ESTABLISHMENT OF WOODY SAVANNAH SPECIES ON VARIOUS MINED SUBSTRATES: TOWARD REHABILITATING SELF SUSTAINING PLANT COMMUNITIES AT NAVACHAB GOLD MINE

A THESIS SUBMITTED IN FULFILMENT

OF THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE

OF

THE UNIVERSITY OF NAMIBIA

BY

HAIMBILI N EMILIA

200729942

FEBRUARY 2015

Main Supervisor: Dr SHIPONENI NDAFUDA

Co-supervisor: Dr CARRICK PETER

ABSTRACT

For many years mining has been a vital component of the development of many countries. Although an important income generator, mining is one of the factors that affect biodiversity and ecosystems.There is an increase in the intensity of environmental damage caused by mining over the years, and thus an increased need to rehabilitate the disturbed ecosystems. The success of any rehabilitation project requires an ecological understanding of natural indigenous vegetation communities. This project investigated the potential use of mined substrates to establish indigenous savannah woody species.

The main objective of this project was to investigate the establishment of indigenous vegetation on mined substrates and develop an understanding of species assemblage and habitat preference in the Karibib thorn bush savannah. The main objective has been set to contribute scientific information to the development of methodologies for using mined substrates to establish self-sustaining, indigenous plant communities and to the development of mine closure and rehabilitation plans. To accomplish this goal, three studies as summarized below were carried out in the form of this MSc.

The first study determined the plant communities and their habitats in the surrounding and around undisturbed ecosystems in the Karibib thorn bush savannah. Here, a vegetation survey was carried out in five undisturbed habitats namely; Marble hills, Sandstone hills, Granite hills, Calcrete plains and Kalahari red sand plains. Walking belt transects were used to collect community data and soil samples were collected in each habitat. Species diversity, composition, evenness and richness were determined for each habitat.

Ordinations and correlations were used to determine the relationships between plant species and soil variables and niche breadth for each plant species was determined to show the degree of specialization for each species. Ordinations of woody vegetation in the Karibib thorn bush savannah indicated that there were fairly distinct species assemblages. Identified species assemblages were related to soil properties.

The second study investigated the germination requirement of eight selected woody species to determine the best seed treatment for each species. Sulphuric acid, acetone and hot water scarification methods were used. For each species, there were significant differences in germination percentage between different seed treatments. Sulphuric acid improved germination in all the species, acetone also improved germination in six species, while hot water improved germination in only two species.

The preceding studies provided context for the main study which investigated the establishment of woody savannah species on various mined substrates, since establishment of vegetation requires the knowledge of species assemblages, habitat preferences as well as germination requirements. Much research has been done on native species on mine land rehabilitation but few studies have correlated native species establishment with mined substrates properties. The third study therefore assessed the suitability of various mined substrates for the establishment of indigenous savanna species and explored which properties make a particular substrate suitable for plant growth. Seven selected species grown from seeds in the nursery were used in this study. Seedling growth and survival was monitored for twelve months in different mined substrates. Growth and survival were correlated and ordinated with substrate chemical and physical properties. Results showed a significant difference in the average growth and survival of seedlings between different species (d.f=6, F=99.779, $p<0.001$) and different substrates (d.f=8, F=21.457, $p<0.001$) and provide evidence that some species had high survival and high growth in most of the substrates (*Acacia senegal*, *Acacia tortilis* and *Acacia erioloba*). On the contrary, some species had high survival and low growth in most of the substrates e.g *Acacia reficiens*. Other species had both poor growth and survival in most of the substrates e.g *Catophractes alexandri* and *Acacia erubescens*. Though species showed differences in growth and survival performances, all species grew to some extent in each substrate.

The project successfully established knowledge on the germination requirements for various savannah species in the Karibib thorn bush savannah. It is crucial to understand the germination requirements of plant species to ensure their successful establishment. The study further indicated the influence of soil properties on the distribution patterns of woody species in the Karibib thorn bush savannah. This was revealed by Canonical Correspondence Analysis (CCA) ordination, showing several tight species groupings which indicated that many species were unique to a single habitat or had a relatively high abundance in a particular habitat. The findings on plant and soil relations in the study area will help in the selection of adaptable species for improving and rehabilitating disturbed arid environments. Furthermore, the study established that the selection of suitable species and substrates to use in rehabilitation projects should be evaluated in terms of both growth performance and survival performance. After all, a suitable substrate will allow species to grow and survive. Similarly, useful suitable species to be used must be able to grow and survive in a range of substrates. The study has therefore built a foundation for future restoration and rehabilitation projects.

DEDICATION

To my parents

My late father, “**Jonas Nghishidi Jacob”** and my mother “**Shuumbwa Petrina**”. You raised a brave woman.

ACKNOWLEDGEMENTS

To the author of time, the season changer and my source of strength, without him, I would never have made it this far. I thank God for coming through for me.

This study was made possible with the financial support from NRI (Nurture Restore Innovate) and Navachab Gold Mine Namibia. The Multidisciplinary Research Centre (MRC) Life Sciences Division at the University of Namibia provided the top up funding for soil analysis and transport. The biological Science Department provided research equipment.

I owe numerous people many thanks for the completion of this thesis. First and foremost my supervisors, Dr Ndafuda Shiponeni and Dr Peter Carrick, for their ongoing assistance in the design, analysis and write up stage of the project. I would not have done it without their help. I am grateful for their valuable guidance throughout the research project and constant encouragement without which this thesis would have been impossible. I have learned a great deal from them and it has been an honour being their student.

I would like to give my deepest appreciation to Mr Uwe Rentel. My entire research at Navachab was made easy, thanks to you. From accommodation to food, staff to assist in the field and transport. Every inquiry was attended to on time, and unconditional assistance was rendered throughout. I would also love to thank Mrs. Bell Marietjie for organizing transport and staff to assist in the field. Daniel and Gotthart, thank you too for all your assistance in the field. I also want to thank the staff for Biological Science

Department at the University of Namibia for all their support.

I want to specially thank Katherine Forsythe for all her assistance with statistical analyses, I learned so much from you. Professor Timm Hoffman, thank you for hosting me at PCU (Plant Conservation Unit), I am grateful.

To Alfeus Shekunyenge, thank you for all the laughs and good times spent working together in the library, your great sense of humour always kept me on, you are a rare friend. Adelheid Kanalelo, Lulia Hamunyela, Henok Nepembe and Johannes Nambahu. You guys made my stay in Karibib memorable, easy and fun. Your friendship means a lot to me and I am happy I met all of you. Magnaem Simon, you are always a constant spring of encouragement, hope and joy. Without your friendship that always carried me through all, I would not have had the courage to especially write up, was it not because of your friendship; my best friend. Mathias Mendoza, you were always there to put a smile on my face, you pushed me to my best limit, you made me believe that I can, and through my write up you were like a power house. David Lehmann, your beautiful friendship, your encouragement and support, made me believe.

To my mother, Petrina Shuumbwa, all my siblings, how can I ever thank you? It’s true what they say, family is everything. I thank you all for your love and support, for loving me and carrying me in your hearts. You guys mean the entire world to me.

Finally, thank you to everyone who contributed to this work and to my life. I have never been an island, thanks to you all.

DECLARATIONS

I, Haimbili Emilia Ndeinekela, declare hereby that this study is a true reflection of my own research, and that this work, or part thereof has not been submitted for a degree in any other institution of higher education.

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Haimbili Emilia Ndeinekela

ACRONYMS

UNAM= University of Namibia

NRI= Nurture Restore Innovate

SER= Society for Ecological Restoration

PCU= Plant Conservation Unit

MRC=Multidisciplinary Research Centre

SEA= Strategic Environmental Assessment

GLM=Generalized Linear Models

CCA= Canonical Correspondence Analysis

ADT=Articulated Dump Trucks

IAI=International Aluminium Institute

Table of Contents

List of Figures

List of tables

List of appendices

Chapter 1: Research rationale and thesis overview

1.1. Introduction

For many years mining has been a vital component of the development of many countries. Although an important income generator, mining is one of the factors that affects biodiversity and ecosystems. Mining has resulted in major impacts, both environmental and social, that have not been fully recognized or dealt with. The direct impacts of mining disturbance to land surfaces are usually severe resulting in the destruction of natural ecosystems. Typically, a portion of land and its biodiversity must be removed, at least for a period of time to allow the extraction of minerals. The challenge is to ensure that mining is part of the solution that enables better outcomes for biodiversity conservation and sustainable development. The obvious important question here is what happens to the land once mining activities comes to an end? This is where restoration and rehabilitation comes in.

Restoration is often confused with rehabilitation but in actual fact, these two imply different things. Though the definition of restoration is debatable, the general consensus is that it involves reinstating the habitats, environmental conditions and plants and animals that were there before any disturbance took place (Mansfeld,2006), and it thus goes beyond rehabilitation which generally mean repairing the impacts of a disturbance on the environment (Wassenaar *et al.*, 2012). Rehabilitation, from the mining industry perspective, means returning the land impacted by the mining activities to a sustainable usable condition. It recognizes that the restoration of what was previously there is simply impossible with current best practice (Chambers of Mines of South Africa, 2008).

Mine rehabilitation is one of the leading themes in the practice of sustainable land management and as established by Sheoran *et al.,* (2010), it has become an important part of the sustainable development strategy in many countries. Sheoran *et al.,* (2010) accentuated that rehabilitation should be a part of an integrated program of an effective environmental management through all phases of resource development from exploration to construction. The importance of rehabilitating mined sites to maintain biological diversity is therefore not only a topic of great concern to the global society but it is increasingly acknowledged (Lubke & Avis, 1999; Sheoran e*t al.*, 2010; Singh *et al*., 2002; Yan *et al*., 2013).

Though there is a strong awareness on the impacts of mining, rehabilitating mined sites remains a challenge worldwide. One of the main challenges, in addition to poor environmental legislation, is poor scientific knowledge on the structure and functioning of disturbed ecosystems (Wassenaar *et al*., 2012). Present day ecologists use the lessons of primary succession in many ways such as to rehabilitate mined lands and to create new habitats. Therefore rehabilitation requires the knowledge of primary succession. Rehabilitation projects differ in their objectives and their procedures of attaining their goals. Most rehabilitation projects aim to establish ecosystems composed of native species and to improve and restore ecosystem functions (Raizada & Juyal, 2012).

Smit (2005) established that we live in an era where environmental issues have culminated in a broad awareness about a whole sort of issues that were formerly only the scholarly domain of scientists. In the past little was known about the technology of rehabilitation. At present more and more people resist the irreversible consequences of bad environmental management, demand more protective measures and desire pro-active planning that aims to identify competence more accurately and improve living conditions (Smit, 2005).

Establishment of vegetation is a critical step in achieving the goal of ecosystem restoration in mining areas (Yan *et al*., 2013). This is usually hindered by physical factors such as high temperatures, low availability of soil moisture and compaction (Singh *et al.*, 2002). Quite a number of methods are used to establish vegetation including, seeding, hydro seeding, seedling planting or transplanting, natural recolonisation and direct topsoil return (Douglas *et al*., 2007). Each method depends on the goal of the rehabilitation project.

In order to ensure a success of any rehabilitation project, the following must be considered: ecological communities in the surrounding undisturbed ecosystems, species occurring there and their habitats, seed dormancy and germination requirements of species, the type of substrates to be rehabilitated and their suitability in supporting establishment of native species involved.

1.2. Background to the study

Navachab is an open pit mine which produces gold bullion for export to the Rand Gold Refinery in South Africa. It was a subsidiary of and solely owned by AngloGold Ashanti since its operation in 1989. In June 2014 it was sold to a UK based QKR Corporation.

In 2007, Navachab Gold Mine commissioned a temporary closure plan as required by Life of Mine and Legislation. In this closure plan, the Grid A open pit was included. Grid A (Figure 1) is a satellite open pit which lies within the mining license of Navachab on a neighbouring farm, Karibib and mining at this site has ceased. Rehabilitation of the waste rock dumps in terms of attempting to slope the side walls has already started in May 2010 and waste rock dump sites near Grid A has been rehabilitated with native species. Further rehabilitation of Grid A will entail scraping access roads and ore storage area that is no longer needed, securing the pit area and removing the infrastructures.

Figure 1: Grid A (open pit which lies within the mining license of Navachab Gold Mine area) prior to rehabilitation, Source: Uwe Rentel

Navachab Gold Mine is ISO 14001 compliant. ISO 14001 provide international standards with specific requirements for an environmental management system to enable an organization to develop and implement a policy and objectives which consider the legal requirements and information about significant environmental aspects. Thus the Enviro Dynamics Consulting was appointed in 2010 to conduct the Biodiversity Assessment on behalf of Navachab Gold Mine to promote sincere appreciation for the study area's natural resources for their protection in the mine.

Navachab Mine has recently delineated additional ore reserves, and was granted an additional 15-year mining license from the Ministry of Mines and Energy. It is inevitable that more mining will cause more damage to the environment, thus it is very crucial to have a plan of rehabilitation after mine closure.

Navachab Gold mine is busy developing rehabilitation and mine closure plans. As an initial step, Navachab has entered into a long-term partnership with Nurture Restore Innovate (NRI) to create a biodiversity (and socio-economic) showcase for mine-closure within the international context and this project stemmed from there. Hence part of the main objective of the study was to make a contribution to this planning.

At this stage, three areas have been identified as priorities: post-mining land-use for the pits; tourism at both Karibib and Navachab; and the long-term sustainability of the town of Karibib and the considerable infrastructural developments that the mine has contributed. Initial projects identified to develop the essential understanding for mine-closure are: Specifications for covers that will allow the re-establishment of fully-functioning, resilient and self-sustaining indigenous ecosystems on waste rock, tailings and other mine sites, Developing an understanding of the structure, functioning and the patterns of dispersion and aggregation of indigenous plant species in undisturbed ecosystems within the mine area, Developing the optimum seed or nursery plant propagation systems for restoration, Getting detailed systems for soil management, covers, plant propagation or seed collection, plant and soil management and maintenance, etc (Speiser, 2012)

1.3. Statement of the problem

This project arises from the need to develop mine closure plans, but recognizing that such plans require sound scientific knowledge on ecological systems involved. In some mines, rehabilitation efforts are made by simply covering the disturbed sites with seeds or with vegetation but often times this results in short term success since no scientific knowledge on properties of the substrates to be rehabilitated nor on the requirements of species or species assemblage in the community is considered. The success of rehabilitation requires scientifically sound knowledge not only of the site to be rehabilitated but also of the surrounding undisturbed systems.

There is an increase in the intensity of environmental damage such as biodiversity loss caused by mining over the years, and thus an increased need to rehabilitate mined sites. Namibia is currently enclosed with 240 abandoned mines most of which are un-rehabilitated ("Minerals Policy of Namibia," n.d.). Gold mining among other mining impacts disturbs the landscape, geological stability and the surrounding ecosystems because large amounts of ore has to be removed to get small amounts of gold. It also creates mountains of toxic waste and artificial landscapes.

Mining substrates originating from deep in the earth or wastes produced from the processing of minerals can present extreme challenges (e.g compaction, low pH, high temperatures and high metal contents) to the colonization of plants and the formation of any kind of self-sustaining ecosystem. It is therefore crucial to study the physical and chemical properties of mined substrates to determine their suitability for vegetation establishment. Both the understanding of surrounding community structure, especially substrate requirements and preferences of key species as well as how plants perform in various mined substrate is required.

1.4. Significance of the study

This project provides the scientific knowledge aspect of the Navachab Mine rehabilitation plan. The work focuses on indigenous savannah species in terms of their establishment requirements and assists in developing the expertise to reassemble the species that have a chance to grow, develop, and ultimately rebuild the local biodiversity on mined substrates and waste rock dumps. The understanding developed through this research has the potential to provide comprehensive solutions for mining impacted sites. The research will also contribute to the unique opportunity at Navachab to create a biodiversity showcase for mine-closure within the international context. Ultimately, the significance of this study is to reduce the impacts of mining on the environment, especially on the Namibian savannah (a biome currently under represented in the national protected area network (Bernard *et al*., 1998)) and therefore to potentially contribute to sustainable land management by maintaining the biodiversity and protecting the environment.

1.5. Research Objectives

The main objective of the study was to investigate the establishment of indigenous vegetation on mined substrates and to develop an understanding of species assemblage and habitat preferences of species in the Karibib thorn bush savannah. This main objective has been set to contribute scientific information to the development of methodologies for using mined substrates to establish self-sustaining, indigenous plant communities and therefore contribute to the development of mine closure and rehabilitation plans.

To achieve this objective, the research addressed the following specific objectives:

- Determine the plant communities and their habitats in the surrounding undisturbed ecosystems in the Karibib thorn bush savannah.

- Investigate the germination requirements of seeds of selected woody species under field conditions.

- Determine if narrow-niched plant species can only grow well in a narrow range of soils comparing to the broad-niched species

- Assess the suitability of various types of mined substrates for the establishment of native species and determine which properties make a particular substrate suitable for plant growth.

1.6. Thesis layout

This thesis consists of six chapters. In chapter 1 of the thesis I have presented a general introduction, problem statement and significance of the study as well as the objectives of the study. It also reviews relevant literatures on restoration and rehabilitation in general, going into depth on mining rehabilitation and highlighting entry points for the current research. Chapter 2 presents a general description of the study area. The third chapter looks at the plant community and habitat structure in the surrounding undisturbed ecosystems in the Karibib thorn bush savanna. Here, the relationships between vegetation and soil properties are explained. The fourth chapter examines the germination requirements of selected savannah woody species. The best treatment of each selected species was determined. Chapter 5 is focusing on the establishment of woody savannah species on various mined substrates. Here growth and survival performance of the selected species in various mined substrates was explored. Growth and survival of seedlings was correlated and ordinated with soil properties. The final chapter (6) is a synthesis that brings together major issues and key findings cutting across all the preceding sections and highlighting policy implications and future research needs.

1.7. Literature review

This review focuses on three components. The first component looks at rehabilitation and restoration including overview, procedure and challenges in mining rehabilitation, the second part provides a review on savannah systems in general, narrowing it down to African and Namibian savannahs. The third component review the autecology of selected woody species found in the Karibib thorn bush savannah.

1.7.1. Overview of ecological restoration and rehabilitation

The Society for Ecological Restoration, (2004) defines ecological restoration as the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed. Ecological restoration is one of the numerous actions that strives to change the biota and physical conditions at a disturbed site, and is commonly confused with restoration. Activities such as reclamation, rehabilitation, mitigation, ecological engineering and various kinds of resource management, including wildlife, fisheries and range management are all encapsulated in ecological restoration. It is therefore important to understand the differences between restoration and rehabilitation.

Rehabilitation shares with restoration a central focus on historical or pre-existing ecosystems as models or references, but the two activities contrast in their goals and strategies. Rehabilitation emphasizes the reparation of ecosystem processes, productivity and services, whereas the goals of restoration include the re-establishment of the pre-existing biotic integrity in terms of species composition and community structure ("The Society for Ecological Restoration," 2004). Even so, restoration, as generally considered here, possibly includes a large majority of project works that has formerly been identified as rehabilitation.

Restoration requires that the re-establishment of plant communities be similar to the original vegetation in structure, function and composition and it also takes into consideration the animal communities. On the other hand, rehabilitation involves the creation of structure and function, without the reinstatement of the original vegetation community. Rehabilitation only necessitates that the establishing planted community be similar to a naturally occurring plant community of the same type as the one occurring in the adjacent area.

1.7.1.1. Mining rehabilitation

It is neither possible nor fitting to give an objective review of all the work done on the research of mine rehabilitation in the past here. It differs extensively in approach, topic, scale and problem, but in spite of the differences in terms and definitions the goal is usually the same. Currently much is known of the discipline and technology of mine rehabilitation and restoration ecology. There is therefore a rich literature of it, as books, journals, conferences and professional societies are dedicated to the topic. However at present, there is no agreed terminology in the rehabilitation of mined land. This review is a brief account of what has been reported in literature to date, in terms of techniques that are used, considerations in revegetation, selection of key species, mined substrate conditions and the importance of seed collection and nursery.

The word rehabilitation in the mining industry is used inter-changeably with reclamation (Sheoran *et al*., 2010; Shrestha & Lal, 2011; Skousen *et al.*, 1994) restoration (Lei & Duan, 2008; Wang *et al*., 2013) and replacement (Bradshaw, 1984). It appears that rehabilitation practices, although based on similar general considerations, are somehow different due to unique set of circumstances each mined area and ecosystem to be rehabilitated represents. Examples: type of mining and severity of disturbance.

According to the International Aluminium Institute (2008), 80% of mines that report to the International Aluminium Institute (IAI) have made considerable financial requirements, devoting human resources, material and equipment for the rehabilitation of land that was used for mining and associated infrastructure, final decommissioning and mine closure. The International Aluminium Institute also reports that quite a number of mines sustain an environmental awareness and training program for all employees and contractors who are involved in rehabilitation. This however does not guarantee success, it is but a starting point.

Ashwath (1992) emphasized that the goal and objectives for rehabilitation of a mine site are such that the operator is required to establish on its disturbed site a stable ecosystem whose plant species composition and density are similar to those existing in the adjacent undisturbed areas of mine site. Monitoring rehabilitation is crucial in order to determine its success and therefore ascertain whether or not all ecosystem functions are self-sustaining and comparable to their original (Ludwig *et al*., 2003). Though a great deal of research has been done on rehabilitation success of mine sites especially in South Africa and Australia this remain a gap in Namibia.

1.7.1.2. Suitability of mining substrates

Johnson *et al*., (1994) stated that the physical and chemical nature of the substrates from mining determines the pattern and duration of succession. Physical texture may be very coarse as in some rock wastes, intermediate as in sand wastes, or very fine as in milled tailings (Cooke & Johnson, 2002). Physically the texture, structure, stability and water availability can present problems; chemically, an extreme pH, lack of nutrients and excess of toxic salts and metals are common.

Waste rock is predominantly composed of boulders and cobbles and has little material of sand, silt and clay dimensions. There is usually a rapid loss of any rain water due to percolation through this open material which can cause challenges in vegetation establishment (Sheoran *et al*., 2010). The passage of machinery over dump surfaces also crushes the rock, inadvertently producing material suitable for plant growth, but the dump slopes generally need an amendment of particle size similar to soil.

Mine substrates impose various adverse effects on plant growth, mostly high levels of various heavy metals and other elements in toxic concentrations but also low amounts of major plant nutrients, acidity, salinity and alkalinity, and poor physical structure (Shu *et al*., 2005). The toxicity of heavy metals and deficiency of major nutrients are often the limiting factors for plant establishment on mine tailings, therefore, the success of reclamation schemes should overcome the two major problems (Bradshaw, 1987). Carvalho *et al* (2013) states that revegetation is not easy due to the fact that mine soils are usually acidic, with low fertility, low content of nutrients (P, Ca, K), high concentrations of heavy metals, and high solubility of toxic metals**.** Apart from these major constraints, other factors such as high surface temperature, moisture, and stability also influence plant establishment on mined substrates.

Therefore, plants that establish on mined substrates need to have abilities to overcome these limiting factors. Conesa *et al*., (2006) established that pH and electrical conductivity are the main factors that determine the establishment of tolerant plant species in mine substrates. In addition, Sheoran *et al.,* (2010) concluded that on mine spoils, nitrogen is a major limiting nutrient and regular addition of fertilizer nitrogen may be required to maintain healthy growth and persistence of vegetation.

1.7.1.3. Revegetation of native species on mined sites

Skousen & Zipper (2010) accentuated that establishing vegetation is an important activity in rehabilitating mined lands. They emphasized that when establishing vegetative groundcover on surface mined sites, the two most important factors influencing species selection should be soil properties and post mining land use.

It is common practice to use indigenous plant species for mine rehabilitation. Many rehabilitation approaches used are largely based on the re-introduction of vegetation by seeding of the rehabilitation sites with indigenous plants e.g. (Raizada & Jayal, 2012; Silva & Corrêa, 2010; Starr *et al.,* 2013; van-Eeden, 2010;). According to the Guide for Surface Coal Mine Reclamation Plans (2009), the establishment of a self-sustaining ecosystem through the application of native seed mixtures and plant materials is a key element of a successful reclamation project.

Chambers (2002) reported that the selection of species for rehabilitation depends on the environmental characteristics of the disturbed site, species life history characteristics and rehabilitation goals. He further explained that following disturbance, initial species establishment depends on seeds and other plant propagules that persist in top soils or that can disperse to the site. As highlighted by Sheoran, *et al*., (2010) seasonal distribution and reliability of rainfall determine the best time to establish vegetation

Investigations into vegetative stabilization of mine wastes should include an examination of the physical and chemical characteristics to assess the suitability of material for plant growth as well as to develop an understanding of surrounding species in terms of their substrate requirements. The physical nature of wastes can sometimes be assessed by an experienced eye, but the chemical content of mining wastes requires analytical investigation.

According to Williamson *et al*., (1972), trees have many uses in rehabilitation. They are an important visual component and can be encouraged to grow on the more extreme sites where agricultural land use would be out of the question. They can tolerate fairly low soil fertility, grow successfully on slopes and can be planted in stony areas with reasonable success. However low pH, lack of nutrients, excess of toxic metals, compaction of the substrates and drought all acts as constraints to their establishment (Williamson *et al*., 1972). Thus great care must be taken in conditioning of waste material, in selection of species and in timing of planting (Williamson, *et al*., 1972)

1.7.1.4. Challenges for restoration/rehabilitation projects in semi-arid environments

According to Audet *et al*., (2013) worldwide, rehabilitation of post-mining sites in the semi-arid and subtropical environments is challenging. This is especially because of availability of water which is critical for the successful rehabilitation of post-mining landscapes. Climatic characteristics of this diverse geographical regions are closely defined by factors such as erratic rainfall and periods of drought and flooding. Critical to and in many situations predominant for the success of post-mining land rehabilitation is the availability of water and hence the climatic characteristic of geographic regions.

According to Whisenant (1993), the restoration of degraded arid lands has several limitations namely: (1) water resource and nutrients levels are uniformly low; (2) harsh micro-environmental conditions limit seedling recruitment; and (3) animals have a greater potential to disrupt restoration efforts in arid systems. Since plant establishment and growth in arid lands is limited by available water, successful restoration strategies increase water availability and/or reduce evaporation and transpiration.

Strategies that increase water availability includes water harvesting, increasing infiltration and increasing water retention. Evapo-transpiration can be reduced with strategies that lower soil and leaf temperatures (shade) and increase litter accumulations on the soil surface. Herbivores and granivores may have large impacts on the vegetation of arid landscapes. They affect the vegetation directly by consuming the vegetation and seeds and indirectly by altering the fire regime. Animals and the arrangement of landscape components also influence the movement of seed across landscapes

1.7.1.5. Seed collections and storage

The availability of viable seeds determine the initial development of a plant community. Seed production varies among both years and sites, influencing plant establishment processes and rehabilitation activities. Seed collection of native species is therefore often limited to good seed production years. So monitoring of the seasonal phenological drift caused by variation in rainfall and temperature is very crucial during seed collections (van-Eeden, 2010).

According to the Guidlines for Native Seed Collection (1999) it is crucial that fully mature (ripe) seeds be collected. This can however be difficult and it requires the collector to correctly determine when the seed is mature and carefully time the harvest accordingly. The Guide further explains that the gap between bud formation and the seeds and fruits maturity differs greatly from a few weeks to as long as several years. The number of flowers and fruits produced may differ to a great extent from year to year and from stand to stand of trees, and is both genetically and environmentally controlled.

Van Eeden (2010) reported on two techniques of collecting seeds namely; hand harvesting and vacuum harvesting. The difference between the two as van Eeden highlighted is that hand harvesting is the most basic way of harvesting seeds done with hands. On the contrary vacuum harvesting uses a specialized tractor-drawn vacuum harvester and it is usually used to harvest seeds in cultivated stands of selected plants.

According to the Guidelines for Seed Collecting (2001) the seeds are usually dried in single layers spread thinly on canvas cloths, screens, or trays elevated from the ground.

After the seeds have dried, they can then be extracted from the pods by beating or thrashing. In some species a mature fruit will often twist and split open to drop the seeds.

The seed collecting guide emphasized that the two most critical necessities for storing seeds are constant temperature and low humidity. Generally a temperature of 10 degrees Celsius or less and 50 percent humidity or lower is ideal. In most cases, fluctuating temperature and humidity harms seeds more than slightly higher constant values of each.

The seed collecting guide also clearly highlight that seeds should be stored in the refrigerator and never in the freezer until one is ready to plant. Low temperatures, humidity, and darkness protect seed longevity. Alternatively, the seeds can also be stored in any place that is cool, dark, and dry, protecting them from insects as much as possible. Seeds should be stored in paper sacks to allow good air circulation and to prevent molding. It is important to include basic information on labels, including date of collection, species name, location of collection, and name of collector

1.7.1.6. Mining rehabilitation in Namibia

Namibia is still very young in the science of mining rehabilitation. Most of the mining companies that have closed down in the past still remain unrehabilitated ("Minerals Policy of Namibia," n.d.). The current operations are either on the infant stages of developing rehabilitation and closure plans, for example Scorpion Zinc Mine (Chambers of Mine, 2010) or plans are on/under review.

The first three leading mining companies to implement the guidelines and to establish Namibian trained environmental rehabilitation teams were Bannerman resources, Swakop Uranium and Reptile Uranium (Chambers of Mine, 2010). Bannerman in Erongo region has been broadly applauded for its post exploration rehabilitation which included the rehabilitation of 387 drill holes in 2010. Moreover, restoration work through Namdeb has concentrated on planting vegetation in raked and blocked off mining vehicle tracks, drill lines and old waste rock dumps (Burke & Cloete, 2004). This was however only successful for a short while.

Burke (2008) also did an experiment in-situ at Sendelingsdrif to assess the survival of *Juttadinteria albata* in post-mining substrate through transplanting and propagation techniques. It was however a simple experiment with no replication and no further follow up. Additionally, a rehabilitation pilot project was carried out at Skilpadberg in the Orange River License Area during the period 31 January – 8 March 2006. Rehabilitation methods included profiling, grading, ripping, track rehabilitation and re-vegetating by transplanting plants that were growing in areas to be profiled, as well as seeding (Burke, 2006a).

The Namibian environmental legislation has been criticized to be fragmented, outdated and poorly legislated (Mansfeld, 2006). There are therefore no regulations on mining rehabilitation and restoration. This is partly because ecological restoration is relatively a new concept in Namibia (Wassenaar *et al.*, 2012). Wassenaar *et al.*, (2012) establishes that lack of capacity, lack of knowledge and lack of clear guidance are the three major constraints to successful restoration planning and implementation in Namibia.

One of the recommendations made by the Strategic Environmental Assessment of the Central Namib Uranium Rush in 2011 was to amend the mining legislation to include specific requirements and standards of rehabilitation. However, at least the environmental act alludes to rehabilitation of damage to the environment.

The Namibian Environmental Management Act (No 7 of 2007) states that a person who causes damage to the environment must pay the costs associated with rehabilitation of damage to the environment and to human health caused by pollution, including costs for measures as are reasonably required to be implemented to prevent further environmental damage. This does not include any specific requirement or guidelines on rehabilitation however.

1.7.2. Savannah systems

There is a wealth of literature on savannah systems (Beard, 1953; Frost *et al*., 1986; Huntley & Walker, 1982; Menaut & Cesar, 1979; J. Menaut, 1983; Mott, William, Andrew, & Gillison, 1985; Rama, 1968; R. Scholes & Walker., 1993; Smit, 2005), however there is no uniformity in the use of the term savannah and therefore no general agreement on the precise definition of savannahs. It appears that different authors define it based on the nature of their studies.

The basic consensus is that savannah vegetation occupies the wide region between dry deserts and humid forests in the tropics and subtropics (Huntley & Walker, 1982). The savannah ecosystem covers about one quarter of the land on our planet and is found in three continents: South America, Africa and Australia. Savannah vegetation covers 40%

of the land area of Africa (Okitsu, 2004), and 65% of southern Africa (Scholes & Archer, 1997). Generally, it consists of a discontinuous crown cover of trees and shrubs with an undergrowth of grasses (Archibold, 1995). Although the principal elements of the vegetation are trees and grasses, the ecology of savannahs is neither that of a forest, nor that of a grassland (Scholes & Walker., 1993). Savannah is typically grassland but where it joins into rainforest it becomes more wooded. Where it joins with desert it becomes an area of bushes and clumps of grass.

According to Frost *et al.*, (1986), a large number of annuals occur in some savannahs. These species vary extensively in their timing and rate of development, and consist of some species which are able to complete their life cycles speedily and opportunistically whenever conditions are suitable (Menaut & Cesar, 1979).

Generally savannah is classified into two main types: Arid and moist savannah. However dry and wet is used interchangeable for arid and moist respectively. There are then subsections of both dry and wet savannahs which are classified differently in different areas of the world based on many factors. Huntley (1982) and Scholes (1990) reported that the main functional distinction within southern African savannahs could be described by leaf size (broad- and fine-leaved savannahs). The effects of soil fertility on the ecology of these two savannahs schematically illustrated the association between environmental factors and leaf size of dominant woody vegetation (Huntley, 1982).

The phenology of woody plants is much less variable. Most of the species in African, Australian and Indian savannahs are deciduous (Frost *et al*., 1986; Menaut & Cesar, 1979; Mott *et al.*, 1985), shedding their leaves during the dry season or when water stressed. In arid savannahs the differences in germination time reflect responses to two opposing selection pressures: firstly the advantage of rapid germination enabling individuals to exploit fully the brief flush of water and nutrients at a start of the short growing season, and secondly the risk that subsequent rains will fail and that the plants will become desiccated before they can reproduce. Given the inherent variability of savannah environments, particularly the stochastic nature of the rainfall, the diversity in phenology found among herbaceous savannah plants is probably a key feature in promoting their coexistence (Frost *et al*., 1986).

In Africa, savannah landscapes clothe 65% of the land surface (Smit, 2005) and therefore have the largest area of savannahs in the world (Frost *et al.*, 1986). Plants in the African savannah ecosystems are adapted to coping with the difficult conditions of a very warm climate, with a wet season followed by a long dry season. The most vegetation type in the savannah is grass. Not many trees are found in the drier parts of the savannah because trees need a lot of water. The Acacia trees have adapted to the difficult climate by developing small waxy leaves to cut down moisture loss, and in the dry season they loses their leaves. Most Acacia species also search for moisture with their long tap roots. Their needle-like thorns reduce moisture loss and protect them from animals (Smit, 2005).

In Namibia, savannah is the most representative type of vegetation encompassing 65% of the territory of Namibia (Okitsu, 2005). Savannah vegetation differs according to its environmentally broad distribution range, from desert to forest. These differences necessarily include not only changes in the performances of the vegetation, including tree cover and height, but also changes in the leaf habits of the vegetation, such as leaf size and seasonality (Okitsu, 2005). Scholes (1990) identified the geographical distribution of different savannah based on leaf habits and discussed the factors controlling their occurrence in Namibia. He categorized the Namibian Savannahs into; deciduous savannah and evergreen nanophyll savannah.

