruits and branch length at Ben-Hur

Figure 13 below shows a highly positive relationship between the number of fruits and branch length. This implicates that the longer the branch the more fruits there will be on it. When tested statistically, this positive correlation was found to be very highly significant (r = 0.957) (P = 0.0001) (appendix 1: table 17).

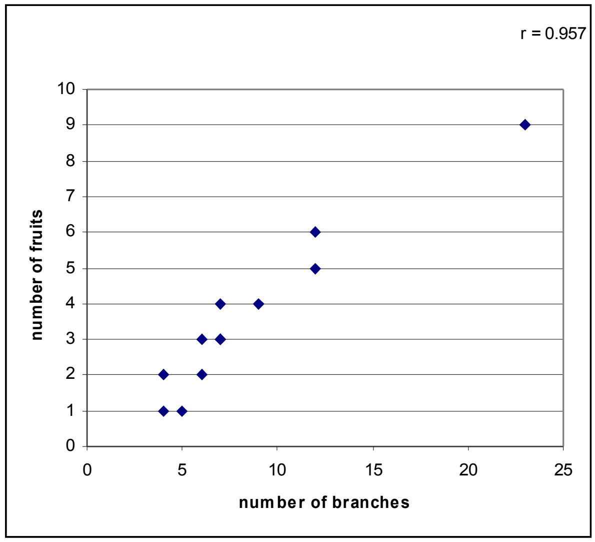

Figure 13 Correlation between the number of fruits and branch length at Ben-Hur

Vergenoeg site

Figure 14 below shows a positive relationship between the number of fruits and branch length. This means that the longer the branch the more fruits there will be on it. When tested statistically, this positive correlation was found to be significant (r = 0.580) (P = 0.010) (appendix 1: table 24).

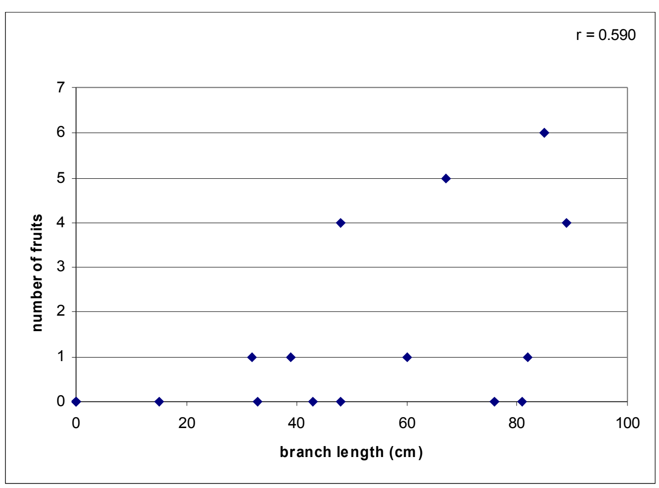

Figure 14 Correlation between the number of fruits and branch length at Vergenoeg

Figure 15 below shows that there was a positive correlation between the number of fruits and the number of branches, implying that the more branches a plant has the more fruits it can produce. This positive correlation was found to be weak and of significance when tested statistically (r = 0.602) (P = 0.008) (appendix1 table 24).

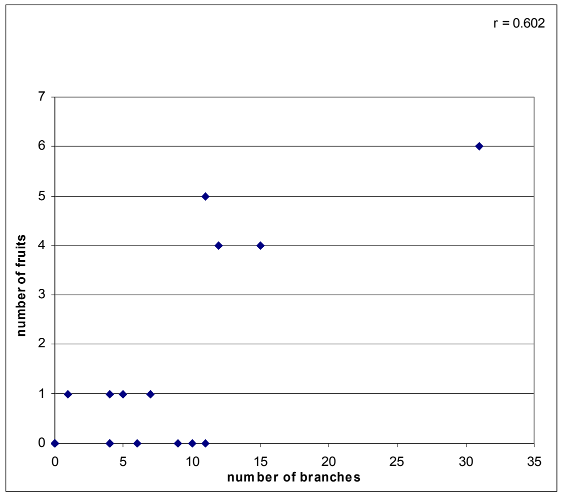

Figure 15 Correlation between the number of fruits and the number of branches at Vergenoeg

5.4.3 Influence of protection from grazing on the number of fruits per plant

Ben-Hur site

On average there were more fruits (*mean ranks*: 11.50, *sum of ranks*=126.50) on *H. procumbens* with protection from grazing, than (*mean ranks*: 6.36, *sum of ranks*=44.50) on *H. procumbens* without protection from grazing (appendix 1: table 19).

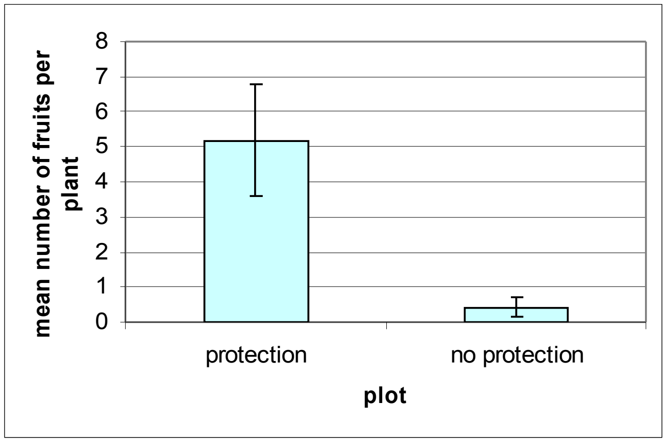

Figure 16 (a) Difference in the number of fruits per plant between plants with protection and plants without protection Ben Hur**.**

Figure 16 (a) above displays the difference between *H. procumbens* protected from grazing and *H. procumbens* not protected from grazing. It displays that there were on average five (5) fruits per plant with protection whereas there was an average of less than a fruit per plant without protection. When this difference was tested statistically, it was found that the difference was of high significance providing evidence that there were more fruits on plants with protection that on plants without protection (P = 0.044) (appendix 1: table 19).

Vergenoeg site

On average there were more fruits (*mean ranks*: 11.50, *sum of ranks*=126.50) on *H. procumbens* protected from grazing, than (*mean ranks*: 6.36, *sum of ranks*=44.50) on *H. procumbens* not protected from grazing (appendix 1: table 23).

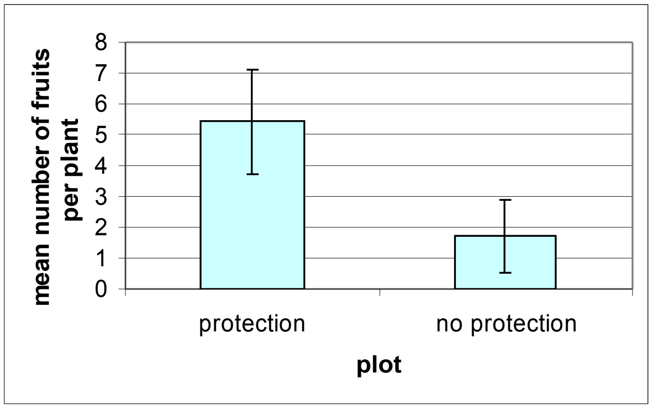

Figure 16 (b) Difference in the number of fruits per plant between fenced and unfenced plots at Vergenoeg.

Figure 16 (b) shows that there were more fruits on *H. procumbens* in the fenced plot than on *H. procumbens* in the unfenced plot. This difference was found to be statistically significant and is therefore evident that there were more fruits on plants in the fenced plot than in the unfenced plot (P = 0.036) (appendix 1: table 23).

The results from this study present evidence that protection from grazing improve the number of fruits *H. procumbens* can produce. This is attributed to the fact that *H. procumbens* without protection are exposed to trampling and livestock grazing when there is less palatable forage.

One factor to consider is the results displayed in figures 13 (a) & 13 (b), where *H. procumbens* protected from grazing had many long branches compared to *H. procumbens* not given protection.

Another factor to consider is the correlation between branches and the number of fruits per plant (figures 12-15). What is important to note in those correlations is that the number of fruits per plant depends on the number of branches and their length, thus the longer the branch, the more nodes producing fruits there can be and that the more of these branches, the more fruits there also will be. This theory is supported by Hachfeld (2003) who found that the reduction in the number of branches reduces nodes where fruits can be produced.

The results from the current study helps to explain the above-mentioned theory supported by Hachfeld (2003), establishing that *H. procumbens* protected from grazing has more and longer branches which determines the number of nodes per plant and ultimately the number of fruits per plant.

Strohbach (1999) observed a pattern of heavy grazing on *H. procumbens* flowers and leaves when there was less forage for livestock at Vergenoeg. This kind of circumstances is what Mayer (2004) maintains to negatively affect fruit set in plants. According to Mayer (2004), fruit set in plants is compromised on overgrazed land due to the trampling and grazing of flowers.

Hachfeld (2003) also upholds that grazing and trampling are a threat to plant production, *H. procumbens* in particular, especially in dry years.

Considering the factors above, it is understandable therefore, that *H. procumbens* given protection from grazing will have more fruits than when the species is without protection.

5.4.4 Influence of protection from grazing on the number and weight of secondary tubers

Ben-Hur site

On average there were more secondary tubers (*mean*: 14.64, *SE*=2.033) on *H. procumbens* protected from grazing, than (*mean*: 8.43, *SE*=0.948) on *H. procumbens* not protected from grazing (appendix 1: table 18).

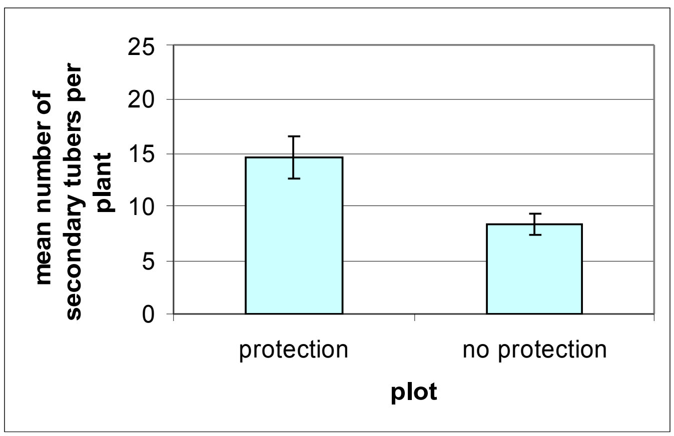

Figure 17 (a) Difference in the number of secondary tubers per plant between plants with protection and plants without protection at Ben-Hur.

Figure 17 (a) shows that there were more secondary tubers on *H. procumbens* with protection than on *H. procumbens* without protection. When tested statistically, this difference was found to be of significance (P = 0.034) (appendix 1: table 18).

Vergenoeg site

On average there were more secondary tubers (*mean*: 19, *SE*=3.256) on *H. procumbens* plants with protection from grazing, than (*mean*: 7.30, *SE*=1.155) on *H. procumbens* plants without protection from (appendix 1: table 22).

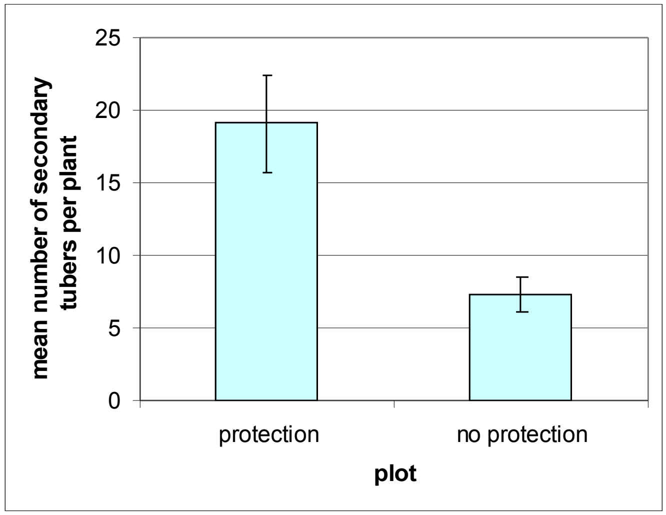

Figure 17 (b) Difference in the number of secondary tubers per plant between plants with protection and plants without protection at Vergenoeg

Figure 17 (b) above displays that there were more secondary tubers on *H. procumbens* with protection than on *H. procumbens* without protection. There were three times more secondary tubers on plants with protection than there were on plants without protection. This difference was found to be of statistical significance (P = 0.008) (appendix 1: table 22).

Ben-Hur site

On average there were larger secondary tubers (*mean*: 2618.64, *SE*=549.329) on *H. procumbens* protected from grazing, than secondary tubers (*mean*: 422.29, *SE*=96.340) on *H. procumbens* not protected from grazing (appendix 1: table 18).

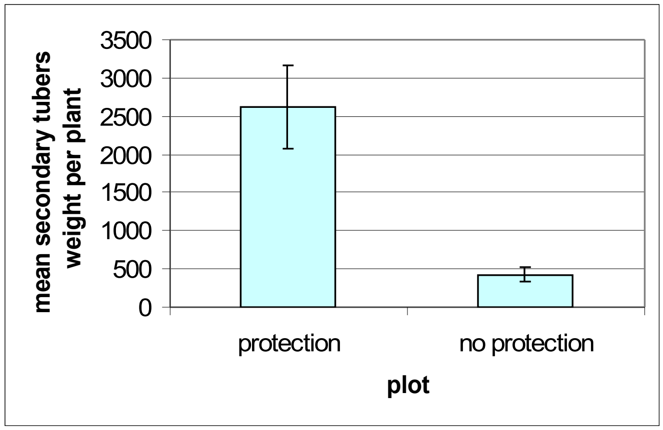

Figure 18 (a) Difference in secondary tuber weight per plant between plants with protection and plants without protection at Ben Hur.

Figure 18 (a) shows that secondary tuber weight was higher on *H. procumbens* with protection than on *H. procumbens* without protection.

Secondary tuber weight from *H. procumbens* with protection was twice more than the weight for those without protection. This difference was found to be of statistical significance (P = 0.006) (appendix 1: table 18).

