TESTING THE SUITABILITY OF MINED SOILS FOR NATIVE SPECIES ESTABLISHMENT AT NAVACHAB GOLD MINE, NAMIBIA

Article · January 2016

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Academic Journal of Science,
CD-ROM. ISSN: 2165-6282 :: 06(01):319–344 (2016)

TESTING THE SUITABILITY OF MINED SOILS FOR NATIVE SPECIES ESTABLISHMENT AT NAVACHAB GOLD MINE, NAMIBIA

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Vegetation re-establishment is a necessary and critical step in achieving the goal of ecosystem restoration on mined soils (Yan, Zhao, & Sun, 2013). This is especially important because mined soils tend to be a poor medium for plant growth, making natural recolonisation a slow process (Wong, 2003). Native species rehabilitation on mined soils has received much attention, but few studies have correlated native species establishment with mined substrate properties. Currently, a knowledge gap exists in Namibia concerning the physical properties of mined substrates and the suitability of these substrates in supporting plant communities. This study tested the suitability of various mined substrates for the establishment of native savanna species and explored which properties make a particular substrate suitable for plant growth. Seven native savanna species, namely; *Acacia senegal*, *A. tortilis, A. erioloba, A. reficiens, A. erubescens*, *Catophractes alexandri* and *Adenolobus garipensis,* were selected, and their potential for restoration of mined soils was assessed. The seven species, grown from seeds in the nursery, were transplanted into nine mixtures of substrates at an experimental field site at Navachab Gold Mine, Namibia. Seedling growth and survival were monitored for 40 months. Soil samples of each substrate were analyzed for chemical and physical properties. The highest survival percentage was recorded in *Acacia senegal* followed by *A. erioloba, A. reficiens*, *A. tortilis, Adenolobus garipensis, Catophractes alexandri* and *A. erubescens*. We suggest that the species survival is determined by its range of tolerance. We found that for most species survival and growth were strongest on calcium and clay substrates. This study showed that species were able to grow outside their natural range of soil conditions, and all the substrates were able to support growth and survival of different species. The survival of the study species was negatively and significantly correlated with sodium and magnesium except *for Adenolobus garipensis*. The surviving seedlings were well developed and reached a large size in three years. The results suggest that *Acacia senegal*, *Adenolobus garipensis*, *Acacia tortilis* and *Acacia erioloba* were the most suitable candidates for the restoration of these soils, as they recorded the highest survival and or growth and therefore showed tolerance to extreme soil conditions.

Keywords: Mined soils, Establishment, Native species, Substrate properties, Rehabilitation.

Introduction

Mining activities often involve the contamination of the environment with potentially toxic elements (Candeias et al., 2011). Mining has resulted in significant environmental and social impacts, which 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 (Johnson & Tanner, 1994). The challenge is to ensure that mining is part of the solution that enables better outcomes for biodiversity conservation and sustainable development (IUCN and ICMM, 2004). 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.

Establishing vegetation is a vital activity in rehabilitating mined lands (Skousen & Zipper, 2010), and it is a critical step in achieving the goal of ecological restoration (Yan et al., 2013). Natural recolonization is a slow process on mined soils because they tend to be a poor medium for plant growth (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 type of self-sustaining ecosystem (Cooke & Johnson, 2002).

It is, therefore, crucial to study the physical and chemical properties of mined substrates to determine their suitability for vegetation establishment. 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 dominant plant nutrients, acidity, salinity and alkalinity, and poor physical structure (Shu, Ye, Zhang, Lan, & Wong, 2005). The toxicity of heavy metals and deficiency of main nutrients are often the limiting factors for plant establishment on mine soils. Therefore, the success of rehabilitation schemes should overcome these two major problems (Coppin & Bradshaw, 1982). Apart from these constraints, other factors such as high surface temperature, moisture, and stability also influence plant establishment on mined substrates (Carvalho, Nabais, & Roiloa, 2013). Therefore, plants that can establish on mined substrates need to have abilities to overcome these limiting factors.

The re-vegetation must be carried out with plant species selected on the basis of their ability to survive and regenerate in the local environment (Fuente, Pardo, Alburquerque, Bernal, & Clemente, 2014). Thus, the use of native species is of particular interest as they are well adapted to the local weather and climate. Arnold, Thornton, & Baumgartl, (2012) stated 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. The selection of appropriate plant species that can establish and grow, on mined substrates is therefore of utmost importance for the successful rehabilitation of degraded mine sites.

Theoretical and empirical evidence suggests that natural vegetation restoration depends on both the availability of seed sources and on the successful seedling establishment (Wang et al., 2013). 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).