The savannahs of Namibia is divided into three main veld types namely the dwarf shrub savannah in the central-south., the various acacia-based tree and shrub savannah associations in the centre and eastern parts, and the Mopani Savannah in the north-west (Burke & Strohbach, 2000; Okitsu, 2005). Savannah with a well-extended crown cover of trees dominates the north-eastern part of Namibia and consists mainly of scattered tall trees that are usually more than 15 m high. The central part of the country is dominated by tree-shrub savannah which is distinguished by a scattered distribution of tall trees and short shrubs. In north-western Namibia, the most common savannah type is dominated by Mopani (Burke & Strohbach, 2000; Okitsu 2005).

1.7.3. The concept of niche

According to Ricklefs & Miller (2000) a niche represents a range of conditions and resource qualities within which an individual or species can survive and reproduce. In other words, it is the role of a species in a community, the conditions in which the species can survive or the way of life that it follows. Ricklefs & Miller (2000) argues that a niche imply that multiple organisms live in the same spatial region at the same time, that do not all belong to the same species, and share only some of the conditions and a subset of its value range with organisms of the other species. Niches of distinct, even closely related species, tend to differ at least in some aspects as interspecific competition minimizes their overlap. Interspecific differences in abundance and distribution can be explained by different niche width and position (Gaston *et al.*, 1997).

When Joseph Grinnell introduced the concept of niche, he was particularly interested in factors determining where given species are found and how niches, generated by the environment, are filled. The knowledge of a species niche determined by its habitat requirements is essential for understanding and even envisaging its geographic distribution. The concept of niche implies that each species has a particular role in an ecosystem and its dynamics can be fulfilled by different species in different places.

Brown (1984) suggested that a species able to exploit a wide range of resources should occupy a larger number of sites, become locally more abundant and thus have a wider geographic range than a rare species, which is restricted to a narrower niche. (Hutchinson, 1958) defined a species fundamental niche as a multidimensional cloud of favorable conditions determined by all environmental variables where the species can reproduce and survive. A realized niche is a subset of the abstract fundamental niche, where the species can persist given the presence of other species competing for the same resources. He claimed that a realized niche always has a narrower range along respective dimensions. For example a species which potentially have a broad humidity niche, may occupy a much narrower range of these conditions in an environment with competing species, since its population growth rate decreases to negative values in some conditions.

1.7.4. Autecology of selected species

Singh *et al*., (2002) put emphasis on the fact that the choice of species to be used in rehabilitation is likely to greatly influence both the rate and the course of rehabilitation processes. The ultimate goal is to create a plant community that will maintain itself indefinitely without attention or artificial aid. This is attained by selecting species adapted to grow, spread and reproduce under severe conditions, provided both by the nature of the moist material and the exposed situation on the dump surface. It is therefore important to understand the autecology of the species to be used, in this case selected from savannah communities in the Navachab surrounding area. The information given for each species depends on current knowledge and availability of information. Some species are understudied and therefore only limited information are available in literature. This study will contribute to some of the missing information.

1.7.4.1. Acacia erioloba (Camel-thorn)

Distribution range

Acacia erioloba is a southern African species, characteristic of Kalahari sandveld. Its range outspreads from southern Angola and Namibia, parts of Botswana, southwestern Zimbabwe, the north west of South Africa and just into south west of Mozambique (R. Barnes, Fagg, & Milton, 1997). *Acacia erioloba* is specifically adapted to the wind-blown sands of the ancient Kalahari Desert. Today, its distribution is still wholly determined by the presence of these sands regardless of rainfall that now varies from <40 in the Namib Desert to 900 mm in the north of its distribution in Zambia. The range of mean daily temperatures are no less extreme and vary from <15°C up to >45°C. Very severe frosts are common over much of its natural distribution (Barnes *et al*., 1997).

Adaptations

According to Barnes (2001) the ecology of *Acacia erioloba* suggests that it is adapted to shallow to deep, infertile, occasionally alkaline sands, beneath which it uses its deep roots to access and use, even brackish deep water containing dissolved nitrates. It may perhaps be restricted to sand owing to the competitive advantage it has on this substrate, in which it can rapidly expand its initial rooting system and it cannot achieve such rapid expansion on heavier soils (Barnes, 2001). In the drier parts of its range, it seems to recruit during sporadic good rainfall, when seedlings use temporary surface moisture to establish a taproot to permanently available groundwater, after this it becomes independent of annual rainfall (Barnes *et al*., 1997; Barnes, 2001). Barnes *et al.*, (1997) establishes that the ability of this species to access water deep in the soil effectively immunizes it from fluctuations in annual rainfall.

Phenology and Germination

Flowering usually begins in July, ending in November, with a sharp flowering peak in September (Barnes *et al*., 1997). Pod production is neither annually cyclic nor predictable (Seely *et al*., 1979). *Acacia erioloba* pods ripen in autumn and winter (Poyton, 1984). Individual trees differ significantly in the time their pods ripen and fall and they become available for browsing animals over an extended period from April over the major part of the species' range.

According to the Forest Awareness and Tree Planting Project (n.d.), the seeds are, like most acacia species, surrounded by a layer of wax, almost impermeable to water. The Forest Awareness and Tree Planting Project suggest treating the seeds with hot water in order to melt the wax and let them soak for 24 hours. They also stated that undamaged seeds found in animal dung will usually germinate well, because the waxy layer has been removed on its passage through the animal. Studies done by Leistner (1961), Lampre (1967) and Hoffman *et al*., (1989) also reported that digestion improves germination rates by softening the seed testa. Meanwhile other studies have found no difference (Barnes, 2001) and several others have found lower germination rates of both *Acacia erioloba* seeds collected from greater kudu and eland dung than those collected directly from trees (Coe & Coe, 1987).

Barnes (1999) suggests that field studies conducted on *A. erioloba* germination rates may be more valuable than laboratory studies, as low water holding capacities of Kalahari sands likely influence observed outcome. According to Briers (1988), *Acacia erioloba* seeds had no light requirement for germination, likely because they often need to be below ground to access sufficient water for this process.

1.7.4.2. ***Acacia tortilis*** **(**Umbrella-thorn)

Distribution range

According to Barnes *et al*., (1997), *Acacia tortilis* is widespread, it favours young alkaline and alluvial soils and, occasionally, sand. It occurs in all countries that fringe the Sahara and is the tree that often extends furthest into the desert. It is native to Angola, Botswana, Egypt, Eritrea, Ethiopia, Iran, Israel, Kenya, Mozambique, Namibia, Qatar, Saudi Arabia, Somalia, South Africa, Sudan, Swaziland, Tanzania, Uganda, United Arab Emirates, Zambia, and Zimbabwe and exotic to Benin, Burkina Faso, Cameroon, Chad, Cote d'Ivoire, Gambia, Ghana, Guinea, India, Liberia, Mali, Mauritania, Niger, Nigeria, Pakistan, Senegal, Sierra Leone and Togo (Orwa *et al*., 2009).

Adaptations

Acacia tortilis can survive at much higher temperatures with a mean annual rainfall of as little as 40mm. Under these conditions it can develop an extensive rooting system that spreads to twice the width of the crown and to a depth of 35m (Fagg & Greaves, 1990) *Acacia tortilis* is drought resistant, can tolerate strong salinity and seasonal waterlogging and generally forms open, dry forests in pure stands or mixed with other species. The long taproot and numerous lateral roots enable it to utilize the limited soil moisture available in the arid areas. It tolerates a maximum temperature of 50◦C and a minimum temperature close to 0◦C.

Phenology and germination

Flowering in *Acacia tortilis* starts in November and lasts till April peaking in November and December. Its fruits are present most of the year, but most commonly from January to June (NBRI, n.d.)

Moustafa & Mansour (2003) stated that *Acacia tortilis* seeds are characterized by a waxy, hard (stony) testa, which make its germination impossible under normal conditions. They studied the effect of improving soil properties on the seedlings of *Acacia tortilis*. In their study they explored the germination requirement and root system of this

Acacia species, investigating its response to different soil conditions. They obtained high percent of germination by soaking seeds in concentrated Sulfuric acid for 20 minutes and in boiling water for 30 minutes.

Loth *et al*., (2005) studied the physiological conditions that stimulate seed germination through a field study. They also conducted laboratory experiments to establish the effect of temperature and light on water imbibition and germination, and the effect of temperature on seed survival. They found out that *A. tortilis* seeds germinate better at sites with a considerable temperature amplitude. At temperatures above 25 ◦C the water absorption rate of the seeds increases exponentially while after imbibition lower temperatures enhance germination. Argaw *et al*., (1999) obtained a 100% germination when he treated *Acacia tortilis* seeds with acid from 30min-2hours.

1.7.4.3. *Acacia senegal* (Gum Arabic Tree)

Distribution range

Acacia senegal has a wide natural distribution in Africa and Asia from Cape Verde and Senegal on the Atlantic coast across to the Red Sea and Indian Ocean coasts of Africa and on to Arabia, reappearing further westwards in the arid parts of north-west India, mainly on the dry hills of Sind and the south-east Punjab (Obeid & Seif El ino, 1970). It is native to Angola, Botswana, Burkina Faso, Eritrea, Ethiopia, Gambia, Kenya, Mali, Mozambique, Namibia, Niger, Nigeria, Senegal, Sudan, Tanzania, Uganda, Zambia, and Zimbabwe, and exotic to Australia, Egypt, India, Pakistan, Puerto Rico, South Africa, Virgin Islands (Orwa *et al.,* 2009).

According to Eisa *et al*., (2008), *Acacia senegal* grows in a range of annual rainfall between 100-800 mm (mainly between 300-400 mm). Orwa *et al.,* (2009) establishes that *Acacia senegal* is associated with a wide range of vegetation types. It prefers clay plains and rocky hill slopes. It grows in coarse-textured, deep sandy soils to dry, rocky soils, slightly acidic to moderately alkaline and intolerant to waterlogging.

Adaptations

Acacia senegal has a remarkable adaptability to drought and tolerates dry periods of 8-11 months (Eisa *et al*., 2008; Orwa *et al*., 2009). It grows on the poorest soils and resists frost (Eisa *et al*., 2008). Cheema & Qadir (1973) stated that since the seedlings of *Acacia senegal* have low water requirement and the shoot cuttings can be propagated vegetatively, *Acacia senegal* appears to be an ideal species for afforestation in arid regions. Ahmed (1986) and Hien (1995) also pointed out that *Acacia senegal* among other species is a valuable afforestation and agroforestry species for soil conservation and regeneration of degraded lands. Parker (1956) reported that *Acacia senegal* has successfully been used for reclothing rocky hills and shifting sand in Jaipur.

Phenology and germination

According to Orwa *et al*., (2009) flowering in *Acacia senegal* starts from June to July in Sudan, December to January in South Africa, February to March in Pakistan, and August to December in India. In Namibia is flowers from October to January and fruit from February to June. Fruits ripen in January in Burkina Faso, July-September in Kenya, August in Pakistan, October in South Africa, and November-December in southern and central Niger (NBRI, n.d.).

Cheema & Qadir (1973) studied the germination requirement of *Acacia senegal* and they obtained highest germination by soaking the seeds in sulphuric acid for 3-15 minutes. They established that the seeds of *Acacia senegal* can successfully be treated with sulphuric acid, alcohol, acetone and by mechanical scarification and dark treatment. Relatively high germination percentages (89-97%) were obtained from seeds treated with sulphuric acid and those that were mechanically scarified (Argaw *et al.*, 1999).

1.7.4.4. ***Acacia reficiens*** (Red-thorn)

Distribution range

According to Mannheimer & Curtis (2009), *Acacia reficiens* is distributed in Angola, South Africa, Swaziland and Namibia. It is found in various habitats, but predominantly on plains. It is also found on hills and in dry rivers. *Acacia reficiens* prefers gravel or rocky/stony substrates including granite and calcrete and seldom on sand (NBRI, n.d.)

Phenology and germination

Acacia reficiens flowers mainly in December and January. It starts producing fruits from February to June and fruits ripe mostly around July (NBRI, n.d.).

1.7.4.5. Acacia erubescens (Blue-thorn)

Distribution range

Acacia erubescens is distributed in Tanzania, the DRC and southwards to Namibia, Botswana and South Africa (Dharani, 2006). It grows in various environments, predominantly on hill slopes and plains, generally on rocky substrates including granite, mica schist and sometimes on sands (NBRI, n.d.).

Phenology and germination

This species flowers in August and peak in October and November (NBRI, n.d.)

1.7.4.6. ***Adenolobus garipensis*** (Butterfly tree) **and *Catophractes alexandri*** (Trumpet-thorn)

Very little is known about the ecology of *Adenolobus garipensis* and *Catophractes alexandri and* so far no autoecological work or germination has been done on this species. There is therefore very little information about these species. This study will contribute to the germination, distribution and range of these species as well as growth and survival patterns in different soils.

Adenolobus garipensis (Figure 2) is found in most habitats but mostly in dry rivers, on hill slopes and on plains. It prefers rocky habitats, but also occurs on gravel and sand (NBRI, n.d.). In Namibia *Adenolobus garipensis* is distributed on the western part of the country from Kunene to Orange River. It flowers sporadically all year round, with a peak in September and October (NBRI, n.d.). In this study it was observed to be in green fruits in March and April and ripe fruits in May.

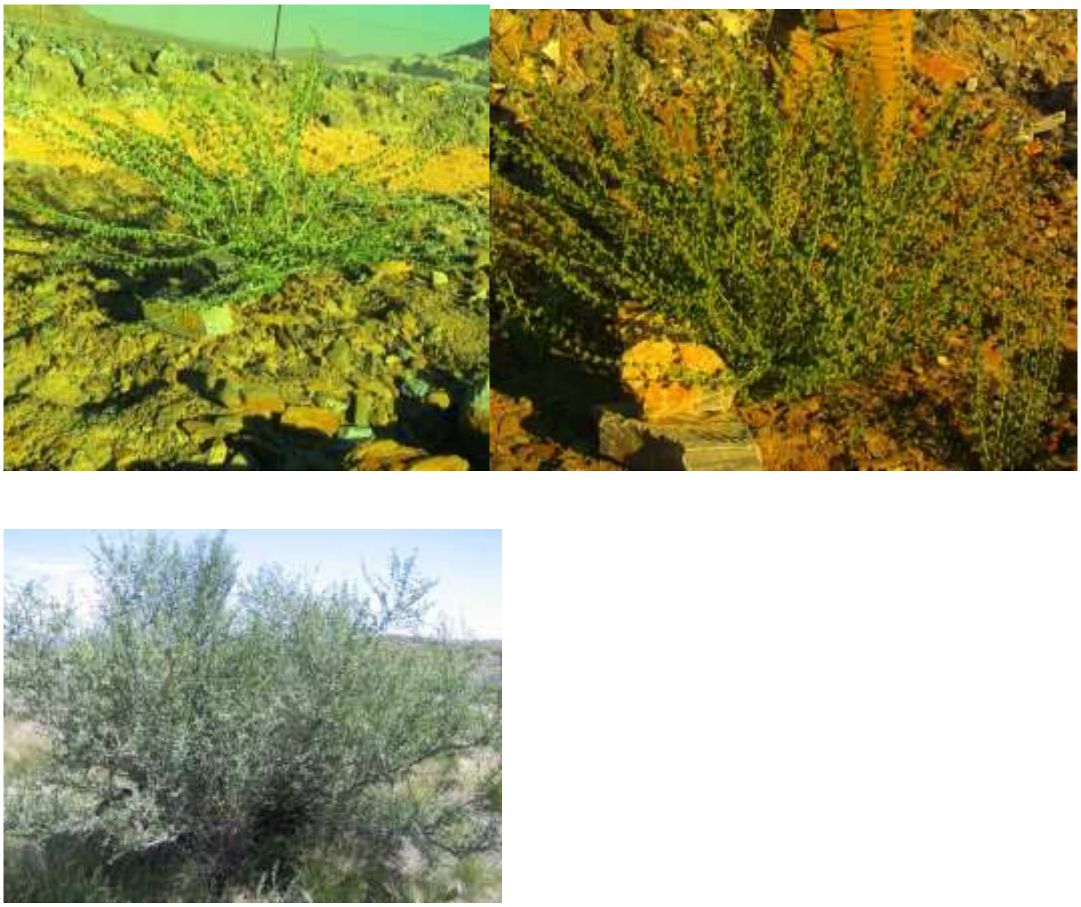

Figure 2: *Adenolobus garipensis* A) young shrub and B) adult shrub (Source: Haimbili Emilia and Photo Guide to Plants of Southern Africa

Catophractes alexandri (Figure 3) is found mainly on the plains, also on hill slopes and along dry rivers,and it often prefer calcrete but also on other rocky substrates. It flowers mainly from September to May (NBRI, n.d.) In this study Catophractes alexandri was observed to be flowering in March and April. The results obtained from the germination trial shows that the seeds of *Catophractes alexandri* posses no dormancy and can germinate easily with no treatment.

Figure 3: *Catophractes alexandri* shrub (source Flora of Zimbabwe)

Chapter 2. Study area

2.1. Location of the study area

Much of the work described in this thesis was done at Navachab but the vegetation surveys and plant community study extended to the surrounding savanna communities. Navachab Gold Mine is located 10km south-west of Karibib town (21°56′S 15°51′E) and 170km north-west of Windhoek on the southern west coast of Africa in Erongo Region, Namibia (Figure 4) (AngloGold Ashanti, 2006).

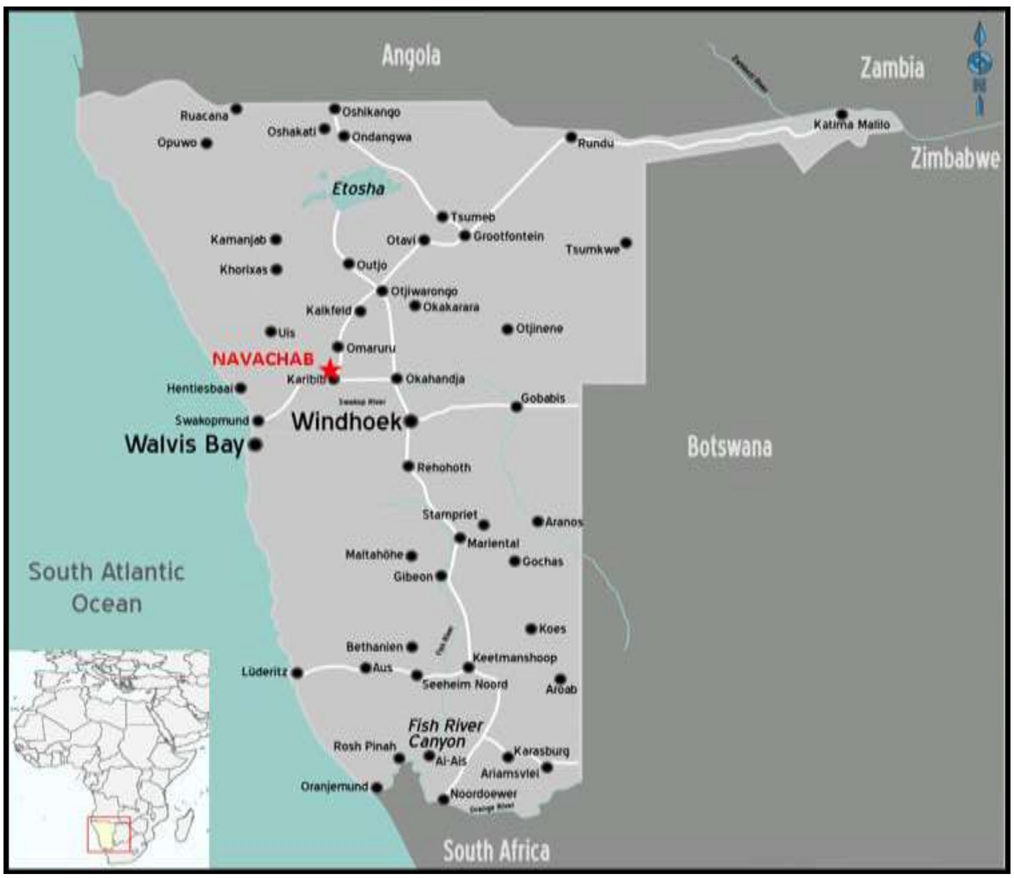

Figure 4: Location of Navachab Gold Mine, Namibia (Source: Speiser, 2012)

2.2. Topography

In Erongo Region, the land rises steadily from sea level to about 1,000 m across the breadth of the Namib. The Namib land surface is mostly flat to undulating gravel plains, punctuated with occasional ridges and isolated ‘inselberg’ hills (MME, 2010). The town of Karibib lies on the edge of the central – western plains stretching from the coast to about 450 km to the east which connects the escarpment. Navachab is located in a valley on the northern margin of the Karibib-Usakos range, at an altitude of 1,100m. These hills trend North East-South West, and may locally extend to over 400m above the calcrete plain. The mining operations lie in a valley between two small ridges that run in a southwest to northeast direction (Speiser, 2012).

2.3. Climate

The climate in Erongo region of Namibia where Navachab falls has been classified as a semi-desert climate, characterised by low summer rainfall, high evaporation, very high maximum temperatures and mild winters (Speiser, 2012). The mean temperatures for summer are from 10˚C to 38˚C and in winter from 1˚C to 24˚C (*Initial Environmental Review Report*, 1997). According to Mendelsohn *et al. (*2009) frost is rare in the area. Evaporation rates range between 2,330 - 2,440 mm per year. The rains are unpredictable, highly inconsistent between years and patchy. Generally rainfall is around 200mm per annum. The annual peak rain occurs from January to March (Speiser, 2012).

According to Speiser (2012) Karibib is relatively dry with an annual average rainfall of 224 mm recorded between 1967 and 1983. From 1980 to 2002 the annual average was 180 mm, no updated long term rainfall data is available after that. Figure 5 depicts the rainfall recorded between 1980 and 2002, with the highest records in 1990 and 1887 and 2002 respectively all above 280 mm. Karibib experiences very hot summers and mild winters. The average annual temperature is 22.3°C with the monthly average maximum temperature of 30°C or more occurring from September to March and the winter month minimums are between 25°C and 28°C (Zunckel., 2008). In 2008 and 2010, Navachab mine received 215 mm, in 2011, the mine recorded the highest rain ever recorded in the area 600mm (Rentel Uwe, personal) meanwhile in 2012 and 2013, the rainfall was below 10 mm.

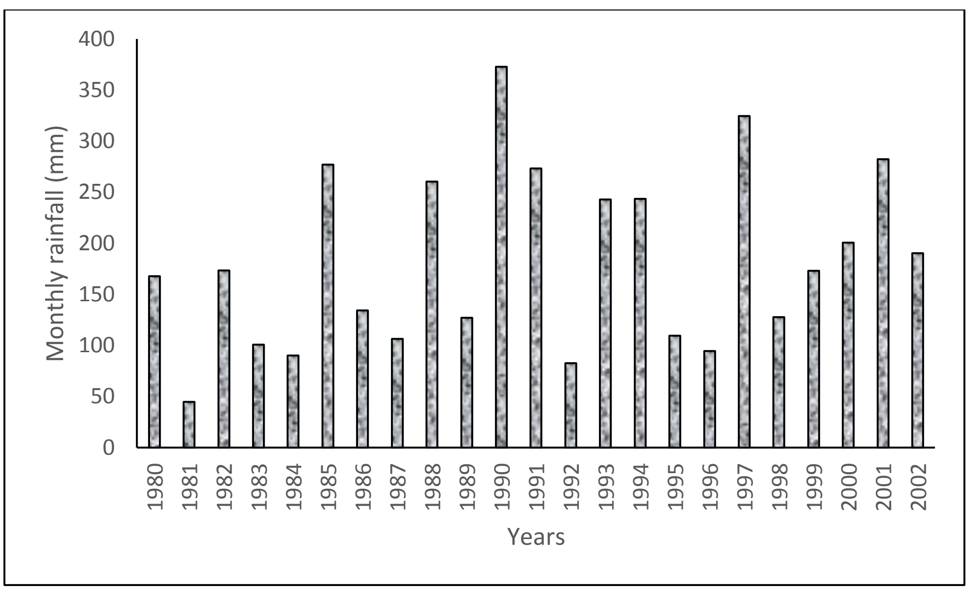

Figure 5: Rainfall (mm) recorded at Karibib between 1980 and 2002 (Source Namibian Meteorological Service).

2.4. Geology

The Mine is located in the Southern Central Zone of the Pan-African Damara Orogen, on the NNE-trending, western limb of the Karibib Dome (Roux *et al*., 2006). According to Kirsters (2005) the scattered gold deposits are located in quartz veins that formed during folding and fold amplification of the Karibib Dome. The Spes Bona Formation, an inter-bedded sequence of biotite schists and para-amphibolites, forms the footwall, and is overlain by a 35m thick calc-silicate and marble unit, followed by a 5m thick amphibolite marker unit, a 50m thick marble unit, and a 35m thick dolomitic marble unit, all of which make up the Okawayo Formation, which hosts the main ore body. There are two sets of quartz sulphide veins of metasomatic origin in biotite schist to the east of the mine, which contain in excess of 50 g/t gold over an unspecified width (Steven, 1994).

The Karibib Formation forms a range of high hills to the northwest of the mine. The Karibib Formation marbles have been subjected to medium-grade amphibolite metamorphism associated with granitic intrusions. A unique feature is band of white, coarse-grained calcite marble from the Karibib formation that cuts through the observatory in NNW-SSE direction. It is almost exposed to the surface. The unconsolidated substrates consist mainly of gravel and sand covered by a desert pavement of medium sized quartz pebbles covering 60-100 % of the soil surface (Burnett, n.d.).

2.5. Vegetation

Karibib falls within a semi desert and savannah ecotone with the main vegetation dominated by Acacia shrubs and trees, also called thorn bush savannah (Initial Environmental Review Report, 1997). The vegetation structure is classified as sparse shrubland dominated by grasslands and scattered trees with an average plant production and high variation in green vegetation biomass (Mendelsohn *et al*., 2009).

According to Speiser (2012), 329 plant species (including infraspecific taxa) were found on the Navachab area of which over 200 were new records for Navachab. Eight major habitats were identified in the greater Navachab mine area: calcareous marble hills, broken red quartzite and sandstone hills, red sand plains, drainage lines, calcrete plains with small watercourses and related outcrops, fountains and waste rock dump.

2.6. Land use

The major land uses in Karibib includes gold mining, residential, commercial, institutional, public open spaces and recreational erven. Approximately 15% or 156 properties in Karibib belong to the AngloGold Ashanti and Erongo Mining and Exploration Company Ltd. The area around the mine has historically been used for limited agricultural purposes which included cattle and sheep farming. The farm is currently managed as a ‘safe haven’ for wildlife and no hunting activities are allowed. The area is mainly suitable for grazing and is currently been utilized as such by wildlife such as Springboks and Kudus (Speiser, 2012). Current infrastructure comprises of access roads, mining quarries, tailing areas, waste rock areas, stockpile areas, beneficiation plant, offices, workshop and other mining related buildings. The town has a very close relationship with Navachab mine. The mine provides assistance with infrastructure services, training, mentoring and systems support.

Chapter 3. Structure and composition of woody vegetation in five communities occurring in the Karibib thorn bush savannah

3.1 Introduction

In the discipline of restoration ecology, studying the vegetation component of undisturbed communities as reference sites is increasingly acknowledged globally (Burke, 2012; Cristescu, 2011; Nowak *et al*., 2002). This is especially important as understanding the vegetation structure of undisturbed communities is required for successful rehabilitation/restoration of disturbed communities. When dealing with rehabilitation, much attention is generally given to the establishment of plant communities similar to those that characterize natural habitats in the area. This requires an understanding of surrounding communities to elucidate what species are occurring there and how the vegetation is structured. The central point why vegetation surveys are done is therefore to characterize the vegetation structure of communities.

Vegetation surveys assist in species selection to be used in rehabilitation projects. The success of any rehabilitation project hence depends on the scientific information of species and species assemblage in the undisturbed communities. Barbour *et al.*, (1987) pointed out that the goal of most rehabilitation and revegetation projects is to recreate (to some predetermined level) the plant cover, distribution, and species composition of the site prior to disturbance, or of a comparable less disturbed reference site. Accurate data on community composition of undisturbed communities is therefore desirable for the planning and evaluation of these projects (Cristescu, 2011).

Lubke & Avis (1999) established that it is important to have information on vegetation and habitat types and baseline studies on the soil and vegetation of communities, especially prior to mining. The establishment of vegetation and the rehabilitation of ecosystems will vary according to site specific environmental conditions, the nature of the soil and various other biotic influences peculiar to the region.

Van de Maarel & Franklin (2013) highlighted that vegetation characteristics are either derived from plant morphological characters, usually called structure, or from the plant species recognized, the floristic composition. The analysis of these will only include a relatively small piece of vegetation which is considered a representative of a larger unit. This is achieved through vegetation sampling and surveys. Various methods of carrying out vegetation surveys exist including point intercepts, quadrats, and circular habitat and land use plots to best characterize community composition and structure across a gradient (Brocklehurst *et al*., 2007).

Studies of vegetation patterns in arid ecosystems within relatively small areas have demonstrated relationships between vegetation patterns and site specific factors such as soil properties, microclimatic and water balance factors (Madliger, 2007; Medinski, 2007; Shiponeni *et al*., 2013). There has been few evaluations of the vegetation structure and composition in the Karibib district e.g a few studies on Navachab environment have been conducted by a range of specialists since the mine's inception (Speiser, 2012), but not along soil gradients. Mohammad (2012) stated that understanding the edaphic variables influencing distribution of plant species and communities remains an important goal in the ecology of terrestrial ecosystems. He further highlighted that composition and distribution patterns of plants are mainly affected by soil properties.

This chapter reports on a study carried out to characterize the vegetation communities and habitat characteristics in five different habitats in the Karibib thorn bush savannah and to provide a description of the dominant woody species as well as associated species in these communities. The findings from this study are used to make suggestions to the selection of species that can be used for revegetation in mined substrates at Navachab (Chapter 5). Determination of plant communities and their habitats in the surrounding undisturbed ecosystems is necessary for management and rehabilitation of ecosystems.

3.2 Methods

3.2.1. Study area

The study was carried out in the Karibib district in Erongo region, Namibia. The study area is located within the general area referred to by Giess (1998), as the semi-desert and savannah transition zone. The biophysical description of Karibib is described in chapter 2. The plant communities in the study area are typical of the arid savannah vegetation. Five vegetation habitats (calcareous marble hills, broken red quartzite and sandstone hills, red sand plains, calcrete plains) that characterize the greater Navachab mine area (Speiser, 2012) were sampled in this study.

3.2.2. Vegetation surveys and habitat data

To study the community composition and structure of the vegetation, five habitats (sandstone hills, marble hills, granite hills, kalahari red sand plains and calcrete plains), (Figure 6) were surveyed in the Karibib district. Each habitat was replicated 5 times and three belt transects were conducted in each replicate habitat. On the hill habitats (sandstone, marble and granite), transects were set up along the hills and the width of each transect was 4 m and the length of each transect ranged from 145–190 m, depending on the altitude range and slope degree. On the plain habitats (kalahari red sand and calcrete plains) up to 300 m x 4 m belt transects were used. The sampling was done in such a way that at least 100 woody individual plants were encountered in each transect regardless of the transect size. In each transect, all woody individuals (above 1 meter) encountered were identified and recorded. The two nearest neighbor plants to all the sampled individual species were identified and their distance to the sampled individual species was measured in order to determine the distribution pattern of the species in the communities. A particular bearing was determined at the start of each transect that was followed throughout to ensure transects were straight and therefore unbiased to the researcher. GPS (Global Positioning System) co-ordinates were taken at the beginning of each transect.

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D

E

Figure 6: Studied habitats A) Kalahari red sand plains B) Marble hills C) Sandstone hills D) Calcrete plains and E) Granite hills (Navachab).

3.2.3 Soil sampling

Soil sub-samples were collected at the center and at the end of each transect using a hand shovel (so two sub-samples per transect). Since each replicate habitat had three transects, a composite sample therefore comprised of 6 subsamples and each habitat had 5 composite samples. Soil samples were taken between 2- 10 cm deep depending on substrate's hardness. The soil samples were placed in paper bags, labeled and stored at room temperature until they were taken to the Analytical soil laboratory in Windhoek for analysis. The samples were analyzed for pH, elemental composition (exchangeable Ca, Mg, P, K and Na, and total N), electrical conductivity, organic matter, organic carbon, calcium carbonate equivalent and soil texture (sand, silt and clay).

3.2.4. Data analysis

Species richness

This was calculated as the total number of woody species encountered in each habitat.

Species diversity

For each habitat replicate, the diversity index was calculated using the Shannon Wiener diversity index (1949) and the diversity index for each habitat was determined using the following formula $H' = \Sigma Pi \ln Pi$.

Where Pi = S / N

S = number of individuals of one species

N = total number of all individuals in the sample

Ln= logarithm to base e

Species evenness

For calculating the evenness of species in each habitat replicate, the Pielou's Evenness Index (e) was used (Pielou, 1966), and the mean evenness index for each habitat was determined.

e = H / In S

H = Shannon – Wiener diversity index

S = total number of species

Differences in the means of these diversity measures (diversity and evenness) between different habitats were determined using GLM (Generalized Linear Models) procedure of R-studio (R Core Team, 2013). A significance level of 0.05 was used to determine if differences between groups were statistically significant.

Frequency of occurrence

The frequency of occurrence was calculated as the proportion (%) of the number of habitats in which each woody species was recorded from the total number of habitats. In this study, species were regarded as either generalists or specialists depending on their occurrences in different habitats.

Niche breadth

Niche breadth is defined as the degree of similarity between the frequency distribution of resources used by members of a population and the frequency distribution of resources available to them (Feinsinger *et al*.,2011). Dash & Mahanta (1993) adopted a similar sense of the term using the term niche breadth as the habitat niche breadth-which is the reality associated with the term, since it is a distance in a niche space. Levin's index of niche breadth (Levins, 1968), for each species was determined to show the degree of specialization for each species using the following formula.

$$\mathbf{B=1/ \sum P_j^2}$$

Where

B= Levin's' measure of niche breadth

P_j= Proportion of individuals found in or using resource state

$P_j=N_j/Y$

N_j = Number of individuals found in or using resource state

Y= Total number of individuals sampled

Bray-Curtis index of similarity

Similarity matrices were constructed using the Bray-Curtis measure (Bray & Curtis, 1957) using the abundance of plant species in habitats. The abundance data used was standardized to proportions calculated as relative abundance for each species.

$$BC_{ij} = \sum \frac{|n_{ik} - n_{jk}|}{(n_{ik} + n_{jk})}$$

Nearest neighbours

For each sampled individual species the two most nearest neighbours were determined by calculating the number of times the species were encountered as neighbours and their percentage to the total number of all the neighbour individuals for each species. This was also done to show species association with each other.

Ordination of woody vegetation data

Generalized Linear Models (GLM) analysis were carried out to determine if there was a significant difference in different soil properties between the different habitats. All the soil data were fit to a Gaussian distribution and R-studio software (R Core Team, 2013) was used to run the GLM.