Vergenoeg site

On average there were larger (*mean ranks*: 15.54, *sum of ranks*: = 217.50) on *H. procumbens* protected from grazing, than (*mean ranks*: 8.25, *sum of ranks* = 82.50) on *H. procumbens* not protected from grazing (appendix 1: table 23).

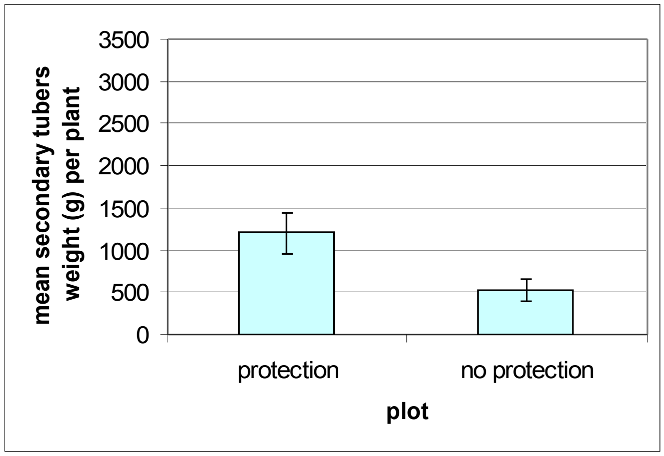

Figure 18 (b) Difference in secondary tuber weights per plant between plants with protection and plants without protection.

Secondary tuber weight from *H. procumbens* with protection was five (5) times higher than from *H. procumbens* without protection from grazing (figure 18 b). This difference was of statistical significance and hence evident that there were higher secondary tuber weights on *H. procumbens* with protection than those without (P = 0.011) (appendix 1: table 23).

The results from both Ben-Hur and Vergenoeg indicate that there were significant differences in the number of secondary tubers between *H. procumbens* protected from grazing and *H. procumbens* not protected from grazing (P = 0.034 & 0.008 respectively)

Since all conditions on all observed plants were the same and the only difference between them was the fact that some were protected from grazing while others were not, the fact that plants with protection had more secondary tubers, implicates that protection from grazing had an influence.

This could be attributed to the fact that, disturbance of above-ground biomass of *H. procumbens* affects its underground biomass as well. This supports findings by Alonso *et al.,* (2001) who concluded that protection from grazing enhances plant growth. It is therefore suggested by these results that plant growth which is known to be favored by protection from grazing, has a positive influence on the number of secondary tubers produced by *H. procumbens.* This is attributed to the results in the previous chapter, where it was established that plant age, determined by the size of the main tuber, grows under favorable conditions like enough rainfall. It is evident from these results that apart from rainfall, protection from grazing also plays an important role in tuber production of *H. procumbens.*

It is known that through above-ground biomass of a plant, activities such as respiration, transpiration, photosynthesis and other activities are made possible within different parts of a plant (Salisbury & Ross, 1985) and ultimately its survivability. In addition, it is also known that through a plant's above-ground biomass, oxygen, hydrogen and carbon are received to be used for the whole plant whilst nutrients like calcium (Ca), phosphorus (P), potassium (K) etc, are acquired through a plant's below-ground biomass (roots) (Harper, 1985; Starr, 1999).

With the background given above, and the knowledge that plants without protection are exposed to grazing and trampling of their above-ground parts each year. The functions explained above which these parts are supposed to be giving to the whole plant are restrained and ultimately, fewer secondary tubers get produced. Once secondary tubers are produced, their enlargement will follow over a period of time. Since the older the plant, the more secondary tubers it has (chapter 4) and that plant growth depends on the amount of nutrients within the plant, trampling and herbivory therefore lead to fewer secondary tubers because nutrients are lost from plants through herbivory and abscission (Pugnaire & Valladares, 1999). This herbivory on active above ground biomass of *H. procumbens* is only possible when there is no protection or other grazing management incentives in place.

5.5 Conclusion

The exposure of *H. procumbens* to trampling and grazing by livestock negatively affects its fruit production since both flowers and branches are broken off and these determine the number of fruits a plant can produce.

This exposure which is only prevented by protection from grazing the plants off, also negatively affects the number and fresh weight of secondary tubers due to the fact that once the above-ground plant parts are not functional, its below-ground production will also be affected. Since the population of this species has to be maintained, protection from grazing will be of benefit to ensure that its future populations continue. Furthermore, better grazing management could also be of benefit in this regard.

Furthermore, management of *H. procumbens* should consider the fact that the number of fruits on *H. procumbens* is determined by its number of branches and their length.

CHAPTER 6

IMPACT OF VEGETATION COEXISTING WITH *H. procumbens* ON TUBER PRODUCTION OF *H. procumbens*

6.1 Introduction

In the wild *H. procumbens* occur with different plant species ranging from those that are potential competitors to those that coexist serenely. Little is known about which of the species coexisting with *H. procumbens* have negative roots deep enough to compete for soil resources with *H. procumbens.* This chapter therefore, presents an investigation of the influence of different plant types and species that coexist with *H. procumbens* on the production of secondary tubers by *H. procumbens.*

6.2 Literature review

6.2.1 Above and below-ground competition with other plants

The coexistence of plant species results from niche requirements (i.e. resource partitioning) and relative competitive ability (Aarssen, 1989).

Plants growing with competition have been found to accumulate less biomass than plants growing with reduced competition (Aguiara *et al.,* 2001). This competition can exist above ground (competing for light for example) or underground where roots of different plants strive for the same soil resources needed for plant survival.

Underground competition has been found to exist even between grasses and young trees, with grasses restricting lateral roots of these young trees (Schaller *et al.,* 2003). However, new field evidence from the Kalahari, where the water table is too low for the tree roots' tapping, revealed that both grasses and shrubs invest the bulk of their roots in the surface horizons (Hipondoka *et al.,* 2003) and still coexist.

Generally, shrubs are known to have tap roots in areas of relatively higher precipitation, but in the Kalahari, they appear to have adapted to a drier climate by presenting an opportunistic phenomena of having no tap roots. Shrubs in these environments tap water from the surface soil layers, though the competition status between shrubs and grasses is not yet known in this environment (Hipondoka *et al.,* 2003).

Belsky (1994) on the other hand established that roots of herbaceous and woody species co-occurred within the same soil horizons, but tree roots extended farther into grasslands at low-rainfall sites than at the high-rainfall sites.

On the other hand, *H. procumbens* in the Kalahari coexist with different plant species including grass species, creepers and shrubs like *Acacia erioloba* and *Acacia hebaclada* (Cole & Strohbach, 2007).

It would be interesting to know the impact of this coexistence on the numbers and weights of secondary tubers produced by *H. procumbens* of the Kalahari, because it is possible that belowground competition has an influence on tuber production for *H. procumbens*.

Bais *et al.,* (2003) further suggest that root exudates might initiate and manipulate biological and physical interactions between roots of different species, and thus play an active role in root to root communication. This communication can be negative, for example many compounds released from plant roots have been shown to have deleterious effects on other plants (Bais *et al.,* 2003).

6.3 Materials and methods

6.3.1 Data collection

Eighteen (18) old reproductive *H. procumbens* plants were observed from Ben-Hur. These plants have been in a fenced off plot since 2001 and not harvested untill 2006. Around each of the eighteen (18) *H. procumbens* plants, a two by two meters (2 X 2 m) quadrant was set. All species found in the quadrant were identified using field identification books where possible. For species that could not be identified in the field, the specimens were collected and pressed to be identified at the National Botanical Research Institute in Windhoek. Basal cover (stem diameter for herbs and shrubs and living tuft diameter for grasses) of each plant within a quadrant was measured using a measuring tape.

The following variables were recorded within each of the eighteen (18) quadrants:

- The total diameter (basal cover) of each species found in that quadrant (collected by measuring tuft and stem diameter per species and adding up the total for each species per quadrant).
- The number of roots of other plants on either side (20 cm) of the main tuber to a depth of 50 and 120 cm. A soil profile was excavated on each observed plant and the roots in the profile were exposed using a sharp stick (Schaller *et al*, 2003). All roots

were then mapped on a graph paper with a 10 X 10cm grid. Density of roots in the grid was classified as follows:

- 0 roots = no density
- 1-10 roots = less dense
- 11-20 roots = dense
- 20-30 roots = very dense

This was done in order to correlate root density with above-ground biomass of other plants. This correlation would help in determining which plants or species (found above-ground) influenced root density (belowground) which would ultimately be investigated on its influence in tuber production of *H. procumbens.*

The 50cm depth was used in the current study considering the fact that grasses in the Kalahari are known to invest more (2/3) of their roots at depths not longer than 50 cm (Hipondoka *et al*, 2002).

The 120cm depth was chosen because Strohbach and Cole (2007) found that this depth is the maximum depth that *H. procumbens* can have its secondary tubers and the main taproot which the plant uses for water and nutrient uptake. Roots of other plants at this depth would therefore compete with those of *H. procumbens.*

The number of secondary tubers and secondary tuber weight were recorded to determine the influence of competition between *H. procumbens* and other plants on *H. procumbens* tuber production.

6.3.2 Data analysis

In order to rank basal cover per quadrant, the area for the 2 X 2 meter quadrant was calculated (400 cm^2).

Basal cover per quadrant was therefore classified according to diameter measurement into four (4) groups as follows:

Table 3 Classification of basal-cover at Ben Hur

Basal-diameter cover	***Percentage cover (%)***	***Class***
0	0	None
1 – 100 cm^2	< 25	Less-covered
101 – 200 cm^2	< 50	Medially-covered
201 – 300	< 75	Highly-covered
301 – 400	76 – 100	Very highly covered

All variables, i.e. number of secondary tubers and secondary tuber weight in each class were averaged with the number of *Harpagophytum procumbens* plants for correlations.

Data was tested for normality and found not to be normally distributed. The Spearman's correlation test was therefore used in this regard because it is the non-parametric correlation test equivalent to Pearson's test.

The following are the cases where Spearman's correlation test was applied:

- belowground root density (at 50 & 120 cm) and the number of secondary tuber,
- below-ground root density (at 50 & 120 cm) and secondary tuber weight,
- above-ground basal cover from other species and below-ground root density of other species, and
- branch length and the number of fruits per plant.

An initial correlation between the number/fresh weight of secondary tubers and root density was sought to determine the influence of below-ground root density (at 50 & 120 cm) on the secondary tubers.

A further correlation between above-ground basal cover and below-ground root density at 50cm and 120 cm was sought to determine the relationship between root density and above-ground basal cover.

In order to determine which plant type/species influenced the relationship between above-ground basal cover and below-ground root density, the total basal cover by plant type was summed and averaged for each quadrant and ultimately for all quadrants.

All plant types were then analyzed using regression in SPSS to determine the presence of which plant type influenced root density below-ground. The Spearman's correlation uses correlation coefficient as a measure of the strength of relationship between two variables.

6.4 Results and Discussion

The following results reveal the findings of the investigation on the influence of vegetation coexisting with *H. procumbens* on the species tuber production.

In order to get a full picture of the plants coexisting with *H. procumbens* in the wild at Ben-Hur, the most important aspect would be to understand the plant type and species that dominates these habitats.

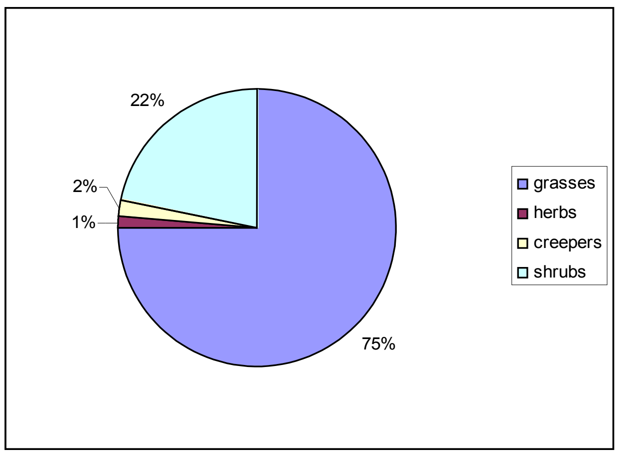

Figure 19 Basal cover dominance by plant type at Ben-Hur.

Figure 19 above shows that basal cover was dominated by grass species more than creeper, herb and shrub species. More than 75% of the total (27.3 %) above-ground basal cover in the fenced plot was by grass species only.

Having established the plant type which dominated in the wild, the next step would be to narrow down to which species constituted much of the dominance from the dominant plant type (grasses).

Grass species encountered included the following:

1. *Stipagrostis uniplumis* dominated overall basal cover more than the other three grass species found growing around *H. procumbens.* This is a perennial grass species that is known to be densely tufted in sandy soils and disturbed areas (Muller, 1984).

2. *Panicum coloratum* was found to be the second dominant grass species with regard to basal cover. This species represeted 17% of the total grass basal cover. It is a perennial species known to be variably tufted, preferring sandy soils (Muller, 1984).

3. *Schmidia kalahariensis* was found to be the third dominant grass species with regards to basal cover. This species represented 14% of the total grass basal cover. It is a tufted increaser annual that prefers sandy and disturbed locations (Oudtshoorn, *et al.,* 1992).

4. *Eragrostis lehmmania* was found to be the least dominant grass species with regards to basal cover. The species represented 7% of the total grass basal cover. The species is a tufted perennial with lower nodes known to sometimes form roots. It is known to prefer sandy to sandy loam soils.

Even though grasses were the dominant plant type, it is important to understand characteristics of species from other plant types like shrub, creeper and herb species that were also found growing close to *H. procumbens*. Understanding this will help in determining which species are a threat and which ones are coexisting without threatening *H. procumbens*.

There were creeper, herbs and shrubs encountered coexisting with *H. procumbens* apart from grasses:

Creeper species recorded included the following:

1. *Acanthosicyos naudinianus* has a thick tuberous root that can grow to one meter in length (SEPASAL, undated). This species was uncommon in its occurrence around *H. procumbens*, there were only a few cases where it was encountered.
2. Another creeper that was encountered in some cases during the study is *Indigofera alternans*. This creeper is widespread throughout southern Africa in sandy soils, along roadsides and disturbed places (Van Rooyen, 2001).