Namibia is a semi-arid country, and worldwide, rehabilitation of post-mining sites in the semi-arid and subtropical environments is challenging (Audet, Arnold, Lechner, & Baumgartl, 2013). This is especially because of availability of water which is critical for the successful rehabilitation of post-mining landscapes. Climatic characteristics of these diverse geographical regions are tightly defined by factors such as erratic rainfall and periods of drought and flooding. Critical to and in many situations predominant to the success of post-mining land rehabilitation is the availability of water and hence the climatic characteristic of geographic regions.

Many scientists have studied different traits that determine the ability of plants to establish themselves in particular environments e.g. (Cingolani, Posse, & Collantes, 2004; Craine, Froehle, Tilman, Wedin, & Chapin, 2001; DeDeyn, Cornelissen, & Bardgett, 2008). Burke (2006) argued 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.

Native species rehabilitation on mined land has received much attention, but few studies have correlated native species establishment with mined substrate's properties. Currently, a knowledge gap exists 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 we report on the comparative survival and vegetative growth of seedlings of several native woody savanna tree and shrub species that can be used in the rehabilitation of mined substrates. The understanding developed through this research has the potential to provide comprehensive solutions for mining impacted sites.

Materials and Methods

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 southwest of Karibib in Erongo Region, Namibia. Navachab makes use of an open cast mining method, which results in two types of mine wastes namely; waste rocks and tailings (Speiser, 2012).

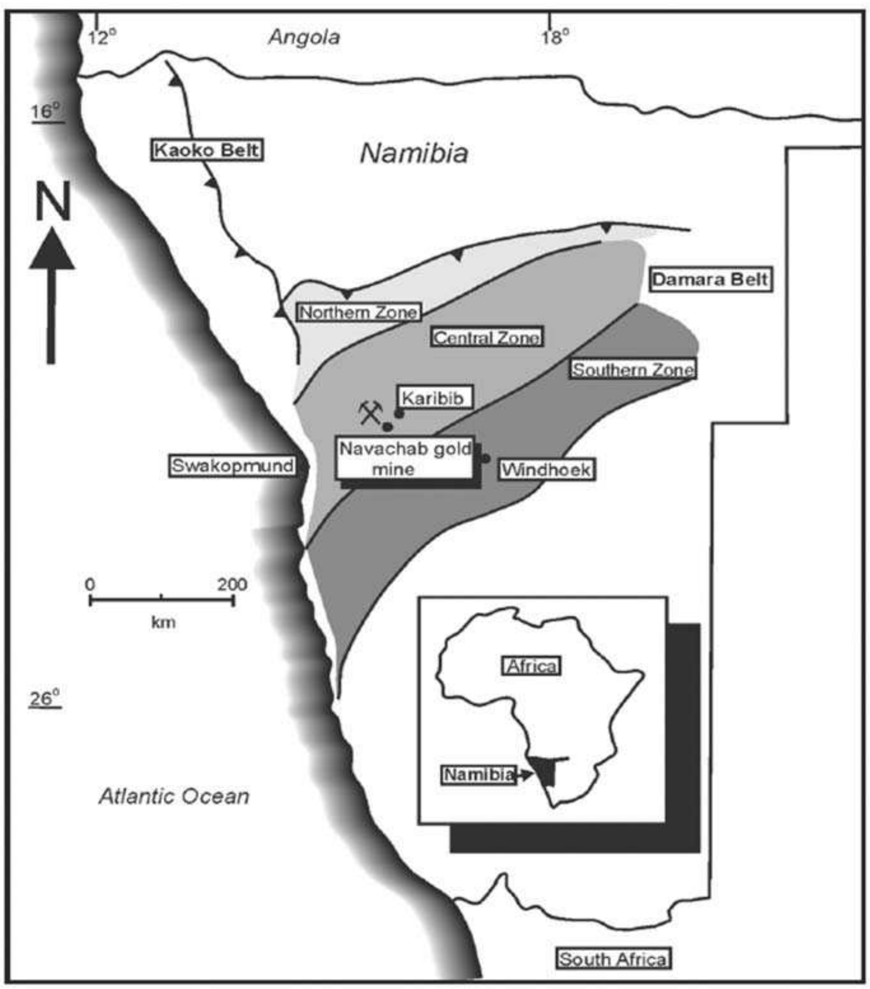

Figure 1. Location of Navachab Gold Mine, Namibia (Kisters 2012)

Seed Collections

About 5000 seeds of each of the seven selected species (*Acacia erioloba, A. senegal, A. erubescens, A. reficiens, A. tortilis, Catophractes alexandri* and *Adenolobus garipensis*) were collected in the Karibib area. Knowledge obtained from a literature review on the phenology of species 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 flowers, fruits, and seeds 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 were used in the seedling establishment experiment.