A direct ordination approach called Canonical Correspondence Approach (CCA) was used to correlate the relative abundance of 15 most abundant species across all the habitats with soil physical and chemical properties. MVSP 3.1 software (Kovach Computing Services, 2007) was used to perform CCA. This is a multivariate method used to elucidate the relationships between the biological assemblages of species and their environment (ter Braak & Verdonschot, 1995). It selects the linear combination of environmental variables that maximizes the description of the species scores and selects the best weights for the environmental variables. This gives the first CCA axis. In CCA, composite gradients are linear combinations of environmental variables, giving a much simpler analysis, and the non-linearity enters the model through a unimodal model for a few composite gradients, taken care of in CCA by weighted averaging. CCA ordination is easier to apply and requires less data than regression. It also provides a summary of the species–environment relations (Chahouki, Azarnivand, Jafari, & Shafizadeh, 2008) . It has the advantage over other techniques in that it focuses on the relations between species and measured environmental variables and so provides an automated interpretation of the ordination axes (ter Braak, 1986).

3.3. Results

Species abundance

A total of forty-three woody plant species belonging to 18 families were found across the habitats (Table 1). The family represented by the highest number of species was Fabaceae (30%) followed by Tiliaceae (12%). The ten most abundant species across all the habitats were *Acacia erubescens, Catophractes alexandri, Acacia reficiens, Commiphora glaucescens, Commiphora virgata, Boscia foetida, Boscia albitrunca, Commiphora tenuipetiolata, Phaeoptilum spinosum* and *Terminalia prunioides* respectively (Figure 7). Only 5 among the ten most abundant species in the study area occurred in Kalahari red sand plains habitat, while this is true, all the ten most abundant species occurred in the marble and sandstone hill habitats (Figure 7). The species that had the highest abundance in the sandy plains were *Phaeoptilum spinosum*, *Catophractes alexandri* in the calcrete plains, *Acacia erubescens* in both granite and sandstone hills and *Commiphora virgata* in marble hills (Table 2). Some species were common in all the sampled habitats such as *Acacia mellifera, Catophractes alexandri, Boscia foetida, Boscia albitrunca*, while some species only occurred in one habitat such as *Acacia erioloba* and *Ehretia alba* (Table 3).

Table 1: Woody species encountered in the Karibib thorn bush savannah and their abundances (Counts of individuals) in different habitats

Species	Family	Sandstone hills	Marble hills	Granite hills	Calcrete plains	Sandy plains
Ehretia alba	Boraginaceae					59
Commiphora americana	Bruseraceae			1	9	1
Commiphora glaucescens	Bruseraceae	45	47	106	1	
Commiphora tenuipetiolata	Bruseraceae	24	99	2	1	
Commiphora virgata	Bruseraceae	59	94	33		
Boscia albitrunca	Capparaceae	64	11	51	9	25
Boscia foetida	Capparaceae	8	37	21	116	11
Maerua parvifolia	Capparaceae	3	8	23	4	3
Maerua schinzii	Capparaceae	12	3	25		
Gymnosporia senegalensis	Celastraceae				16	1
Combretum apiculetum	Combretaceae	22		35		
Terminalia prunioides	Combretaceae	28	9		31	18
Croton gratissimus	Euphorbiaceae	43		22		
Euphorbia guerichiana	Euphorbiaceae	6	1		3	
Acacia erioloba	Fabaceae					*42*
Acacia erubescens	Fabaceae	*169*	*18*	*169*	*34*	
Acacia hebeclada	Fabaceae					*2*
Acacia mellifera	Fabaceae	3	2	2	29	44
Acacia reficiens	Fabaceae	12	82	22	117	
Acacia senegal	Fabaceae	1	48	2	31	
Acacia tortilis	Fabaceae	1		4	39	
Adenolobus garipensis	Fabaceae	1	35		6	
Albizia anthelmintica	Fabaceae			4	6	67
Dichrostachys cinerea	Fabaceae	1		5	1	40
Elephantorrhiza suffruticosa	Fabaceae		18	3		
Parkinsonia africana	Fabaceae				5	56
Prosopis spp.	Fabaceae					1
Catophractes alexandri	Jacaranda	7	45	20	122	84
Rhigozum trichotomum	Jacaranda	2		4		74
Sterculia africana	Malvaceae	16	16	32		
Ficus cordata	Moraceae		1			
Moringa ovalifolia	Moringacea	7				
Phaeoptilum spinosum	Nyctaginaceae	9	1	6	5	77

Ximenia americana	Olacaceae	1			7	
Ziziphus mucronata	Rhamnaceae				1	
Salvadora persica	Salvadoraceae				1	
Lycium eenii	Solanaceae					12
Grewia bicolor	Tiliaceae	10		3		
Grewia flava	Tiliaceae	10		3	1	8
Grewia flavascens	Tiliaceae	5				
Grewia tenax	Tiliaceae	13	14	1	36	
Grewia villosa	Tiliaceae	13	7		7	
Cyphostema currorii	Vitaceae	1				

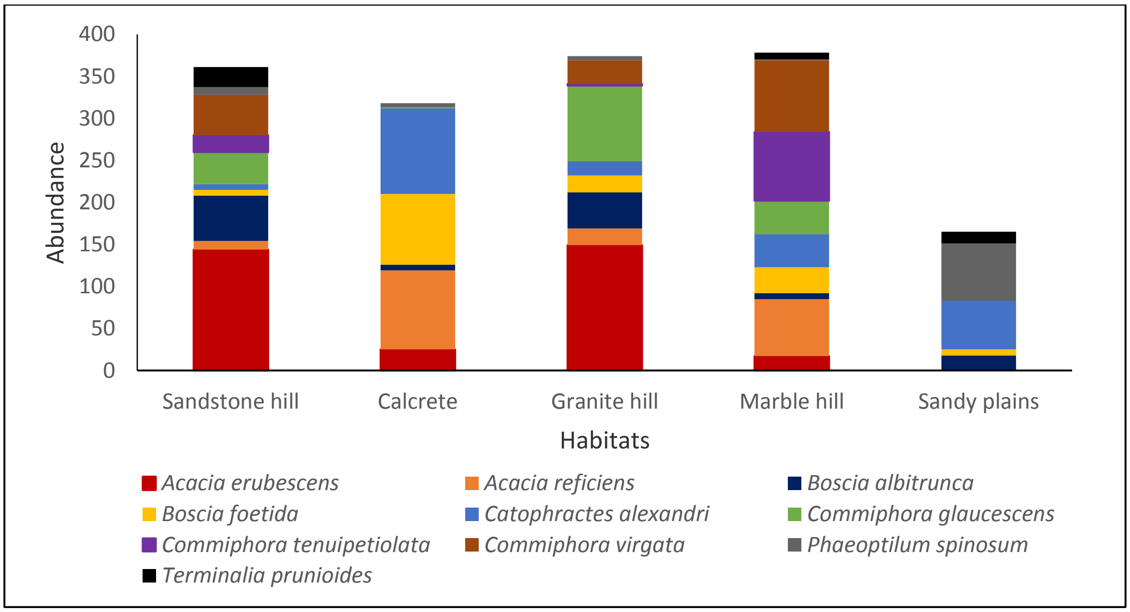


Figure 7: Abundance of the ten most abundant species in all the sampled habitats in the Karibib thorn bush savanna

Table 2: Ten most abundant species in each sampled habitat in the Karibib thorn bush savannah

Rank	Calcrete plains	Sandy plains	Granite hills	Sandstone hills	Marble hills
1	*C. alexandri*	*P. spinosum*	*A. erubescens*	*A. erubescens*	*C. virgata*
2	*A.reficiens*	*A. anthelmintica*	*C. glaucescens*	*B. albitrunca*	*C. tenuipetiolata*
3	*B. foetida*	*C. alexandri*	*B. albitrunca*	*C. virgata*	*A. reficiens*
4	*A.tortilis*	*R. trichotomum*	*C. apiculetum*	*C. glaucescens*	*C. glaucescens*
5	*G. tenax*	*E. alba*	*C. virgata*	*C. gratissimus*	*C. alexandri*
6	*T. prunioides*	*P. africana*	*S. africana*	*T. prunioides*	*A.senegal*
7	*A. erubescens*	*A. mellifera*	*M. parvifolia*	*C. tenuipetiolata*	*B. foetida*
8	*A. mellifera*	*D. cinerea*	*A.reficiens*	*C. apiculetum*	*A. garipensis*
9	*A. senegal*	*A. erioloba*	*B. foetida*	*G. villosa*	*A. erubescens*
10	*G. senegalensis*	*B. albitrunca*	*C. alexandri*	*S. africana*	*E. suffruticosa*

Table 3: Categories of frequency of occurrence (%) for all the sampled species in the five habitats studied

Frequency occurrence of 100%/Species occurring in all 5 habitat	**Frequency occurrence of 80%/Species occurring in 4 habitats**	**Frequency occurrence 0f 60%/ Species occurring in 3 habitats**	**Frequency occurrence of 40% /Species occurring in 2 habitats**	**Frequency occurrence of 20% /Species occurring in 1 habitat**
Acacia mellifera	*Acacia erubescens*	*Acacia tortilis*	*Combretum apiculetum*	*Acacia erioloba*
Boscia foetida	*Acacia reficiens*	*Adenolobus garipensis*	*Croton gratissimus*	*Acacia hebeclada*
Boscia albitrunca	*Acacia senegal*	*Albizia anthelmintica*	*Elephantorrhiza suffruticosa*	*Cyphostema*
Catophractes alexandri	*Commiphora glaucescens*	*Commiphora americana*	*Grewia bicolor*	*Ehretia alba*
Maerua parvifolia	*Commiphora tenuipetiolata*	*Commiphora virgata*	*Gymnosporia senegalensis*	*Ficus cordata*
Phaeoptilum spinosum	*Dichrostachys cinerea*	*Euphorbia guerichiana*	*Parkinsonia africana*	*Grewia flavascens*
	Grewia flava	*Grewia villosa*		*Lycium eenii*
	Grewia tenax	*Maerua schinzii*		*Moringa ovalifolia*
	Terminalia prunioides	*Rhigozum trichotomum*		*Prosopis*
		Sterculia africana		*Salvadora persica*
				Ziziphus mucronata

Niche breadth

Species such as *Boscia foetida*, *Catophractes alexandri and Terminalia prunioides* recorded the highest niche breadth values, while others were narrow-niched such as *Acacia erioloba*, *Ehretia alba* and *Moringa ovalifolia* (Table 4).

Table 4: Niche breadth value for each species sampled arranged in descending order

Species	Levin's B (niche breadth)
Terminalia prunioides	3.44
Boscia albitrunca	3.40
Catophractes alexandri	3.17
Grewia flava	2.78
Grewia villosa	2.73
Maerua parvifolia	2.68
Sterculia africana	2.67
Acacia erubescens	2.60
Commiphora virgata	2.58
Acacia reficiens	2.58
Commiphora glaucescens	2.56
Grewia tenax	2.46
Boscia foetida	2.41
Acacia mellifera	2.29
Euphorbia guerichiana	2.17
Maerua schinzii	2.06
Acacia senegal	2.06
Combretum apiculetum	1.90
Croton gratissimus	1.81
Phaeoptilum spinosum	1.58
Grewia bicolor	1.55
Commiphora tenuipetiolata	1.53
Commiphora americana	1.46
Adenolobus garipensis	1.40
Dichrostachys cenerea	1.36
Elephantorrhiza suffruticosa	1.32
Albizia anthelmintica	1.31
Ximenia americana	1.28
Acacia tortilis	1.26
Parkinsonia africana	1.18
Rhigozum trichotomum	1.16
Gymnosporia senegalensis	1.12
Acacia erioloba	1.00

Acacia hebeclada	1.00
Cyphostema currorii	1.00
Ficus cordata	1.00
Grewia flavascens	1.00
Lycium eenii	1.00
Moringa ovalifolia	1.00
Prosopis spp.	1.00
Salvadora persica	1.00
Ziziphus mucronata	1.00
Ehretia alba	1.00

Species richness

The highest species richness was recorded in sandstone hills habitat (30 species), followed by granite hill (25 species) and calcrete plains (25 species) and the lowest species richness was recorded in the sandy plains habitat (19 species) (Figure 8).

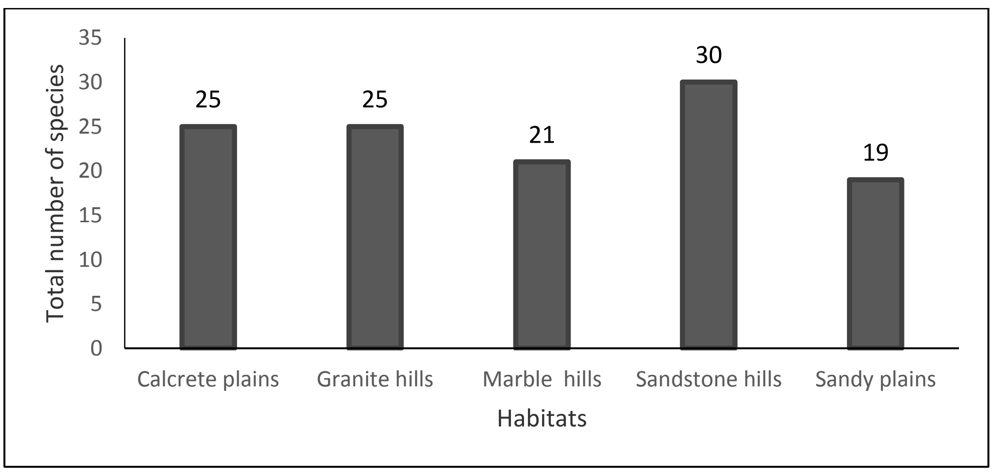


Figure 8: Total number of species encountered in each sampled habitat in the Karibib thorn bush savannah

Species diversity and evenness

The GLM analysis establishes that there was no significant difference in species diversity (P=0.824, F=0.374 and DF =4) and evenness (P=0.208, F= 1.619 and DF=4) between the habitats (Fig 9 A and B; Appendix 1.1).

A B

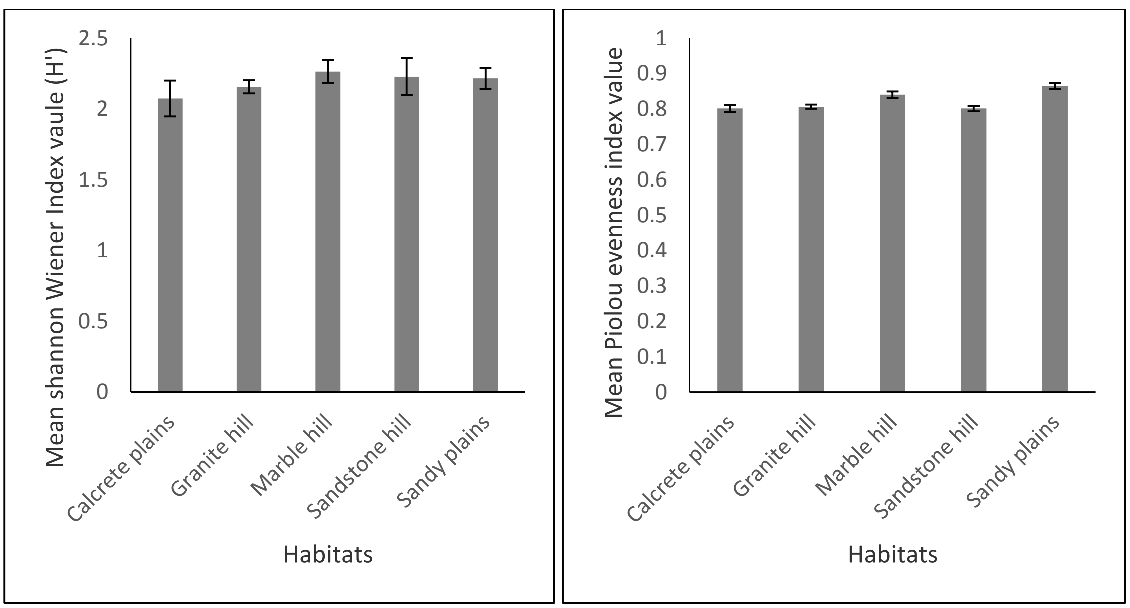


Figure 9: A) Mean Shannon Wiener diversity index (H') and B) Pielou's Evenness Index (e) value for each sampled habitat in Karibib thorn bush savannah

Habitat similarity

The Bray Curtis similarity index showed that Granite hills and sandstone hills were more similar (71%), followed by marble hills and sandstone hills (53%). Kalahari red sand plain was more dissimilar with all the hill habitats and similar with calcrete plains only with 29% (Table 5).

Table 5: Bray Curtis similarity index (%) of different habitats in terms of species composition

	Sandstone	Marble	Granite	Calcrete
Sandstone				
Marble	52.81			
Granite	71.16	34.14		
Calcrete	21.77	41.47	22.29	
Red sand	14.07	15.72	13.73	29.03

Nearest neighbours

It appears that most species were more associated with themselves as the highest percentage of their first and second nearest neighbours were with conspecifics (Table 6). Many species were associated with either themselves or with the most abundant species in the area. About 70% of the two nearest neighbours to *Acacia erubescens, Acacia reficiens, Catophractes alexandri* and *Rhigozum trichotomum* were conspecifics.

Table 6: Percentages (%) for the two most nearest neighbours for each woody species sampled

Species	Two most nearest neighbours	% of neighbours
Acacia erioloba	*Ehretia alba*	23
	Rhigozum trichotomum	23
Acacia erubescens	*Acacia erubescens*	69
	Acacia erubescens	67
Acacia hebeclada	*Phaeoptilum spinosum*	100
	Ehretia alba	50
Acacia mellifera	*Catophractes alexandri*	19
	Catophractes alexandri	16
Acacia reficiens	*Acacia reficiens*	48
	Acacia reficiens	46
Acacia senegal	*Acacia senegal*	25
	Acacia senegal	22
Acacia tortilis	*Acacia tortilis*	31
	Acacia tortilis	28
Adenolobus garipensis	*Adenolobus garipensis*	40
	Acacia reficiens	26
Albizia anthelmintica	*Phaeoptilum spinosum*	29
	Phaeoptilum spinosum	24
Boscia albitrunca	*Acacia erubescens*	33
	Acacia erubescens	22
Boscia foetida	*Acacia erubescens*	28
	Boscia foetida	22
Catophractes alexandri	*Catophractes alexandri*	75
	Catophractes alexandri	66
Combretum apiculetum	*Combretum apiculetum*	56
	Combretum apiculetum	54
Commiphora americana	*Boscia foetida*	33
	Acacia erubescens	17
Commiphora glaucescens	*Commiphora glaucescens*	43
	Commiphora glaucescens	35
Commiphora tenuipetiolata	*Commiphora tenuipetiolata*	26
	Commiphora tenuipetiolata	20
Commiphora virgata	*Commiphora virgata*	38
	Commiphora virgata	36
Croton gratissimus	*Croton gratissimus*	69
	Croton gratissimus	47
Cyphostema	*Commiphora tenuipetiolata*	100
	Commiphora tenuipetiolata	100
Dichrostachys cinerea	*Dichrostachys cinerea*	68

	Dichrostachys cinerea	50
Ehretia alba	*Ehretia alba*	91
	Ehretia alba	87
Elephantorrhiza suffruticosa	*Commiphora virgata*	30
	Acacia erubescens	20
Euphorbia guerichiana	*Commiphora glaucescens*	29
	Acacia erubescens	14
Grewia bicolor	*Boscia foetida*	22
	Acacia reficiens	22
Grewia flava	*Phaeoptilum spinosum*	17
	Acacia erubescens	17
Grewia flavascens	*Commiphora glaucescens*	40
	Commiphora glaucescens	40
Grewia tenax	*Grewia tenax*	27
	Acacia reficiens	22
Grewia villosa	*Grewia villosa*	27
	Grewia villosa	27
Gymnosporia senegalensis	*Grewia tenax*	25
	Gymnosporia senegalensis	17
Lycium eenii	*Lycium eenii*	88
	Lycium eenii	50
Maerua parvifolia	*Acacia erubescens*	29
	Maerua parvifolia	21
Maerua schinzii	*Acacia erubescens*	26
	Acacia erubescens	22
Moringa ovalifolia	*Moringa ovalifolia*	38
	Acacia erubescens	25
Parkinsonia africana	*Parkinsonia africana*	25
	Parkinsonia africana	19
Phaeoptilum spinosum	*Phaeoptilum spinosum*	45
	Phaeoptilum spinosum	42
Prosopis	*Acacia erioloba*	100
	Albizia anthelmintica	100
Rhigozum trichotomum	*Rhigozum trichotomum*	75
	Rhigozum trichotomum	70
Salvadora persica	*Ximenia americana*	100
	Albizia anthelmintica	100
Sterculia africana	*Acacia erubescens*	28
	Commiphora glaucescens	19
Terminalia prunioides	*Terminalia prunioides*	24
	Terminalia prunioides	20
Ximenia americana	*Acacia reficiens*	33
	Boscia foetida	33

Ziziphus mucronata	*Boscia foetida*	100
	Boscia foetida	100

Ordinations and correlations of vegetation with soil variables

PH was highest in the sandstones hills and lowest in the calcrete plains, electrical conductivity and CaCO3 was highest in granite hills and lowest in calcrete plains. The highest sand content was recorded in the sandy plains and lowest in the marble hills. Low clay content was recorded in all the habitats, all below 5 %. Highest calcium was recorded in sandstone hills and lowest in calcrete plains (Table 7).

The abundance of *Phaeoptilum spinosum*, *Acacia mellifera*, *Albizia anthelmintica*, *Ehretia alba* and *Rhigozum trichotomum* were significantly and positively correlated with sand (%). The abundance of *Acacia senegal*, *Acacia reficiens*, *Commiphora tenuipetiolata*, *Commiphora virgata*, were significantly correlated with silt. The abundance of *Acacia senegal*, *Acacia reficiens*, *Boscia foetida* and *Commiphora tenuipetiolata* were significantly positively correlated with sodium and potassium. The abundance of *Commiphora virgata*, *Commiphora tenuipetiolata*, *Commiphora glaucescens* and *Acacia erubescens* were significantly and positively correlated with clay (Table 8a-b). GLM establishes that there was a significant difference in all the soil properties tested between habitats except in clay content, total nitrogen and organic matter (Table 9).

The relationship between species abundance and soil variables was also analyzed by CCA ordinations in addition to correlations. In the elucidation of the CCA diagram, the following points should be noted: The soil variables are represented by arrows. Each arrow representing a soil variable points in the direction of maximum change of that soil variable across the ordination direction. Soil variables with long arrows are more strongly correlated with the ordination axes than those with short arrows, and so more closely related to the plant species or pattern of community variation shown in the ordination diagram. Based on the CCA results, 96.7 % of vegetation-soil variation was explained by axis 1-3 (Table10). Axis 1 (Eigenvalue: 0.624) accounted for 50.725% of variance. The factors corresponded to the first axis were, sand, silt, potassium and phosphorus (Table 10). 30.48% of variation was explained by axis 2 (Eigenvalue: 0.387). Clay, sodium and pH were represented by the second axis among which, sodium had the highest correlation with this axis. 15.5% of variance was explained by the third axis (Eigenvalue: 0.191). Total nitrogen, conductivity, CaCO3 and magnesium were associated with the third axis among which conductivity had the highest correlation with this axis. Correlation between axis 1, 2, 3 and species-edaphic variables were 1, 1, 1 respectively. Monte Carlo test for the first three axis was highly significant ($P<0.001$). To better explain and analyze the most important edaphic factors influencing the vegetation, the position of species are described based on axis 1 - 2 (Figure10 a) and 1 – 3 (Figure 10b). The correlations observed in the CCA ordinations are similar to the ones indicated by the Pearson correlations.

Table 7: Soil properties in each habitat represented as means and standard deviations

Properties	Sandstone hills		Granite hills		Calcrete plains		Marble hills		Sandy plains	
	Mean	Std.Dev	Mean	Std.Dev	Mean	Std.Dev	Mean	Std.Dev	Mean	Std.Dev
pH (H2O) electrometric	**8.02**	0.25	**7.88**	0.12	**7.74**	0.20	**7.24**	0.17	**7.70**	0.44
Conductivity (mS/m)	**23.16**	7.19	**27.49**	3.65	**17.94**	3.39	**10.61**	5.07	**12.60**	8.17
% CaCO3 equivalent	**1.81**	0.39	**2.12**	0.84	**1.31**	1.11	**0.14**	0.04	**0.27**	0.15
Org matter (% m/m OM)	**2.97**	2.93	**3.31**	2.10	**2.81**	1.26	**0.96**	0.83	**0.69**	0.76
Org carbon (% m/m C)	**1.72**	1.70	**1.92**	1.22	**1.63**	0.73	**0.56**	0.48	**0.42**	0.42
Total Nitrogen (% N m/m)	**0.24**	0.14	**0.26**	0.13	**0.20**	0.06	**0.11**	0.07	**0.13**	0.10
Sand (%)	**70.46**	6.27	**65.18**	10.45	**46.74**	3.15	**83.06**	15.15	**91.98**	6.42
Clay (%)	**2.30**	0.76	**3.37**	0.84	**4.15**	0.97	**4.15**	7.29	**0.81**	0.75
Silt (%)	**27.25**	5.82	**31.45**	9.65	**49.11**	2.23	**12.80**	7.90	**7.21**	5.92
Magnesium (mg Na/kg)	**317.06**	191.91	**409.76**	30.44	**294.78**	39.24	**97.36**	84.80	**100.13**	52.29
Sodium (mg Na/kg)	**21.39**	12.80	**11.95**	11.00	**24.52**	17.95	**2.39**	1.43	**4.94**	2.71
Calcium (mg Na/kg)	**5178.00**	927.44	**3605.00**	1813.71	**1867.60**	734.20	**641.06**	332.01	**648.18**	317.52
Phosphorus (mg P /kg)	**33.46**	29.86	**29.36**	23.08	**4.72**	0.74	**9.64**	2.19	**4.98**	3.40
Potassium (mg Na/kg)	**423.90**	173.14	**330.72**	161.26	**548.68**	275.18	**152.29**	139.52	**131.57**	63.00

Table 8A-B: Correlations of soil properties with the fifteen most abundant species across all the habitats sampled in the Karibib thorn bush savanna. Correlations in bold are significant at p=less than 0.05.

A

Properties	*P. spinosum*	*A. erubescens*	*A. mellifera*	*A. reficiens*	*A. senegal*	*A. anthelmintica*	*B. albitrunca*	*C. tenuipetiolata*
pH (H2O) electrometric	-0.179	-0.424	0.307	**0.596**	0.394	0.096	**-0.676**	-0.168
Silt (%)	**-0.686**	-0.123	**-0.575**	**0.632**	**0.800**	**-0.627**	-0.434	**0.727**
Sand (%)	**0.721**	0.070	**0.626**	**-0.613**	**-0.785**	**0.672**	0.383	**-0.741**
Calcium (mg Na/kg)	**-0.507**	-0.006	0.003	**0.726**	0.338	-0.346	-0.382	-0.263
Magnesium (mg Na/kg)	**-0.611**	0.143	-0.389	**0.521**	0.375	**-0.507**	-0.241	0.082
Potassium (mg Na/kg)	**-0.652**	-0.319	-0.369	**0.828**	**0.901**	**-0.546**	**-0.633**	**0.631**
Sodium (mg Na/kg)	**-0.534**	-0.455	-0.165	**0.896**	**0.921**	-0.400	**-0.771**	**0.535**
% CaCO3 equivalent	**-0.570**	0.087	-0.270	**0.580**	0.367	-0.445	-0.302	-0.022
Clay (%)	**-0.842**	**0.570**	**-0.966**	0.155	0.293	**-0.924**	0.368	**0.609**
Organic matter (% m/m OM)	**-0.705**	**0.683**	-0.424	**0.653**	**0.517**	**-0.594**	-0.320	0.193
Conductivity (mS/m)	-0.478	0.164	-0.219	0.445	0.199	-0.360	-0.197	-0.170
Organic carbon (% m/m C)	**-0.699**	0.082	-0.418	**0.652**	**0.516**	**-0.587**	-0.325	0.190
Total Nitrogen (% N m/m)	**-0.501**	0.032	-0.207	**0.561**	0.358	-0.371	-0.340	-0.041
Phosphorus (mg Na/kg)	-0.443	0.302	-0.026	0.440	-0.037	-0.321	-0.028	**-0.543**

B

properties	*B. foetida*	*C. alexandri*	*C. glaucescens*	*C. virgata*	*E. alba*	*R. trichotomum*	*T. pruniodes*
pH (H2O) electrometric	**0.676**	**0.659**	-0.050	-0.430	-0.030	-0.038	-0.261
Silt (%)	0.301	-0.080	0.403	**0.622**	**-0.621**	**-0.633**	-0.495
Sand (%)	-0.274	0.134	-0.434	**-0.662**	**0.660**	**0.671**	0.487
Calcium (mg Na/kg)	**0.840**	0.489	0.084	-0.351	-0.492	-0.496	0.016
Magnesium (mg Na/kg)	0.447	0.054	**0.557**	0.073	**-0.577**	**-0.567**	**-0.548**
Potassium (mg Na/kg)	**0.560**	0.204	0.160	0.434	**-0.584**	**-0.606**	-0.280
Sodium (mg Na/kg)	**0.685**	0.410	-0.027	0.264	-0.463	-0.492	-0.161
% CaCO3 equivalent	**0.559**	0.188	0.447	-0.062	**-0.538**	**-0.531**	-0.441
Clay (%)	-0.147	**-0.708**	**0.622**	**0.858**	**-0.845**	**-0.840**	-0.201
Organic matter (% m/m OM)	**0.541**	0.095	0.480	0.155	**-0.666**	**-0.664**	-0.443
Conductivity (mS/m)	0.481	0.157	0.492	-0.171	-0.456	-0.441	-0.479
Organic carbon (% m/m C)	**0.541**	0.100	0.477	0.150	**-0.659**	**-0.657**	-0.446
Total Nitrogen (% N m/m)	**0.550**	0.229	0.418	-0.105	-0.466	-0.459	-0.466
Phosphorus (% N m/m)	**0.657**	0.303	0.221	-0.481	-0.461	-0.448	0.037

Table 9: GLM analysis results to determine differences in soil variables between different habitats. Significant differences are indicated by *P<0.05, **P<0.01, ***P<0.001

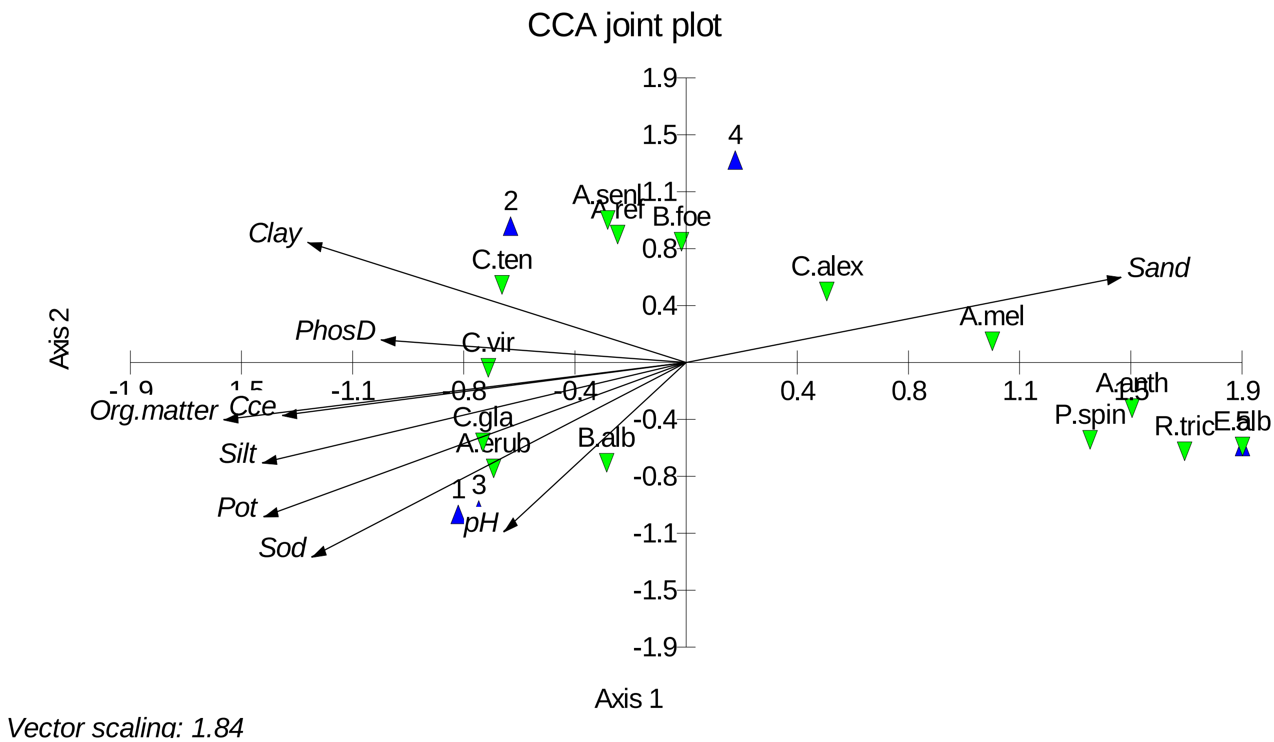
Response variable	**Determinant variable**	**d.f**	**F-ratio**	**P**
pH (H2O) electrometric	Habitats	4	5.154	0.0051**
	Error	20		
Conductivity (mS/m)	Habitats	4	4.959	0.0061**
	Error	20		
Total Nitrogen (% N m/m)	Habitats	4	1.834	0.1618
	Error	20		
Phosphorus (% N m/m)	Habitats	4	5.023	0.0057**
	Error	20		
Potassium (% N m/m)	Habitats	4	4.693	0.0078**
	Error	20		
Magnesium (% N m/m)	Habitats	4	7.748	0.0006***
	Error	20		
Calcium (% N m/m)	Habitats	4	19.736	<0.0001***
	Error	20		
Sand (1%)	Habitats	4	15.495	<0.0001***
	Error	20		
Silt (1%)	Habitats	4	15.888	<0.0001***
	Error	20		
Clay (1%)	Habitats	4	1.156	0.3596
	Error	20		
Organic carbon (% m/m C)	Habitats	4	2.509	0.0744
	Error	20		

Table 10: Results from the CCA analysis for abundance of species ordinated with soil properties.