The herb species found was *Elephantorrhiza elephantine.* It was occasionally encountered in colonies with tuberous roots. It is known to arise from a massive underground tuberous root (Hyde & Wursten, 2007).

Shrub species found were *Acacia erioloba* and *Acacia hebeclada* subsp *hebeclada*

Acacia erioloba is a very deep-rooted species and tap roots have been found at 45 m depth in boreholes. It is adapted to arid conditions by having an extensive root system (Smit, 1999).

Acacia hebeclada subsp *hebeclada* is also known to be a deep rooted species (Smit, 1999).

6.4.1 Relationship between above-ground basal cover and below-ground root density

The correlation between above-ground basal cover and below-ground root density is important in order to establish whether the presence or absence of certain plant types or species above ground determined root density belowground at 50cm and 120cm around *H. procumbens.*

6.4.1.1 Correlation between above-ground basal cover and below-ground root density at 50 cm depth

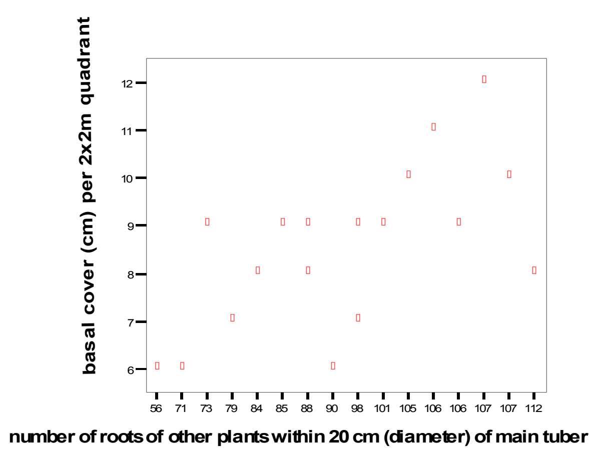

Figure 20 (a) Relationship between above-ground basal cover and the number of roots of other plants representing root density from other species found close to *H. procumbens* at 50 cm depth.

Figure 20 (a) shows that as the number of roots of other plants increase, basal cover also increases. The relationship displayed in figure 20 above was found to be a significant relationship (P=0.007) (appendix 1: table 27). With the correlation coefficient at *r:* 0.614 (appendix 1: table 27), the positive relationship between basal cover and the number of roots of other plants is strong.

6.4.1.2 Correlation between above-ground basal cover and below-ground root density at 120 cm depth

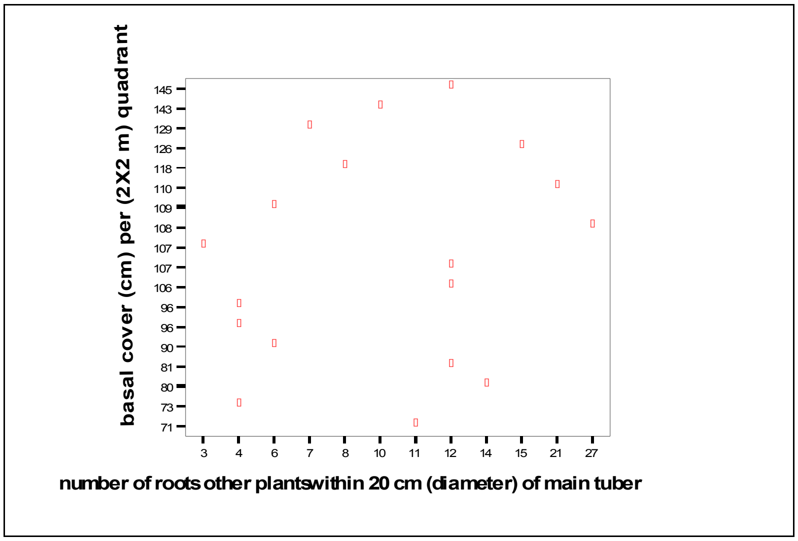

Figure 20 (b) Relationship between above-ground basal cover and the number of roots of other plants representing root density from other species found close *H. procumbens* at 120 cm depth.

Figure 20 (b) shows that as the number of roots of other plants increase, basal cover neither increase nor decrease. There was therefore a non-significant relationship between the number of roots of other plants and above-ground basal cover (P=0.318) (appendix 1: table 28).

The result that there was a significant positive relationship found between above-ground basal cover and below-ground root density at 50cm depth implies that the higher the basal cover above-ground, the higher the root density below-ground at 50 cm. The result therefore suggest that most species that dominated above-ground cover had their roots at 50cm depth. Therefore by measuring tuft and basal cover of species found above-ground, below-ground root density at 50cm can be estimated.

There was a non-significant relationship between root density of other plants and above-ground basal cover at the depth of 120cm. As above-ground basal cover increased, root density of other plants remained unchanged at this depth. The result implies that plants that dominated basal cover did not have their root densities at depths of 120cm. This is important because at this depth *Harpagopytum procumbens* have most of its secondary tubers. Therefore, species found to dominate above-ground basal cover can coexist with *Harpagopytum procumbens* because competition for resources such as soil moisture and nutrients would be less if any.

6.4.2 Relationship between below-ground root density and the presence of different plant types above-ground

6.4.2.1 Correlation between plant type and root density at 50 cm depth

The regression analysis shows that grasses and shrubs, among other predictors (creepers and herbs), were positively related with the number of roots of other plants found at 50 cm depth. Grasses had the highest (*b*: 2.797) positive relationship with the number of roots of other plants followed by shrubs (*b*: 0.870) compared to creepers (*b*: -0.118) and herbs (*b*: 0.003) (appendix 1: table 29). As grass and shrub basal diameter increases, the numbers of roots of other plants found at 50cm depth also increase. Moreover, grasses had the greater contribution (*t*: 4.619, P = 0.0001) to the decrease of roots of other plants below-ground, followed by shrubs (*t*: 4.149, P = 0.001) compared to creepers (*t*: -0.457, P = 0.655) and herbs (*t*: 1.559, P = 0.141) and grasses (appendix 1: table 29). By measuring the total shrub and grass diameter within a 2X2 m area, the number of roots of other plants below-ground can therefore be predicted, despite the presence herbs and creepers.

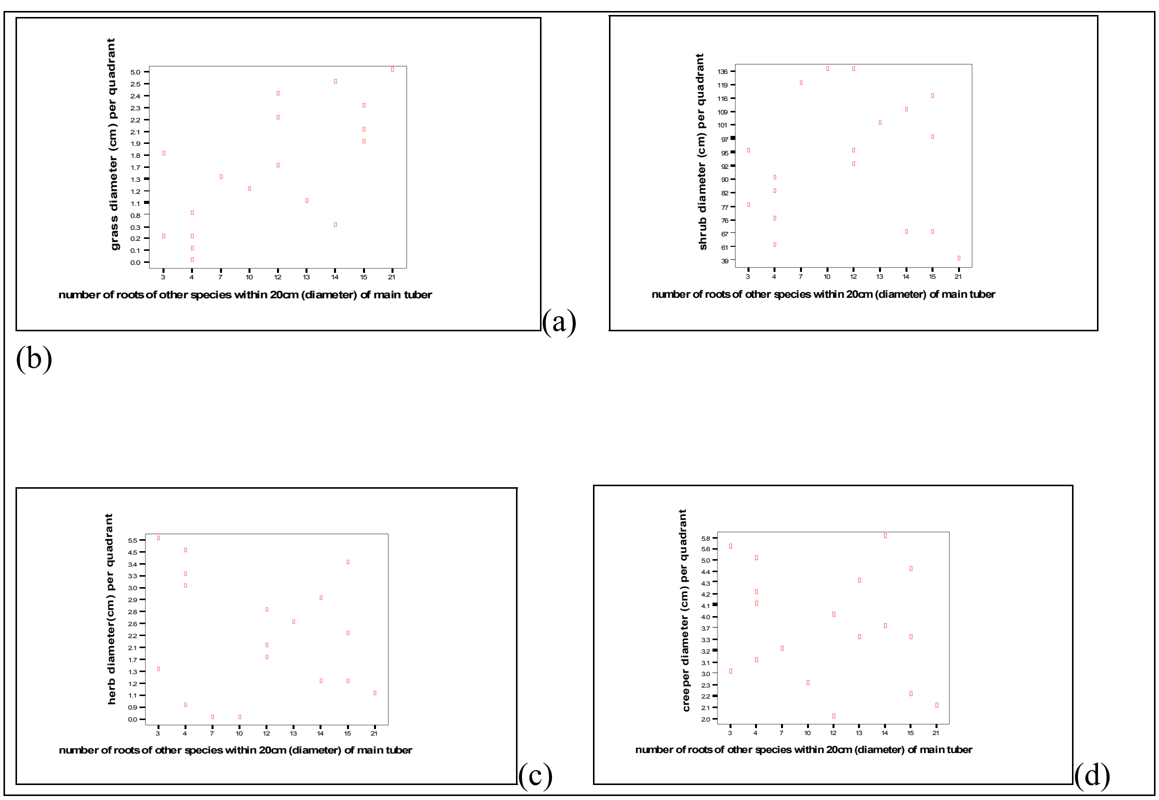

Figure 21 Relationship between (a) grass diameter and root density of other species, (b) shrub diameter and root density of other plants, (c) herb diameter and root density of other species and (d) creeper diameter and root density of other plants presented by means of the number of roots found close *H. procumbens* at 50 cm depth.

Figure 21 (a) shows a general linear trend between grass diameter and root density of other plants found at 50 cm depth within 20 cm diameter of the main tuber. The relationship is positive since larger values on the x-axis yield larger values on the y-axis, thus above average in shrub diameter tends to be associated with above average in root density.

Figure 21 (b) above, shows a combination of linear and scattered relationships between grass diameter and root density of other plants found at 50 cm depth within 20 cm diameter of the main tuber. This relationship is positive since larger values on the x-axis at most cases yield larger values and few cases moderate values on the y-axis, thus above average shrub diameter also tends to be associated with above average in root density.

Figure 21 (c) above shows a scattered relationship between herb diameter and root density of other plants found at 50 cm depth within 20 cm diameter of the main tuber, thus above average herb diameter has no association with above average in root density.

Figure 21 (d) above, shows a scattered of relationship between creeper diameter and root density of other plants found at 50 cm depth within 20 cm diameter of the main tuber, thus above average creeper diameter has no association with above average in root density.

The results imply that grasses, which were the dorminant plant type had most of their roots below-ground at 50 cm depth. The results also imply that shrubs, which in this case were *Acacia erioloba* and *Acacia hebeclada* subsp *hebeclada,* also had a superficial root system. This is in line with Hipondoka *et al.,*(2003) who established that shrubs in the Kalahari have developed a shallow root system to adapt to a drier climate, presenting an opportunistic phenomenon. Grasses and shrubs were therefore determinants of root density at 50 cm depth.

6.4.2.2 Correlation between plant type and root density at 120 cm depth

Results found indicate that roots found at this depth were of shrub species than creepers, herbs and grass species.

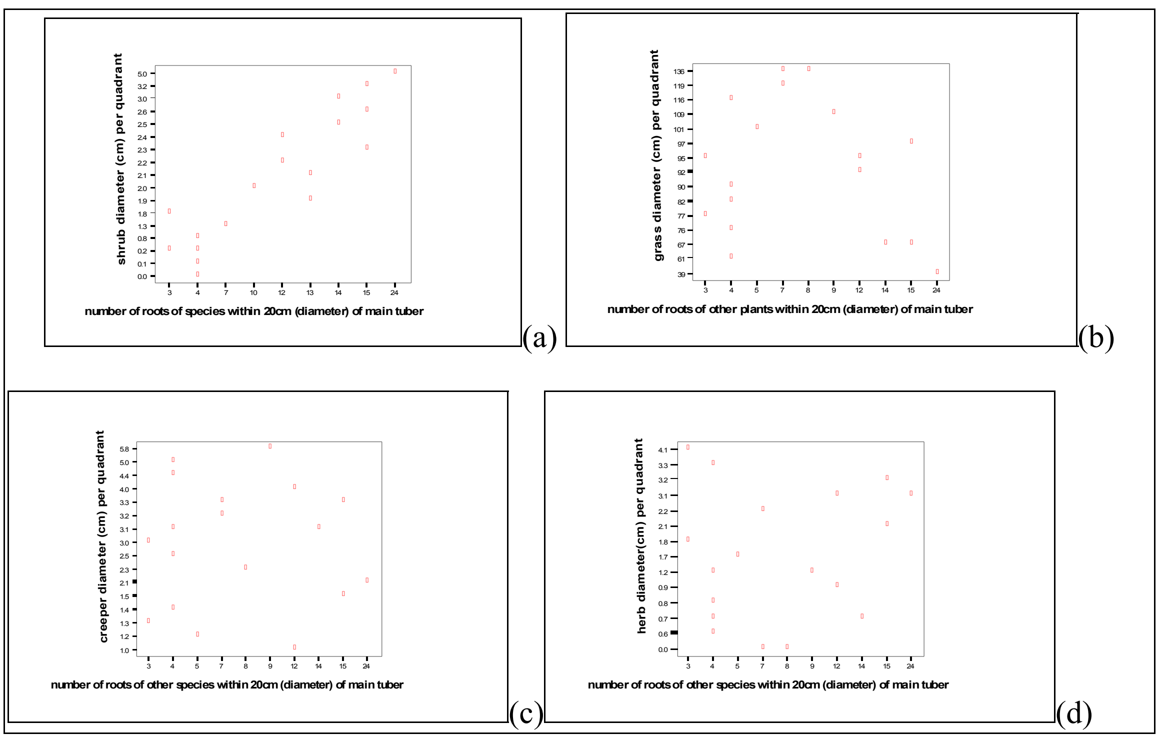

Figure 22 Relationship between (a) shrub diameter and root density of other species, (b) grass diameter and root density of other plants, (c) creeper diameter and root density of other species and (d) herb diameter

and root density of other plants presented by means of the number of roots found close *H. procumbens* at 120cm depth.