Raising Seedlings in the Nursery

The seeds of different species were treated with sulphuric acid prior to sowing and planted in polythene bags (10 cm in diameter and 20 cm long) filled with locally collected river sand, and seedlings (Figure 2) were raised in the nursery at Navachab Gold Mine for three months. A sprinkler irrigation system was employed to keep the soil moist and to 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 2. Seedlings grown in the nursery at Navachab Gold Mine, Namibia

Experimental Site Preparation and Transplant Experiment

The seedling establishment experimental site was set up at Grid A (a flat area on the waste rock dump in the mine section). Grid A has 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 1), and they were arranged in a randomized plot design (Figure 3 and 4).

Table 1. 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) sand	K

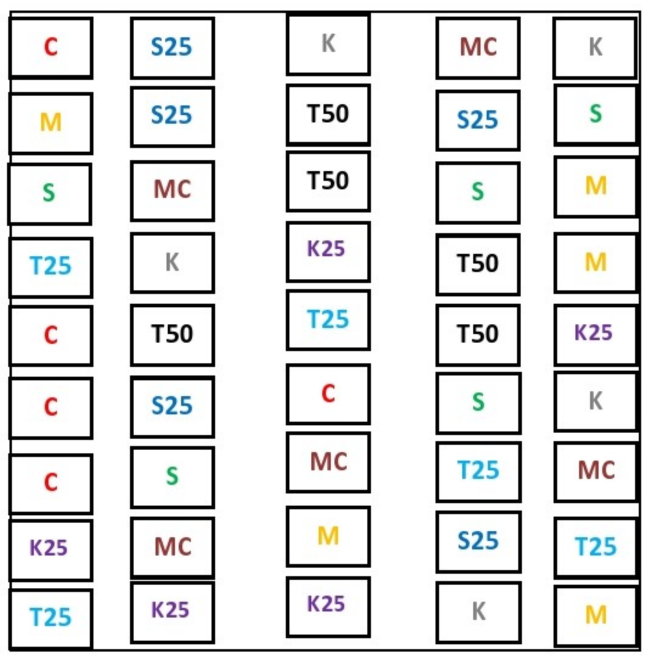

Figure 3. A randomized plot design for the substrate seedling experiment at Grid A Navachab Gold Mine. The codes refer to the different substrates described in Table 1

Figure 4. Mined substrates and mixtures of substrates at the experimental site, Navachab Gold Mine, Namibia

Each plot (Fig 3) 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. Between every two rows of substrate plots, a small access road was left.

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. 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 the rain season in the area. No further supplementary watering took place after May 2013.

Assessment and Monitoring of Seedling Growth and Survival

The growth and survival of seedlings were assessed and monitored once a month from December 2012 to March 2013 and once every two months from April 2013 to January 2014 and the last monitoring was done in April 2016. At each monitoring session, the cumulative stem length of each surviving seedling was measured, and mortality for each species in each plot was recorded.

Figure 5. Measuring the stem length of a flourishing *Adenolobus garipensis* at the experimental site, Navachab Gold Mine at 6 months

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. The samples were 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, infiltration rate was also determined in each substrate plot. 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 a depth of 5 cm, 200 ml of water was poured into the container and the time it took for the water to percolate completely into the soil was recorded as the rate of infiltration.

Data Analysis

Seedling growth was calculated as the increase in cumulative stem length, from the beginning to the end of the experiment.

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 the 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 consisted of values of soil variables. In addition, correlation matrices were used to identify the substrate's chemical properties and physical properties 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 the various 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.

Results

Seedlings Survival

About 60% of all seedlings were still surviving after twelve (Figure 6), and after three years, only 45% of all seedlings had survived Despite the decrease in survival after three years, the surviving plants were fully developed and healthy. There was a general decline in the survival of all seedlings, the greatest occurring after 4 and 12 months (Fig 7).

General Linear Model (GLM) procedure revealed that there was a significant difference in the survival of seedlings between different substrates (Table 2). GLM also established that there was a significant difference in the survival of seedlings between different species. There was no significant interaction between substrates and species in determining the survival of seedlings as revealed by the General Linear Model (GLM) analysis (Table 2).