	Axis 1	Axis 2	Axis 3
Eigenvalues	0.624	0.387	0.191
Percentage	50.725	30.480	15.559
Cumulative Percentage	50.725	82.204	97.763
Cumulative Constructive Percentage	50.725	82.204	97.763
Species-environmental correlations	1	1	1

Table 11: Pearson correlation of soil variables with the CCA ordination axes

	Envi. Axis 1	Envi. Axis 2	Envi. Axis 3
pH (H2O) electrometric	-0.338	-0.611	0.692
Silt (%)	-0.785	-0.362	0.075
Sand (%)	0.805	0.309	-0.037
Potassium (% N m/m)	-0.783	-0.557	0.042
Sodium (% N m/m)	-0.694	-0.703	0.061
CaCO3	-0.748	-0.191	0.634
% CaCO3 equivalent	-0.701	0.434	-0.412
Organic matter (% m/m OM)	-0.856	-0.206	0.469
Phosphorus (% N m/m)	-0.565	0.083	0.545


CCA joint plot
Axis 1
Axis 2
Clay
PhosD
Org.matter
Cce
Silt
Pot
Sod
pH
Sand
C.ten
C.vir
C.gla
A.erub
B.alb
A.senl
A.ref
B.foe
C.alex
A.mel
A.anth
P.spin
R.tric
E.alb
1
2
3
4
5
Vector scaling: 1.84

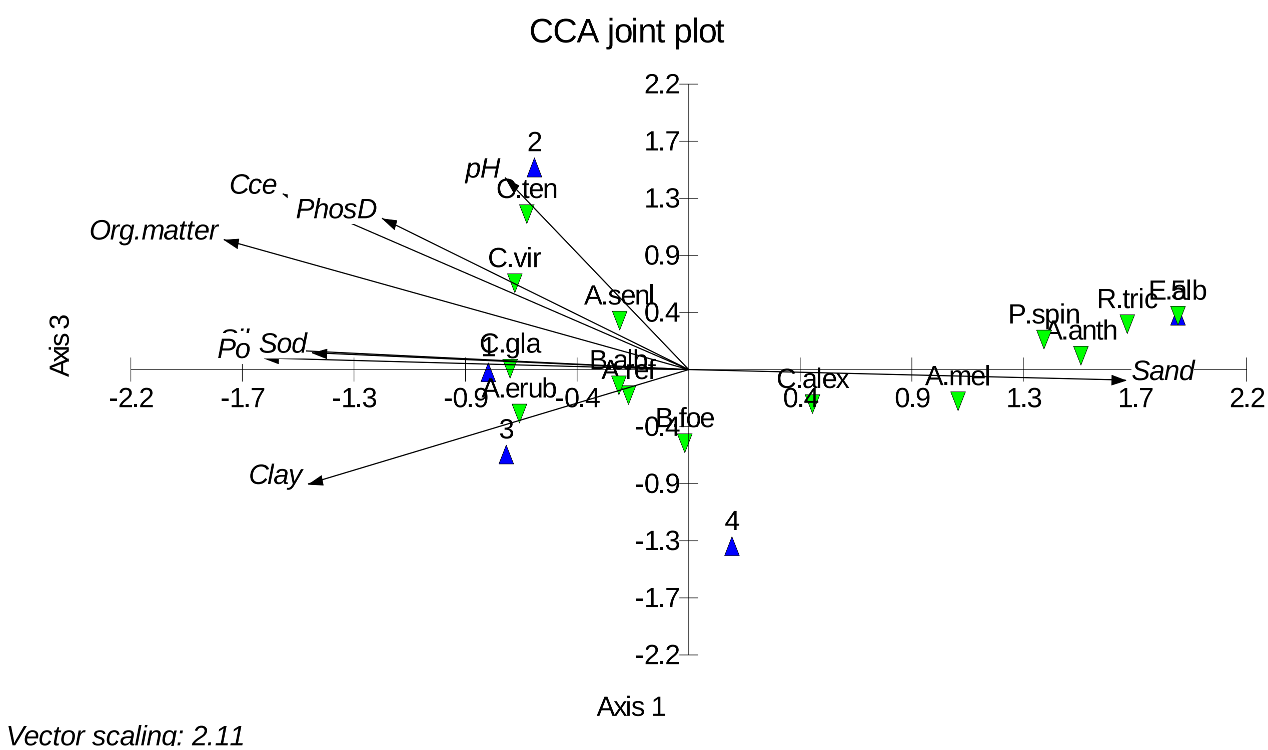

CCA joint plot
Axis 1
Axis 3
Cce
PhosD
Org.matter
pH
Sod
Po
Clay
Sand
C.ten
C.vir
A.senl
C.gla
B.alb
A.ref
A.erub
B.foe
C.alex
A.mel
P.spin
A.anth
R.tric
E.alb
1
2
3
4
5
Vector scaling: 2.11

Figure 10*:* The distribution of 15 most abundant species encountered in the Karibib thorn bush savannah. Canonical correspondence analysis (CCA) ordination diagram with habitats (▼), species (▲) and environmental variables (arrows); first axis is vertical, second and third axes are horizontal. Shown also are the projections of the habitats labelled as; 1=Sandstone hills, 2=.Marble hills, 3=Granite hills, 4=Calcrete plains and 5= Red sand plains. The species are: P. spin = *Phaeoptilum spinosum*, C.alex = *Catophractes alexandri*, T. prun = *Terminalia prunioides,* A. ref = *Acacia reficiens*, A.sen=*Acacia senegal*, C.ten = *Commiphora tenuipetiolata*, A.erub = *Acacia erubescens,* = C. glau= *Commiphora glaucescens*, E. alb=*Ehretia alba*, R.tri= *Rhigozum trichotomum* and A.me= *Acacia mellifera*. The environmental variables are: clay, silt, sand, sod=sodium, pot=potassium, Org.m= organic matter, pH, Cce=Calcium carbonate equivalents, and PhospD=Phosphorus

3.4. Discussion

The present study suggests that there was no difference in species diversity and evenness amongst all habitats. This implies that in terms of diversity of woody plants, these communities did not differ much in species complexity and hence no habitat was more diverse than another. Shaukat *et al*., (1978) established that diversity is a measure of complexity of form and function within a community and it gives an idea of how species are organized in the community.

A high degree of similarity in species composition was found between sandstone hills habitat and granite. On the contrary, these two habitats showed a high degree of dissimilarity to both sandy plains and calcrete plains. It can be speculated that perhaps there was niche similarity among species occurring in granite hills and sandstone hills, meaning the species there perhaps share common biochemical attributes, hence similarity in abundance patterns as well. Several experimental studies have documented similarity of observed ecological niches among species for a variety of taxa and ecological traits (e.g., Peterson et al. 1999; Chazdon et al. 2003; Burns and Strauss 2011). The three most abundant species in these two habitats were *Acacia erubescens, Commiphora glaucascens* and *Boscia albitrunca*. These were also the two habitats that were comparatively more nutrient rich.

It was observed that species richness was highest in sandstone hill habitats and lowest in the sandy plains. Several explanations exist to support this observation. It is provided that the studied habitats differ considerably in soil properties. Many studies have found relationships between changes in species richness and a gradient of nutrient availability (e.g. Grime, 1973; Okland *et al*., 2003). Species richness is usually low at low nutrient levels, increases to a peak at intermediate levels and declines more gradually at high nutrient levels. The sandy plains had the lowest nutrient levels in this study, while the sandstone hills had the highest nutrient levels. This perhaps explain why species richness was lowest in sandy plains and highest in sandstone hills habitat. It is also possible that other factors in these habitats may be contributing to their differences in species richness. For example, environmental heterogeneity (Orians, 1982), temperature (Austin, Pausas, & Nicholls, 1996), topography (Wolf et al., 2012) and disturbance (Hobbs & Huenneke, 1992) among others. Huston (1994) reviewed species richness extensively, and regarded patterns of species richness as being determined by the interaction of disturbance with environmental gradients and competitive exclusion.

It was observed that some species have wide niche breadths such as *Catophractes alexandri, Acacia erubescens*, *Terminalia prunioides, Acacia reficiens* among others. Other species were more confined to one or two habitats and showed scarcity, and hence narrow niched. This included, *Acacia erioloba*, *Moringa ovalifolia* and *Ehretia alba* among others. Grime (1977) accentuated that niche dynamics assumes that there are differences among species in their multidimensional niches that should give rise to patterns in the abundance and distribution of each species. Normally plants compete for various resources such as nitrogen and water and this facilitate niche requirement for each species because some species are better able to tolerate harsh conditions than others. Niche differences can facilitate species coexistence when, for example, one species is better able to tolerate low levels of phosphorus while another species is tolerant of low nitrogen levels. This demonstrates that species do indeed differ in their multidimensional niches. The point at which various resources become limiting for survival and reproduction varies among species. This perhaps explain the differences in niche sizes obtained in this study.

Result in this study provided some indication of the influence of soil variables on the distribution patterns of the woody species in the Karibib thorn bush savannah. The CCA ordination revealed several tight species groupings which indicated that many species were unique to a single habitat or had a relatively high abundance in a particular habitat. The important driver of the patterns observed in the present study seems to be soil texture, organic matter, pH and cations. Soil texture has been found to influence plant composition and distribution under the same climatic conditions and to limit arid and semi-arid plant dynamics by affecting local soil moisture regimes (Baghestani, 1993; He *et al*; Li *et al*.,2007). Soil texture can affect the movement and availability of air and water in soil, water supply and the rate and depth of leaching (Mohammad, 2012).

The species that were associated with Kalahari red sand plains were *Ehretia alba, Catophractes alexandri, Albizia anthelmintica, Acacia mellifera, Acacia erioloba* and *Rhigozum anthelmintica* among others in low abundance. The sandy soils of the Kalahari sandveld are characterized by low nutrient content and are porous, allowing rapid and deep infiltration of water (Burke, 2006). Colwell (2009) concluded that the species that characterize any natural community differ in relative abundance, usually with a few species quite common and most species much less so. This was also presented in this study where several species were common in all the habitats studied, while some only occurred in one or two habitats.

The species that were more associated with the presence of silt and clay were the *Commiphora* species, *Boscia albitrunca* and *Acacia erubescens*. These species were also strongly associated with organic matter and cations such as sodium and potassium. As a result they were also found in habitats (granite and sandstone hills) that were rich in silt and clay content and in organic matter. According to Verberk (2012) comparing species abundance among communities can be difficult because communities often comprise many different species whose abundance profiles differ widely among the communities.

It is clear from the results that some species exhibit greater niche specialization than others rendering them narrow-niched while others are broad-niched. Levins (1968) states that wide-niched species are better suited to uncertain environments as opposed to narrow-niched species. Characteristic hill species, such as *Acacia erubescens, Commiphora glaucascens, Maerua parvifolia* and *Sterculia africana* are correlated with a combination of soil variables, essentially presenting hill habitats, while *Acacia erioloba, Catophractes alexandri, Acacia tortilis and Rhigozum trichotomum,* were more correlated with plains. Variables found to impact the distribution and abundance of species included pH, soil texture, organic matter, potassium and sodium. The abundance of the most abundant species were distributed according to these variables.

It can thus be established that the ecology of different plant communities in Karibib thorn bush savannah occupy habitats characterized by different soil characteristics and the ecology of plants differ in their composition and structure. The study of soil-vegetation relationships can be very useful for classifying and analyzing composition and distribution patterns of plants in relation to soil properties. It will also be a guidance for managing and reclaiming degraded lands in arid and semi-arid environments. The findings on the plant and soil relations in the study area will help in the selection of adaptable species for rehabilitating mines and or degraded land in arid environments by showing how different species are distributed along soil gradients. Knowledge of ecological communities in the surrounding undisturbed ecosystems is needed to ensure a success of any rehabilitation project. This is because rehabilitation necessitates that the established planted community be similar to a naturally occurring plant community of the same type as the one occurring in the adjacent area.

Chapter 4: Testing seed pre-treatment methods for increasing germination in eight savanna woody species

4.1. Introduction

Disturbed mined lands are normally rehabilitated with native species (Fung, 1984). However, several potentially useful species may not be used to their full potential because of problems associated with overcoming seed dormancy. Parera & Ruiz (2003) stated that revegetation of disturbed mined lands, particularly in arid environments, is often hindered by low seedling establishment. In Namibia this is particularly true because information on seed biology and germination cues of keystone species is lacking and the climate is dry and hot.

Understanding the seed biology of species used in revegetation projects is vital for ensuring establishment of seedlings. For example, pre-treating seeds prior to seed sowing to stimulate germination or assuage seed dormancy is the first step in overcoming the various challenges and may increase the likelihood of seed germination and seedling establishment (Commander *et al*., 2009). The dormancy imposed by hard seed coats has been reported as a mechanism to survive extreme environmental conditions, and it is a common phenomenon in leguminous seeds (Bradbeer, 1988)

The purpose of pre-treatment is to equally ensure that seeds will germinate, and that germination is fast and uniform. Pre-treatment methods have been established and defined for many species. Nevertheless, dormancy still results in low germination rates for several species, partially because of lack of knowledge on their seed physiology and because of variation in dormancy rates.

There are a number of ways used to improve germination of seeds (Hossain *et al*., 2005; Lisar *et al*., n.d.). Chemical scarification is widely used to overcome the strength of seed covering structures in many species. Using sulphuric acid is one of the effective chemical scarification methods and it is extensively used to enhance germination (Nadjafi *et al*., 2006; Narbona *et al*. , 2006; Olvera-Carillo *et al*., 2003). The challenge in using this strong acid however is optimizing the soaking periods of seeds in a way that improve germination without destroying the seeds.

Hot water treatment has also proven effective in improving seed germination (Hossain *et al*., 2005; Mohammad *et al.*, 2013; Travlos *et al*., 2007). The use of acetone for seed treatment is however understudied. Though some studies reported its negative effects on seed germination (e.g. Gerald & Heidmann, 1992; Milborrow, 1963; Tao & Khan, 1974) in other experiments acetone application increased seed germination (Crozier *et al*., 1972; Newell *et al.*,1996).

The nature of seed dormancy and germination in most Acacia savannah species has been studied (Argaw *et al*., 1999; Hussien *et al.*, 2011; Kassa *et al*., 2010), but the conclusions have varied from one study to another, and vary in different regions of Africa. This is probably due to diverse range of climatic conditions. No germination studies on savannah species have been carried out in Erongo region in Namibia.

The work reported in this chapter was undertaken to study the effects of different scarification methods (sulphuric acid, acetone, hot water and cold water (at room temperature as a control), and different soaking periods on seed germination of 8 woody savannah species in order to determine the best seed dormancy treatment method for species that could potentially be used in revegetation in mined substrates at Navachab. The findings can be used in mine rehabilitation projects where the germination may need to be enhanced in order to establish seedlings in a predictable manner. The studied species can also be used in the rehabilitation of agricultural and other disturbed lands in the arid savannah biome as well as other biomes.

4.2. Materials and Methods

4.2.1. Study area

The seed germination experiment was conducted during the period May 2013- June 2013 in the nursery at Navachab Gold Mine (21° 56' 0" S and 15° 50' 0" E), located 10 km south west of Karibib in Erongo Region on the western part of Namibia. Seeds were collected locally in the surrounding communities primarily within the Karibib area. The biophysical description of the study area has been given in Chapter 2. The average maximum temperature between May and June was 32 degree Celsius and minimum of 7 degree Celsius (Figure 11).

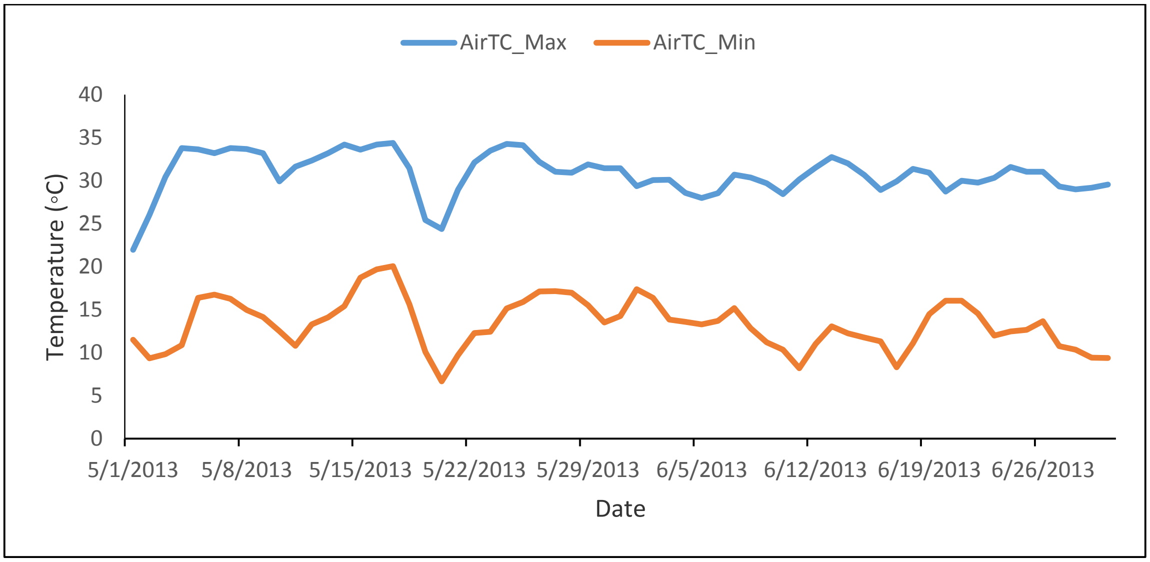


Figure 11: Daily minimum and maximum temperatures (^{0}C) during the study period (May and June 2013), at Navachab Gold Mine (Source; Uwe Rentel).

4.2.2. Seed collection

Seeds of the following species: *Acacia erioloba*, *Acacia reficiens*, *Acacia tortilis*, *Adenolobus garipensis*, *Acacia senegal*, *Albizia anthelmintica*, *Commiphora glaucescens* and *Terminalia prunioides were* collected from local stands of native plant communities, primarily within the Karibib area, in the period from November 2012 to March 2013 to be used in the germination experiment. The fruits were collected directly from plants and as fallen seeds directly from the ground. The seeds of all leguminous species were extracted manually from their fruits.

4.2.3. Experimental design and Seed treatment

A seed germination test was conducted to test the germinability of the collected seeds. Seeds were germinated on moist filter papers in petri dishes in the green house at UNAM. Two methods of seed treatment were applied to the seeds: Sulphuric acid and smoke treatment (commercial smoke extract, with gibberellic acid.) in different soaking periods. The treatments that were applied were: immersion in acid for 1min, immersion in acid for 15 minutes, immersion in acid for 30 min and immersion in acid for 1 hour, or soaking for 14 hours in a dilute smoke solution that was prepared by adding one part commercial karrikinolide (smoke treatment) to nine parts water. The germination was monitored and best seed treatment for each species was determined (Table 12).

Table 12: Results of the seed germination test done for studied species prior the experiment

Species	Germination percentage %	Soaking period (in sulphuric acid)
Albizia anthelmintica	90	1 minute
Acacia senegal	52	1 minute
Acacia reficiens	30	30 minutes
Acacia tortilis	20	1 hour
Terminalia prunioides	0	1 hour
Acacia erioloba	40	1 hour
Commiphora glaucescens	10	1 hour
Adenolobus garipensis	20	30 minutes

For the main germination experiment a randomized block design was adopted for the study. Basic treatment types included four scarification methods (sulphuric acid, acetone, hot water and cold water (at room temperature as a control) that were used at different soaking periods. In the nursery, the treated seeds were sown in polythene bags (8cm diameter and 10cm length) filled with locally collected river sand. For each species, 5 seeds/bag were used and 20 bags/treatment. All the seeds of each species were sown at a depth of 2 cm. The seeds were watered every day for 45 minutes using a sprinkler irrigation system in the nursery, which would thoroughly saturate the soil within the bags.

4.2.3.1. Treatment with sulphuric acid and acetone

Species were roughly categorized into three groups according to how hard or soft their seed coats are (Table 13) based on the trial germination experiment. This was done in order to optimize the treatment levels and hence the soaking periods varied according to the hardness of the seed coats of the different species (Table 13).

Table 13: Seed hardness categories of different species

Soft testa	**Hard testa**	**Very hard testa**
A. senegal	*A. reficiens*	*T. prunioides*
A. anthelmintica	*A. erioloba*	*C. glaucescens*
	A. tortilis	
	A. garipensis	

For sulphuric acid (98%) and acetone (100%) treatments the solution was added separately to containers, each with 100 seeds, and left to soak for the chosen soaking periods (Table 14).

Table 14: Soaking periods (mins/hours) of seeds for different species in acetone and sulphuric acid used in the germination experiment at Navachab Gold Mine, Namibia

Species	Acetone (100%) / and Sulphuric acid (98%) soaking periods														
	1m	5m	10m	15m	20m	30m	45m	1h	1.5h	2h	2.5h	3h	3.5h	4h	5h
A.senegal	√	√	√	√	√										
A.anthelmintica	√	√	√	√	√										
A.erioloba						√	√	√	√	√		√			
A.reficiens						√	√	√	√	√		√			
A.tortilis						√	√	√	√	√		√			
A. garipensis						√	√		√	√		√			
C. glaucescens									√		√		√		
T. pruniodes										√		√		√	√

4.2.3.2. Treatment with hot water and cold water (at room temperature) as a control

For all eight species hot water scarification was accomplished by immersing 100 seeds of each species in hot tap water at 90°C and left to cool for 12 hours prior to sowing. For the cold water (at room temperature) as a control, 100 seeds of each species were soaked in water at room temperatures for 12 hours prior to sowing.

4.2.4. Data recording

Germination was recorded daily from the date of sowing for 36 days. Germination was recorded for a seed when at least 0.5 cm of the cotyledon protruded above the surface of the soil, as described by Hossain *et al.*, (2005). Daily germination percentages were summed up to obtain cumulative germination percentages for each pre-sowing treatment and species, on each assessment date.

4.2.5. Data analysis

For all treatments, germination percentages (GP) were calculated as the average of the 20 replicate polyethylene bags for each species and treatment separately on the 36th day. Germination rate was also measured and expressed as peak value (PV), an index of germination speed which was calculated as the quotient of the highest value of the cumulative germination percentage, divided by the number of days from the beginning of the test (Czabator, 1962; Hossain *et al.*, 2005). For each species in each treatment, the number of days it took for 50% of the seeds to germinate (T_{50}) was also recorded.

One way ANOVA using Genstat 8.1 (Copyright 2005, Lawes Agricultural Trust) was used to determine if there was a significant difference in the germination data (germination percentage (GP), time to 50% germination (T_{50}) and Peak Value (PV)) for each species between different treatments. Where significant differences were detected by ANOVAs, Tukey's post-hoc test was applied. One way ANOVA was also used to determine if there was a significant difference in germination percentage between species when cold water and hot water treatments were used.

4.3. Results

Hot water and cold water (control) treatment compared across all the species

One way ANOVA established that there was a significant difference in germination percentage between different species, when both cold water (control) treatment ($p<0.0001$) and hot water treatment ($p<0.0001$) were used (Table 15). Both cold water and hot water treatments resulted in no germination in *T. pruniodes* and *C. glaucescens*. The highest germination (72%) when cold water was used, was recorded in *A. anthelmintica* and the highest germination (64%) when hot water was used was recorded in *Acacia senegal* and *Albizia anthelmintica* (Figure 12). These two basic treatments resulted in less than 50% germination in all other species.

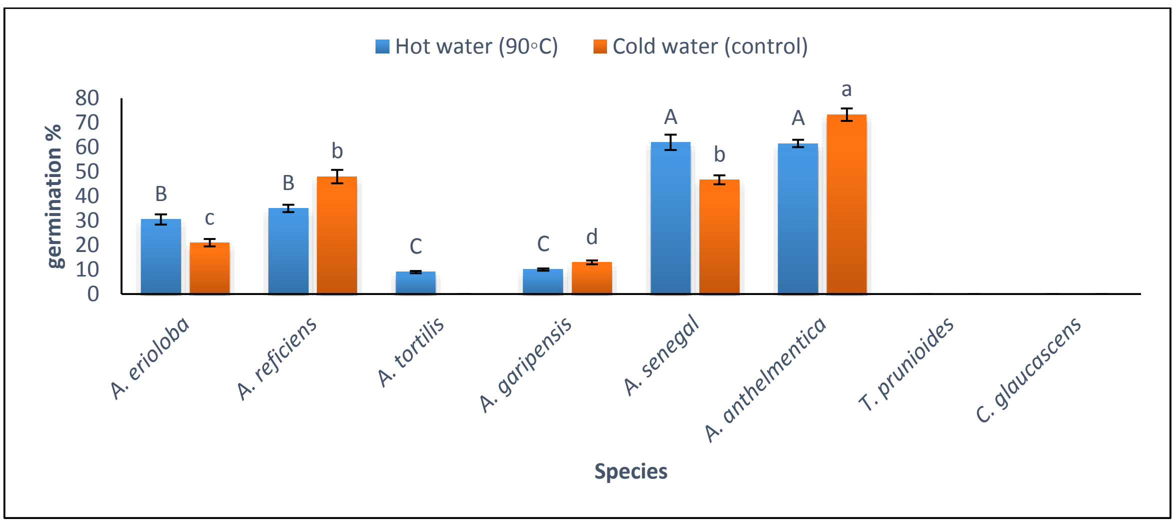


Figure 12: Effect of hot water and cold water (control) treatment on the germination percentage of all the eight species used in the germination experiment at Navachab Gold Mine. Bars represent standard errors of the mean. Different uppercase letters indicate

significant difference in hot water treatment and lower case letters indicate significant difference in cold water treatment.

Table 15: One-way Analyses of Variance for the effect of cold water (control) and hot water on the germination percentage amongst all the studied species used in the germination experiment at Navachab Gold Mine.

Response	Factor	d.f	F-ratio	P
Germination in cold water	Species	7	15747	<0.0001
Germination in hot water	Species	7	6398.1	<0.0001

Different pre-sowing treatments compared among all the species

In all the species, one way ANOVA showed that there was a significant difference in GP, PV and T50 between different treatments used (Table 16).

In *Acacia erioloba*, soaking in sulphuric acid (98%) for 45 minutes produced the highest germination percentage (80%), significantly different to all other treatments. Soaking in cold water (control) produced the lowest germination percentage (30%) (Figure 13a). The highest germination speed (PV) and the shortest time period to obtain 50% germination was obtained when the seeds of *Acacia erioloba* were soaked in sulphuric acid (98%) for 45 minutes (Figure 13 b-c).

In *Acacia reficiens*, the highest percentage germination (81%) was obtained by soaking the seeds in sulphuric acid (98%) for 45 minutes, followed by soaking the seeds in acetone for 2 hours. The lowest germination was obtained by soaking the seeds in acetone for 30 minutes (Figure 14 a). The highest germination speed (PV) and the shortest time period to obtain 50% germination was obtained by soaking the seeds in sulphuric acid (98%) for 45 minutes (Figure 14 b-c). Soaking the seeds in sulphuric acid (98%) for 3 hours yielded the longest time period to obtain 50% germination. Using hot water and cold water (at room temperature), as well as soaking in both sulphuric acid (98%) and acetone for 30 minutes did not reach 50% germination (Figure 14 b).

In *Acacia tortilis*, the highest germination (94%) was obtained by soaking the seeds in sulphuric acid (98%) for 1 hour, though this was not significantly different to soaking the seeds in acetone for an hour. The use of sulphuric acid (98%) in this species produced more than 80% germination in all the soaking periods. No germination occurred when cold water (control) was used and hot water produced the lowest germination percentage (Figure 15 a). The highest germination speed was obtained by soaking the seeds in sulphuric acid (98%) for 1 hour and the lowest speed was obtained when the seeds were soaked in hot water (Figure 15 c). The shortest time it took the seeds to reach 50% germination was obtained by soaking the seeds in sulphuric acid (98%) for 1 hour and longest period was obtained by soaking seeds in acetone for 30 minutes (Figure 15 b).

In *Acacia senegal*, the highest germination percentage (74%) was obtained by soaking the seeds in sulphuric acid (98%) for 15 minutes, followed by soaking the seeds in hot water The lowest germination percent was produced by soaking the seeds in acetone for 20 minutes (Figure 16 a). The highest germination speed was obtained when the seeds were soaked in sulphuric acid (98%) for 15 minutes (Figure 16 c) and the shortest time period to reach 50% germination was also obtained when the seeds were soaked in sulphuric acid (98%) for 15 minutes (Figure 16 b). Not every treatment reached 50% germination.

In *Albizia anthelmintica,* all the soaking periods when sulphuric acid (98%) was used produced more than 90% germination (Figure 17 a). All the treatment used including control was able to produce more than 60% germination (figure 17 a). Soaking the seeds in sulphuric acid (98%) for 5 minutes reached 50% germination within the shortest time period (Figure 17 b), and the highest germination speed was obtained when the seeds were soaked in acetone for 15 minutes. The lowest speed was obtained when the seeds were soaked in cold water (control) (Figure 17 c). All the treatments reached 50% germination in this species (Figure 17 b).

In *Adenolobus garipensis* the use of acetone yielded very low germination percentage, all below 30%. The highest germination percentage (93%) was obtained by soaking the seeds in sulphuric acid (98%) for 45 minutes and lowest was obtained when cold water (control) was used (Figure 18 a). The highest germination speed and the shortest time period to reach 50% germination was also obtained when the seeds were soaked in sulphuric acid (98%) for 45 minutes (Figure 18 b-c). Using acetone as well as hot and cold water treatment did not reach 50% germination.

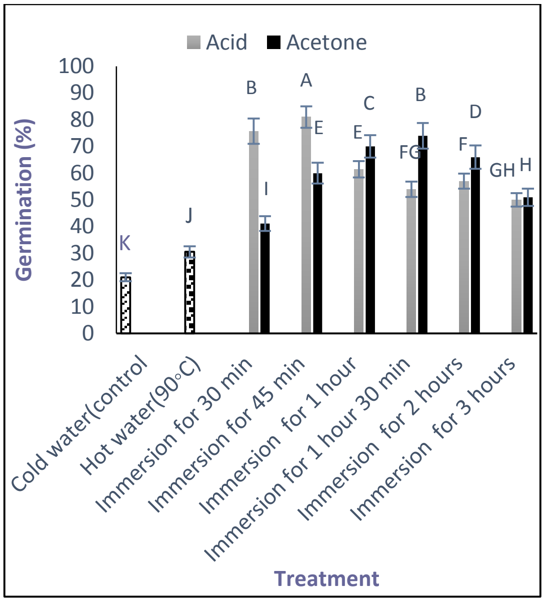
In *Terminalia prunioides* and *Commiphora glaucescens* the use of acetone, hot water and cold water (control) treatment did not result in any germination. (Figure 19a and 20a). Though the use of sulphuric acid (98%) resulted in some germination in

Terminalia prunioides, it was extremely low, below 10% on average (Fig 19 a). The use of sulphuric acid (98%) also resulted in some germination in *Commiphora glaucescens* which the highest (42%) was produced by soaking the seeds in sulphuric acid (98%) for 2 hours and 30 minutes (Fig 20 a). No seed treatment reached 50% germination in both species, and the speed of germination in both species was very low (Figure 19b and 20b).

Table 16: One-way Analyses of Variance for the effects of pre-sowing seed treatment on the germination parameters (GP (germination percent), PV (peak value) and T50 (time to reach 50% germination)) of eight species used in the germination experiment at Navachab Gold Mine.

Species	Germination parameters	Sum of squares	df	Mean square	F	significance
A. erioloba	GP	71560.0	13	5504.6	7590.4	< 0.0001
	PV	378.9	13	29.2	201.7	< 0.0001
	T_{50}	11714.4	13	901.1	2299.8	< 0.0001
A. reficiens	GP	66435.0	13	5110.4	4180.7	< 0.0001
	PV	990.9	13	76.2	364.2	< 0.0001
	T_{50}	1587.6	13	122.1	1185.5	< 0.0001
A. tortilis	GP	240893.0	13	18530.2	21887.0	< 0.0001
	PV	6056.1	13	465.9	65.6	< 0.0001
	T_{50}	1763.2	13	135.6	589.0	< 0.0001
A. senegal	GP	28888.4	11	2626.2	488.2	< 0.0001
	PV	627.3	11	57.0	690.5	< 0.0001
	T_{50}	59730.0	11	543.0	3467.9	< 0.0001
A. anthelmintica	GP	24911.0	11	2264.7	1115.2	< 0.0001
	PV	1959.7	11	178.2	206.2	< 0.0001
	T_{50}	391.4	11	35.6	231.8	< 0.0001
A. garipensis	GP	169883.0	11	15443.9	10756.0	< 0.0001
	PV	1381.6	11	125.6	3063.3	< 0.0001
	T_{50}	2493.3	11	226.7	1995.3	< 0.0001
T. prunioides	GP	1068.7	9	118.7	4.1	< 0.0001
	PV	0.2	9	0.01	5.3	< 0.0001
C. glaucescens	GP	37893.0	7	5413.3	485.1	< 0.0001
	PV	61.6	7	8.7951.0	33407.0	< 0.0001

A



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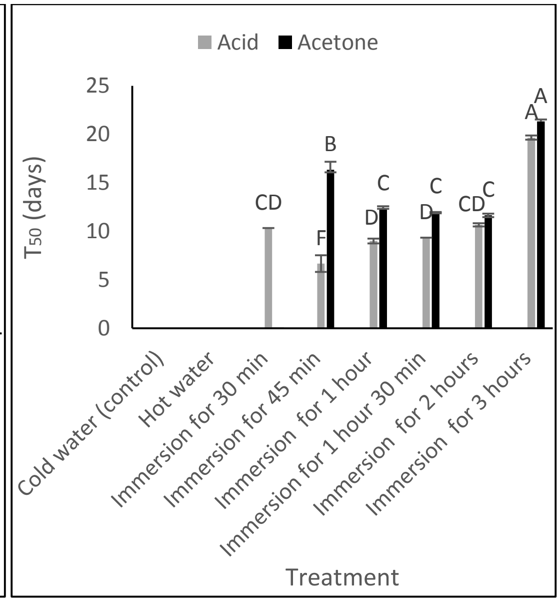

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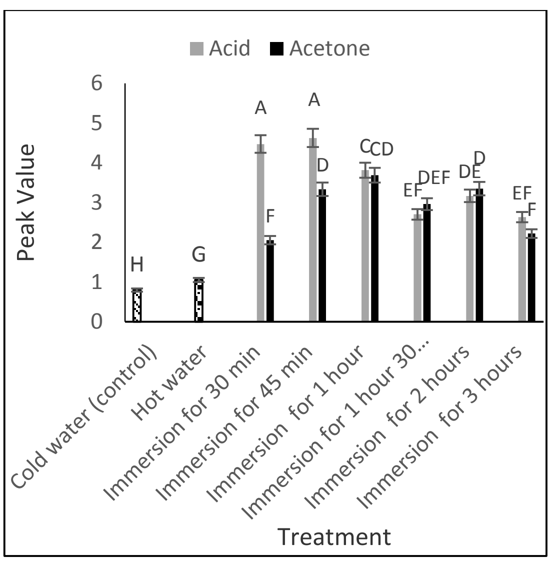

Figure 13: Effect of various pre-sowing treatments on GP (germination percent), PV (peak value) and T50 (time to reach 50% germination) of *Acacia erioloba* seeds used in the germination experiment at Navachab Gold Mine. Bars represent standard errors. Different uppercase letters indicate significant difference among means within entry.