Figure 22 (a) shows a general linear trend between shrub diameter and the root density of other plants found at 120 cm depth within 20 cm diameter of the main tuber. The relationship is positive, thus above average in shrub diameter tends to be associated with above average root density.

Figure 22 (b) above, shows a scattered of relationship between grass diameter and root density of other plants found at 120 cm depth within 20 cm diameter of the main tuber, thus above average grass diameter has no association with above average in root density.

Figure 22 (c) above also shows a scattered style of relationship between creeper diameter and root density of other plants found at 120 cm depth within 20 cm diameter of the main tuber, thus above average creeper diameter has no association with above average in root density.

Figure 22 (d) above, shows a scattered of relationship between herb diameter and root density of other plants found at 120 cm depth within 20 cm diameter of the main tuber, thus above average herb diameter has no association with above average in root density.

The regression analysis shows that shrubs were positively related with root density of other plants found at 120 cm depth. Shrubs had the highest (*b*: 1.361) positive relationship with root density of other plants compared to creepers (*b*: -0.323), herbs (*b*: 0.535) and grasses (*b*: -0.007) (appendix 1: table 30). As shrub diameter increases, root density of other plants found at 120 cm depth also increases. Moreover, shrubs had the greater (*t*: 5.173, P = 0.0001) contribution to the decrease and increase of roots of other plants below-ground compared to creepers (*t*: -1.196, P = 0.250), herbs (*t*: 1.152, P = 0.267) and grasses (*t*: -0.534, P = 0.601) (appendix 1: table 30). Therefore, by measuring the total shrub diameter within a 2X2 m area, root density of other plants below-ground (at 120cm depth) can therefore be predicted, despite the presence of herbs, creepers and grasses.

Shrubs encountered in this study were *Acacia erioloba* and *Acacia hebeclada* subsp *hebeclada.* These are deep-rooted species with roots known to extend to 87cm depth (Smit, 1999). It therefore makes sense that shrubs were the only plant type to influence below-ground root density found at 120cm depth. Shrubs would therefore pose a more serious competition threat to *H. procumbens* rather than grasses because they have a root system in the same soil layer as *H. procumbens.* Despite the fact that 75% of basal cover was due to grass species, their presence did not influence root density at 120 cm depth below-ground. The presence of shrubs in quadrants where it was encountered, had an influence to root density at 120 cm below-ground. This is why shrub species would be a threat to *H. procumbens* than grass species even if basal cover is dominated by grasses more than shrubs. Shrubs constituted 22% of the total basal cover for plants found around *H. procumbens.*

All the grass species (*Stipagrostis uniplumis*, *Panicum coloratum, Schmidia kalahariensis,* and *Eragrostis lehmmania*) encountered in this study therefore, had their roots in superficial soil layers in contrast to *H. procumbens* that invested in deeper layers where shrubs were also found to have their roots.

Creeper species recorded were *Acanthosicyos naudinianus* and *Indigofera alternans.* These are species that are known to be deep-rooted and as it was observed when encountered. The result that they were found to have no relationship with below-ground root density, can therefore be based on the fact that they were rarely encountered. Creepers only contributed 2% of basal cover in the plots of study, making it insignificant to being a threat to *H. procumbens* plants at Ben-Hur.

The only herb species encountered was *Elephantorrhiza elephantine.* It is known to have massive underground tuberous roots (Hyde & Wursten, 2007). With this in consideration, the result indicating that there was no relationship with below-ground root density, can also be based on the fact that they were rarely encountered. Herbs only contributed 1% of basal cover in the plots of study, making it insignificant to being a threat to *H. procumbens* plants at Ben-Hur.

6.4.3 Correlation between below-ground root density and the number and fresh weight of secondary tubers

Having established the plant type that determines root density belowground at each depth, it is of importance to establish the link between these plant types and *H.*

procumbens. Therefore, the correlation between root density of other plant types and the number of secondary tubers of *H. procumbens* was sought.

6.4.3.1 Correlation between the number of secondary tubers and root density at 50cm depth

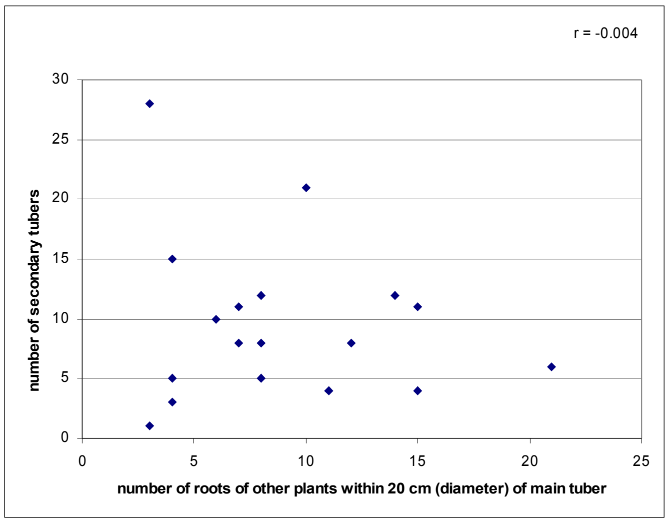

Figure 23 (a) Relationship between the number of secondary tubers and the number of roots of other plants representing root density from other species found close to *H. procumbens* at 50 cm depth.

Figure 23 (a) shows a general negative trend in the correlation between the number of secondary tubers and the number of roots of other plants: as the number of roots of other plants increases, the number of secondary tubers decreases. However this trend was not significant (P = 0.989) (appendix 1: table 24).

6.4.3.2 Correlation between the number of secondary tubers and root density at 120cm depth

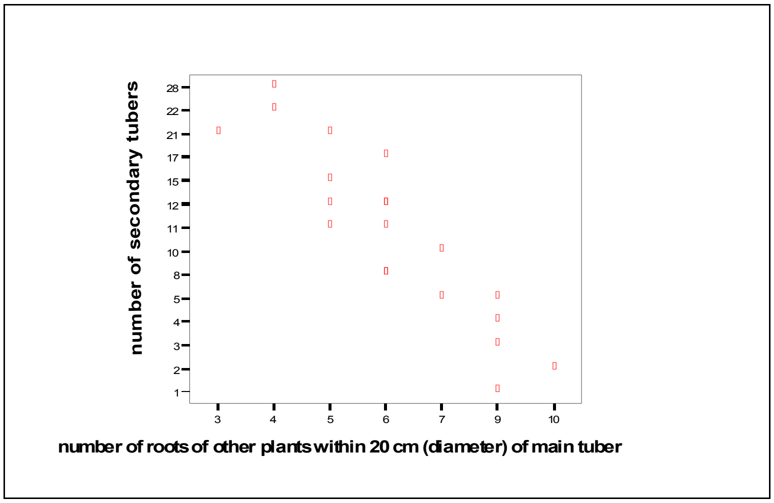

Figure 23 (b) Relationship between the number of secondary tubers and the number of roots of other plants representing root density from other species found close *H. procumbens* at 120 cm depth.

Figure 23 (b) shows that there was a negative correlation between the number of secondary tubers and the number of roots of other plants at the depth of 120 cm. This relationship was found to be highly significant (P = 0.000) (appendix 1: table 25). The correlation coefficient is negative (r = -0.916) (appendix 1: table 25) which therefore means that as the number of roots of other plants increase, the number of secondary tubers decrease.

Most secondary tubers were found between 65 - 120cm depth and to a lesser extent between 30 cm and 65cm depth. Secondary tubers found at superficial depths (30 - 65cm) were observed to be smaller in size compared to those found in deeper positions (65 - 120cm).

Another interesting observation was that roots found at 120 cm depth were larger than the finer roots found at 50 cm depth. Roots at this depth are usualy tap roots and lateral roots from these tap roots. The only plant types with such a type of rooting system are shrubs than grasses fibrous root systems in top soil layers.

It is also vital to understand the link between the plant types (found to determine below-ground root density) and *H. procumbens.* The relationship to be sought will be on root density of these plant types and its influence on the weight of secondary tubers of *H. procumbens*.

6.4.3.3 Correlation between secondary tuber weight and root density at 50cm depth

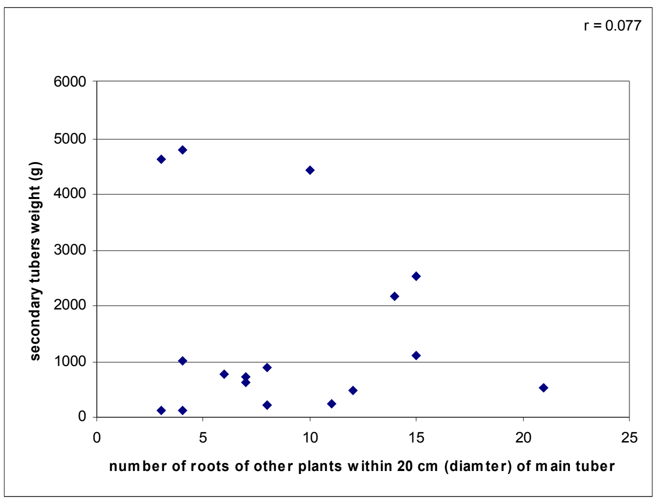

Figure 24 (a) Relationship between secondary tuber weight and the number of roots of other plants representing root density from other species found close *H. procumbens* at 50 cm depth.

Figure 24 (a) shows that there was a negative correlation trend between the fresh weight of secondary tubers and the number of roots of other plants at the depth of 50 cm. The trend shown is that as the number roots of other plants increase, the fresh weight of secondary tubers decrease. This was however a non-significant relationship (P = 0.762) (appendix 1: table 26).

6.4.3.4 Correlation between secondary tuber weight and root density at 120 cm depth

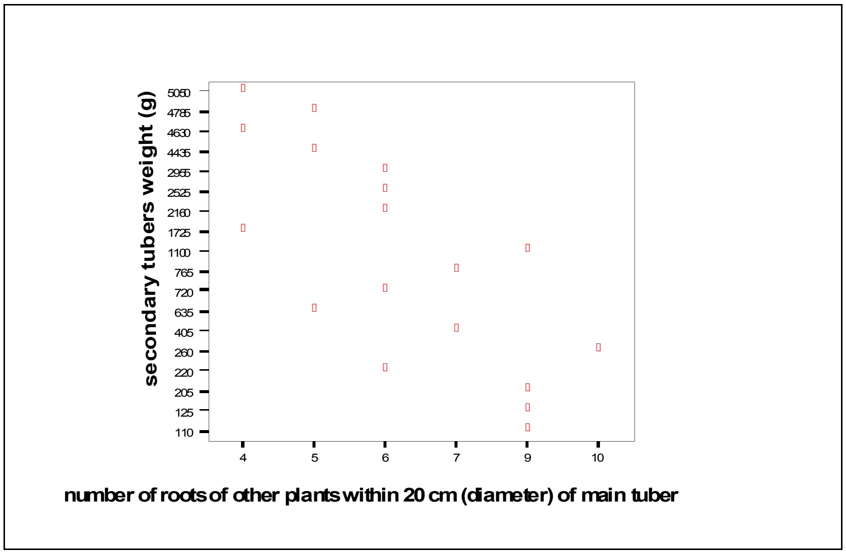

Figure 24 (b) Relationship between secondary tuber weight and the number of roots of other plants representing root density from other species found close *H. procumbens* at 120 cm depth.

Figure 24 (b) shows that as the number of roots of other plants increases at 120 cm depth, the fresh weight of secondary tubers decrease. This correlation was found to be highly significant *H. procumbens* (P = 0.000) (appendix 1: table 26). With the correlation coefficient of -0.759, the negative correlation was very strong.

Root density of other plants at 50cm was found to have no significant relationship with the number of secondary tubers produced by *H. procumbens* (P = 0.989) (appendix 1: table 23).

Since most secondary tubers were found in deeper soil layers, superficial roots from other plants which were mostly found at 50cm depth had little impact in competing for resources such nutrients and water (moisture) with *H. procumbens.* This lack of competition led to roots at 50cm depth to have no influence on the number and weight of secondary tubers produced by *H. procumbens.*

These results support those of Hachfeld (2003) who maintains that in order for species to coexist, they must overcome or avoid competition. Therefore the usage of different layers of below-ground organs to avoid spatial competition for soil water and soil nutrients are benefiting coexistence of *H. procumbens* and shallow rooted species.

Root density of other plants at 120cm was found to have a significant relationship with the number of secondary tubers produced by *H. procumbens* (P = 0.000) (appendix 1: table 2). The higher the root density of other plants was, the fewer the secondary tubers on *H. procumbens.* This is attributable to the fact that below-ground organs (roots) of other species were in the same soil layer as *H. procumbens.* This situation implies that competition for soil moisture and nutrients between *H. procumbens* and other species that had their roots within the same layer was possible.

Root density of other plants at 120cm was also found to have a significant relationship with the fresh weight of secondary tubers produced by *H. procumbens*. This is also attributable to the fact that below-ground organs (roots) of other species were in the same soil layer as *H. procumbens.* This suggests that the presence of root density of other plants brought competition for soil moisture and nutrients between *H. procumbens* and such species.

This is also in line with Hachfeld (2003) who held that if species are unable to avoid or overcome competition, coexistence is affected. Coexistence is affected in this case in that, *H. procumbens* is unable to produce as many secondary tubers as it would in situations where competition is absent.

6.5 Conclusion

Coexistence of *H. procumbens* and other deep-rooted species like *Acacia erioloba* and *Acacia hebeclada* subsp *hebeclada* has negative impacts on tuber production of *H. procumbens.* This was evident where the presence of shrubs influenced root density found at 120cm depth, which subsequently correlated negatively with the number and fresh weight of secondary tubers of *H. procumbens.*

The presensence of grass species encountered in this study does not pose a serious threat to *H. procumbens* in terms of competition since the two were found to utilize different soil layers. This helps *H. procumbens* farmers in that instead of leaving the soil where *H. procumbens* is managed bare the presence of grasses would help in avoiding topsoil erosion which would end up in higher run-off after rains subsequently limiting drainage capacities of soils where *H. procumbens* grows. This however, does not guarantee any threat from grasses on *H. procumbens* at all, because very dense stands of grasses would utilize all the moisture received from rainfall in the top-soil layer, reducing penetration of moisture to the subsoil where water resource is utilized by *H. procumbens* (Strobach, 1999).