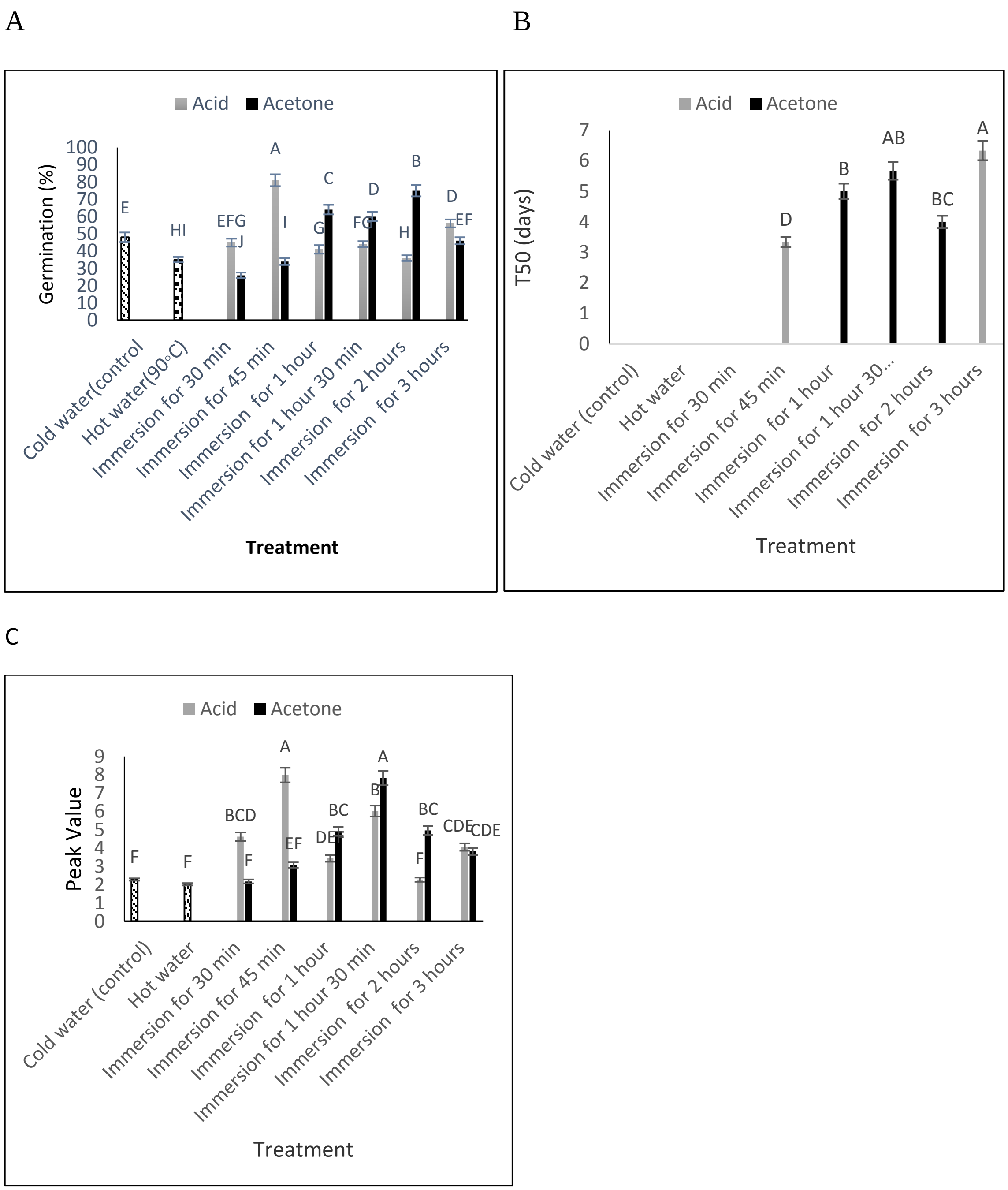

Figure 14: Effect of various pre-sowing treatments on GP (germination percent), PV (peak value) and T50 (time to reach 50% germination)) of *Acacia reficiens* seeds used in the germination experiment at Navachab Gold Mine. Bars represent standard errors. Different uppercase letters indicate significant difference among means within entry.

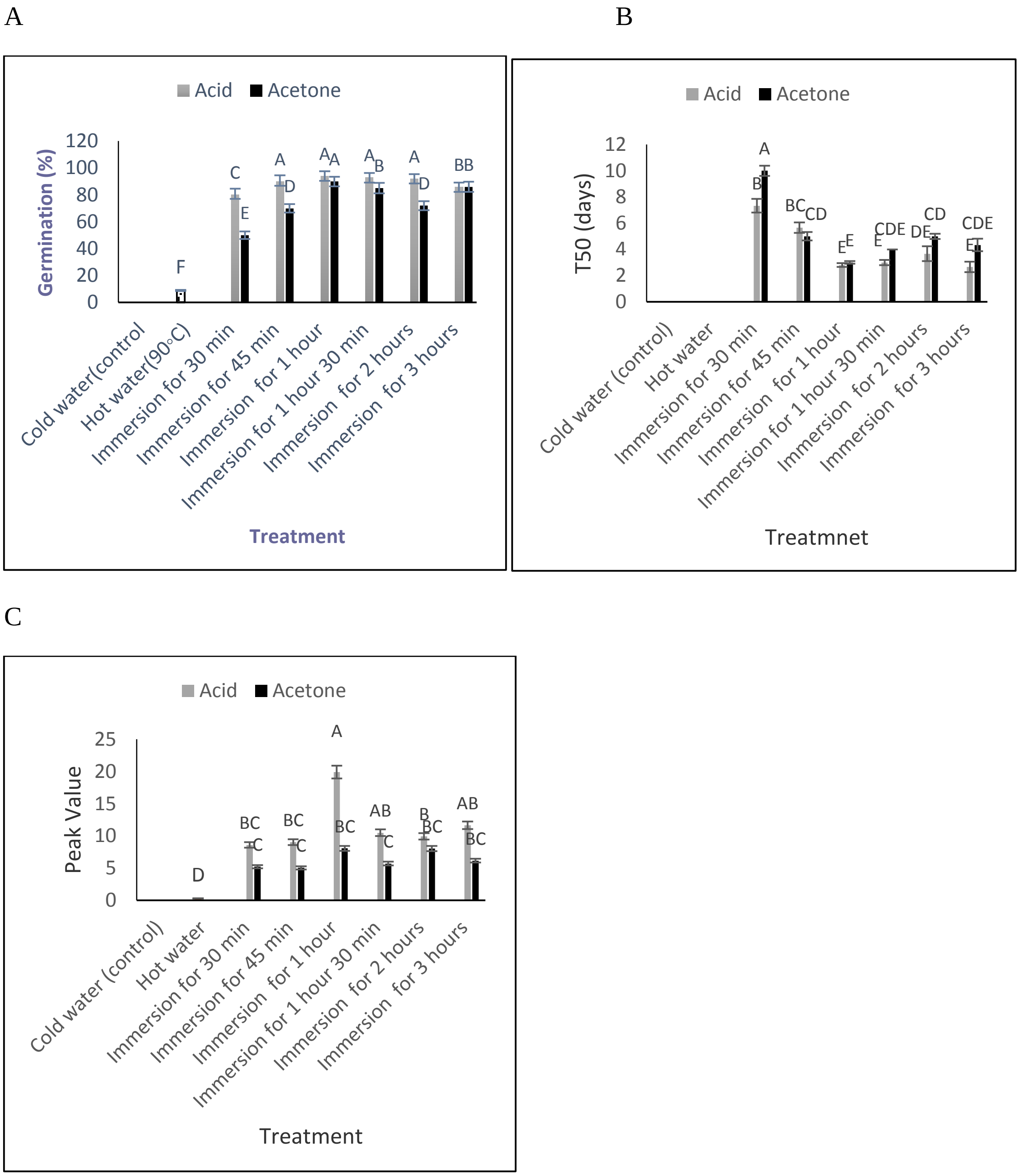

Figure 15: Effect of various pre-sowing treatments on GP (germination percent), PV (peak value) and T50 (time to reach 50% germination) of *Acacia tortilis* seeds used in the germination experiment at Navachab Gold Mine. Bars represent standard errors. Different uppercase letters indicate significant difference among means within entry.

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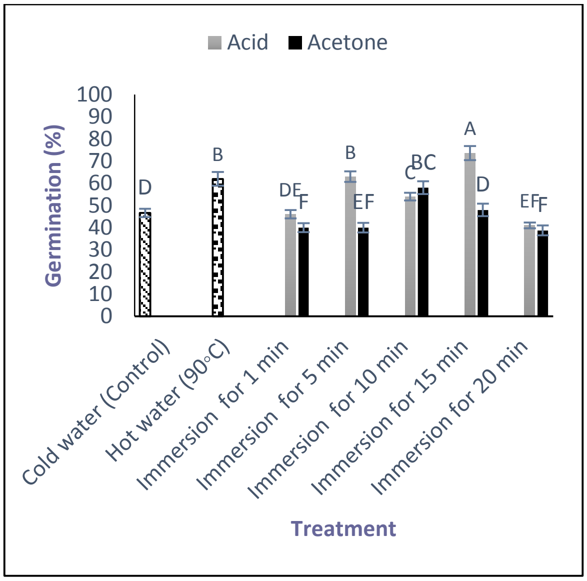

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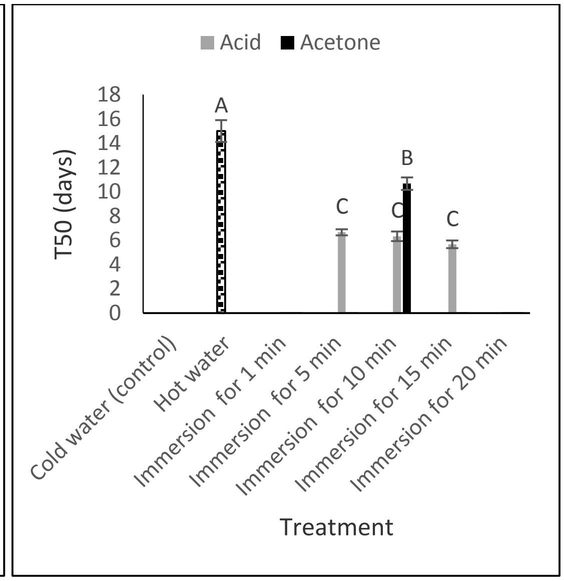

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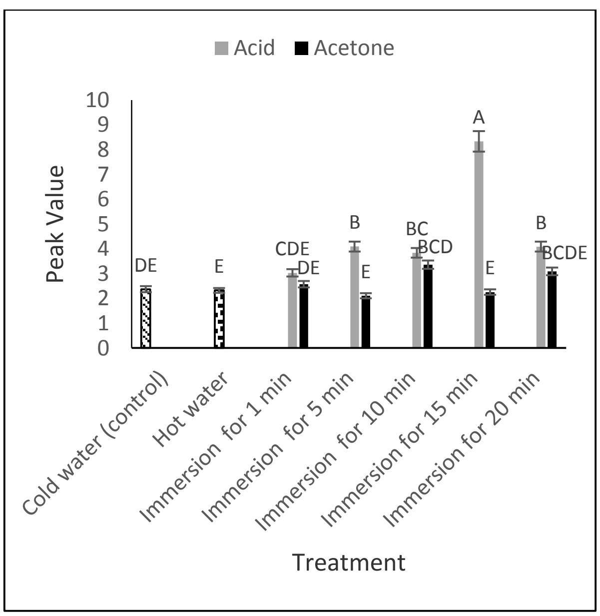

Figure 16: Effect of various pre-sowing treatments on GP (germination percent), PV (peak value) and T_{50} (time to reach 50% germination) of *Acacia senegal* seeds used in the germination experiment at Navachab Gold Mine. Bars represent standard errors. Different uppercase letters indicate significant difference among means within entry.

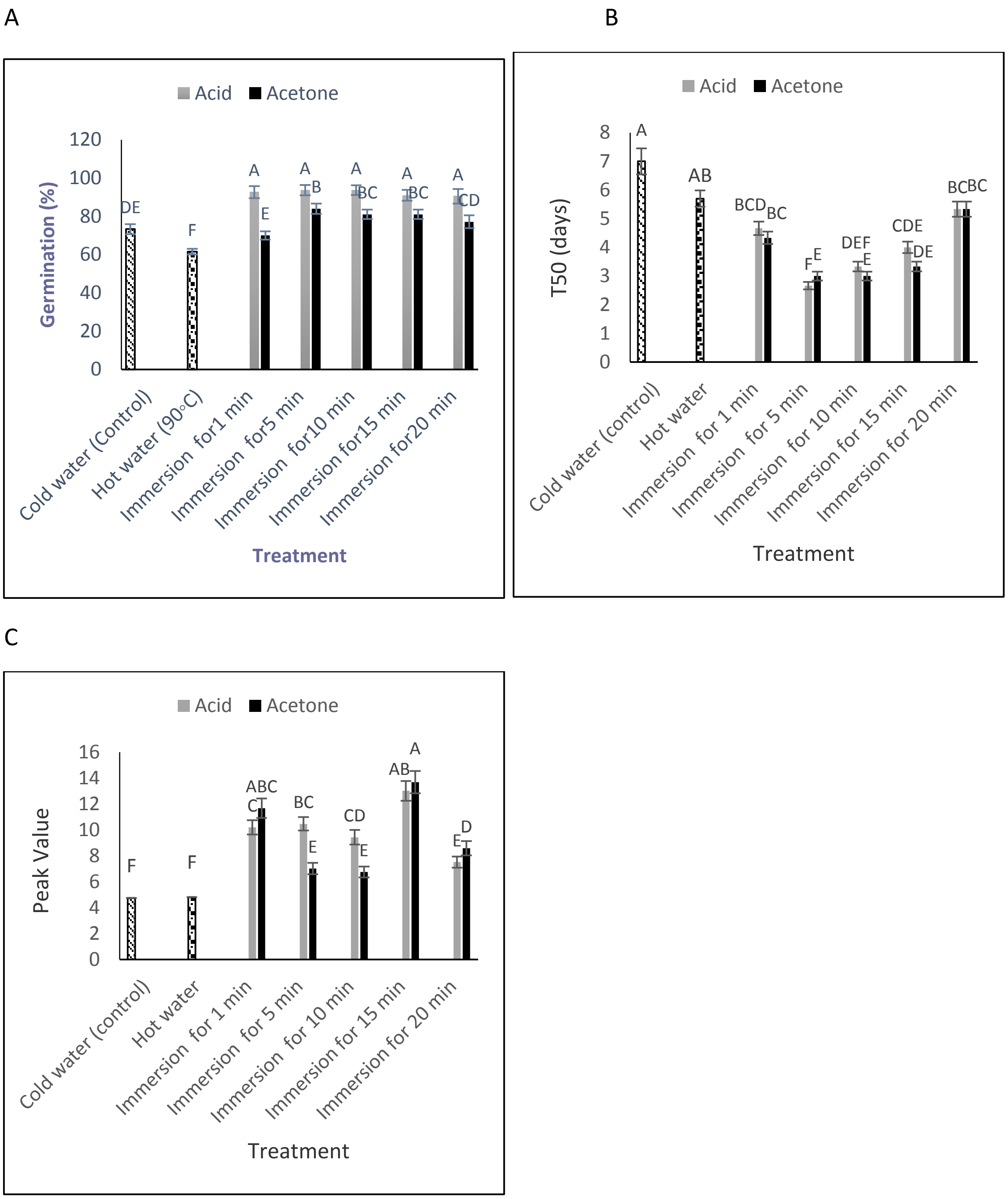

Figure 17: Effect of various pre-sowing treatments on GP (germination percent), PV (peak value) and T_{50} (time to reach 50% germination) of *Albizia anthelmintica* seeds used in the germination experiment at Navachab Gold Mine. Bars represent standard errors. Different uppercase letters indicate significant difference among means within entry.

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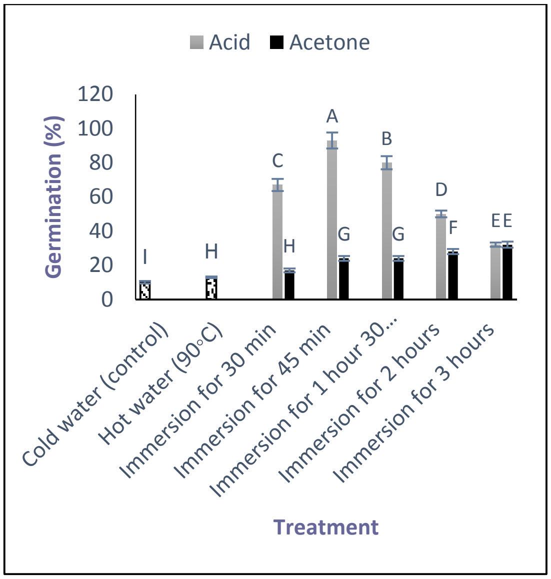

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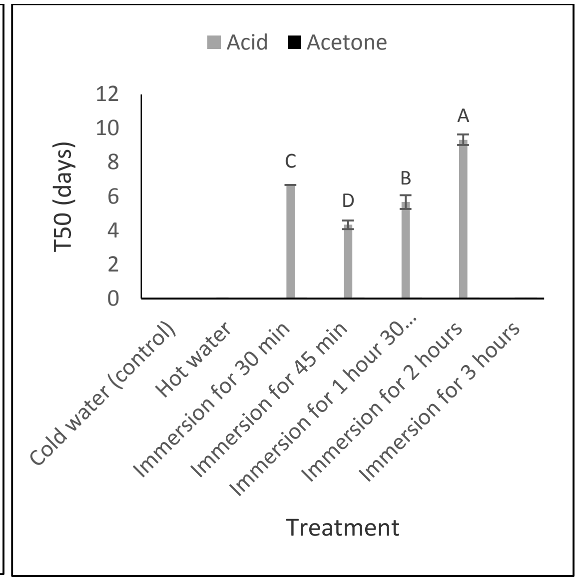

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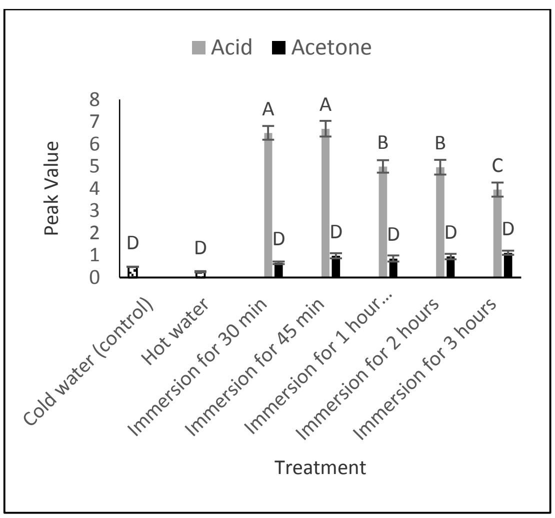

Figure 18: Effect of various pre-sowing treatments on GP (germination percent), PV (peak value) and T50 (time to reach 50% germination) of *Adenolobus garipensis* seeds used in the germination experiment at Navachab Gold Mine. Bars represent standard errors. Different uppercase letters indicate significant difference among means within entry.

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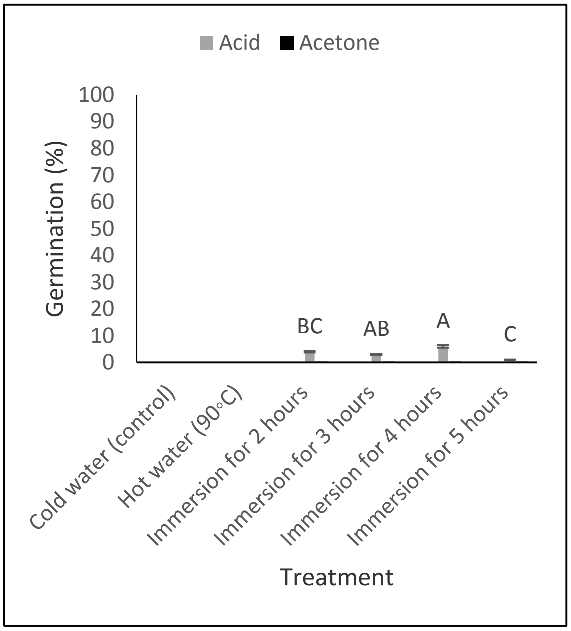

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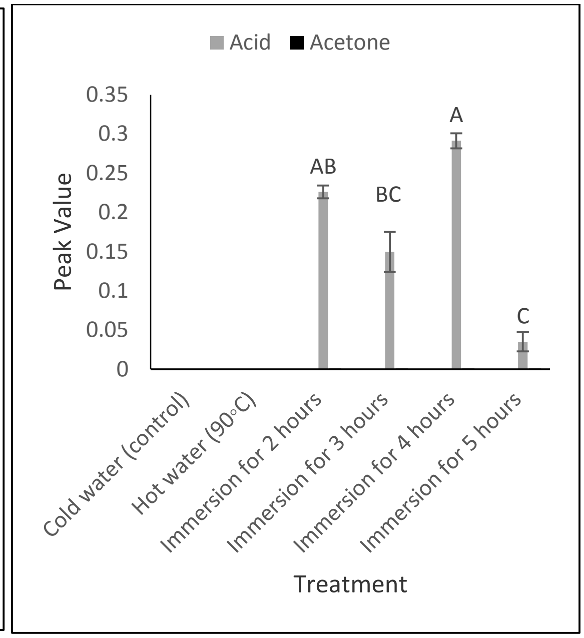


Figure 19: Effect of various pre-sowing treatments on GP (germination percent) and PV (peak value) of *Terminalia prunioides* seeds used in the germination experiment at Navachab Gold Mine. Bars represent standard errors. Different uppercase letters indicate significant difference among means within entry.

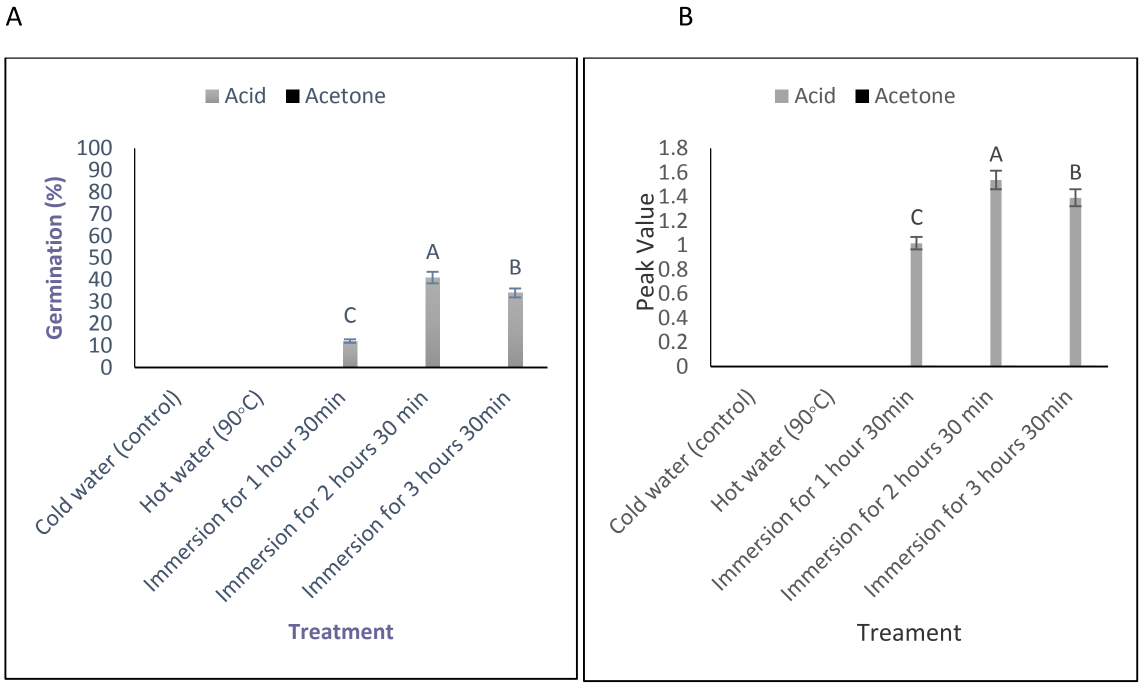


Figure 20: Effect of various pre-sowing treatments on GP (germination percent) and PV (peak value) of *Commiphora glaucescens* seeds used in the germination experiment at Navachab Gold Mine. Bars represent standard errors. Different uppercase letters indicate significant difference among means within entry.

Best treatment for each species

The treatment that resulted in the highest percentage germination in each species was also the best sulphuric acid treatment for each species (Figure 21). The best treatment for *Albizia anthelmintica* was soaking the seeds in sulphuric acid (98%) for 5 minutes, the best for *Acacia senegal* was soaking the seeds in sulphuric acid (98%) for 15 minutes, for *Acacia erioloba*, *Acacia reficiens* and *Adenolobus garipensis* was soaking the seeds in sulphuric acid (98%) for 45 minutes. The best treatment for *Acacia tortilis* was soaking the seeds in sulphuric acid (98%) for 1 hour, for *Commiphora glaucascens*, it was soaking the seeds in sulphuric acid (98%) for 2 and half hours and for *Terminalia prunioides* soaking the seeds in in sulphuric acid (98%) for 4 hours.

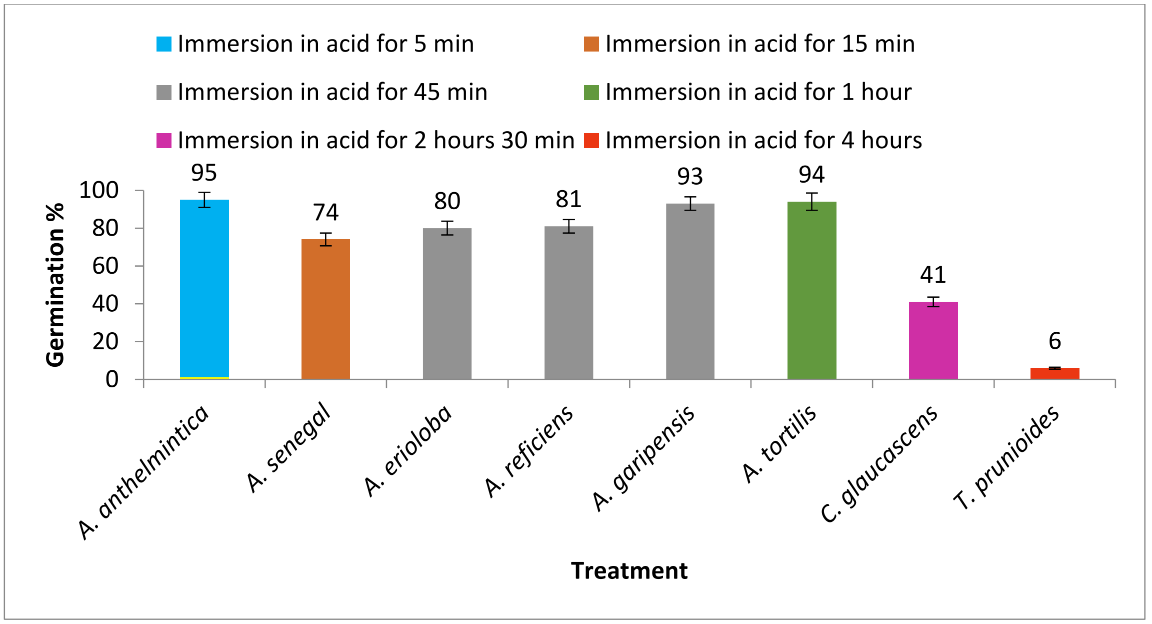


Figure 21: Best sulphuric acid seed treatment of the 8 studied species used in the germination experiment at Navachab Gold Mine (bars represent standard errors).

Best acetone treatment for each species

The best acetone treatment for *Albizia anthelmintica* was soaking the seeds in acetone for 5 minutes, the best for *Acacia senegal* was soaking the seeds in acetone for 10 minutes, for *Acacia erioloba,* soaking the seeds in acetone for 1 and half hours, for *Acacia reficiens,* soaking the seeds in acetone for 2 hours and *Adenolobus garipensis* was soaking the seeds in acetone for 3 hours. The best acetone treatment for *Acacia tortilis* was soaking the seeds in acetone for 1 hour, while the use of acetone in treating *Commiphora glaucascens* and *Terminalia prunioides* seeds did not result in any germination (Figure

22).

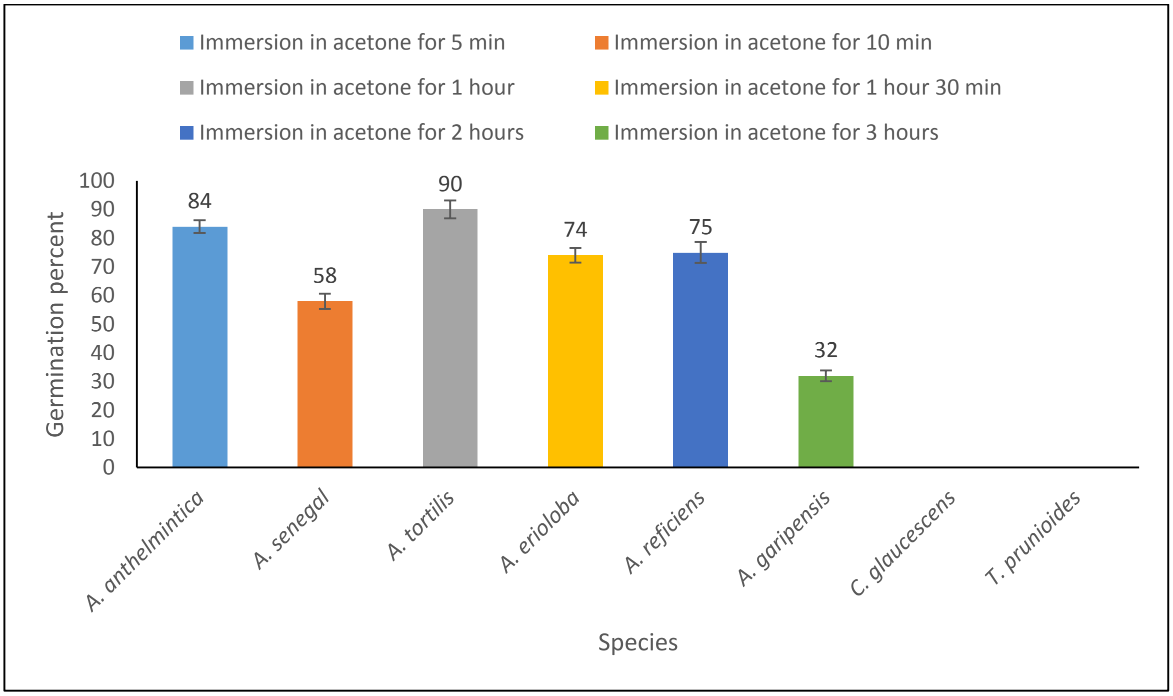


Figure 22: Best acetone seed treatment of the 8 studied species used in the germination experiment at Navachab Gold Mine (bars represent standard errors).

4.4. Discussion

A number of conclusions can be drawn regarding the seed treatment of the eight studied species. First, it is clear that the use of sulphuric acid (98%) positively influenced the total seed germination and germination rate of all the species (Figure13-19) except for *Terminalia prunioides.* This implies that sulphuric acid scarification alone is effective in breaking seed-coat imposed dormancy in all the seven species. While this is true, the germination was also influenced by how long the seeds were soaked in sulphuric acid (98%). The result indicates that all the soaking periods in sulphuric acid (98%) positively influenced both the speed and total germination of *Acacia erioloba*, *Acacia tortilis*, *Adenolobus garipensis*, *Albizia anthelmintica* and *Commiphora glaucescens*.

In all the above mentioned species the germination percentage obtained using cold water (control) was lower than the germination percentage obtained in all other treatments, thus concluding that all the soaking period improved germination. However, for each species, there was a best soaking period that resulted in the highest total germination and speed. This implies that each species has its optimum soaking time in sulphuric acid. Above and below this period the germination will be lower. This is in line with what (Iman, Saeed, & Mohammad, 2012) concluded that, the lower effectiveness of some chemical scarification treatments can be explained by two factors: (i) the seed coat did not erode enough to break dormancy after a short time of exposure to sulphuric acid or (ii) sulphuric acid penetrated enough to kill or damage the embryo.

Though sulphuric acid (98%) also improved germination in *Acacia reficiens* and *Acacia senegal*, not all the soaking periods resulted in germination higher than that obtained when cold water (control) was used. This also indicate that above a certain period of seed soaking in sulphuric acid (98%), the seeds are destroyed and only few are able to germinate. Normally seeds with a hard testa will require to be soaked in the acid much longer than the seeds with a soft testa, and this is also evident in this study. Mudaris *et al.*, (1999) speculated that sulphuric acid scarification causes a wearing of the seed coat resulting in embryo accessibility to water and oxygen, both of which are essential to germination. While this is also true, if the seeds are soaked for too long, the acid may destroy the seed embryo. It is therefore important to emphasize the need to elucidate the acid treatment requirement of each species. As much as it is important to understand the advantage of using acid to improve seed germination, it is equally important to understand the requirement of its use in different species.

These results corresponds with the report of Okunomo & Bosah (2007) on the superiority of sulphuric acid treatment compared with other tested treatments on germination of *Acacia senegal* seeds. Likewise, Pipinis *et al*., (2011) noted that sulphuric acid (98%) treatment proved more effective than nitric acid and alcohol in breaking seed dormancy.

The evidence from the results presented herein suggest that soaking seeds of *Acacia erioloba*, *Acacia reficiens* and *Adenolobus garipensis* in sulphuric acid (98%) for 45 minutes most improves the final germination (80% 81% and 93% respectively) and speed in these species. Hoffman *et al*., (1989) also obtained high germination (90%) by soaking the seeds of *Acacia erioloba* in sulphuric acid in different soaking periods between 30-60 minutes. Similarly, Materechera & Materechera (2001) also obtained high germination in *Acacia erioloba* by sulphuric acid for 40 minutes.

In the case of *Acacia tortilis*, all the sulphuric acid (98%) treatments resulted in considerably higher percentages and its best germination (94%) was obtained when the seeds where soaked in sulphuric acid (98%) for 1 hour. Germination response of *Acacia tortilis* seeds to sulphuric acid in the present study was similar to that reported by El-Azazi *et al*., (2013) where all sulphuric acid treatments increased final percentage germination relative to the control by as much as 70%. Teketay (1996) studied the effect of sulphuric acid on *Acacia tortilis* seeds and obtained 100% germination in all the soaking periods between 30 minutes and 2 hours. In the present study, the germination percent obtained in soaking periods between 30 minutes and 3 hours ranged from 86-94%. It appears that even after 3 hours of soaking, the seeds of *Acacia tortilis* are still not destroyed. Argaw *et al*., (1999) also found similar results when he treated *Acacia tortilis* seeds with sulphuric acid from 30-120 minutes, all the treatments resulted in significantly higher percentage germination (80-100%).

The highest germination (74%) and speed in *Acacia senegal* was obtained when the seeds were soaked in sulphuric acid (98%) for 15 minutes, while that of *Albizia anthelmintica* (93%) was obtained when the seeds were soaked in sulphuric acid (98%) for 5 minutes. Okunomo and Bosah (2007), obtained highest germination of 90% by soaking the seeds of *Acacia senegal* in sulphuric acid (60%) for 20 minutes while 70%

germination was recorded for seeds soaked for 15 minutes. (Gill *et al.*, 1996) obtained 90% germination using sulphuric acid for 15 minutes.