The presence of the creepers and herbs found in this study is also another concern because they are deep rooted plants that are potentially able to compete for soil nutrients and soil water despite these plant types constituting a small percentage of basal cover.

Managing the presence of creepers ad herbs is beneficial to *H. procumbens* managers who would want maximum production from the species whilst managing the plant sustainably.

CHAPTER 7

THE EFFECT OF SULPHURIC ACID AND EFFECTIVE MICRO-ORGANISMS ON SEED GERMINATION

7.1 Introduction

Part of managing *H. procumbens* sustainably under domestication and to some extent in the wild is through regeneration from its seeds. This is needed because of demands that have existed over the years. Currently in Namibia, the supply of *H. procumbens* seedlings to farmers is a constraint to its cultivation and therefore a reliable means to constantly supply seedlings is desired. Supply of seedlings is hampered by poor germination rates of *H. procumbens*. The current germination rate of *H. procumbens* in Namibia varies from 1-2% (Kelly, 2003) to 37% (Kumba *et al.,* undated) which are still considered to be low rates. Poor germination rates have been attributed to a hard seed coat.

There have been several experiments to enhance germination rates in *H. procumbens* but their results still leave much to be desired. Among many was the experiment using sulphuric acid (Ernst *et al.,* 1988) which resulted in no germination at all. Effective Microorganisms (EM) have been widely used to enhance germination of several species with dormant germination characteristics (Khan *et al.* (2006).

This chapter presents an investigation on breaking dormancy in *H. procumbens* seeds using different concentrations of sulphuric acid and effective microorganisms.

7.2 Literature review

7.2.1 Influence of sulphuric acid on breaking dormancy

Sulphuric acid is a strong acid produced by dissolving sulphur trioxide in water and is very corrosive (Titiema *et al.,* 1992,). Its ability to corrode helps in breaking seed-coats to expose the embryo to water, soil and light for germination (Ellis *et al,* 1985).

Concentrated H_2SO_4 (95%) has been widely used and found to enhance germination of, *inter-alia*, *Tamarindus indica* (Muhammad & Amusa, 2003), *Melaleuca quinquenervia*

*(*Rayachhetry *et al.,* 1998), *Phytolacca americana* (Edwards *et al.,* 1988), *Atriplex nummularia* (Abu-Zanat & Samarah, 2005), *Bowdichia virgilioides* (Sampaio *et al.* 2001), *Leucaena diversifolia* (Bertalot & Nakagawa,1998), and *Dodonaea viscosa* (Baskin & Baskin, 2004). All the above-mentioned species are known to have a hard seed coat impermeable to water like that of *H. procumbens.*

Concentrated sulphuric acid has however failed to enhance germination in *H. procumbens,* resulting in no germination. Using concentrated H_2SO_4 is known to be disadvantageous because it can damage seeds of some species (Ellis *et al,* 1985). This may have been the case with the experiment on *H. procumbens* (Ernst *et al.,* 1988) where no germination was recorded after scarification of seeds in concentrated H_2SO_4. This is because concentrated sulphuric acid causes too much damage to seeds, accounting for poor germination (Jin *et al.,* 2006).

Fifty percent (50%) sulphuric acid has also been used to break seed dormancy in some species. In *Parkia biglosa* it enhanced germination of seeds to the same percentage as did seventy percent (70%) sulphuric acid, though ninety percent (90%) sulphuric acid enhanced germination the most (Aliero, 2004) in that particular species. One dormant species among others where 50% sulphuric acid enhanced germination incude *Tamarindus indica* (Muhammad & Amusa, 2003). In studies where 50% sulphuric acid has enhanced seed germination, soaking periods varied from 1 – 60 minutes.

Eighteen percent (18%) sulphuric acid has also been used to break seed dormancy of some species (Bertalot & Nakagawa, 1998)

Considering the fact that 95% sulphuric acid has already failed to enhance seed germination of *H. procumbens,* 50% sulphuric acid or less could aid in this regard accounting for better results.

7.2.2 Influence of Effective Micro-organisms on germination

The concept of Effective Micro-organisms (EM) was developed by Higa & James (1994). EM consist of mixed cultures of beneficial and naturally-occurring micro-organisms that can be applied as inoculants to increase the microbial diversity of soils and plants. It is comprised mainly of lactic acid bacteria, photosynthetic bacteria, yeasts, and actinomycetes that are commonly found in soil. All of these are mutually compatible with one another and can coexist to increase microbial diversity (Higa & James, 1994).

The microbes in EM have the ability to break down the organic matter thus releasing beneficial soluble substances such as amino acids, sugars, alcohol, hormones and similar organic compounds that are absorbed by plants and enhancing plant growth (Higa, 1999).

Research has shown that the inoculation of EM cultures to the soil/plant ecosystem can improve soil quality, soil health, and the growth, yield, and quality of crops. Siqueira *et al., (*undated) found that EM increased seed germination and vigor in carrot, cucumber, pea, beet, and tomato species. Khan *et al.* (2006) present further evidence that EM (1% & 2%) in enhance seed germination. Though species investigated above do not posses hard seed coats, it would be interesting to know if the same principle applies to hard-coated seeds like those of *H. procumbens.*

7.2.3 Germination requirements

According to Hanson (1985) and Ellis *et al.,* (1985) the following factors among others have to be considered: seed viability, dormancy, temperature, light, growth medium and water.

7.2.4 Seed viability

In previous years, researchers depended on germination tests to estimate seed viability. Researchers in recent years have found that using other methods other than germination gives reliable estimates on viable seeds since germination does not consider difficulties such as dormancy, empty seeds and slow germinating seeds (Ellis *et al..,* 1985).

7.2.5 Dormancy and triphenyltetrazolium chloride (TTC) test

Dormancy is the condition in a viable seed which prevents it from germinating when supplied with factors normally considered adequate for germination (Ellis *et al.,* 1985). Dormancy exists in various forms like ecological, hardseededness, enforced and other forms (Ellis *et al.,* 1985). Thick seed coats like that of *Garcinia cowa* seeds have been found to act as mechanical barriers to both water permeability and radicle protrusion (Liu *et al.,* 2005).

Seeds of *H. procumbens* in particular have strong dormancy mechanisms (Veenendaal, 1984) which may be governed by the thick seed coat, endosperm and embryo of the seed (Ernst *et al.*, 1988). Any of these three could be the cause for some seeds not to germinate.

The 2, 3, 5 triphenyltetrazolium chloride (TTC) test which has been previously recognised as the official stain by the International Seed Testing Association could be used to test for overall viability (Vujanovic *et al.,* 2000).

The TTC test is useful in germination experiments because it allows the researcher to take empty seeds into consideration. This is made possible because seeds have to be cut in halves before they are put in the TTC solution. The result will ultimately give an indication as to what proportion is potentially able to germinate.

7.2.6 Germination temperature

One of the requirements for germination to initiate is an appropriate temperature regime (Ellis *et al.,* 1985). This is due to the fact that temperature in the natural environment regulates timing of germination for most species (Hartman *et al.,* 1997).

Temperature and day length fluctuate on seasonal basis (Bradbeer, 1988). In the Southern Hemisphere days are longer than nights in the summer season, a period during which plants like *H. procumbens* get active in terms of recruitment of seedlings, growing branches and development of flowers and fruits (Burghouts, 1985). This season is associated with higher temperatures and rain.

Since seeds in the soil are subjected to fluctuating temperatures (Bradbeer, 1988), germination experiments should always consider this fact.

Chemical treatments, pre-chilling and alternating temperatures can promote seed germination for hard-coated seeds (Ellis *et al.,* 1985). Depending on the seed type and species though, some studies have established that constant temperatures for seed germination experiments are more useful than alternated temperatures (Abreu & Garcia, 2005). However, some studies such as Silveira, *et al*., 2004 and Silva *et al*., 2002, established that alternating temperatures improve seed germination.

Considering the fact that the seed coat of *H. procumbens* is known to influence dormancy in germination of the species (Ernst *et al..,* 1988), it has been suggested that altering very high and very low temperature could be a trigger for *H. procumbens* germination (Kok, 1986).

7.2.7 Effect of light on germination

Light is known to influence the expression of seed dormancy in many species, although its influence may be dependent on the presence of other dormancy-breaking agents (Ellis *et al.,* 1985).

For some species photoperiods of more than twelve (12) hours have been found to positively influence germination (Neto *et al.,* 2003), whilst for some species light has been found to have no influence on seed germination at all (Martins *et al.,* 2000).

7.2.8 Growth medium

Growth medium have been recommended to be non-toxic to germinating seedlings, free of fungi and of a porous texture for aeration and moisture for the germinating seedlings (Justice, 1972).

Paper, rolled towels and sand are some of the recommended germination substrates by Ellis *et al.* (1985). Sand as a substrate is mostly used for large seeded species (Ellis *et al.,* 1985) with longer germination periods. The species under investigation (*H. procumbens*) has dormancy that presents it with longer germination periods.

7.3 Materials and methods

7.3.1 Data collection

A total of one thousand (1000) seeds from fruits collected at Vergenoeg were used for this experiment. The fruits were collected from several plants from both the fenced and unfenced plots. Seeds from these fruits were dried and cleaned before the experiment took place.

A seed viability test was done to estimate the percentage of viable seeds which would help in deciding whether it is worthwhile to apply dormancy-breaking treatments considering the proportion of seeds that remain dormant despite using dormancy-breaking treatments. The 2, 3, 5 triphenyltetrazolium chloride (TTC) test was used to test for seed viability.

From the initial one thousand (1000) seeds, hundred and fifty (150) seeds were used to test for seed viability. These seeds were imbibed in water for twenty-four (24) hours after which they were each bisected through the embryo with a razor blade. One half of the seed was discarded and the other was placed in 1% TTC (staining) solution for one hour in darkness at 30ºC. The stained seeds were then washed three times in distilled water to remove excess TTC in order to make the embryo transparent, making them easier for evaluation (Ellis *et al.,* 1985). Seeds that showed to be stained (pink) on their embryos were recorded as viable and those that were not stained were recorded as non-viable.

The TTC test was used this way because the methodology has been recommended for members of the Pedalicae family known to be hard seed-coated (Ellis *et al.* 1985).

The remaining eight hundred and fifty (850) seeds were then washed in 10% Jik solution to avoid any fungal developments (Awodele *et al.,* 2007). These seeds were then availed for germination in five (5) treatments. These seeds were then availed for the germination experiment described below.

Five (5) different treatments for the germination experiment were set-up as follows:

a) pre-treatment of seeds with 18% sulphuric acid for 20 minutes (H_2SO_4 18%);
b) pre-treatment of seeds in 50% sulphuric acid for 20 minutes (H_2SO_4 50%);

c) pre-treatment of seeds in 1% Effective Micro-organisms for twenty-four (24) hours (EM 1%);

d) pre-treatment of seeds in 2% Effective Micro-organisms for twenty-four (24) hours (EM 2%)

e) soaking seeds only in water for 24 hours to serve as the experiment's control (Control).

In each treatment, five (5) replicates of thirthy-four (34) seeds each were used.

Justification for treatments selection

The first and second treatments (18% & 50% H_2SO_4) were chosen because; the previous germination experiment on *H. procumbens,* which used high (95%) concentrations of sulphuric acid (Ernst *et al.,* 1988) resulted in no germination at all due to such high concentrations.

Lower concentrations of sulphuric acid have enhanced germination of some species and could do the same for *H. procumbens.* Therefore, this study repeats the same experimental method as that by Ernst *et al.,* (1988) for except with reduced sulphuric acid concentration (18% and 50%), assuming that the reason there was no germination in the previous study was that the concentration was too high and burnt the seeds.

The third and fourth treatments (1% & 2% EM) were chosen because research (Khan *et al.,* 2006) has revealed that 1% & 2% EM concentrations enhance germination. As mentioned earlier that though species investigated by Khan *et al* (2006) do not posses hard seed coats, it would be interesting to know if the same principle would apply to hard-coated seeds like those of *H. procumbens.*

Furthermore, research has shown that the inoculation of EM cultures to the soil/plant ecosystem can improve soil quality, soil health, and the growth, yield, and quality of crops (Higa & James, 1994). Siqueira *et al. (*undated) have also found that EM increases seed germination and vigor for example in carrot, cucumber, pea, beet, and tomato species.

After the above-mentioned treatments, sand with ferralic Arenosols from Vergenoeg was prepared as a growth substrate. This sand was prepared in accordance with Justice (1972) and Hanson (1985) who recommended the growth substrate to be sterilized. As mentioned earlier, sand as a substrate is mostly used for large seeded species (Ellis *et al.,* 1985) with longer germination periods and was therefore preferred in this regard because *H. procumbens* has dormancy that presents it with longer germination periods.

Seeds were then sown according to their treatments in 25 x 20 cm bags of sand at 2cm depth (Ellis *et al.,* 1985).

They were put in a growth chamber set at 10˚C for 10 hours and 38˚C for 14 hours with the higher temperature being in light. The daily altered temperature was used in accordance with Kok (1986) who suggested that alternating very high and very low temperatures could be a trigger for *H procumbens* germination.

Each bag was watered with 100ml of water every day considering the water-holding capacity of the bags of sand used. Light was set for fourteen (14) hours and ten (10) hours in darkness for the whole germination period. This was done considering that summer days, when *H. procumbens* germinate in the field, are longer than summer nights.

The response variable which in this experiment was the numbers of seedlings germinating per bag and subsequently per treatment was recorded. The recording was done for three (3) weeks on a daily basis from the sixth day after sowing.

7.3.2 Data analysis

Data was tested for normality using the Kolmogorov-Smirnov normality test in SPSS and was found to be normally distributed (appendix 2: table 2). After data was found normally distributed, the One-Way Analysis of variance from SPSS statistical program was employed to test for mean differences (Field, 2005) in the number of seedlings germinated between the five (5) treatments.

In order to decide which of the treatments differed, the least significant difference test (LSD) (Field, 2005) was used (appendix 2: table 3 b).

7.4 Results & Discussion

The following results are from both the viability test and the germination experiment.

Table 4 Seed viability test results

Total fruits	Total seeds	Sample size	Percentage viability	
			Viable	**Non-viable**
10	1000	150	82% ±	18% ±

According to table 4 eighty-two percent (82%) of seeds tested were viable while the remaining eighteen percent (18%) were non-viable. This is attributed to the fact that some seed capsules were empty and some were partially damaged by some insect species which infested containers where these seeds were kept for a period since being harvested from seed pods. The seeds were kept for eight months before they were used for the germination experiment. Germination percentage was therefore based on these results in order to give a true reflection of the exact influence of the applied treatments.

According to table 5 pretreated seeds initialized germination in the first week compared to the untreated seeds from the control which gave no germination at all at the end of the first week. Most seedlings of pretreated seeds (except seeds pretreated in EM) germinated in the second week whereas most seedlings from the control germinated in the third week.

This implies therefore that pretreatment of *H. procumbens* seeds with sulphuric acid and/or effective micro-organisms cuts down on the germination period. This could be beneficial to *H. procumbens* stakeholders who germinate the species to supply to farmers in cases where demand is high for seedlings.

Table 5 Total seedling germination per week for each treatment:

Treatment	**Total number germinating by week**		
	Week 1	Week 2	Week 3
H_2SO_4 18%	9	14	12
H_2SO_4 50%	12	19	16
EM 1%	11	25	12
EM 2%	13	35	14
Untreated	0	2	7

One-Way Analysis of variance on germination rates for all treatments showed a significant difference between treatments (P = 0.000) (appendix 2: table 3 a). Pre-treatment of seeds with effective micro-organisms gave the highest germination rate overall.

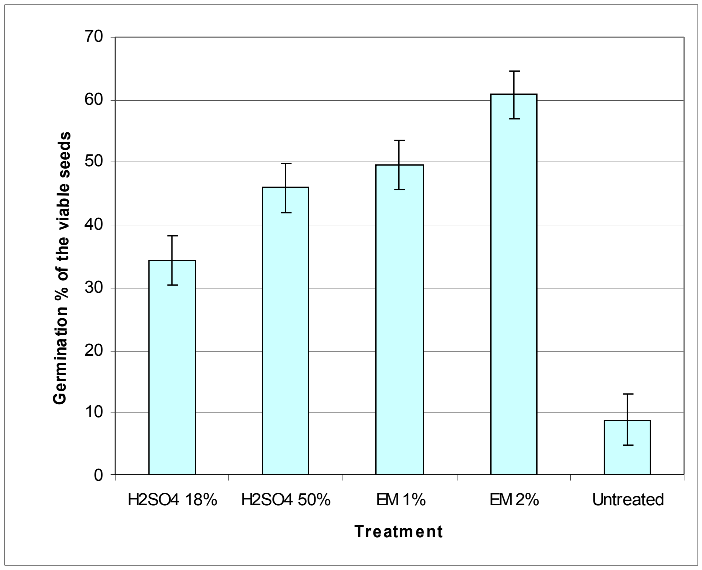

Figure 25 Differences in germination percentage between treatments: (H_2SO_4 18%) = pre-treatment of seeds with 18% sulphuric acid for 20 minutes, (H_2SO_4 50%) = pre-treatment of seeds in 50% sulphuric acid for 20 minutes, (EM 1%) = pretreatment of seeds in 1% Effective Micro-organisms for twenty-four (24) hours, (EM 2%) = pre-treatment of seeds in 2% Effective Micro-organisms (EM) for twenty-four (24) hours, (Untreated) = soaking seeds in water only for 24 hours to serve as the experiment's control,

Figure 25 shows that pre-treatment of seeds with EM had the highest germination percentage followed by sulphuric acid compared to the lowest germination percentage with untreated seeds.

Pre-treatment of seeds with 18% and 50% sulphuric acid gave 35% and 47% germination respectively compared to 9% germination given by the control (appendix 2 (table 3 b). This is attributed to the fact that scarification of seeds with sulphuric acid (H_2SO_4) broke seed coats making it easy enough for the water and oxygen to be absorbed by the seed which later germinates. It is known that *H. procumbens* seed coats contain waxy materials that sometimes block water and oxygen entry to the seeds causing dormancy

(Ellis *et al.,* 1985 and Kok, 1986). When this dormancy mechanism is broken therefore, seed germination is made possible. As evident in the results of the current study, 50% sulphuric acid resulted in a higher (47%) germination rate than 18% suggesting that the higher concentration (H_2SO_4 50%) was more corrosive to break seed coats of more seeds than the lower concentration (H_2SO_4 18%). This implies that in the wild, *H. procumbens* seeds will need extreme conditions in order to expose its seeds for germination. Extreme conditions may come through very cold and very hot temperatures experienced at both Ben Hur and Vergenoeg throughout the year. According to Baskin and Baskin,(2004) temperature in nature plays a vital role in stimulating germination through high- or fluctuating habitat temperatures that seeds are exposed to after they are brought to the soil surface.

The addition of adequate rains from which seed coats absorb more water would lead to seed coats softening to extents that they open allowing water and oxygen to get to the embryo from which germination will begin. Once seed coats are soft, it is also possible for animals trampling on the seeds to help in cracking the testa open. This may suggest why germination in the wild is very low in *H. procumbens.*

The results of the current study support those found by other scientists like Zhang *et al.*, (2006), Muhammad & Amusa, (2003), Rayachhetry *et al.,* (1998). Though their results were on different species, the same principle underlying those results has been found to apply to *H. procumbens* as well.

Pre-treatment of seeds with 1 and 2% Effective Micro-organisms (EM) gave 48% and 68% germination respectively compared to 9% germination from the control (appendix 2: table 1). This was a very-highly significant difference (P = 0.000) (appendix 2: table 3 b). These results are evident of the fact that EM have the ability to release beneficial compounds that are absorbed by plants and enhancing plant germination. These results imply that, like sulphuric acid, EM has the ability to breakdown the seed coat exposing the seed to germination. This is attributed to the fact that microbes in EM have the ability to breakdown organic matter (Higa, 1999) of which in this case may have eaten the seed coat away.

Even though higher concentrations EM 2% gave higher germination (62%) percentage than lower concentrations (EM 1%), the fact that there is not much difference between 1% and 2% EM solutions gives stakeholders an advantage to be investing almost the same amounts of money that will enable them to continuously use 2% EM yielding them higher germination rates. It is however, a different case for stakeholders using high concentrations of H_2SO_4 because 50% solution will require that they have H_2SO_4 in abundance in order to germinate more seedlings over a long period.

7.5 Conclusion

EM has provided evident results to be one of the alternatives for germinating *H. procumbens* seeds. Sulphuric acid also enhances germination provided its concentration is not too high to damage the seed embryo as well.

In order to contribute to a full understanding on the influence of EM and sulphuric acid on *H. procumbens,* further research on the establishment of *H. procumbens* seedlings pre-treated with EM or H_2SO_4 would help in making concrete conclusion on its overall effect on the plant. This would be beneficial to all stakeholders of *H. procumbens* in sustainably managing the species sustainably. This was not possible to be done within the current study due to time constraints.

The knowledge of germination enhancement through EM and H_2SO_4 is helpful to potential suppliers of seedlings for cultivation of *H. procumbens.* This will bring advancement in the sustainable management of the species which got concerns from stakeholders who were anxious of the future of *H. procumbens.*

CHAPTER 8

OVERALL CONCLUSIONS & RECOMMENDATIONS

The fact that *H. procumbens* produced more secondary tubers when rested from harvesting for five years is evident from the results of the current study at the Vergenoeg site. Secondary tuber weight was also found different with more weight observed on plants rested from harvesting for five (5) years than on those rested from harvesting for two (2) years. This implies that local community and other harvesters will gain maximum productivity from these plants if they rest them for five years than the usual two years. Since the number of secondary tubers was equal but different in weight at Ben-Hur, it is recommendable to rest these plants for five (5) years as well.

Poor community members that are involved in harvesting and selling of *H. procumbens* tubers could financialy gain more from the same plants if they harvest once in five years compared to the two harvests they would have made within the same period of time. The results from the current study at Vergenoeg implicate that a harvester would need to harvest nineteen (19) plants to get one (1) kilogram (valued at N$20) of dried tubers if such plants were not harvested for the past two years, whereas a harvester would only need to harvest eight (8) plants to get one (1) kilogram of dried secondary tubers if such plants were not harvested for five (5) years. If harvesters do not harvest for two years only, even the numbers of plants to be harvested would be limited to few individuals due to many plants each of them would need to harvest. Meanwhile if they do not harvest for five years, two harvesters would benefit from the same number of plants an individual harvests when such plants were harvested twice within the same period of time.

The results from the current study at Ben-Hur implicate that in order for a harvester to get one (1) kilogram of dried tubers, they only need to harvest five (5) plants if such plants were not harvested for the past five (5) years, compared to eight (8) plants they would harvest if such plants were harvested twice within the same period of time.

Local harvesters should therefore consider that the current practice of not harvesting a plant for only two years is not sustainable as envisaged to be. This will in the long run ensure a sustainable resource management of the species.

This could be achieved by having groups of plants to be harvested each year, introducing a five-year rotational harvesting system. With this kind of management, harvesters would get to know how much resource (*H. procumbens* plants) is available and how many people can benefit each year. This would help in them managing the resource more carefull knowing the future economic gains for the whole community avoiding 'tragedy of the commons' where the resource is utilized without responsible conservation concerns in mind.

Considering that harvesters benefit more by harvesting bigger secondary tubers rather than small ones, equal number of secondary tubers produced, for example at Ben Hur, does not mean they will benefit in the same way regardless of the period the plants were rested.

Indigenous people should however not depend on the resting period to ensure future populations through fruiting, since these plants can produce equal numbers of fruits irrespective of how long they are not harvested.

Harpagophytum procumbens is in its prime stage at old reproductive age (tuber diameter: > 3.5) and therefore, it would be recommendable to harvesters that they consider rather harvesting old reproductive plants than mature reproductive plants, in order to provide mature reproductive plants time to also reach old reproductive age. Considering that these plants have been found to benefit harvesters more if they were not harvested for five years compared to when they would be harvested for two years, old reproductive plants not harvested for five (5) years would benefit locals if managed by means giving them these conditions. With a rotational harvesting system, particular plants would be harvested at the old reproductive age, which produces more secondary tubers whilst other plants in young reproductive and mature reproductive age groups are given time to develop into old reproductive age.

To ensure future populations of *H. procumbens* through their fruits, areas where they grow need to be properly managed. Protection from grazing could also be a useful management tool among other means of management in these communal areas. This protection would ensure that these plants avoid trampling and grazing by livestock, allowing them to fruit and produce secondary tubers without disturbances. Protection from grazing could be done during the plant's growing season (Hachfeld, 2003). After this period, when grasses and shrubs are drying out and less forage is available for livestock elsewhere, livestock can then be allowed to forage in the fence after harvesting of *H. procumbens* has been completed. This kind of management would help the local indigenous people to sustain the plant's population and at the same time manage grazing pressure on available forage in areas where the plant is naturally growing

The results of the current study reveal that grasses can be allowed to coexist together with *H. procumbens* to avoid soil erosion and other functions being lost if only *H. procumbens* remain in plots. However, there should not be shrubs that have been found in the current study to have deeper roots within the same layer as those of *H. procumbens,* leading to competition which ultimately will negatively influence tuber production in *H. procumbens.* The presences of shrubs around H. procumbens poses a threat to the plant and therefore should be removed since roots (from shrubs) were found to have a negative correlation with the production of secondary tubers in *H. procumbens* and such were found to be from shrubs.

Effective Micro-organisms and sulphuric acid have been found to be alternatives in enhancing seed germination in the dormant *H. procumbens* seeds. These results come as a relief to the current situation in the management of *H. procumbens* especially to stakeholders contemplating on supplying seedlings for the cultivation of the species.

Further research should consider investigating the influence of the combination of factors (resting period, age, protection from grazing, above cover and belowground root density of other plants) on fruit and tuber production of *H. procumbens.*

Further research should also consider investigating the establishment of seedlings that germinated from seeds treated with Effective Micro-organisms.

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APPENDICES

Appendix 1

Table 1 (a) *H. procumbens* plants not harvested for two years and those not harvested for five years and their attributes at Vergenoeg.