The use of sulphuric acid (98%) however produced very low germination in *Terminalia prunioides.* This result is in correspondence with Mbaratha (1985) in which the results showed that sulphuric acid (98%) produced very low germination, as opposed to mechanical scarification test. Likoswe *et al*., (2008) established that Terminalia species present difficulties in germination in many parts of the world. In general nicking is known to best break physical dormancy of seeds of Terminalia species (Doran *et al*., 1983; Hossain *et al*., 2005; Tietema *et al*., 1992)

The use of acetone in this study also improved germination in all the species except in *Adenolobus garipe*nsis, *Terminalia prunioides* and *Commiphora glaucescens*. There are various studies reporting on the negative effects of acetone on seed germination. Milborrow (1963) and Tao & Khan (1974) reported that acetone had no adverse effect on germination. Heidmann (1986) reported that soaking ponderosa pine seeds in acetone, even for 1 hour, repressed germination. In other experiments acetone application increased seed germination (Crozier *et al.*, 1972, Newell *et al.*, 1996). In this study, *Acacia erioloba* obtained 74% germination by using acetone for 1 hour 30 minutes, *Acacia reficiens* obtained 76% germination by soaking the seeds in acetone for 2 hours, *Acacia tortilis* obtained 90% germination by soaking the seeds for 1 hour, *Acacia senegal* obtained 58% germination for 10 minutes and *Albizia anthelmintica* 90% germination by soaking the seeds in acetone for 5 minutes.

In this study hot water only improved germination in *Acacia senegal* and *Acacia erioloba,* where total germination was higher than in the control. Chris (1994) studied the effects of pre-sowing treatments in hot water in four species (*Acacia albida, Acacia senegal, Acacia tortilis* and *Acacia nilotica)* and duration of water soaking treatments did not increase level of germination. Similar results were found by Argaw *et al* (1999).

Cold water resulted in lower germination in all the species, except in *Acacia senegal* and *Albizia anthelmintica*. This indicates that these seeds have a soft testa and are thus able to germinate easily with no treatment. Smith *et al*., 2009) established that *Albizia anthelmintica* is a non-dormant orthodox species and germination is usually completed between 3 and 14 days with no need for any treatment.

This study has provided important information on the germination requirement of various savannah species to contribute to a successful germination and nursery production of species for rehabilitation of mined sites in semi-arid regions. It is important to note that before sowing, species with physical dormancy will need to be scarified to allow imbibition and therefore be able to germinate. Using sulphuric acid and acetone improved germination in almost all the studied species, and I suggest pretreating seeds with these chemicals prior to sowing. It is however important to consider the optimum soaking period for each species because seeds differs in their degree of dormancy.

Chapter 5: Growth and survival of seedlings in various mined substrates

5.1. Introduction

Establishment of vegetation is a critical step in achieving the goal of ecosystem restoration in mining areas (Yan *et al.*, 2013). This is especially important because mined soils generally tend to be a poor medium for plant growth, making natural recolonisation a slow process that could be accelerated by proper rehabilitation (Wong, 2003). Compared to normal soils, mined substrates that result from deep in the earth or wastes produced from the processing of minerals can cause extreme challenges to the colonization by plants and the formation of any kind of self-sustaining ecosystem (Cooke & Johnson, 2002).

The establishment of plants on mined substrates is hindered by physical factors such as high temperatures, low availability of soil moisture, and compaction (Singh *et al*., 2002). The chemical and physical properties of mined substrates differ substantially from undisturbed soils (Rao & Tarafdar, 1998). For example, Vogel & Kasper (2002) studied mined soils on an abandoned gold mine and found that they differ considerably from undisturbed natural soils. They reported that mine soils possess weak physical structure and instability, have extremely low pH, deficient in macronutrients and contain toxic amounts of metals. Angel *et al*., 2008 also reported that mine soil material is a structure-less accumulation of fragmented rocks, subsoil, and soil that is often less weathered than the original soil profiles.

Plants that can establish and grow on such soils have to be able to cope with the severe soil conditions. The selection of appropriate plant species that can establish and grow, in mined substrates is therefore of utmost importance for the successful rehabilitation of degraded mined sites. Arnold *et al*., (2012) contended that the integration of native plant communities for the purpose of restoring degraded landscapes (e.g. post-mined and long established field agricultural sites) is often desirable because of their essentially low maintenance requirements. Furthermore, these native species are often more adapted to the local weather and climate.

Theoretical and empirical evidence suggests that natural vegetation restoration depends on both the availability of seed sources and on successful seedling establishment (Wang *et al*., 2013). These authors pointed out that the period between seed germination and seedling establishment is considered to be one of the most vulnerable transitions in the lifecycle of plants. In arid and semi-arid climates, drought is one of the major causes of mortality in natural seedling populations (Bochet & Garcıa, 2004).

Many scientists have studied different traits that determine the ability of plants to establish themselves in particular environments e.g. (Cingolani *et al*., 2004; Craine *et al*.,2001; deDeyn *et al*.,2008). Burke (2006) states that morphological traits, and physiological attributes determine a plant's competitive ability and its ability to tolerate disturbances. Several adaptations such as the ability to tap groundwater as well as use rain water effectively give certain plants a competitive advantage over plants competing at the same site. Tree species coexistence along light gradients has received much attention but the degree to which species perform differentially along soil resource gradients remains unclear (Baraloto *et al*.,2006). Currently, knowledge gap exist in Namibia concerning the physical properties of mined substrates and the suitability of these substrates in supporting plant communities.

This study aims to assess the suitability of various mined substrates for the establishment of native species and determine which properties make a particular substrate suitable for plant growth and survival. Furthermore, the study aims to determine if there are plant species that prefer a narrow range of soil substrates, and which species establish and grow well in a wide range of soil substrates. Here I report on the comparative survival and vegetative growth of seedlings of several native woody savannah tree and shrub species that can be used in rehabilitation of mined substrates.

5.2. Materials and Methods

5.2.1. Study area

This study was carried out at Navachab Gold Mine (21° 56' 0" S, 15° 50' 0" E), located on the Navachab Farm, 10km south west of Karibib in Erongo Region, Namibia. The biophysical description of Navachab area is described in chapter 2. Navachab make use of an open cast mining method, which results in two types of mine wastes namely; waste rocks (rock that is fractured and removed in order to gain access to or upgrade ore) which are dumped in the nearby surrounding, and tailings (finely ground material left over in containment areas or discharged to receiving waters after valuable metals are extracted) (Speiser, 2012). The highest rainfall recorded at Navachab during the study period of 2012 to 2013 was 8mm (Figure 23) and maximum temperature of 41 degree Celsius with a minimum of 5 degree Celsius (Figure 24).

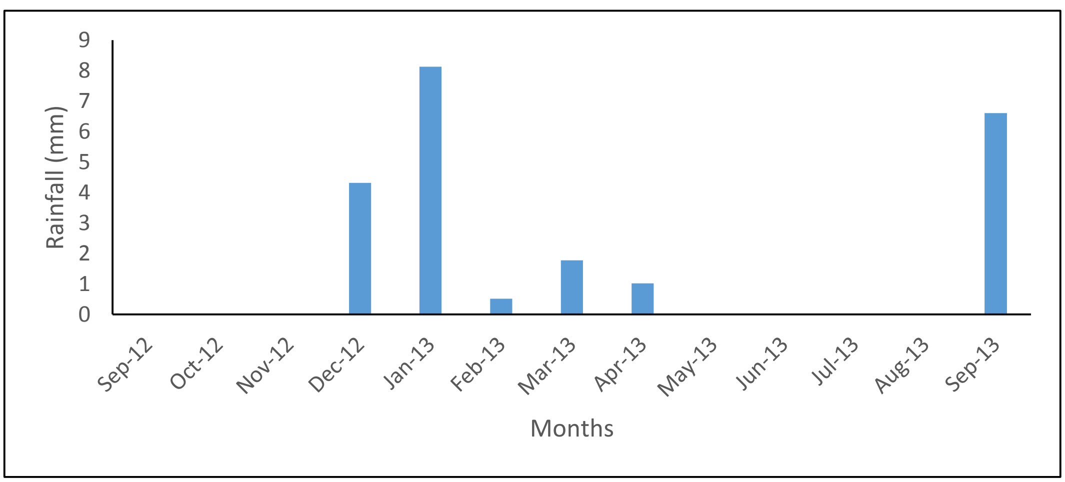


Figure 23: Monthly rainfall (mm) at Navachab (September 2012 to October 2013), source: Navachab Gold Mine

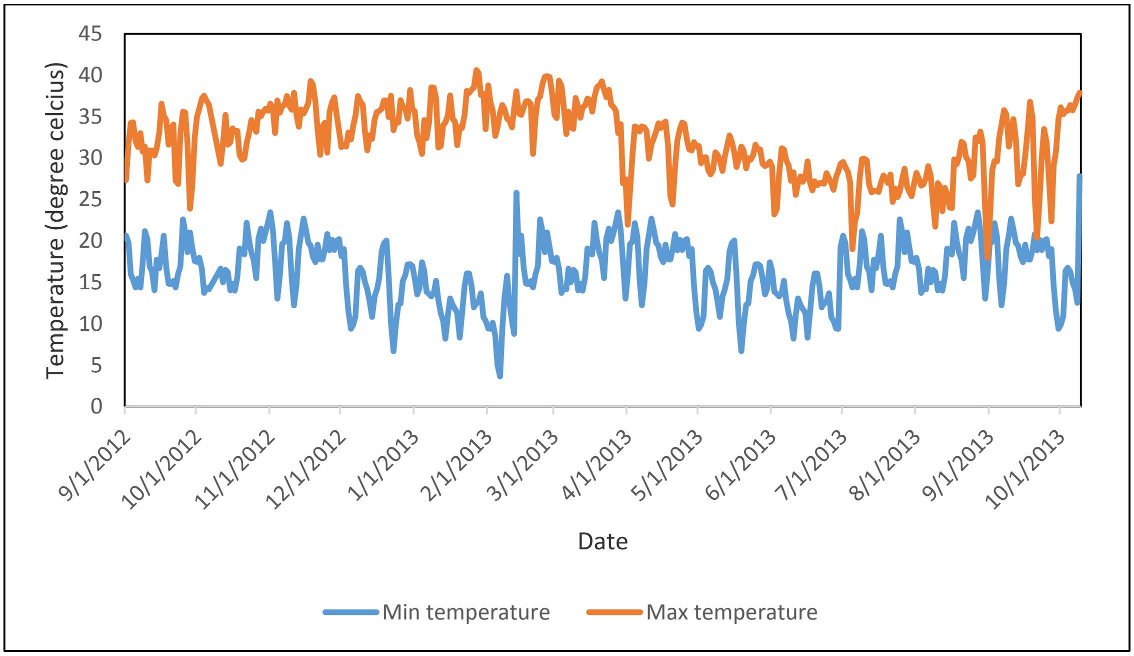


Figure 24: Daily min and max temperatures (^{0}C) at Navachab (09/ 2012 to 09/2013, source: Navachab Gold Mine

5.2.2. Seed collections

About 5000 seeds of each of the 7 selected species (*Acacia erioloba, A. senegal, A. erubescens, A. reficiens, A. tortilis, Catophractes alexandri and Adenolobus garipensis)* were collected in the Navachab surrounding plant communities. Knowledge obtained from literature review on the phenology of species (chapter 2) and regular field inspections conducted at least every two weeks during the period April 2012 to June 2012, guided the timing of seed collection of these species. During these regular field inspections, by walking through the communities, species in flower, fruit, and seed were noted (to monitor the phenological stages of species). Mature seeds were placed into paper bags and carefully air dried at ambient temperature. Seeds were hand collected from the ground and from trees. The seeds were collected in order to produce 250-500 healthy seedlings of each selected species in the nursery that could be used for the seedling establishment experiment.

Figure 25: Seeds (in the drying room) collected from the Karibib area that were used to produce seedlings for the seedling establishment experiment Navachab Gold Mine, Namibia

5.2.3. Seed treatment trials and germination test

A small germination trial was conducted to test the germinability of the collected seeds and to determine which germination treatment was best for each species. Seeds were germinated on moist filter papers in petri dishes in the green house at UNAM. Two methods of seed treatment were applied to the seeds: Sulphuric acid and smoke treatment in different soaking periods. The treatments that were applied were: immersion in acid for 1min, immersion in acid for 15 minutes, immersion in acid for 30 min and immersion in acid for 1 hour, or soaking for 14 hours in a dilute smoke solution that was prepared by adding one part commercial karrikinolide (smoke treatment) to nine parts water. The germination was monitored and best seed treatment for each species was determined (Table 17).

Table 17: Pre-sowing treatment methods used to enhance seed germination for all the species

Species	**Treatment**	**Duration of treatment**
Acacia erubescens	Sulphuric Acid	1 minute
Acacia senegal	Sulphuric Acid	1 minute
Acacia reficiens	Sulphuric Acid	30 minutes
Acacia tortilis	Sulphuric Acid	1 hour
Acacia erioloba	Sulphuric Acid	1 hour
Catophractes alexandri	Smoke treatment	14 hours
Adenolobus garipensis	Sulphuric Acid	30 minutes

5.2.3. Raising seedlings in the nursery

The seeds of different species were treated as per Table 17 and sown in poly bags (10 cm in diameter and 20 cm long) filled with locally collected river sand and seedlings (Figure 26) were raised in the nursery at Navachab Gold Mine for three months. A sprinkler irrigation system was employed to keep the soil moist and encourage germination. Watering was done every day for the first three weeks for 45 minutes. During this period most seeds germinated, and the watering was therefore reduced to once every second day for two weeks. In order to create a hardening period for the seedlings, the watering was reduced further to twice a week, followed by once a week, and lastly once in two weeks before they were transplanted.

Figure 26: Seedlings grown in the nursery at Navachab Gold Mine, Namibia

5.2.5. Experimental site preparation and transplant experiment

The seedling establishment experiment site was set up at Grid A (flat area on the waste rock dump in the mine section). Grid A will become the long-term seedling establishment experimental research site. A range of substrates (marble, calcrete, schist, kalahari (red) sand, and tailings) that result from gold mining activities at Navachab were used in this experiment. These substrates were brought to the site and mixed in the pre-determined ratios (Table 18) and they were arranged in a randomized plot design (Figure 27 and 28).

Table 18: A list of the nine substrate types used in the seedling establishment experiment at Grid A, Navachab Gold Mine, Namibia

	Substrate description/ composition	**Substrate code**
1	100% Marble	M
2	100% Calcrete	C
3	Mixed waste rock (75% marble + 25% calcrete)	M-C
4	75% mixed waste rock + 25% tailings	T-25%
5	50% mixed waste rock + 50% tailings	T-50%
6	75% mixed waste rock + 25% schist	S-25%
7	75% mixed waste rock + 25% Kalahari (red) sands	K-25%
8	100% schist	S
9	100% Kalahari (red) sands	K

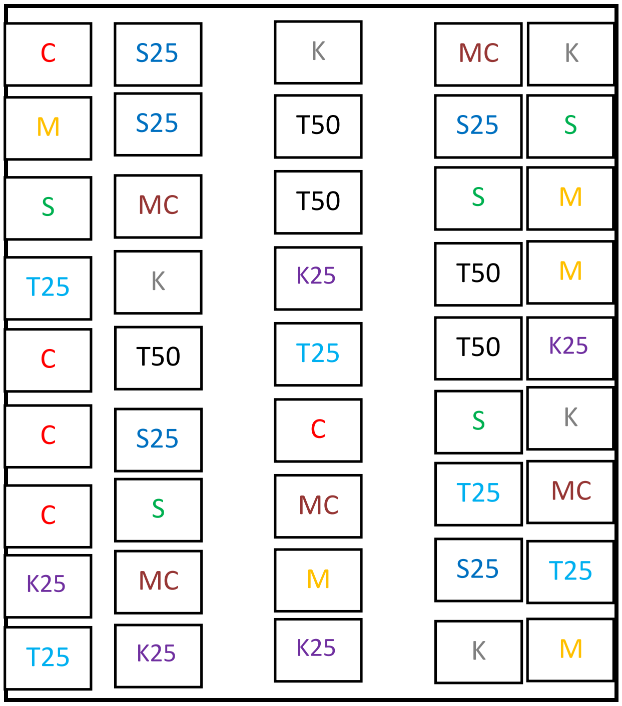


Figure 27: A randomized plot design for the substrate seedling experiment site at Grid A Navachab Gold Mine. The codes refer to the different substrates described in Table 18.

Figure 28: Mined substrates and mixtures of substrates at the experimental site, Navachab Gold Mine, Namibia.

Each plot (Fig 27) represents a 4 x 4 m area consisting of one ADT (Articulated Dump Trucks) dump load of substrate (35 tons). Five replicates of each substrate type were set out in a randomized design across the site. A buffer area of 40cm remained between adjacent substrate plots where soil mixing may have occurred. A small access road was left between every two rows of substrate plots.

The transplanting of seedlings from the nursery to the experimental site took place from the last week of November 2012 to the first week of December 2012. Two hundred and twenty five seedlings of each of the following species were transplanted; *Acacia erioloba, A. senegal, A. erubescens, A.reficiens, A.tortilis, Catophractes alexandri* and *Adenolobus garipensis*. Five seedlings of each species were transplanted in each replicate substrate type (plot), resulting in 35 seedlings in each plot (5 seedlings x 7 species). Since each of the nine substrates were replicated five times, a total of 1575 seedlings were transplanted.

Although transplanting was planned to coincide with the rainfall season and therefore the growing season in the area (Dec - April), the rainfall was extremely low that season (Figure 23). The seedlings were therefore given supplementary watering once a week (approximately 750 ml per seedling) until March 2013 to avoid desiccation of seedlings from dry and hot weather that prevailed. Watering was then reduced to once every two weeks in April till May 2013, which approximate the normal end of rain season in the area. No further supplementary watering took place after May 2013.

5.2.6. Assessment and monitoring of seedling growth and survival

The growth and survival of seedlings was assessed and monitored once a month from December 2012 to March 2013 and once every two months from April to November 2013. At each monitoring session the maximum height, the cumulative stem length of each surviving seedling were measured, the leaves of each seedling were counted, and mortality for each species in each plot was recorded.

A

B

Figure 29: A) Seedlings growing in various substrates B) Measuring stem length of a flourishing *Adenolobus garipensis* at the experimental site, Navachab Gold Mine.

5.2.7. Soil physical and chemical properties

In order to test for chemical and physical characteristics of growth media, soil samples were taken from each plot to form up a composite sample of each substrate and sent to the Analytical Soil Lab in Windhoek for analyses of the following properties: pH, elemental composition (exchangeable Ca, Mg, P, K and Na, and total N), electrical conductivity, organic matter, organic carbon, calcium carbonate equivalent, and soil texture (sand, silt and clay).

In addition to soil sampling, field capacity and infiltration rate were also determined in each substrate plot. For field capacity determination, a depression (20cm wide and 5 cm deep) was made in each plot and was watered to saturation. After 24 hours a sample of each substrate was taken from each depression and collected in zip lock plastic bags. The samples were sieved (2mm sieve) to remove stones/gravel and rocks. The samples were then weighed and left to dry in the oven (110◦C) for 48 hours. The samples were then weighed again to determine field capacity as the percentage of moisture content to the mass of the dry sample.

In this study infiltration rate was determined manually using a cylindrical plastic container (200ml and open on both ends). In each plot the container was gently placed into the soil at depth of 5 cm, 200 ml of water was poured into the container and the time it took for the water to completely percolate into the soil was recorded as the rate of infiltration.

5.2.8. Data Analysis

Seedling growth was calculated as the increase in cumulative stem length, height and number of leaves of each seedling from the beginning (December 2012) to the end (November 2013) of the experiment. Cumulative stem length was selected to be used as a measure of growth in this study, ruling out the number of leaves on the basis of some species being deciduous and height on the basis that it does not include the length of every stem and branch and therefore growth in multi branched/stemmed species will be poorly represented. Nevertheless, the 3 measures of growth showed strong positive correlations (Table 19**)** between each other.

Table 19: Pearson correlations among growth variables of all species in the ninth month after transplanting at the experimental site, Navachab gold mine Significant differences are indicated by *P<0.05, **P<0.01, ***P<0.001

	Cumulative stem length	**Number of leaves**	**Height**
Cumulative stem length		0.6094**	0.6076**
Number of leaves	0.6094**		0.7819***
Height	0.6076**	0.7819***	

Canonical Correspondence Analysis (CCA) was used to elucidate the relationships between growth and survival of seedlings and the soil properties. Canonical Correspondence Analysis (CCA) is a special ordination method, widely used in ecological studies, that performs a constrained ordination using two data matrices, one of species occurring in various samples and one of the environmental characteristics of those samples. It is a direct ordination method that incorporates environmental data directly into the analysis. Each sample point lies at the centroid of the points for species that occur in those samples (Braak & Verdonschot, 1995b). MVSP 3.1 software (Kovach Computing Services, 2007) was used to perform CCA. In CCA, two matrices were used; one matrix was composed of the growth and/or survival values for species and the other was composed of values of soil variables.

In addition, correlation matrices were used to identify the substrate's chemical properties, physical properties, as well as water related soil properties (infiltration rate and field capacity) and their relationship with seedling growth (cumulative stem length increase) and survival using Statistica v. 12, (StatSoft Inc., 1984-2013).

A generalized linear model (GLM) procedure in R, (R Core Team, 2013) was used to determine if there was a significant difference in survival and growth (cumulative stem length) of seedlings between different substrates and between different species. GLM was also used to test the interaction between species and substrates in determining survival and growth of seedlings. The survival data was fit to a Gaussian distribution and growth (cumulative stem length increase) data was fit to a quasi-poisson distribution. Where significant F-values were obtained, differences between individual means were tested using Tukey-HSD tests.

5.3. Results

5.3.1. Seedlings survival

About 60% of all seedlings were still surviving twelve months after being transplanted at the experimental site (Figure 30). There was a general decline in the survival of seedlings, the greatest decline occurring in the fourth month (March), after which the survival remained almost constant at 60%, throughout the dry winter months.

General Linear Model (GLM) procedure revealed that there was a significant difference in the survival of seedlings between different substrates (Table 20). GLM also established that there was a significant difference in the survival of seedlings between different species. There was no significant interaction between substrate and species in determining the survival of seedlings as revealed by the General Linear Model (GLM) analysis (Table 20).

In the twelfth month, *Acacia senegal* showed the highest survival percentage (74%) followed by *Acacia tortilis* (72%) and *Acacia erioloba* (71%) respectively (Fig 32a). At the lower end, species with survival percentage below 50% were *Acacia reficiens, Catophractes alexandri and Adenolobus garipensis* (Figure 32a). Among substrate types, the highest survival of seedlings was recorded in S25 and K25, followed by T25 and MC respectively. Survival was lowest in M, C and K (Figure 32b).While some species recorded high survival percentage in almost all the substrates such as *Acacia senegal* and *Acacia tortilis*, others had poor survival percentage in almost all the substrates, for example *Adenolobus garipensis* and *Catophractes alexandri* (Figure 33).

Table 20: Results of GLM for seedling survival 12 months after transplanting at the experimental site (Grid A), Navachab Gold Mine.

Factor	d.f	F-ratio	P
Substrates	8	16.1421	<0.0001
Species	6	18.1510	<0.0001
Substrates*Species	48	1.3769	0.06235
Error	252		

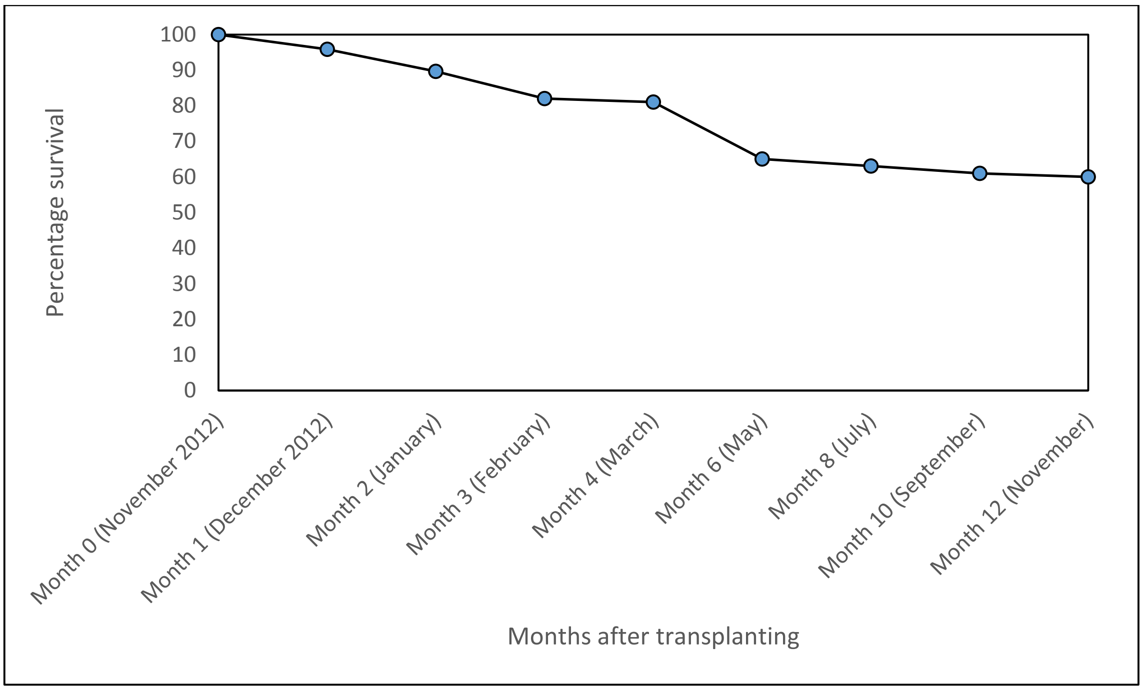


Figure 30: Survival percentages of all seedlings transplanted at the experimental site (Grid A, Navachab Gold Mine) from the first to the twelfth month.

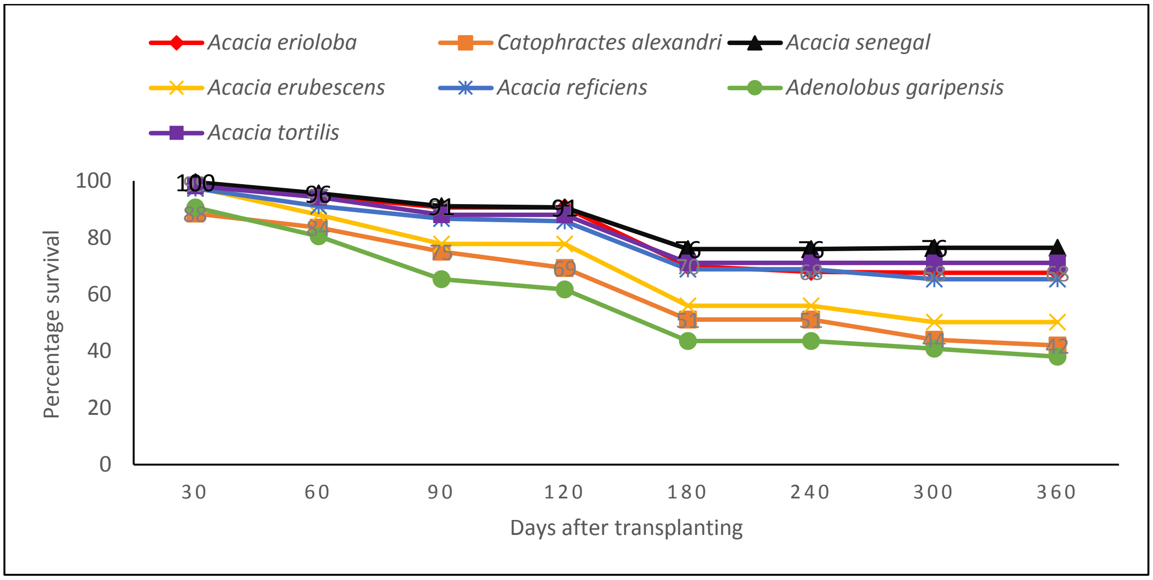


Figure 31: Survival percentage of seedlings of all the species across all the substrates from one month to 12 months after transplanting at Grid A experimental site, Navachab.

A **B**

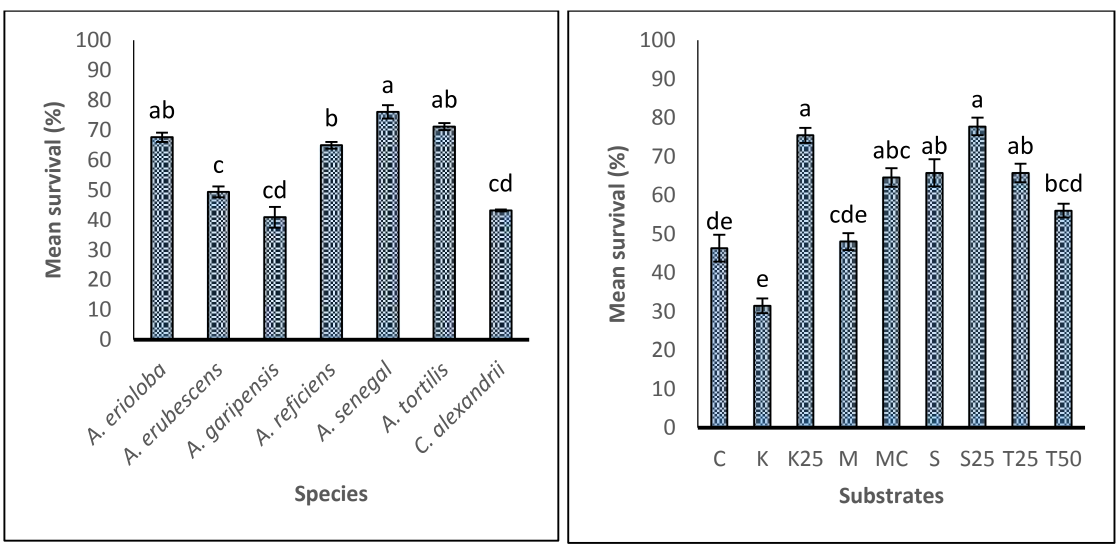
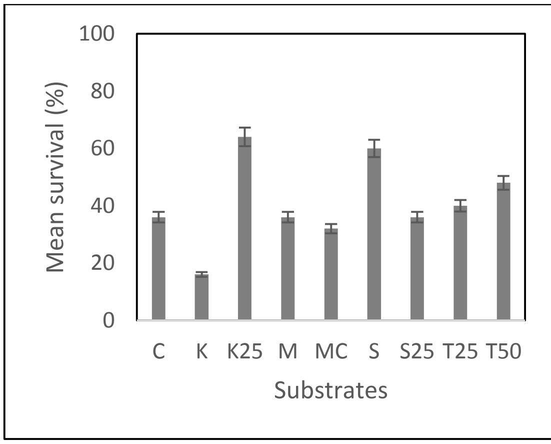
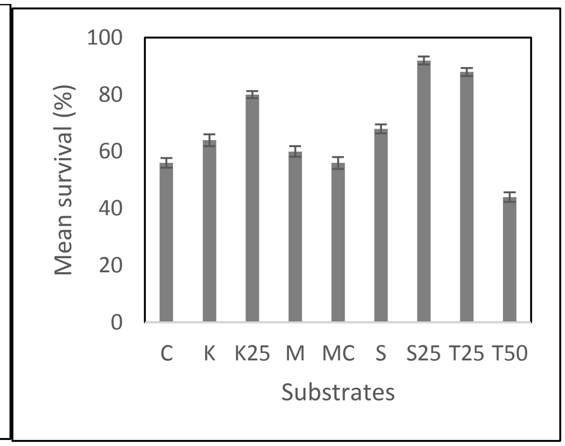


Figure 32: A) Mean survival percentage of all seedlings across all seven species and B) mean survival across all nine substrates, 12 months after transplanting the seedlings at the experimental site (Navachab Gold Mine, Namibia). (Bars are standard errors of the mean, different lowercase letters indicate significant difference among means within entry).

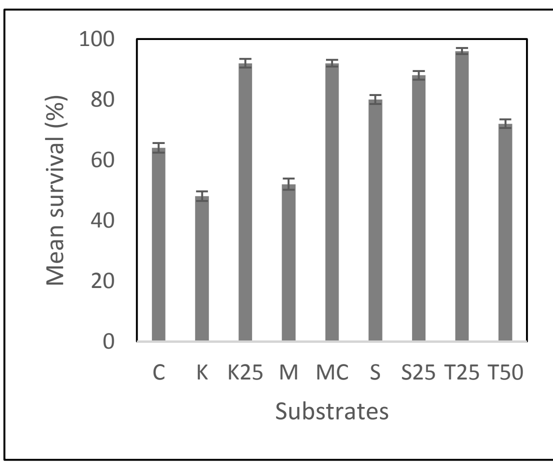
A


100
80
60
40
20
0
Mean survival (%)
C K K25 M MC S S25 T25 T50
Substrates

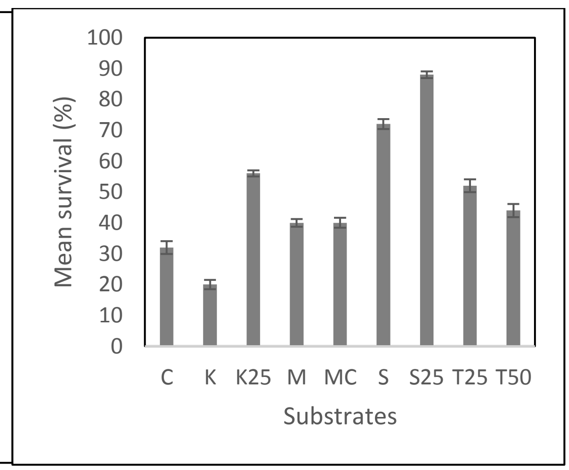
B


100
80
60
40
20
0
Mean survival (%)
C K K25 M MC S S25 T25 T50
Substrates

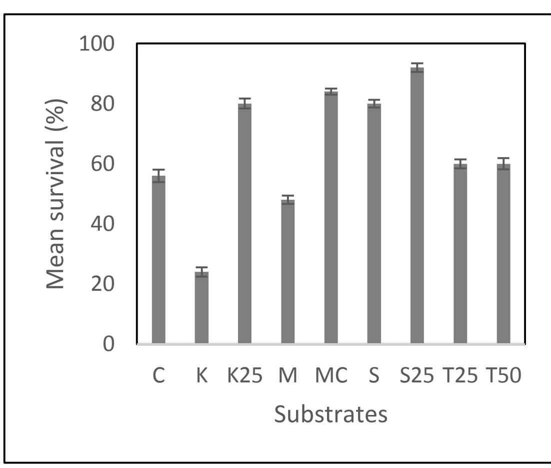
C


100
80
60
40
20
0
Mean survival (%)
C K K25 M MC S S25 T25 T50
Substrates

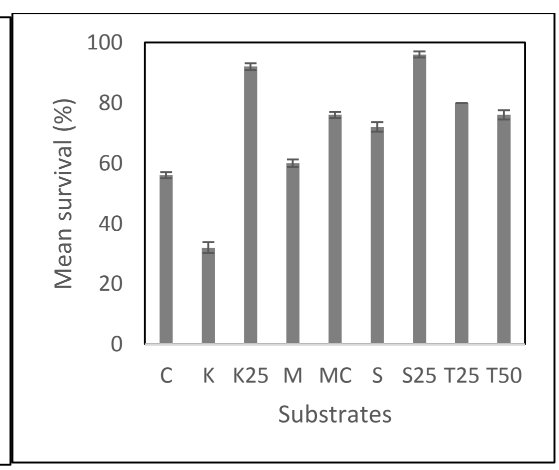
D


100
90
80
70
60
50
40
30
20
10
0
Mean survival (%)
C K K25 M MC S S25 T25 T50
Substrates

E


100
80
60
40
20
0
Mean survival (%)
C K K25 M MC S S25 T25 T50
Substrates

F


100
80
60
40
20
0
Mean survival (%)
C K K25 M MC S S25 T25 T50
Substrates

G

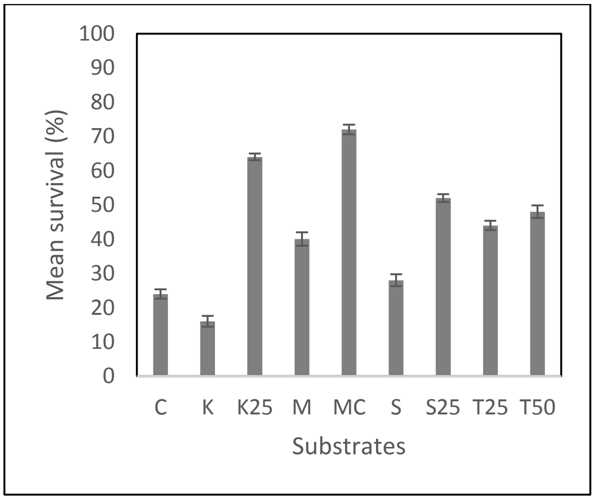


Figure 33: Survival performance of all species in different substrates at 360 days after transplant at the experimental site (Grid A) Navachab Gold Mine, Namibia. (Bars are standard errors). Species are: A) *Adenolobus garipensis* B) *Acacia erioloba* C) *Acacia senegal* D) *Acacia erubescens* E) *Acacia reficiens* F) *Acacia tortilis* G) *Catophractes alexandri*

5.3.2. Seedling growth

The GLM procedure of R (R Core Team 2013) revealed that there was a significant difference between growth (cumulative stem length increase) of seedlings in different substrates and among different species (Table 21). It also showed that there was no significant interaction between substrate and species in determining growth of seedlings (Table 21).

The average growth of all the seedlings for all the species across all the substrates was 78 cm in the twelfth month and the seedlings show a general increase in vegetative growth (cumulative stem length increase) from 2 months to 12 months (Figure 34). Increased growth (cumulative stem length increase) in seedlings was observed in all the species every month (Figure 34 a-b). For easier graphical presentation, *Adenolobus garipensis* was separately presented on the basis that its growth (cumulative stem length increase) was over 10 times higher than all the other species, therefore rendering it incomparable with the rest of the species. The highest growth was recorded in *Adenolobus garipensis* showing an average growth of about 600 cm in the twelfth month. This was followed by *Acacia senegal* and *Acacia erioloba* respectively. The lowest growth was recorded in *Catophractes alexandri* followed by *Acacia erubescens* (figure 36).

Acacia erioloba grew best in K followed by K25 and it grew poorest in S25 (Figure 37 a). *Acacia erubescens* also grew best in K followed by MC and it grew poorest in S. *Acacia senegal* grew best in K25 and K, and it grew poorest in S. *Acacia reficiens* grew best in T25 and poorest in S. *Acacia tortilis* grew best in K and MC and poorest in S25. *Catophractes alexandri* grew best in MC and poorest in S (Figure 37 a-f). *Adenolobus* *garipensis* had above average growth (more than 78 cm) in all the substrates and its highest growth was recorded in S (Schist), where the growth was more than twice higher than in other substrates (Figure 37g). Figure 37 shows that most species grew best or second best in K, K25 and MC and poor growth in most of the species was recorded in S and S25.

Table 21: Results of GLM for seedling growth (cumulative stem length) 12 months after transplanting at the experimental site (Grid A), Navachab Gold Mine

Factor	d.f	F-ratio	P
Substrates	8	21.457	<0.0001***
Species	6	99.779	<0.0001***
Substrates*Species	48	1.336	0.0819
Error	252		

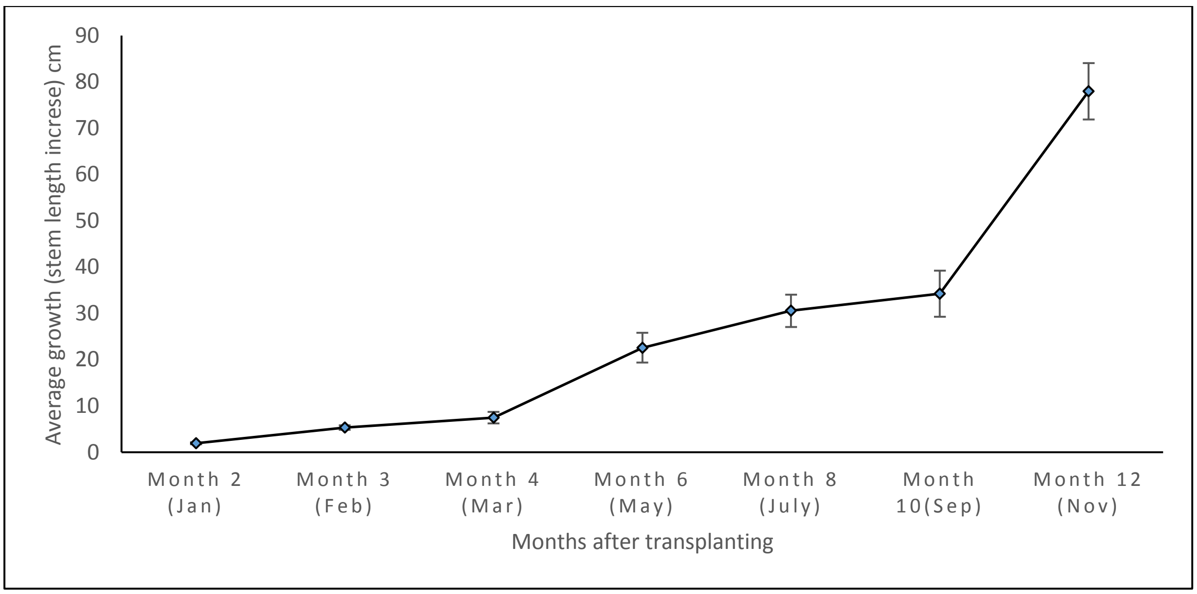
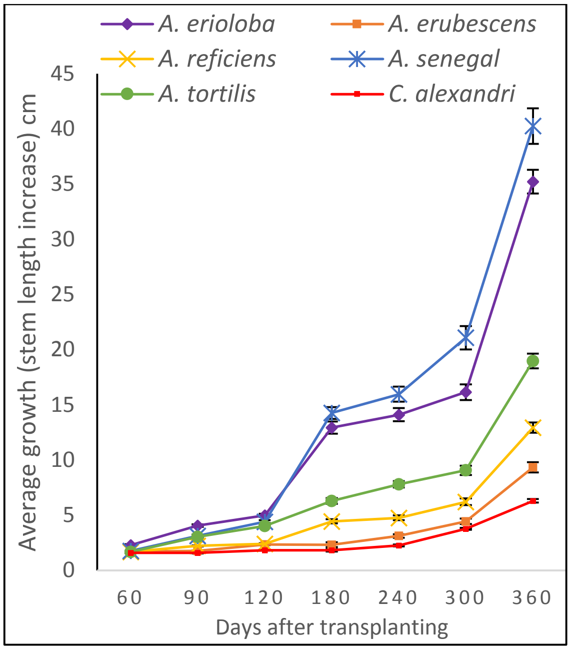


Figure 34: Average growth (cumulative stem length) of all seedlings across all the substrates at the experimental site (Grid A, Navachab Gold Mine) from the second to the twelfth month

A



B

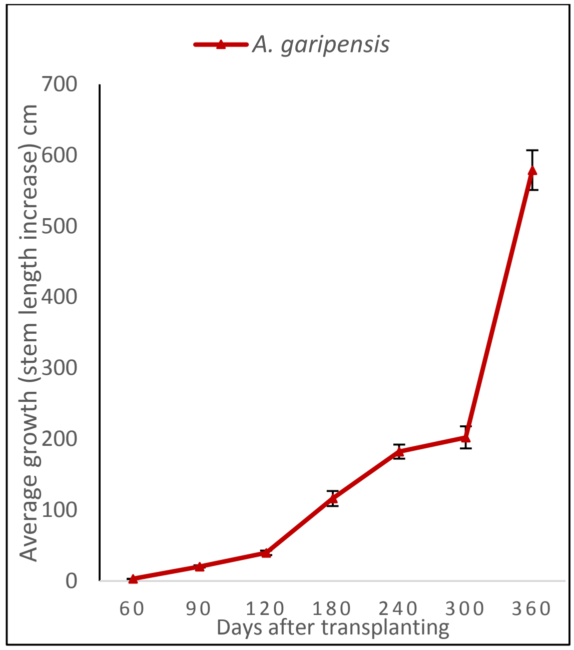


Figure 35: Average growth of seedlings across all the substrates for the six species (A) and for *Adenolobus garipensis* (B) from 2 month to 12 months after transplanting at Grid A experimental site, Navachab, (Bars are standard errors).

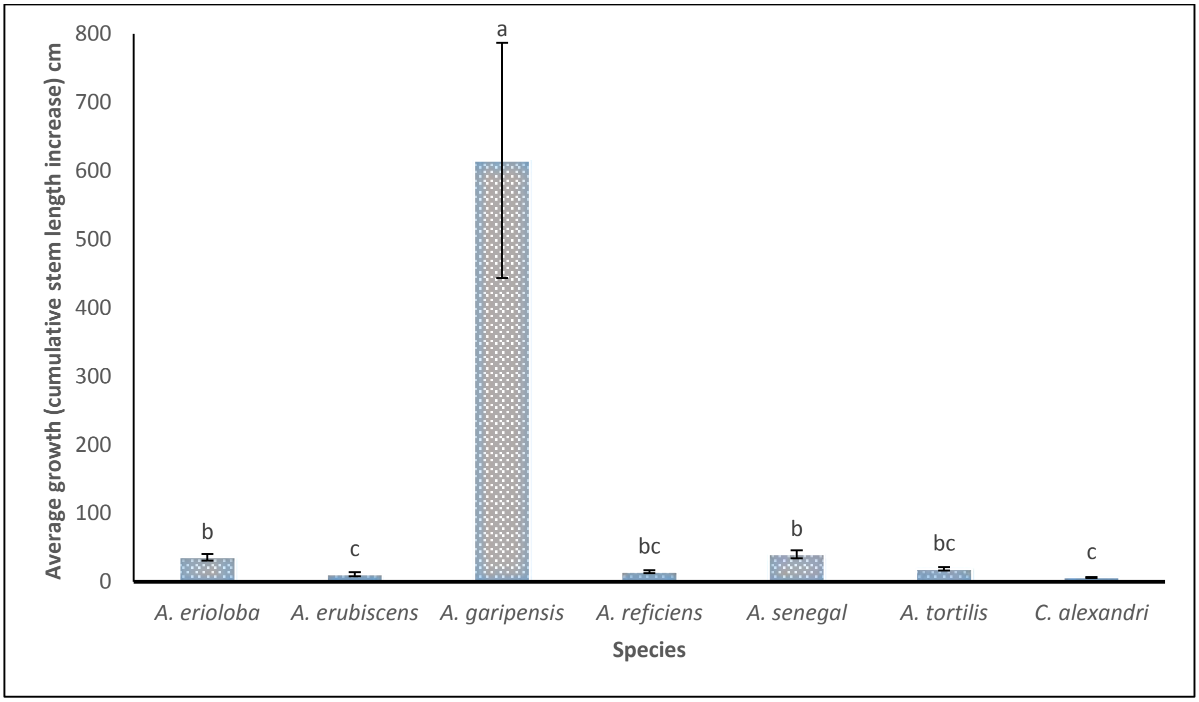
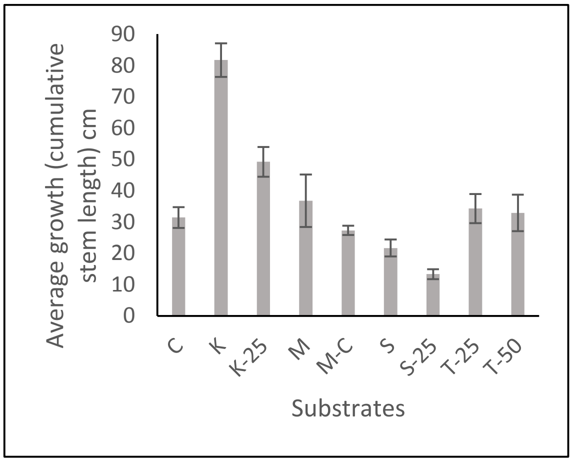
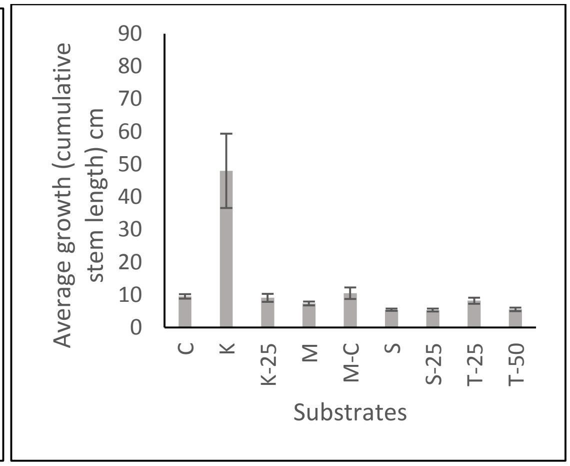


Figure 36: Average growth (cumulative stem length increase) of seedlings in all seven species 12 months after transplanting into the experimental site (Navachab Gold Mine, Namibia). Bars are standard errors, different lowercase letters indicate significant difference among means within entry.

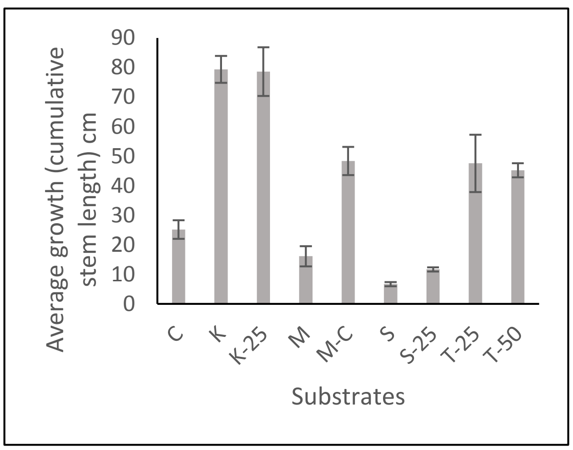
A


Average growth (cumulative stem length) cm
90
80
70
60
50
40
30
20
10
0
C
K
K-25
M
M-C
S
S-25
T-25
T-50
Substrates

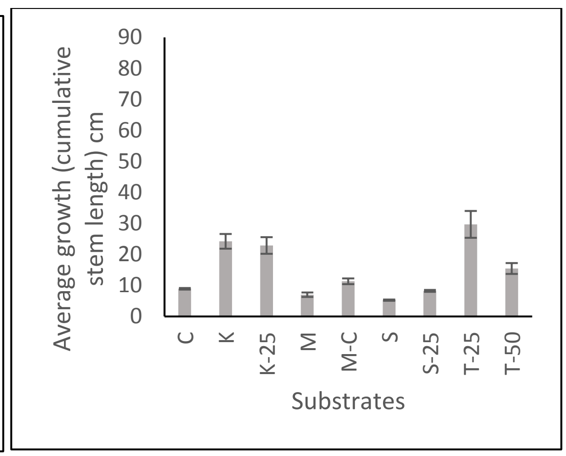
B


Average growth (cumulative stem length) cm
90
80
70
60
50
40
30
20
10
0
C
K
K-25
M
M-C
S
S-25
T-25
T-50
Substrates

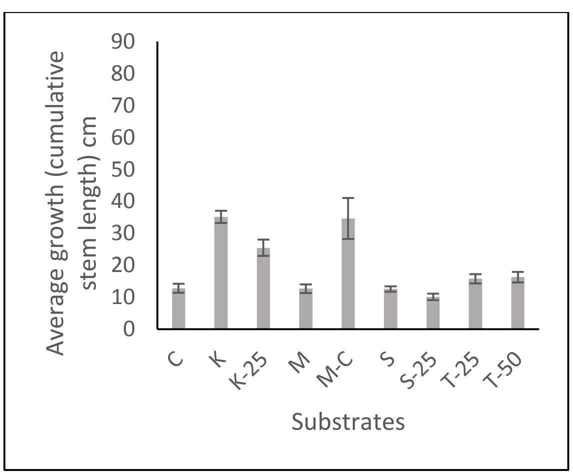
C


Average growth (cumulative stem length) cm
90
80
70
60
50
40
30
20
10
0
C
K
K-25
M
M-C
S
S-25
T-25
T-50
Substrates

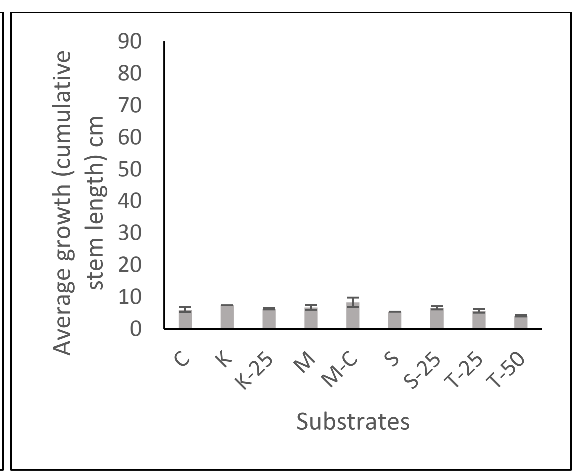
D


Average growth (cumulative stem length) cm
90
80
70
60
50
40
30
20
10
0
C
K
K-25
M
M-C
S
S-25
T-25
T-50
Substrates

E


Average growth (cumulative stem length) cm
90
80
70
60
50
40
30
20
10
0
C
K
K-25
M
M-C
S
S-25
T-25
T-50
Substrates

F


Average growth (cumulative stem length) cm
90
80
70
60
50
40
30
20
10
0
C
K
K-25
M
M-C
S
S-25
T-25
T-50
Substrates

G

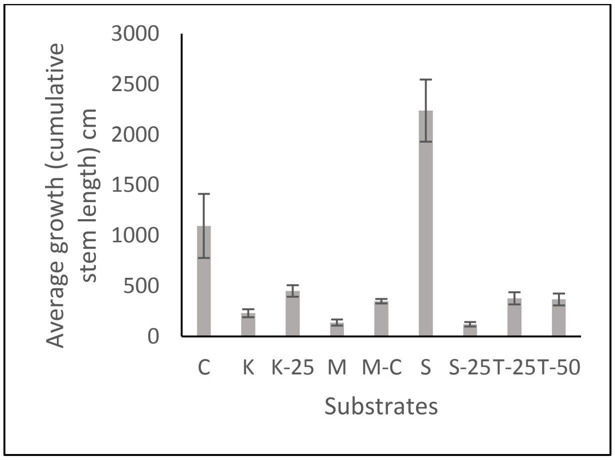


Figure 37: Growth (cumulative stem length increase) of all the 7 species compared in different substrates at twelve months after transplant at Grid A, Navachab, Namibia (Bars are standard errors of the mean). Species are: A) *Adenolobus garipensis* B) *Acacia erioloba* C) *Acacia senegal* D) *Acacia erubescens* E) *Acacia reficiens* F) *Acacia tortilis* G) *Catophractes alexandri*

5.3.4. Soils

The substrates were slightly alkaline to alkaline (pH content ranged from 7.9-8.5). Total nitrogen content was less than 0.1% in all the substrates. Conductivity was highest in S25 (122.1m/Sm) and lowest in M (4.9 m/Sm). Phosphorus was highest in S25 (43 mg P /kg) and MC (41 mg P /kg) and lowest in T50 (0 mg P /kg). Sodium, potassium and magnesium were highest in S and lowest in M. Calcium was highest in S25 and lowest in M. Highest sand content was recorded in K and highest clay content was recorded in S25. (Table 22).

Table 22: Soil physical and chemical properties of the nine substrates presented as actual values

Properties	S	C	S-25	K	T-50	M-C	T-25	K-25	M
pH (H_2O) electrometric	8.3	8.7	7.9	8.5	8.0	8.2	8.3	8.2	8.0
Conductivity (mS/m)	39.1	18.4	122.1	8.7	104.0	76.8	51.4	93.4	4.9
Total Nitrogen (% N m/m)	0.05	0.03	0.07	0.08	0.05	0.06	0.03	0.09	0.03
Organic carbon (% m/m C)	<0.1	<0.1	0.1	<0.1	0.2	0.1	0.2	0.1	<0.1
% $CaCO_3$ equivalent	1.0	1.5	5.9	0.2	5.8	5.9	5.2	5.9	0.2
Organic matter (% m/m OM)	0.1	<0.1	0.2	0.1	0.3	0.2	0.3	0.1	<0.1
Phosphorus (mg P /kg)	3	2	43	3	0	41	3	1	1
Sodium (mg Na/kg)	171	72	73	9	51	36	65	81	3
Potassium (mg Na/kg)	141	62	92	68	72	75	106	60	61
Magnesium (mg Na/kg)	289	213	205	47	124	171	168	133	50
Calcium (mg Na/kg)	4550	4305	5312	973	4891	4974	4808	4688	266
Sand (%)	65.9	90.0	73.0	96.2	69.6	79.6	62.3	83.4	99.8
Silt (%)	30.9	9.4	23.2	2.6	28.6	18.5	34.7	14.4	0.0
Clay (%)	3.2	0.6	3.8	1.2	1.8	2.0	3.0	2.2	0.2

Ordinations and correlations of chemical and physical properties with growth and survival of seedlings

Growth of *Acacia erioloba* and *Acacia erubescens* was significantly positively correlated with infiltration rate and sand (%). On the other hand survival exhibited a positive and significant correlation with clay (%) in *Acacia erioloba*. Survival of *Acacia erubescens* was significantly positively correlated with clay, conductivity and most of the cations. Growth of *Catophractes alexandri* was significantly positively correlated with sand, and its survival was significantly correlated with calcium carbonate equivalent, conductivity and phosphorus. Growth of *Acacia senegal* and *Acacia tortilis* was significantly correlated with total nitrogen and their survival was significantly correlated with calcium carbonate equivalent, calcium, conductivity and clay, this was also observed for *Acacia reficiens*. The growth and survival of *Adenolobus garipensis* was significantly positively correlated with sodium, potassium, magnesium and calcium (Table 23 a-b).

Based on the CCA results, 93% of seedling growth-soil variation was explained by axis 1-2 (Table 24 a). Axis 1 (Eigenvalue: 0.18) accounted for 86.5% of variance. Magnesium and sodium (showing the longest arrows) were more correlated with this Axis and therefore closely related with the species (*Adenolobus garipensis*) in that ordination (Figure 38). PH was also strongly associated with axis 1. Axis 2 (Eigenvalue0.014) accounted for 6.5% of variance. Infiltration rate (showing the longest arrow) was more correlated with axis 2 (Table 25a) and therefore closely related to the species in that ordination (*Acacia erioloba* and *Acacia erubescens*). Conductivity and CaCO3 were also represented by Axis 2.

In seedling survival, 91% of variance between soil properties and survival of seedlings was explained with axis 1-3. Axis 1(Eigen value 0.016) explained 43.3% of variance and was dominated by CaCO3 and conductivity. This axis was associated with *Catophractes alexandri* and *Acacia tortilis*. Axis 2 (Eigen value 0.011) was strongly correlated with sodium, magnesium and potassium (Table 25 b) and associated with *Adenolobus garipensis* and *Acacia erubescens* (Figure 39). It explained only 29.9% of variance. Axis 3 (Eigen value 0.006) explained only 17.5% of variation and was more represented by clay.

Table 23: a-b: Growth and survival of each species correlated with various soil properties (Correlations marked in bold are significant at P<0.05).

A

Variable	*A. erioloba*		*C. alexandri*		*A. senegal*		*A. erubescens*	
	Growth	Survival	Growth	Survival	Growth	Survival	Growth	Survival
% CaCO3 equivalent	-0.385	0.306	-0.093	**0.829**	0.226	**0.819**	-0.446	0.424
Calcium (mg Na/kg)	**-0.624**	0.239	-0.304	0.483	-0.110	**0.847**	**-0.575**	**0.546**
Clay (%)	-0.465	**0.696**	-0.174	0.337	-0.170	**0.766**	-0.305	**0.844**
Conductivity (mS/m)	-0.458	0.307	-0.198	**0.725**	0.047	**0.700**	-0.453	**0.631**
Magnesium (mg Na/kg)	**-0.711**	0.205	-0.259	0.017	**-0.548**	**0.560**	**-0.540**	**0.592**
Organic carbon (% m/m C)	0.308	-0.352	0.069	**-0.834**	-0.280	**-0.791**	0.381	-0.399
Organic matter (% m/m OM)	-0.070	-0.383	0.044	-0.378	-0.402	**-0.566**	-0.154	-0.399
pH (H2O) electrometric	0.422	-0.230	0.116	**-0.620**	0.255	-0.272	0.459	**-0.590**
Phosphorus (mg P /kg)	-0.461	0.277	**0.568**	**0.541**	-0.217	0.442	-0.153	0.422
Potassium (mg Na/kg)	-0.442	0.372	-0.305	-0.143	-0.474	0.398	-0.260	**0.612**
Sand (%)	**0.561**	-0.346	**0.521**	-0.289	0.214	**-0.754**	**0.501**	**-0.631**
Silt (%)	**-0.561**	0.305	**-0.543**	0.281	-0.215	**0.740**	**-0.512**	**0.598**
Sodium (mg Na/kg)	-0.491	0.254	-0.448	-0.075	-0.399	0.469	-0.447	**0.625**
Total Nitrogen (% N m/m)	0.411	0.283	0.324	0.298	**0.590**	0.161	0.422	0.170
Field capacity	**-0.725**	-0.271	**-0.605**	-0.165	**-0.788**	0.021	**-0.744**	0.224
Infiltration rate	**0.834**	-0.183	0.303	**-0.665**	0.469	**-0.657**	**0.972**	-0.617

B

Variable	*A. tortilis*		*A. garipensis*		*A. reficiens*	
	Growth	Survival	Growth	Survival	Growth	Survival
% CaCO3 equivalent	0.076	**0.815**	-0.368	0.295	0.278	**0.669**
Calcium (mg Na/kg)	-0.186	**0.727**	0.249	**0.508**	-0.003	**0.749**
Clay (%)	-0.192	**0.706**	0.204	0.382	0.093	**0.724**
Conductivity (mS/m)	-0.073	**0.843**	-0.245	0.382	0.031	**0.754**
Magnesium (mg Na/kg)	-0.428	0.420	**0.748**	**0.513**	-0.405	**0.635**
Organic carbon (% m/m C)	-0.116	**-0.791**	0.459	-0.235	-0.370	**-0.607**
Organic matter (% m/m OM)	-0.393	-0.415	0.016	-0.181	-0.439	-0.414
pH (H2O) electrometric	0.258	**-0.647**	0.405	-0.244	0.213	**-0.519**
Phosphorus (mg P /kg)	0.157	0.422	-0.280	-0.277	-0.311	**0.614**
Potassium (mg Na/kg)	-0.351	0.263	**0.674**	0.391	-0.149	0.400
Sand (%)	0.315	**-0.640**	-0.329	**-0.519**	-0.128	**-0.591**
Silt (%)	-0.319	**0.622**	0.335	**0.522**	0.129	**0.568**
Sodium (mg Na/kg)	-0.416	0.398	**0.858**	**0.745**	-0.269	0.551
Total Nitrogen (% N m/m)	**0.581**	0.182	-0.206	0.025	0.265	0.234
Field capacity	**-0.838**	0.168	0.450	0.408	**-0.572**	0.164
Infiltration rate	**0.536**	**-0.842**	-0.083	**-0.679**	0.331	**-0.769**

Table 24: Results from the CCA analysis for A) Seedling growth and B) seedling survival

A

	Axis 1	Axis 2
Eigenvalues	0.18	0.014
% variation explained	86.50	6.57
Cumulative Percentage	86.50	93.06
Cum.Constr.Percentage	86.50	93.06
Spec.-env. correlations	1	1

B

	Axis 1	Axis 2	Axis 3
Eigenvalues	0.02	0.01	0.01
Percentage	43.26	29.90	17.49
Cum. Percentage	43.26	73.17	90.66
Cum.Constr.Percentage	43.26	73.17	90.66
Spec.-env. correlations	1	1	1

Table 25: Correlations of the environmental variables with the axis 1 and 2 for A) seedling growth and B) seedling survival

A

	Environmental Axis 1	Environmental Axis 2
% CaCO3 equivalent	0.341	-0.904
Calcium (mg Na/kg)	-0.599	-0.692
Clay (%)	-0.348	-0.231
Conductivity (mS/m)	0.162	-0.792
Magnesium (mg Na/kg)	-0.937	0.067
pH (H2O) electrometric	-0.23	0.45
Phosphorus (mg P /kg)	0.209	-0.205
Potassium (mg Na/kg)	-0.616	0.174
Sand (%)	0.525	0.357
Silt (%)	-0.536	-0.366
Sodium (mg Na/kg)	-0.833	0.094
Field capacity	-0.852	0.019
Infiltration rate	0.524	0.725
Total nitrogen	0.51	-0.081

B

	Environmental Axis 1	Environmental Axis 2	Environmental Axis 3
% CaCO3 equivalent	-0.578	-0.231	0.327
Calcium (mg Na/kg)	-0.423	0.255	0.174
Clay (%)	0.015	0.38	0.613
Conductivity (mS/m)	-0.516	0.1	0.489
Magnesium (mg Na/kg)	-0.046	0.664	0.147
pH (H2O) electrometric	0.45	-0.16	-0.651
Phosphorus (mg P /kg)	-0.3	-0.185	0.83
Potassium (mg Na/kg)	0.226	0.605	0.225
Sand (%)	0.144	-0.403	-0.185
Silt (%)	-0.159	0.395	0.138
Sodium (mg Na/kg)	0.056	0.81	-0.065
Field capacity	-0.116	0.656	-0.216
Infiltration rate	0.718	-0.397	-0.22
Total nitrogen	-0.092	-0.125	0.27

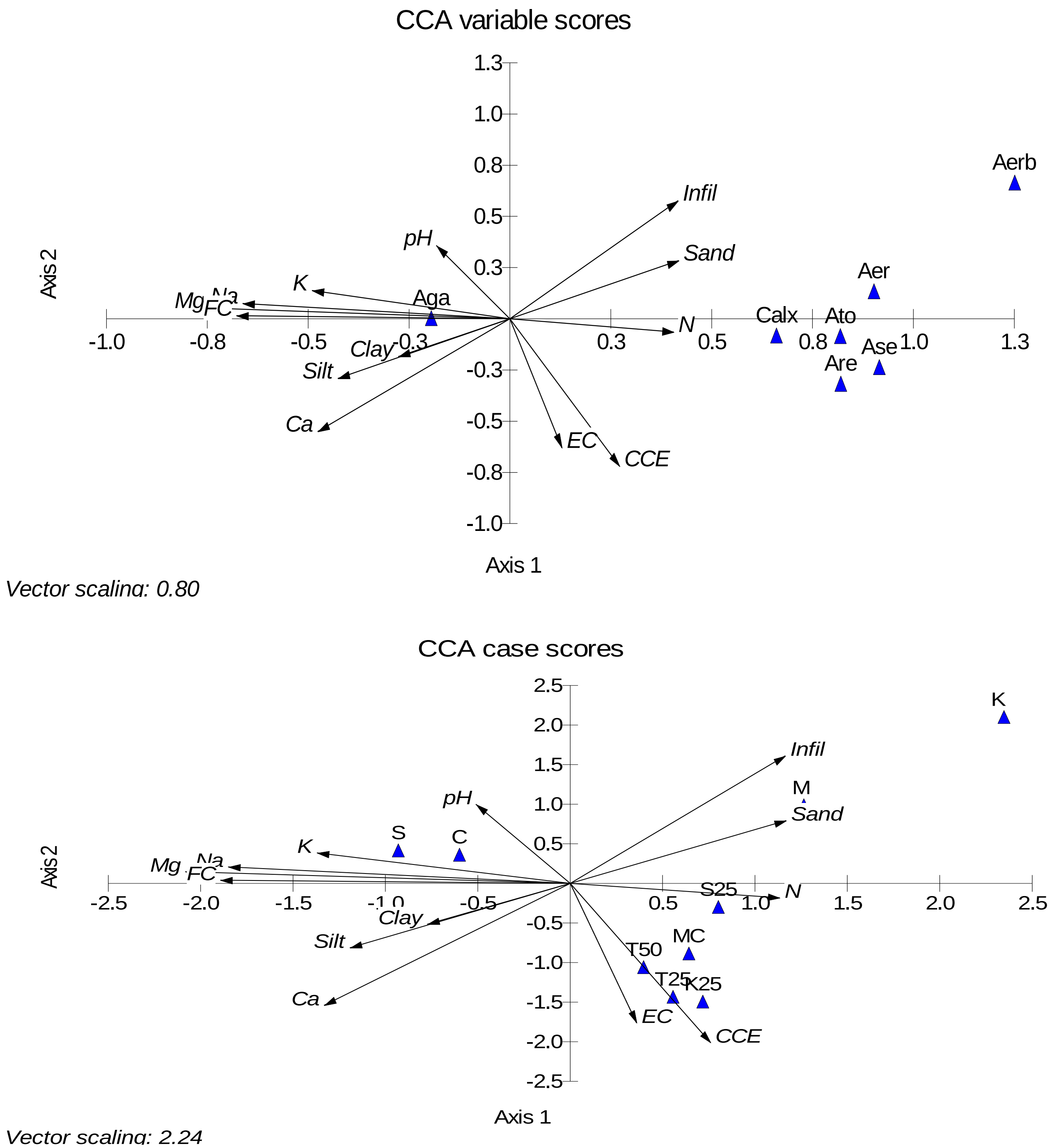


Figure 38: CCA-ordination of species A)growth and B)substrates in relation to soil properties based on Axis 1and 2.