2 years not harvested plants				5 years not harvested plants			
plant #	*# of fruits*	*# of tubers*	*tubers weight*	*plant #*	*# of fruits*	*# of tubers*	*tubers weight*
2	0	6	430	9	0	12	588
6	0	4	170	17	12	14	1442
10	14	7	650	18	6	11	812
11	15	18	1650	21	0	11	592
12	1	0	0	23	7	44	1572
22	5	15	1400	24	1	20	1018
30	0	4	420	25	0	13	1290
48	0	5	200	29	22	36	1775
57	1	2	40	31	2	12	1042
				38	13	25	1740
				47	2	8	701
				50	3	24	1090
				53	5	17	1580
				54	3	18	1100
				62	1	8	780
				64	0	14	1174
				65	5	34	3900
				73	8	17	1070

Table 1 (b) Means (averages), standard deviations (stdev) and standard errors (se) of the number of fruits, numbers and weights of secondary tubers between plants not harvested for two years and plants not harvested for five (5) years at Vergenoeg.

	fruits		tubers		Weight	
	2-year not harvested	*5-year not harvested*	*2-year not harvested*	*5-year not harvested*	*2-year not harvested*	*5-year not harvested*
average	4	5	6.777778	18.77778	551.1111	1292.556
stdev	6.164414	5.810741	5.932491	10.18393	591.9553	748.5434
se	2.054805	1.369605	1.977497	2.400375	197.3184	176.4334

Table 2 Test for normality using the Kolmogorov-Smirnov test on the three variables (fruits, secondary tubers and secondary tuber weight) of *H. procumbens* for the two (2) and five (5)-year not harvested plants at Vergenoeg

		Kolmogorov-Smirnov(a)			Shapiro-Wilk		
	resting period	*Statistic*	*df*	*Sig.*	*Statistic*	*df*	*Sig.*
tubers	2	.263	9	.073	.864	9	.106
	5	.197	18	.063	.857	18	.011
		Kolmogorov-Smirnov(a)			Shapiro-Wilk		
	resting period	*Statistic*	*df*	*Sig.*	*Statistic*	*df*	*Sig.*
weight	2	.248	9	.118	.834	9	.050
	5	.204	18	.046	.725	18	.000
		Kolmogorov-Smirnov(a)			Shapiro-Wilk		
	Resting period	*Statistic*	*df*	*Sig.*	*Statistic*	*df*	*Sig.*
fruits	2	.353	9	.002	.687	9	.001
	5	.195	18	.069	.814	18	.002

Table 3 Mann-Whitney test for the difference in the number of fruits between the two(2)-year not harvested plants and the five (5)-year not harvested plants at Vergenoeg.

	Resting period	*N*	*Mean Rank*	*Sum of Ranks*
fruits	2	9	12.00	108.00
	5	18	15.00	270.00
	Total	27		

	Fruits
Mann-Whitney U	63.000
Wilcoxon W	108.000
Z	-.940

Asymp. Sig. (2-tailed)	.347
Exact Sig. [2*(1-tailed Sig.)]	.375(a)

Table 4 Independent-Samples T-Test for the difference in the number of secondary tubers between the two (2)-year not harvested plants and the five(5)-year not harvested plants at Vergenoeg.

	resting period	*N*	*Mean*	*Std. Deviation*	*Std. Error Mean*
	2	9	6.78	5.932	1.977
	5	18	18.78	10.184	2.400

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	*Sig.*	*t*	*df*	*Sig. (2-tailed)*	*Mean Difference*	*Std. Error Difference*	*95% Confidence Interval of the Difference*	
									Lower	Upper
tubers	Equal variances assumed	2.301	.142	-3.250	25	.003	-12.000	3.692	-19.604	-4.396
	Equal variances not assumed			-3.858	24.209	.001	-12.000	3.110	-18.416	-5.584

r-value $= \sqrt{(t^2/t^2+df)}$

$= \sqrt{(-3.250^2/-3.250^2+25)}$

$= \sqrt{(10.563/35.563)}$

$= 0.54$

Table 5 Mann-Whitney test for the difference in secondary tuber weight between the two-year not harvested plants and the five-year not harvested plants at Vergenoeg.

	resting	*N*	*Mean Rank*	*Sum of Ranks*

	period			
weight	2	9	8.22	74.00
	5	18	16.89	304.00
	Total	27		

	Weight
Mann-Whitney U	29.000
Wilcoxon W	74.000
Z	-2.675
Asymp. Sig. (2-tailed)	.007
Exact Sig. [2*(1-tailed Sig.)]	.006(a)

Table 6 (a) *H. procumbens* plants not harvested for two (2) years and those not harvested for five (5) years and their attributes at Ben Hur.

2 years not harvested plants				5 years not harvested plants			
plant #	*# of fruits*	*# of tubers*	*tubers weight*	*plant #*	*# of fruits*	*# of tubers*	*tubers weight*
8	1	18	1550	7	0	9	1605
10	0	11	1080	14	1	8	1480
17	0	12	2300	16	0	1	110
23	0	12	3600	20	1	12	1960
24	0	25	2765	25	14	15	4785
33	0	8	430	27	0	11	1825
52	3	7	1090	29	1	5	1020
71	0	11	1260	30	4	12	2160
75	0	2	350	31	0	17	2955
77	0	17	830	32	1	12	5050
80	0	7	900	36	6	22	1725
84	0	5	320	37	6	28	4630
88	6	11	550	47	0	10	1280
				48	5	11	2525
				59	0	21	4435
				60	2	10	1656
				69	0	9	1720
				70	0	4	1100
				97	1	7	1530
				100	0	10	1765

Table 6 (b) Means (averages), standard deviations (stdev) and standard errors (se) of the number of fruits, numbers and weights of secondary tubers between plants not harvested for two (2) years and plants not harvested for five (5) years at Ben Hur.

	fruits		tubers		Weight	
	2-year not harvested	*5-year not harvested*	*2-year not harvested*	*5-year not harvested*	*2-year not harvested*	*5-year not harvested*
average	0.769231	2.1	11.23077	11.7	1309.615	2265.8
stdev	1.786703	3.477749	6.057418	6.391606	1006.43	1387.408
se	0.495542	0.777648	1.680025	1.429207	279.1335	310.234

Table 7 Test for normality using the Kolmogorov-Smirnov test on the three variables (fruits, secondary tubers and secondary tuber weight) of *H. procumbens* for the two (2) and five (5)-year not harvested plants at Ben Hur.

		Kolmogorov-Smirnov(a)			Shapiro-Wilk		
	resting period	*Statistic*	*df*	*Sig.*	*Statistic*	*df*	*Sig.*
Fruits	2	.424	13	.000	.542	13	.000
	5	.324	20	.000	.657	20	.000
Tubers	2	.252	13	.035	.908	13	.201
	5	.231	20	.006	.927	20	.138
weight	2	.201	13	.195	.876	13	.078
	5	.237	20	.004	.850	20	.005

Table 8 Mann-Whitney test for the difference in the number of fruits, number of secondary tubers and secondary tuber weight between the two (2)-year not harvested plants and the five (5)-year not harvested plants at Ben Hur.

	resting period	*N*	*Mean Rank*	*Sum of Ranks*
	2	12	13.58	163.00
	5	20	18.25	365.00
	Total	32		
	2	13	16.81	218.50
	5	20	17.13	342.50
	Total	33		
	2	13	11.92	155.00
	5	20	20.30	406.00
	Total	33		

	fruits	*tubers*	*Weight*
Mann-Whitney U	85.000	127.500	64.000
Wilcoxon W	163.000	218.500	155.000
Z	-1.509	-.093	-2.432
Asymp. Sig. (2-tailed)	.131	.926	.015
Exact Sig. [2*(1-tailed Sig.)]	.182(a)	.928(a)	.014(a)

Table 9 (a) *H. procumbens* plants on the influence of parent tuber size on its number of fruits, number of secondary tubers and secondary tuber weight at Ben Hur

main tuber diameter	no of fruits	no of tubers	tubers weight
2.91	0	5	405
3.54	1	8	480
2.65	0	1	110
3.88	1	6	540
4.04	14	15	4785
2.6	0	3	125
2.75	1	5	1020
4.05	4	12	2160
5.51	0	17	2955
4.99	1	12	5050
4.51	6	22	1725
3.81	6	28	4630
3.71	0	10	1280
3.11	5	11	2525
4.81	0	21	4435
3.41	2	2	260
2.88	0	8	720
3.35	0	4	1100
2.95	1	4	230
4.11	0	10	765

Table 10 Test for normality using the Kolmogorov-Smirnov test on the three variables (fruits, secondary tubers and secondary tuber weight) of *H. procumbens* for mature and old plants at Ben Hur.

		Kolmogorov-Smirnov(a)			Shapiro-Wilk		
	age	*Statistic*	*df*	*Sig.*	*Statistic*	*df*	*Sig.*
fruits	2	.282	9	.037	.686	9	.001
	3	.314	11	.003	.735	11	.001
Weight	2	.215	9	.200(*)	.788	9	.015
	3	.204	11	.200(*)	.871	11	.081
Tubers	2	.249	9	.114	.917	9	.368
	3	.198	11	.200(*)	.939	11	.509

Table 11 Spearman's correlation test showing correlation coefficients and correlation significance between *H. procumbens* size and the number of fruits per plant.

Correlations

			main tuber diameter	no of fruits
Spearman's rho	main tuber diameter	Correlation Coefficient	1.000	.227
		Sig. (2-tailed)	.	.337
		N	20	20
	no of fruits	Correlation Coefficient	.227	1.000
		Sig. (2-tailed)	.337	.
		N	20	20

Table 12 Pearson's correlation test showing correlation coefficients and correlation significance between *H. procumbens* size and the number of secondary tubers per plant.

Correlations

		main tuber diameter	no of tubers
	Pearson Correlation	1	.674(**)
	Sig. (2-tailed)		.001
	N	20	20
	Pearson Correlation	.674(**)	1
	Sig. (2-tailed)	.001	
	N	20	20

** Correlation is significant at the 0.01 level (2-tailed).

Table 13 Pearson's correlation test showing correlation coefficients and correlation significance between *H. procumbens* size and the fresh weight of secondary tubers per plant.

		main tuber diameter	tubers weight
main tuber diameter	Pearson Correlation	1	.668(**)
	Sig. (2-tailed)		.001
	N	20	20
tubers weight	Pearson Correlation	.668(**)	1
	Sig. (2-tailed)	.001	
	N	20	20

Table 14 (a) *H. procumbens* plants on the influence of protection from grazing on the number of fruits, number and fresh weight of secondary tubers at Ben Hur

Protection				**No protection**			
plant #	*# of tubers*	*tubers weight*	*# of fruits*	*plant #*	*# of tubers*	*tubers weight*	*# of fruits*
14	8	480	1	3	8	220	0
20	6	540	15	32	11	635	0
25	15	4785	4	44	5	205	0
30	12	2160	8	45	12	895	0
31	17	2955	0	51	8	310	2
32	12	5050	12	57	9	411	0
36	22	1725	6	64	6	280	1
37	28	4630	9				
47	10	1280	0				
59	21	4435	2				
100	10	765	0				

Table 14 (b) Means (averages), standard deviations (stdev) and standard errors (se) of the number of fruits, numbers and weights of secondary tubers between fenced and unfenced plants at Ben Hur.

	fruits		tubers		tubers weight	
	protection	*no protection*	*protection*	*no protection*	*protection*	*no protection*
average	5.181818	0.428571	14.63636	8.428571	2618.636	422.2857
stdev	5.250108	0.786796	6.741999	2.507133	1821.919	254.8919
se	1.582967	0.297381	2.032789	0.947607	549.3294	96.3401

Table 15 Test for normality using the Kolmogorov-Smirnov test on the three variables (fruits, secondary tubers and secondary tuber weight) of *H. procumbens* for plants with protection and plants without protection at Ben Hur. The presence of protection is

represented by 1 and its absence is represented by 2.

		Kolmogorov-Smirnov(a)			Shapiro-Wilk		
	protection	*Statistic*	*df*	*Sig.*	*Statistic*	*df*	*Sig.*
Tubers	1	.198	11	.200(*)	.939	11	.509
	2	.146	7	.200(*)	.960	7	.821
Tuber weight	1	.204	11	.200(*)	.871	11	.081
	2	.242	7	.200(*)	.846	7	.112
Fruits	1	.310	11	.004	.791	11	.007
	2	.421	7	.000	.646	7	.001
Branchlength	1	.133	13	.200(*)	.944	13	.505
	2	.224	9	.200(*)	.840	9	.058
#branches	1	.300	13	.002	.743	13	.002
	2	.192	9	.200(*)	.917	9	.364

Table 16 Pearson's correlation test showing correlation coefficients and correlation significance between the number of fruits and branch length of *H. procumbens* at Ben-Hur

		branchlength	Fruits
Branchlength	Pearson Correlation	1	.894(**)
	Sig. (2-tailed)		.000
	N	11	11
Fruits	Pearson Correlation	.894(**)	1
	Sig. (2-tailed)	.000	
	N	11	11

Table 17 Pearson's correlation test showing correlation coefficients and correlation significance between the number of fruits and the number of branches of *H. procumbens* at Ben-Hur.

		number of branches	Fruits
number of branches	Pearson Correlation	1	.957(**)
	Sig. (2-tailed)		.000
	N	13	13
Fruits	Pearson Correlation	.957(**)	1
	Sig. (2-tailed)	.000	
	N	13	13

Table 18 Independent-Samples T Test for the difference in the number of secondary tubers secondary tuber weight, branch length and number of branches between plants with protection and plants without protection at Ben Hur. The presence of protection is represented by 1 and its absence is represented by 2.

	protection	*N*	*Mean*	*Std. Deviation*	*Std. Error Mean*
# of tubers	1	11	14.64	6.742	2.033

	2	7	8.43	2.507	.948
tubers weight	1	11	2618.64	1821.919	549.329
	2	7	422.29	254.892	96.340
Branchlength	1	13	53.58	23.920	6.634
	2	9	12.00	4.583	1.528
# branches	1	13	8.38	5.075	1.408
	2	9	3.22	1.093	.364

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	*Sig.*	*t*	*df*	*Sig. (2-tailed)*	*Mean Difference*	*Std. Error Difference*	*95% Confidence Interval of the Difference*	
									Lower	Upper
# of tubers	Equal variances assumed	5.866	.028	2.315	16	.034	6.208	2.682	.523	11.893
	Equal variances not assumed			2.768	13.737	.015	6.208	2.243	1.389	11.027
tubers weight	Equal variances assumed	24.748	.000	3.135	16	.006	2196.351	700.479	711.401	3681.300
	Equal variances not assumed			3.938	10.608	.002	2196.351	557.713	963.273	3429.428
branchlength	Equal variances assumed	10.582	.004	5.113	20	.000	41.577	8.132	24.614	58.540
	Equal variances not assumed			6.107	13.250	.000	41.577	6.808	26.898	56.256
#branches	Equal variances assumed	4.759	.041	2.926	20	.008	5.051	1.727	1.450	8.653
	Equal variances not assumed			3.492	13.321	.004	5.051	1.447	1.934	8.169

r-value $= \sqrt{(t^2/t^2+df)}$
$= \sqrt{(2.315^2/2.315^2+16)}$
$= \sqrt{(5.359/21.359)}$
$= 0.50$

Table 19 Mann-Whitney's U-test for the difference in the number of fruits between plants with protection and plants without protection at Ben Hur. The presence of protection is represented by 1 and its absence is represented by 2.