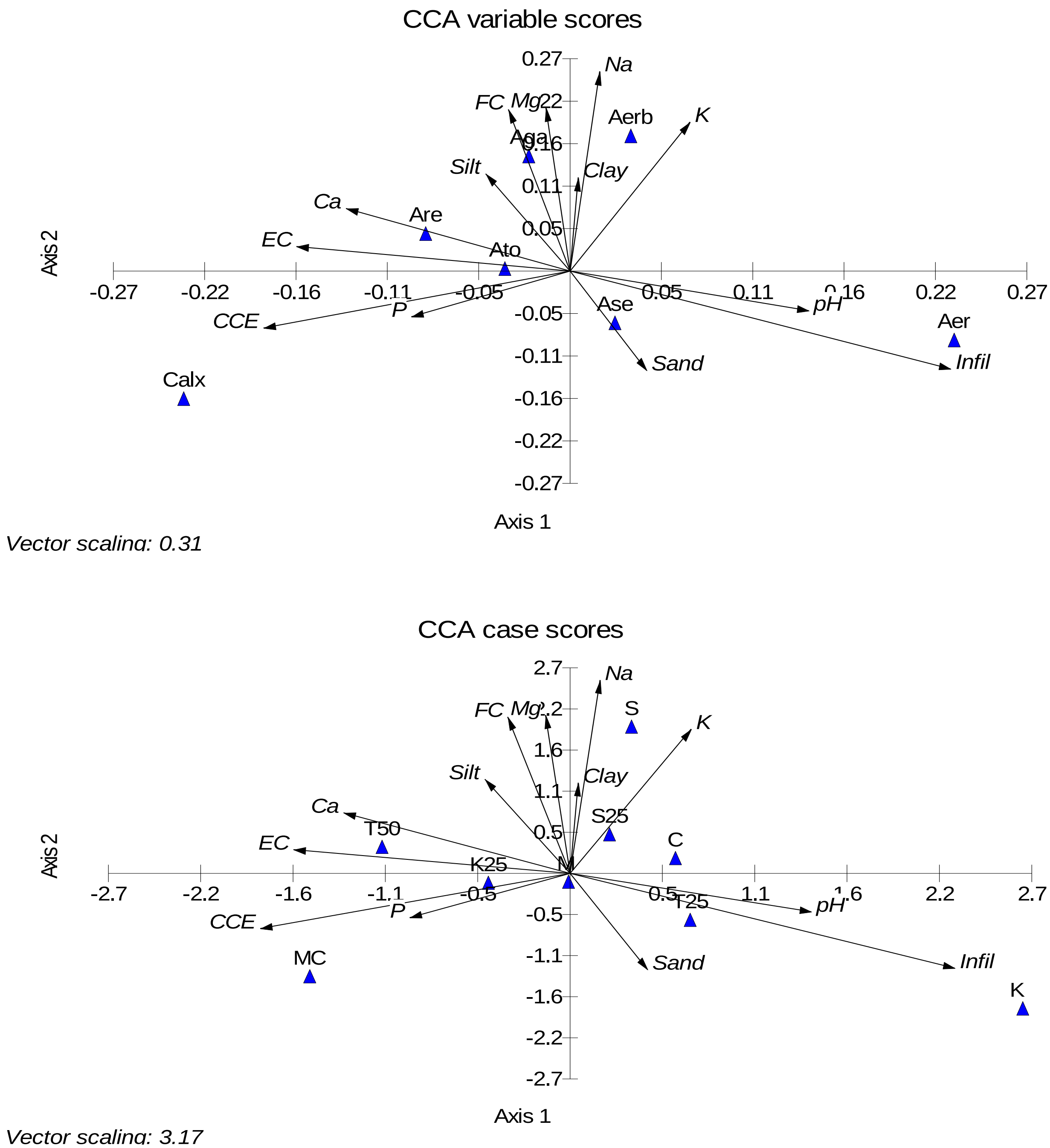


Figure 39: CCA-ordination of species survival and substrates in relation to soil properties based on Axis 1and 2.

Figure 38 and 39 ordination diagram: ▲ = species/substrates and soil properties are represented by arrows. First axis is vertical and second axis is horizontal. Shown also are the projections of the substrates labelled as: K, K25, S25, S, M, T25, T50, C and MC (abbreviations are explained in Table 18). The species are: Calx= *Catophractes alexandri*, Are=*Acacia reficiens*, Ase=*Acacia senegal*, Aerb = *Acacia erubescens*, Aer=*Acacia erioloba*, Ato=*Acacia tortilis* and Aga= *Adenolobus garipensis*. The environmental variables are: clay, silt, sand, K=potassium, N=Nitrogen, pH, CCE=Calcium carbonate equivalents, P =Phosphorus, Na=Sodium, Mg=Magnesium, FC= field Capacity, Infil=Infiltration rate, Ca=Calcium and EC= conductivity

5.4. Discussion

5.4.1. Seedling survival

The survival percentage of seedlings decreased considerably in the fourth month (March) after transplanting and remained constant throughout the winter months (July-September). It was during March that the watering of the seedlings was reduced from once a week to once in two weeks. Reducing the supplement of water led to an increase in seedling mortality. Many studies have implicated the role of water stress as a significant cause of woody seedling mortality (Davis e*t al*., 1999; Inouye *et al*., 1994; Walker *et al*.,1981; Williams & Hobbs, 1989). The results also indicate that after the fourth month, percentage survival remained constant. This indicates that once the seedlings are established, they have a pretty good chance to survive.

Percentage survival was highest in *Acacia senegal* followed by *Acacia tortilis* and *Acacia erioloba* respectively. The species showing the lowest survival was *Adenolobus garipensis*, followed by *Catophractes alexandri* and *Acacia erubescens.* Several explanations exist for these trends. All plants need water while establishing their roots and during periods of extended droughts. While this is true, some species are highly adaptable and have high tolerance compared to others. The survival of any species in different environments and conditions is thus determined by its ability to adapt quickly and establish itself.

Mohamed (2005) states that *Acacia senegal* is adapted to soil water stress through morphological and physiological mechanisms. Mohamed further contended that *Acacia senegal* is capable of physiological adjustment in response to an increase or decrease in soil moisture. This helps it to avoid the damaging effects of water deficits and contribute to an increase in the intrinsic water use efficiency. Ultimately, this adaptive strategy enables *A. senegal* to survive and develop in adverse dry land environments. Other studies have reported that *Acacia senegal* have deep tap roots and far reaching lateral roots that could potentially redistribute soil water from deep layers (Hocking, 1993; Räsänen, 2002) This could reflect adaptation to drought by maintaining a stable photosynthetic activity even under low leaf water potential. This might explain why it has a high percentage survival. It seems then that the responsive stomata and deep root systems in *A. senegal* both appear to increase the ability of this species to endure drought for considerable periods of time without becoming viciously dehydrated and this is in correspondence with what Kramer (1988) also reported.

The establishment of plants is highly dependent on their root systems, which if it is not well developed makes it susceptible to drought and other factors. Weber *et al*., (2008) concluded that trees that produce a deeper taproot access soil moisture at greater depths, allowing them to grow for a longer period of time during the dry season. The ability of trees to tap deeper soil water when upper soil layers dry out has been reported in woody species in different types of habitats (Elfeel & Al-Namo, 2011; Mensforth *et al*., 1994; Sun & Dickinson, 1995).

Elfeel & Al-Namo (2011) assessed the effect of imposed drought stress on the growth of seedlings, water use efficiency and survival of three arid zone species (*Acacia tortilis, Salvadora persica* and *Leptadenia pyrotechnica)* and they found that the best survival under water stress conditions was recorded in *A. tortilis*. In addition to that, *A.*

tortilis had higher biomass production and significantly higher root to shoot ratio. This implies that the efficiency of this species under drought conditions is high. Changes in root to shoot ratio in response to water stress, represents one of the most adaptive mechanisms in plants tolerance to water stress (Gorka *et al*., 2010). *Acacia tortilis* has well developed taproot and it is an opportunistic water use, this gives it a survival advantage. The same is true for *Acacia erioloba* (Barnes *et al*., 1997). Barnes stated that where the annual rainfall is less than 250 mm *Acacia erioloba* probably depends upon its extraordinary capacity to root to great depths to gain access to ground water supply. This perhaps explains why these two species also had high survival.

Stahl *et al*., (2013) states that the adaptation of plant species to their biotic and abiotic environment is manifested in their traits. Plant adaptation strategies are manifested in a suit of whole-plant performances including reproduction, growth and survival. Each of these is administered by a particular set of morphological, anatomical or physiological traits. Characterizing plant strategies therefore requires the knowledge of many traits.

Slot, *et al.*, (2012) concluded that the flexibility of biomass allocation is a key to growth and survival of trees exposed to variable levels of harsh conditions. Early scientists hypothesized that plants hold functional equilibrium between below and above ground biomass (Brouwer, 1962; Werger, 1983). This implies that under constant conditions there is a balance between biomass investment in the shoots and in the leaves. If the external conditions are changed, plants have the capacity to coordinate their shoot and root growth to adapt to the changed conditions.

In supporting the functional equilibrium hypothesis, Brouwer (1962) argued that plants in dry conditions are expected to invest proportionally large amounts of biomass in water acquisition and transport structures. Plants in dry environments thus trade off high investment in water acquisition and transport against investments in leaves, leading to reduced light capture and subsequently lower growth rates (Weber *et al*., 2007). This in short refers to plants that use a conservative resource use strategy. These trait associations align with those reported by Markesteijn & Poorter, (2009) showing high investment in protection and survival structures (dense wood, thick bark, heavy seeds), combined with features favored under low water availability (taproot and ring-porous wood).

Though this might be true, Stahl *et al*., (2013), contended that there is a particular group of plants that uses a resource use strategy suited to quickly exploit suitable habitats (tall stature, small wind dispersed seeds, high vegetative spread rates) at the cost of protection and maintenance. These species tend to have higher growth rates and low survival often supporting shallow roots. Examples include species of the genera *Alcer*, *Aesculus* and *Cercocarpus* (Stahl *et al*., 2013)

In this study, *Adenolobus garipensis* had lowest survival and highest growth. It seems to have a competitive characteristic of rapid growth in leaves and stems, thus investing on the above ground biomass than on the lower ground biomass. It can thus be implied that it does not use the conservative resource use strategy. Plants that do not use this strategy usually grow fast and have low survival as they do not invest in their roots, which are the most important in establishment.

In terms of survival performance in different substrates, the present study indicate that survival was highest in S-25, followed by K-25, S, MC and T50 respectively, and lowest in K, C and M respectively. Generally a good substrate has both chemical and physical properties that promote growth and survival. Survival in most species was significantly correlated with conductivity, calcium, clay and CaCO3 equivalents (Table 23 a-b). High level of the above mentioned soil properties were also recorded in S-25, K-25, S, MC and T50, and the lowest amounts were recorded in K, C and M. It appears that the seedlings survived well in the growth media with high clay content, conductivity, calcium and CaCO3.

According to Morgan (2008) calcium is considered a secondary macronutrient for plant survival. The fundamental role of calcium in plants is in the strengthening of the cell walls. Peter (2005) and Hodges (2010) stated that among the defects of low levels of calcium include poor root development. Though there are other factors that are crucial to the survival of seedlings, perhaps calcium is one of them. It appears that survival of seedlings was also more inclined to soils with high conductivity. Conductivity is an indirect measure of salinity. Shannon (1997) stated that salinity reduces plant growth and photosynthesis due to the complex effects of osmotic, ionic, and nutritional interactions, this are however still poorly understood.

Joseph *et al*., (2007) stated that the number of woody species that will reach their full growth potential on soils with ECs $\geq$8 dS/m are very limited. A number of species will survive but grow at a reduced rate and vigor on soils with ECs between 6 and 10 dS/m. In this study all the substrates had EC more than 8dS/m except in M and K. All the substrates falls under the category of strongly saline soils as proposed by Joseph *et al.*, (2007) as soils with EC of more than 16dS/m. The highest EC was recorded in S25, and this was the substrate that recorded the highest seedling survival and poorest growth. The composition of salts contributing to the values of EC are actually not known. Dierickx, (n.d.) concluded that it is mostly represented by sodium, calcium, potassium and magnesium. Although the species were able to survive in very saline substrates, their growth were suppressed.

Soil texture is an important characteristic of soil and affects water holding capacity, drainage properties, root development and more. Coppin & Bradshaw (1982) established that some mine wastes are coarse and open textured especially if they have been loose tipped. If material is very coarse, initial establishment of plants may require the addition of fine material. Marble (M) is a very course and rocky substrate and may limit root penetration. This perhaps also contributed to the low survival in this substrate. Generally sandy soils are frequently limited in nutrient availability, as they are readily leached and it is not surprising that it recorded the lowest seedling survival. Sheoran *et al.*, (2010) contended that mine soils with sandy textures cannot hold as much water or nutrients as finer textured soils like loams, silts and clay. Silts and clay are finer textured soils and have a tendency to form surface crusts, often contain high level of soluble salts.

5.4.2. Seedling growth

The notion that the competitive ability of a plant species varies according to the conditions in which it is growing is still debatable (Grime, 1977). Grime (1977) argues that differences in competitive ability may result due to the fact that environments differ in the extent to which they allow the competitive potential of a species to be realized. Secondly, these same characteristics may be subject to genetic variation. This being said, each plant species has its own niche and substrate requirement. Each species therefore has its greatest competitive ability in its own niche. Despite each species having its own niche, some species are able to establish themselves in a range of soils and substrates, having a broad range of tolerance.

Harpole (2012) argued that because many factors limit species, and because no species is best adapted for all conditions, species have tradeoffs, which allow them to perform better in some environments, but necessarily worse in others. In this study, a tradeoff between growth and survival was observed in *Adenolobus garipensis*. As it was previously discussed that *Adenolobus garipensis* seems to invest more on growth than establishment, this perhaps explains why it had highest growth in all the substrates. Perhaps traits that enhance growth were greater in the studied environment (water scarcity, light) than traits that enhance survival in this species. How to integrate growth and survival in order to evaluate overall performance of species is an important challenge left for future studies.

While all other species recorded poorest growth in schist (S), *Adenolobus garipensis* had its highest growth in schist. It grew over ten times better in this substrate than in the rest of the substrates. Schist is also the substrate showing the highest levels of sodium and the growth of *Adenolobus garipensis* was strongly correlated with sodium. Sodium is generally known to inhibit plant growth. However, some species, especially halophytes and some plants with the CAM- or C4-photosynthetic pathway, grow better in the presence of sodium (Lee & van Iersel, 2008).

Lee and van Iersel (2008) studied the effects of sodium chloride on growth, morphology, and physiology of Chrysanthemum (*Chrysanthemum morifolium*). They found that plant height and the area of the uppermost fully expanded leaf were both significantly decreased by increasing concentrations of NaCl. Their results provide clear evidence that NaCl can inhibits plant growth. Perhaps *Adenolobus garipensis* has a high tolerance of salinity and thus it was able to grow very well in a substrate where other species grew very poorly.

Next after *Adenolobus garipensis*, *Acacia senegal* recorded the highest growth. *Acacia senegal* is well adapted to extreme drought (Raddad, 2006) as previously discussed. In this study, it is the one species that has performed consistently well in terms of growth and survival.

The highest growth of *Acacia erioloba* was recorded in K (kalahari red sand). This was however expected because *Acacia erioloba* is a characteristic of Kalahari sandveld (Barnes *et al*., 1997). According to Barnes (2001), this species's ecology suggests that it is adapted to shallow to deep, infertile, occasionally alkaline sands, beneath which it uses its deep roots to access and use, even brackish (Midgley *et al.*, 2004) deep water containing dissolved nitrates. Though several studies have concluded that this species is invariably confined to sandy soils, Barnes (2001) established that *Acacia erioloba*, *Acacia tortilis* and *Acacia senegal* all have potential both inside and outside their natural ranges. The results in this study correspond with Barnes conclusion. *Acacia erioloba*, *Acacia tortilis* and *Acacia senegal* recorded high growth in almost all the substrates including heavy substrates such as marble and schist. It is interesting however that not all species originally suspected to be generalists such as *Acacia erubescens* and *Catophractes alexandri* performed comparatively well. *Acacia erioloba* normally known to be confined to sandy soils managed to grow and survived in rocky substrates.

The highest growth in most of the species was recorded in K25, MC and T25. These substrates also recorded highest survival of seedlings compared to the rest of the substrates. As discussed earlier, these substrates were rich in calcium, clay, CaCO3 and conductivity which were also positively correlated and ordinated with survival of most of the studied species. Perhaps these properties make them preferable to other substrates. Other properties that were positively correlated with growth of seedlings included total nitrogen and phosphorus. According to Ines & Terezinha (2004) metabolic processes leading to increases in vegetative and reproductive growth and yield is utterly dependent upon the adequate supply of nitrogen.

Catophractes alexandri and *Acacia erubescens* were the two species that had poor performance in terms of both growth and survival in all the substrates. Different plant species may not have the same range of adaptability and may require a narrow range of nutrients to survive. Some species are better adapted to certain conditions as a result of key characteristics that allow them to survive in the presence of competition. Though all the species were able to establish, some had better survival and growth performance in all the substrates such as *Acacia senegal, Acacia tortilis* and *Acacia erioloba,* while others such as *Adenolobus garipensis* had high growth and poor survival. We speculate that differences in individual functional traits clearly underlie species differences in growth and survival of seedlings.

It is important to note that though growth and survival performances differed among species, all the studied species were able to grow and survive in all the substrates. There was no substrate where a particular species did not grow at all. This study has provided evidence that all the studied species were able to grow outside their natural ranges. Species such as *Acacia erioloba* usually confined to sandy soils and *Acacia tortilis* usually confined to alluvial soils were able to survive and grow comparatively well in all the substrates. These two species were determined to have narrow niche sizes in chapter 3 and also had low frequency occurrence, hence rendering them specialists in this study and yet have proven otherwise.

Chapter 6: General discussion, conclusions and recommendations

The main objective of this study was to investigate the establishment of indigenous vegetation on mined substrates and develop an understanding of species assemblage and habitat preference in the Karibib thorn bush savannah. This main objective has been set to contribute scientific information to the development of methodologies for using mined substrates to establish self-sustaining, indigenous plant communities and therefore contribute to the development of mine closure and rehabilitation plans. To accomplish this goal I investigated four specific objectives all covered in three different studies as reported in the 3 data chapters above.

The objective of this chapter is to give a synthesis of findings from the three studies and discuss the implications with a special focus on mining rehabilitation. Firstly I present an investigation on the structure, composition and habitats of woody vegetation in five communities in the Karibib thorn bush savannah, in order to establish knowledge on species assemblage and habitat preferences in the area surrounding Navachab Gold Mine. The relationships between vegetation and soil variables in these communities were explored. The success of any rehabilitation project require sound scientific knowledge on the habitats, species and species assemblage in the surrounding undisturbed communities.

Secondly, I present an investigation on the germination requirement of selected species in these communities in order to elucidate the best seed treatment for each selected species. This was particularly important because seed dormancy often present challenges in ecological restoration projects. In order to successfully establish vegetation in any area, knowledge on the germination requirement of the plant species to be used is required.

Thirdly, I present an assessment on the suitability of various mined substrates for the establishment of indigenous savannah species and explored which properties make a particular substrate suitable for plant growth. It is equally important to understand how species perform along soil gradients in terms of growth and survival. This provides knowledge on habitat preferences and gives insights on which species are able to grow in which soils. Ultimately it provides knowledge on which mined substrates are suitable for plant growth.

For each section, effort was made to synthesize the findings from the three chapters. Finally the main conclusions of this research are presented and recommendations toward new research that will contribute to improved mining rehabilitation approaches are discussed.

6.1. Plant community and habitat structure in the surrounding undisturbed communities

It was observed that there was no significant difference in species diversity and evenness between the five studied habitats, but the habitats differed in species richness. The highest species richness was recorded in the Sandstone hill habitats and the lowest was recorded in the Kalahari red sand plains. While it is true that in many cases high species richness means high species diversity, different outcomes for species richness and species diversity is not unusual in plant community ecology (Bock *et al*., 2007). This is because species diversity takes into account a second parameter, evenness, whilst species richness simply looks at species count. Diversity therefore also depends on how evenly distributed the species are and a community with high species richness but dominated by one or two species will have low species diversity, which was the case in my study, thus I found no difference in species diversity because even in habitats that had a high number of species, the species were not evenly distributed.

It was observed that Sandstone and Granite hills were more similar in terms of species composition characterized by three common and most abundant species in both habitats namely; *Acacia erubescens, Boscia albitrunca* and *Commiphora glaucescens*. However Kalahari red sand was dissimilar with all the other communities comprised of species such as *Acacia erioloba* and *Ehretia alba* that are only occurring in this habitat. This is an indication of species assemblages in relation to soil properties.

Ordinations of woody vegetation in the Karibib thorn bush savannah indicated that there were fairly distinct species assemblages. Identified species assemblages were related to soil properties. It can thus be established that soil properties contributed to an extent to the distribution patterns of woody species in the Karibib thorn bush savanna. Muhammad *et al*., (2008) concluded that one of the main factors influencing plant distribution is the type of soil. Most plants are specially adapted to specific soil types. However differences in vegetation patterns are determined by other major factors such as topography, temperature and disturbances. The important driver of the patterns observed in the present study seems to be soil texture, organic matter, pH and cations as revealed by the CCA ordination.

The abundance of the ten most abundant species was strongly influenced by cations (such as potassium and sodium), pH, organic matter and soil texture. Though in reality many of these species (e.g. *Acacia erubescens, Catophractes alexandri, Acacia reficiens* etc) grow in a wide range of habitats, this study has also shown that these species all have an affinity for a particular soil property. Examples, *Acacia erubescens* is strongly ordinated and correlated with organic matter and clay. As a result it had its highest abundance in habitats that recorded high organic matter and clay content (sandstone and granite hills). *Acacia reficiens* is strongly correlated with potassium and sodium and its highest abundance is recorded in calcrete plains (the habitat with the highest potassium and sodium content). The above mentioned species however were not found in Kalahari red sand plains.

Linking this to the assessment of growth and survival of *Acacia erubescens* in mined substrates, it was observed that its performance was comparatively poor. One observation made in the study was that most mined substrates recorded high sand content all above 65% and very low organic matter. It is interesting that species that were common in many or all the studied habitats performed poorly in terms of growth and survival in mined substrates such as *Acacia erubescens*. I was expecting broad niched species such as *Acacia erubescens* and *Catophractes alexandri* to perform well and narrow niched species such as *Acacia erioloba* to perform poorly. The opposite was however true. Brown (1984) claimed that species that have a broader niche are predicted to be locally more abundant and to have larger ranges, because they are able to grow in more habitats and to colonize additional regions with a different habitat spectrum than species with a smaller niche breadth. He suggested that a species able to exploit a wide range of resources should occupy a larger number of sites than a species which is restricted to a narrower niche. Austin & Smith (1989) stated that attempts to investigate species distribution patterns should be based on the realised niche which is usually evaluated by environmental variables which was the case in this study. In many cases however studies on niche dimensions use the most often easily available environmental variables such as temperature or rainfall, not taking into consideration important site factors such as soil water and nutrient availability.

Coming back to Brown's argument, perhaps this is only true if soil niche breadths are considered. If perhaps the mined substrates were rich in clay, organic matter or other properties that this species has an attraction for, its growth and survival performance will be good. Perhaps widespread species have a broader temperature/rainfall niche but not necessarily a broader soil niche. Our results show that species were able to grow out of their natural ranges. Many reclamation experiments do soil amendments to accommodate different species. However I suggest that it is best to assess the soil properties of mined substrates and see how different native species perform in terms of growth and survival before considering to amend mined soils. The suitability of mined soils for vegetation establishment must first be assessed. The present study found that all the mined substrates used in the study were suitable for plant growth. So mined soils do not always need to be amended to make them suitable but one need to investigate the suitable species to use based on their growth and survival in these substrates. Selecting species based on how widely distributed they are in the environment is not good enough. One need to also study how they grow on mined substrates. In this study we found that species which were narrowly distributed were able to grow in a wider range of mined soils compared to the widely distributed species. So trials of plant growth in mined soils are crucial as well as assessing the chemical and physical properties of soils of different habitats where potential species are occurring.

It can thus be established that the ecology of different plant communities from different sites in the Karibib thorn bush savannah, showed variation in nature, structure, composition of vegetation and occupy habitats characterized by different soil characteristics. The study of soil-vegetation relationships can be very useful for detecting and analyzing composition and distribution pattern of plants in relation to edaphic factors. It will also be a guidance for managing and reclaiming degraded lands in arid and semi-arid environments. The findings on the plant and soil relations in the study area will help in the selection of adaptable species for improving and rehabilitating disturbed arid environments by showing how different species are distributed along soil gradients and in which soil they grow in.

6.2. Testing seed pre-treatment methods for increasing germination in eight savanna woody species

Eight selected woody species were used in the germination experiment in order to determine the best seed treatment for each species. In this study, the results suggest that sulphuric acid was the best scarification method in all the studied species, and optimum soaking period was established for each species. This is because different seeds differ in the degree of dormancy. Some seeds possess soft seed testa as opposed to others. It is important to note that above and beyond a certain immersion period, the seeds soaked in sulphuric acid will result in low or no germination at all. This is because the seed coat either did not erode enough to break dormancy after a short time of exposure to sulphuric acid or sulphuric acid penetrated enough to kill or damage the embryo. Acetone was also found to be effective in breaking the dormancy of the six studied species, and hot water resulted in a poor performance in most of the species. While most of the species seem to require an acid or acetone seed treatment to achieve higher germination rate, there are also species in these communities such as *Acacia senegal* and *Albizia anthelmentica* where germination above 60% could be achieved by soaking seeds in cold/hot water. It is possible however that there are other scarification methods that are best for these species that were not included in this study.

The evidence from the results presented herein suggest that soaking seeds of *Acacia erioloba*, *Acacia reficiens* and *Adenolobus garipensis* in sulphuric acid (98%) for 45 minutes best improves the final germination (80% 81% and 93% respectively) and germination speed in these species. In the case of *Acacia tortilis* its best germination (94%) was obtained when the seeds where soaked in sulphuric acid (98%) for 1 hour. The highest germination (74%) and speed in *Acacia senegal* was obtained when the seeds were soaked in sulphuric acid (98%) for 15 minutes, while that of *Albizia anthelmintica* (94%) was obtained when the seeds were soaked in sulphuric acid (98%) for 5 minutes.

This study has provided useful information on the germination requirements of various savannah species that have potential to be used in rehabilitation projects in the semi-arid areas. Germination requirements of species is needed to ensure that germination and nursery production of species for rehabilitation of mined sites is successful. It is important to note that before sowing, species with physical dormancy will need to be scarified to allow imbibition and therefore be able to germinate. Using sulphuric acid and acetone improved germination in almost all the studied species, and I therefore suggest the use of acetone and sulphuric acid to treat seeds prior to sowing, taking into considerations the soaking periods for each species in each chemical.

Two of my study species (*Terminalia prunioides* and *Commiphora glaucescens*) germinated with low percentages regardless of soaking periods in both sulphuric acid and acetone. Additional studies are necessary to further explore the requirements for dormancy breaking and germination in these species. Perhaps in *Terminalia prunioides* it is important to consider the time of seed collections as stated by Likoswe *et al* (2008) that this is crucial for successful regeneration and recruitment of this tree species. There is a necessity for biological studies that may perhaps lead to the development of maturity indices of *T. pruniodes* fruit seeds that may facilitate collection of seeds that can provide optimal germination rates.

6.3. Establishment of seedlings in various mined substrates

A number of standard factors are considered in making decisions on selecting which species can be used for rehabilitation and revegetation. This include selecting species with desirable characteristics. More important is to obtain information about the specific habitat requirement and thus matching species to habitat. This is the core of successful rehabilitation and it requires sound knowledge on the substrate requirement of selected species and how they perform in different substrates. In this study, the above factors were considered.

The objective of determining if there are species that can only grow in a narrow range of soils and if there are species that are able to establish and grow well in a wide range of soils was addressed. Though some species grew and survived poorly in some substrates, all the studied species were able to grow and survive (whether poor or high) in all the substrates. There was no substrate were a particular species did not grow at all. This study has provided evidence that all the studied species were able to grow outside their natural ranges. In fact, species originally suspected to be specialists such as *Acacia erioloba* usually confined to sandy soils and *Acacia tortilis* usually confined to alluvial soils were able to survive and grow comparatively well in all the substrates compared to some generalists such as *Catophractes alexandri* and *Acacia erubescens*.

It is worth mentioning that some species had high survival in most of the substrates (*Acacia senegal, Acacia tortilis* and *Acacia erioloba*). In the same way, they also recorded high growth in most of the substrates. These species are highly recommended because of their growth and survival performance. There were also species that even though they showed high survival percentage, their average growth in most of the substrates was low e.g *Acacia reficiens*. Other species had both poor growth and survival in most of the substrates e.g *Catophractes alexandri* and *Acacia erubescens* while others such as *Adenolobus garipensis* had lowest survival and yet highest growth in all the substrates. It is speculated that this species does not use a conservative strategy but has a competitive advantage of rapid growth, investing on the above ground biomass than on the roots.

The result also provide evidence that all the substrates were suitable for plant growth. While this was true, some substrates such as K25, MC and T25 recorded high survival and high growth of seedlings in most of the species, while some recorded very poor growth and survival of seedlings such as T50, C and M. Other substrates showed a tradeoff between growth and survival. Substrates such as S25 recorded highest overall survival of seedlings and very poor growth in most of the species. It appears that though the seedlings were surviving, they were not growing in this particular substrate. Perhaps the environment was sufficient for survival but not favorable for growth. Substrates such as K, recorded poor survival of seedlings and yet high growth. It appears that most seedlings were not able to survive in this substrate but the ones that survived grew well. This substrates is not recommended for use in rehabilitation projects.

It is important to therefore note here that the selection of suitable species and substrates to use will be evaluated both in terms of growth performance and survival performance. After all, the best substrate will allow species to grow and survive. Similarly, the best species to be used must be able to grow and survive in a range of substrates.

Generally, each plant species has specific relations with environmental variables. These relations are because of habitat condition, plant ecological needs and tolerance range. Understanding the indicator of environmental factors of a given site leads us to recommend adaptable species for reclamation and improvement of that site and similar sites. This study provides fundamental data of edaphic factors in this region. Understanding relationships between soil variables and growth/survival of the species in this area helps us to apply these findings in management and rehabilitation of degraded land in arid and semi-arid ecosystems. I speculate that differences in individual functional traits clearly underlie species differences in growth and survival of seedlings.

6.4. Main conclusions and recommendations

In conclusion, the study successfully established knowledge on the germination requirements for various savannah species in the Karibib thorn bush savannah. It is crucial to understand the germination requirement of plants species to ensure successful establishment of these species. The study also revealed the role of soil in determining community patterns in a savannah ecosystems. The findings on the plant and soil relations in the study area will help in the selection of adaptable species for improving and rehabilitating disturbed arid environments. Furthermore, the study also established that the selection of suitable species and substrates to use in rehabilitation projects should be evaluated both in terms of growth performance and survival performance.

Recommendations

- There is a lack of innovative research programmes in Namibia that focus on the problems of rehabilitating mined lands occurring in arid and semi-arid savannah ecosystems. As a result there is also lack of research on the essential structure and function of Namibian arid savannah ecosystems. Such studies will provide much needed information on the rehabilitation of mined sites in these ecosystems.
- More emphasis should be put on the germination of *Terminalia prunioides* and Commiphora species, as they are under studied. There is therefore a need to study these species in-depth.
- This study recommends the following species as suitable candidates for rehabilitation and revegetation projects in the arid and semi-arid environments; *Acacia senegal*, *Acacia tortilis* and *Acacia erioloba*. These species has displayed good performance in terms of growth and survival in all the substrates meaning that they can establish in many other substrates. *Acacia reficiens* also exhibited potential to be used in rehabilitation. While growth by these species was comparatively much lower, it showed high survival in most of the substrates. Perhaps it is a slow grower but it definitely warrants its inclusion in revegetation programs as it has a high chance of surviving. *Adenolobus garipensis* can also be used as it grow really fast, but care must be taken to make sure the right growth media is used. In this study, it had high growth and survival in a sodium rich substrate (Schist).

- There is a need to undertake experimentation of more savannah woody species and substrates at mine sites as this study was only limited to seven species.
- Carry out and compare different methodologies of using waste rocks for revegetation
- More ecological surveys must be conducted to provide knowledge on vegetation and their relationship with soil characteristics in arid savannah communities as this can be helpful for future rehabilitation and to know their current biodiversity situation and future continuity status.

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Appendix

Appendix 1.1: GLM analysis results for Shannon Wiener Diversity Index and Pielou's Evenness Index between habitats sampled in the Karibib thorn bush savannah

Response variable	Determinant variable	d.f	F-ratio	P
Shannon Wiener Index	Habitats	4	0.374	0.824
	Error	20		
Pielou's Evenness Index	Habitats	4	1.619	0.208
	Error	20		

Appendix 1.2: All the species encountered in the sampled habitats in the Karibib thorn bush savanna

Species	family	Abundance
Acacia erioloba	Fabaceae	30
Acacia erubescens	Fabaceae	335
Acacia hebeclada	Fabaceae	2
Acacia mellifera	Fabaceae	62
Acacia reficiens	Fabaceae	192
Acacia senegal	Fabaceae	59
Acacia tortilis	Fabaceae	36
Adenolobus garipensis	Fabaceae	35
Albizia anthelmintica	Fabaceae	66
Boscia albitrunca	Capparaceae	129
Boscia foetida	Capparaceae	149
Catophractes alexandri	Jacaranda	223
Combretum apiculetum	Combretaceae	48
Commiphora americana	Bruseraceae	6
Commiphora glaucescens	Bruseraceae	168
Commiphora tenuipetiolata	Bruseraceae	105
Commiphora virgata	Bruseraceae	161
Croton gratissimus	Euphorbiaceae	45

Cyphostema	Vitaceae	1
Dichrostachys cinerea	Fabaceae	38
Ehretia alba	Boraginaceae	54
Elephantorrhiza suffruticosa	Fabaceae	20
Euphorbia guerichiana	Euphorbiaceae	7
Grewia bicolor	Tiliaceae	9
Grewia flava	Tiliaceae	18
Grewia flavascens	Tiliaceae	5
Grewia tenax	Tiliaceae	49
Grewia villosa	Tiliaceae	26
Gymnosporia senegalensis	Celastraceae	12
Lycium eenii	Solanaceae	8
Maerua parvifolia	Capparaceae	34
Maerua schinzii	Capparaceae	23
Moringa ovalifolia	Moringacea	8
Parkinsonia africana	Fabaceae	48
Phaeoptilum spinosum	Nyctaginaceae	88
Prosopis	Fabaceae	1
Rhigozum trichotomum	Jacaranda	63
Salvadora persica	Salvadoraceae	1
Sterculia africana	Malvaceae	53
Terminalia prunioides	Combretaceae	75
Ximenia americana	Olacaceae	6
Ziziphus mucronata	Rhamnaceae	1