	Fence	*N*	*Mean Rank*	*Sum of Ranks*
Fruits	1	11	11.50	126.50
	2	7	6.36	44.50
	Total	18		
			Fruits	
Mann-Whitney U			16.500	

Wilcoxon W	44.500
Z	-2.092
Asymp. Sig. (2-tailed)	.036
Exact Sig. [2*(1-tailed Sig.)]	.044(a)

Table 20 (a) *H. procumbens* plants observed on influence of protection from grazing on its number of fruits, number of secondary tubers and fresh weight of secondary tubers at Vergenoeg

Protection				**No protection**			
plant #	*# of tubers*	*tubers weight*	*# of fruits*	*plant #*	*# of tubers*	*tubers weight*	*# of fruits*
9	4	588	0	3	12	710	0
17	6	442	12	5	11	1540	12
18	11	812	6	12	3	120	0
21	11	592	0	34	12	880	1
23	44	1572	7	35	3	98	0
24	20	1018	1	37	4	240	3
25	13	290	0	55	7	332	0
29	36	1775	22	56	8	563	0
31	12	1042	2	63	9	592	0
38	25	1740	13	66	4	223	1
47	8	701	2				
50	24	1090	3				
54	18	1100	3				
65	34	3900	5				

Table 20 (b) Means (averages), standard deviations (stdev) and standard errors (se) of the number of fruits, numbers and weights of secondary tubers between plants with protection and plants without protection at Vergenoeg. The presence of protection is represented by *fence* and its absence is represented by *unfenced*.

	branclength		# of branches		fruits		tubers		tubers weight	
	Fenced	*unfenced*	*fenced*	*unfenced*	*fenced*	*unfenced*	*fenced*	*unfenced*	*fenced*	*Unfenced*
Average	63.14	13.20	13.00	5.00	5.428571	1.7	19	7.3	1190.143	529.8
Stdev	5.054	1.225	5.054	1.225	6.333237	3.743142	12.18448	3.653005	906.2116	441.2368

se/se mean	7.548	1.604	1.351	0.408	1.692629	1.183685	3.256439	1.155182	242.1952	132.3711

Table 21 Test for normality using the Kolmogorov-Smirnov test on the three variables (fruits, secondary tubers and secondary tuber weight) of *H. procumbens* for plants with protection and plants without protection at Vergenoeg. The presence of protection is represented by 1 and its absence is represented by 2.

		Kolmogorov-Smirnov(a)			Shapiro-Wilk		
	protection	*Statistic*	*df*	*Sig.*	*Statistic*	*df*	*Sig.*
Tubers	1	.189	14	.190	.922	14	.236
	2	.217	10	.200 .200	.880	10	.129
Tuber weight	1	.254	14	.015	.770	14	.002
	2	.173	10	.200 .200	.869	10	.098
Fruits	1	.221	14	.063	.815	14	.008
	2	.374	10	.000	.534	10	.000
#branches	1	.406	14	.000	.631	14	.000
	2	.380	10	.000	.669	10	.000
Branclength	1	.369	14	.000	.654	14	.000
	2	.381	10	.000	.640	10	.000

Table 22 Independent-Samples T Test for the difference in the number of secondary tubers, branch length and number of branches between plants with protection and plants without protection at Vergenoeg. The presence of protection is represented by 1 and its absence is represented by 2.

	protection	*N*	*Mean*	*Std. Deviation*	*Std. Error Mean*
# of tubers	1	14	19.00	12.184	3.256
	2	10	7.30	3.653	1.155
Branc length	1	14	63.14	28.240	7.548
	2	10	13.20	5.073	1.604
#branches	1	14	13.00	5.054	1.351
	2	9	5.00	1.225	.408

	Levene's Test for Equality of Variances		t-test for Equality of Means					
	F	*Sig.*	*t*	*df*	*Sig. (2-tailed)*	*Mean Differen ce*	*Std. Error Differen ce*	*95% Confidence Interval of the Difference*

									Lower	Upper
# of tubers	Equal variances assumed	9.869	.005	2.927	22	.008	11.700	3.997	3.411	19.989
	Equal variances not assumed			3.386	16.109	.004	11.700	3.455	4.379	19.021
branclenth	Equal variances assumed	24.961	.000	5.495	22	.000	49.943	9.088	31.095	68.790
	Equal variances not assumed			6.473	14.159	.000	49.943	7.716	33.411	66.475
#branches	Equal variances assumed	9.864	.005	4.626	21	.000	8.000	1.729	4.404	11.596
	Equal variances not assumed			5.670	15.277	.000	8.000	1.411	4.997	11.003

r-value $=\sqrt{(t^2/t^2+df)}$

$=\sqrt{(2.927^2/\text{-}2.927^2+22)}$

$=\sqrt{(8.567/30.567)}$

$=0.53$

Table 23 Mann-Whitney's U-test for the difference in the number of fruits and secondary tubers weight between plants with protection and plants without protection at Vergenoeg. The presence of protection is represented by 1 and its absence is represented by 2.

	protection	*N*	*Mean Rank*	*Sum of Ranks*
Tuber weight	1	14	15.54	217.50
	2	10	8.25	82.50
	Total	24		
Fruits	1	14	15.04	210.50
	2	10	8.95	89.50
	Total	24		

	Tuber weight	*Fruits*
Mann-Whitney U	27.500	34.500
Wilcoxon W	82.500	89.500
Z	-2.489	-2.140
Asymp. Sig. (2-tailed)	.013	.032

Exact Sig. [2*(1-tailed Sig.)]	.011(a)	.036(a)

Table 24 Spearman's correlation test showing correlation coefficients and correlation significance between *H. procumbens* and other types of plants and within *H. procumbens* plant parts.

			Below-ground density	*tubers*	*weight*
Spearman's rho	*Below-ground density*	Correlation Coefficient	1.000	-.004	.077
		Sig. (2-tailed)	.	.989	.762
		N	18	18	18
	tubers	Correlation Coefficient	-.004	1.000	.771(**)
		Sig. (2-tailed)	.989	.	.000
		N	18	18	18
	weight	Correlation Coefficient	.077	.771(**)	1.000
		Sig. (2-tailed)	.762	.000	.
		N	18	18	18

Table 25 Spearman's correlation test showing correlation coefficients and correlation significance between below-ground root density and the number of secondary tubers at 120 cm depth

			Below-ground density	tubers
Spearman's rho	Below-ground density	Correlation Coefficient	1.000	-.916(**)
		Sig. (2-tailed)	.	.000
		N	18	18
	tubers	Correlation Coefficient	-.916(**)	1.000
		Sig. (2-tailed)	.000	.
		N	18	18

Table 26 Spearman's correlation test showing correlation coefficients and correlation significance between below-ground root density and the fresh weight of secondary tubers at 120 cm depth

Correlations

			number of roots	secondary tuber weight
Spearman's rho	number of roots	Correlation Coefficient	1.000	-.759(**)
		Sig. (2-tailed)	.	.000
		N	18	18
	secondary tuber weight	Correlation Coefficient	-.759(**)	1.000
		Sig. (2-tailed)	.000	.
		N	18	18

** Correlation is significant at the 0.01 level (2-tailed).

Table 27 Spearman's correlation test showing correlation coefficients and correlation significance between below-ground root density at 50 cm depth and above-ground basal cover of other plants.

Correlations

			Below-ground density	above ground

Spearman's rho	Below-ground density	Correlation Coefficient	1.000	.614(**)
		Sig. (2-tailed)	.	.007
		N	18	18
	above ground	Correlation Coefficient	.614(**)	1.000
		Sig. (2-tailed)	.007	.
		N	18	18

** Correlation is significant at the 0.01 level (2-tailed).

Table 28 Spearman's correlation test showing correlation coefficients and correlation significance between below-ground root density at 120cm depth and the above-ground basal cover.

Correlations

			Below-ground density	above ground
Spearman's rho	Below-ground density	Correlation Coefficient	1.000	.318(**)
		Sig. (2-tailed)	.	.125
		N	18	18
	above ground	Correlation Coefficient	.318(**)	1.000
		Sig. (2-tailed)	.125	.
		N	18	18

** Correlation is significant at the 0.01 level (2-tailed).

Table 29 Multiple regression on plant types to determine which plant type's presence influences the below-ground root density of other plants found at 50 cm depth.

Variables Entered/Removed(b)

Model	Variables Entered	Variables Removed	Method
1	shrubs, creepers, grasses, herbs(a)	.	Enter

a All requested variables entered.
b Dependent Variable: Below-ground density

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.903(a)	.815	.763	2.603

a Predictors: (Constant), shrubs, creepers, grasses, herbs

ANOVA(b)

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	419.252	4	104.813	15.470	.000(a)
	Residual	94.854	14	6.775		
	Total	514.105	18			

a Predictors: (Constant), shrubs, creepers, grasses, herbs
b Dependent Variable: Below-ground density

Coefficients(a)

Model		Unstandardized Coefficients		Standardized Coefficients		
		B	Std. Error	Beta	B	Std. Error
1	(Constant)	-.790	3.312		-.239	.815
	shrubs	.870	.017	.539	4.149	.001
	creepers	-.118	.257	-.055	-.457	.655
	herbs	.003	.515	.216	1.559	.141
	grasses	2.797	.606	.654	4.619	.0001

a Dependent Variable: Below-ground density

Table 30 Multiple regression on plant types to determine which plant type's presence influences below-ground root density of other plants found at 120 cm depth.

Variables Entered/Removed(b)

Model	Variables Entered	Variables Removed	Method
1	shrubs, creepers, herbs, grasses(a)	.	Enter

a All requested variables entered.
b Dependent Variable: Below-ground density

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.873(a)	.763	.700	3.399

a Predictors: (Constant), shrubs, creepers, herbs, grasses

ANOVA(b)

Model		Sum of Squares	df	Mean Square	F	Sig.

1	Regression	557.646	4	139.412	12.067	.000(a)
	Residual	173.304	15	11.554		
	Total	730.950	19			

a Predictors: (Constant), shrubs, creepers, herbs, grasses
b Dependent Variable: Below-ground density

Coefficients(a)

Model		Unstandardized Coefficients		Standardized Coefficients		
		B	Std. Error	Beta	B	Std. Error
1	(Constant)	7.392	1.400		5.279	.000
	grasses	-.007	.013	-.092	-.534	.601
	creepers	-.323	.270	-.153	-1.196	.250
	herbs	.535	1.333	.178	1.152	.267
	shrubs	1.361	.263	.830	5.173	.0001

a Dependent Variable: Below-ground density

Appendix 2

Table 1 The number of seedlings that germinated according to treatments and attributes of treatments they germinated from. There were 34 seeds sown in 5 replicates for each treatment: H_2S0_4 18% treatment was pretreatment of seeds in 18% sulphuric acid for twenty (20) minutes; H_2SO_4 50% was pretreatment of seeds in 50% sulphuric acid for twenty (20) minutes, EM 1% was pretreatment of seeds in 1% Effective Micro-organisms, EM 2% was pretreatment of seeds in 2% Effective Micro-organisms, and control treatment with seeds untreated, only imbibed in water for 24 hours before germination.

	H_2SO_4 18%	*H_2SO_4 50%*	*EM 1%*	*EM 2%*	*Untreated (control)*
germination percentage (%) per treatment based on 82% viability	34.3	45.9	49.7	60.8	8.8
Germination per bag/per treatment					
Bag 1	5	8	8	15	4
Bag 2	9	9	9	10	1
Bag 3	8	7	11	11	1
Bag 4	6	10	9	12	3
Bag 5	7	13	11	14	0
average number of seedlings germinated per bag/treatment	7	9.4	9.6	12.4	1.8
Stdev	1.58113883	2.302172887	1.341640786	2.073644135	1.643167673

Table 2 Test for normality using the Kolmogorov-Smirnov test on germination data of *H. procumbens* seeds using different experimental treatments

	treatment	Kolmogorov-Smirnov(a)			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
germination	1	.237	5	.200(*)	.961	5	.814
	2	.197	5	.200(*)	.943	5	.685
	3	.273	5	.200(*)	.852	5	.201
	4	.180	5	.200(*)	.952	5	.754
	5	.287	5	.200(*)	.914	5	.490

Table 3 (a) ANOVA table for the test of differences between the five experimental treatments on germination.

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	324.240	4	81.060	26.318	.000
Within Groups	61.600	20	3.080		
Total	385.840	24			

Table 3 (b) Least Significant Differences between treatments

(I) treatment	(J) treatment	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Upper Bound	Lower Bound
1	2	-3.000(*)	1.110	.014	-5.32	-.68
	3	-3.200(*)	1.110	.009	-5.52	-.88
	4	-6.000(*)	1.110	.000	-8.32	-3.68
	5	4.600(*)	1.110	.001	2.28	6.92
2	1	3.000(*)	1.110	.014	.68	5.32
	3	-.200	1.110	.859	-2.52	2.12
	4	-3.000(*)	1.110	.014	-5.32	-.68
	5	7.600(*)	1.110	.000	5.28	9.92
3	1	3.200(*)	1.110	.009	.88	5.52
	2	.200	1.110	.859	-2.12	2.52
	4	-2.800(*)	1.110	.020	-5.12	-.48
	5	7.800(*)	1.110	.000	5.48	10.12
4	1	6.000(*)	1.110	.000	3.68	8.32
	2	3.000(*)	1.110	.014	.68	5.32
	3	2.800(*)	1.110	.020	.48	5.12

	5	10.600(*)	1.110	.000	8.28	12.92
5	1	-4.600(*)	1.110	.001	-6.92	-2.28
	2	-7.600(*)	1.110	.000	-9.92	-5.28
	3	-7.800(*)	1.110	.000	-10.12	-5.48
	4	-10.600(*)	1.110	.000	-12.92	-8.28

* The mean difference is significant at the .05 level.