Table 2. Results of GLM for seedling survival 40 months after transplanting at the experimental site (Grid A), Navachab Gold Mine

```
Model: Gaussian, link: identity

Response: Survival

                  Df Deviance Resid. Df   Resid. Dev    F        Pr(>F)
NULL                           314      249465
Substrate          8    51134   306      198331   10.9187    0.0000112 ***
Species            6    16932   300      181399   4.8207     0.0001119 ***
Substrate:Species 48    33879   252      147520   1.2057     0.1823737
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
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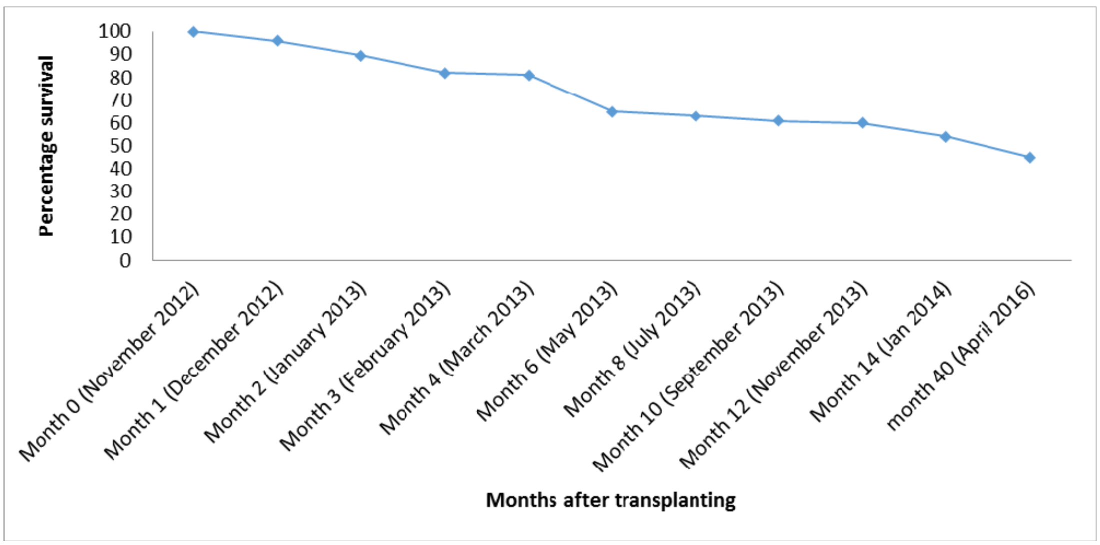


Figure 6. Survival percentages of all seedlings transplanted at the experimental site (Grid A, Navachab Gold Mine) from 1 month to 40 months

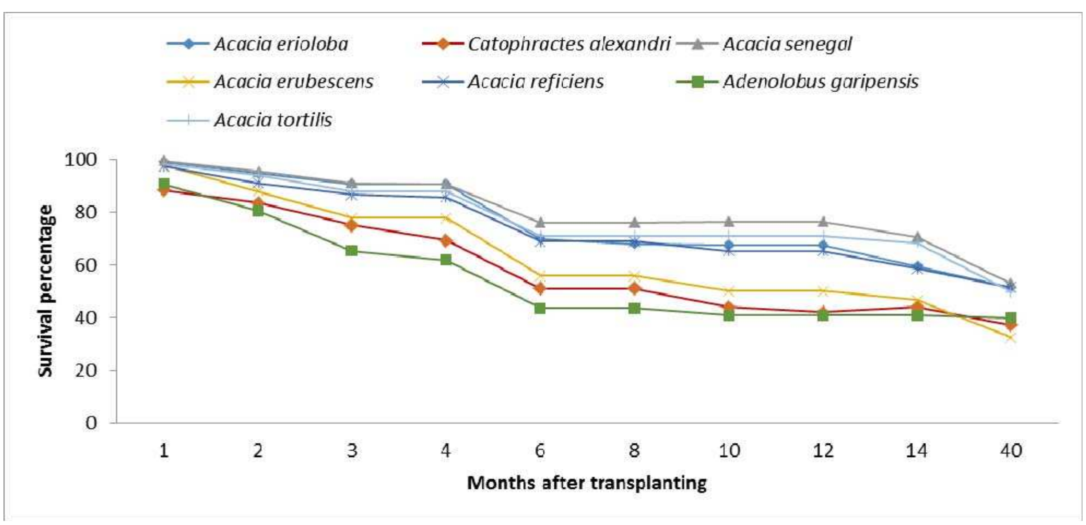


Figure 7. Survival percentage of seedlings of all the species across all the substrates from one month to 40 months after transplanting at Grid A experimental site, Navachab

In the fortieth month, *Acacia senegal* showed the highest survival percentage (53%) followed by *Acacia erioloba* (52%), *Acacia reficiens* (52%) and *Acacia tortilis* (50%) respectively (Fig 8a). At the lower end, species with survival percentage below 50% were *Adenolobus garipensis* (42%) *Catophractes alexandri* (37%) and *Acacia erubescens* (32%) (Figure 8b). Among substrate types, the highest survival of seedlings was recorded in K25 followed MC, S25 and by T25 respectively. Survival was lowest in C, M and K (Figure 8b).

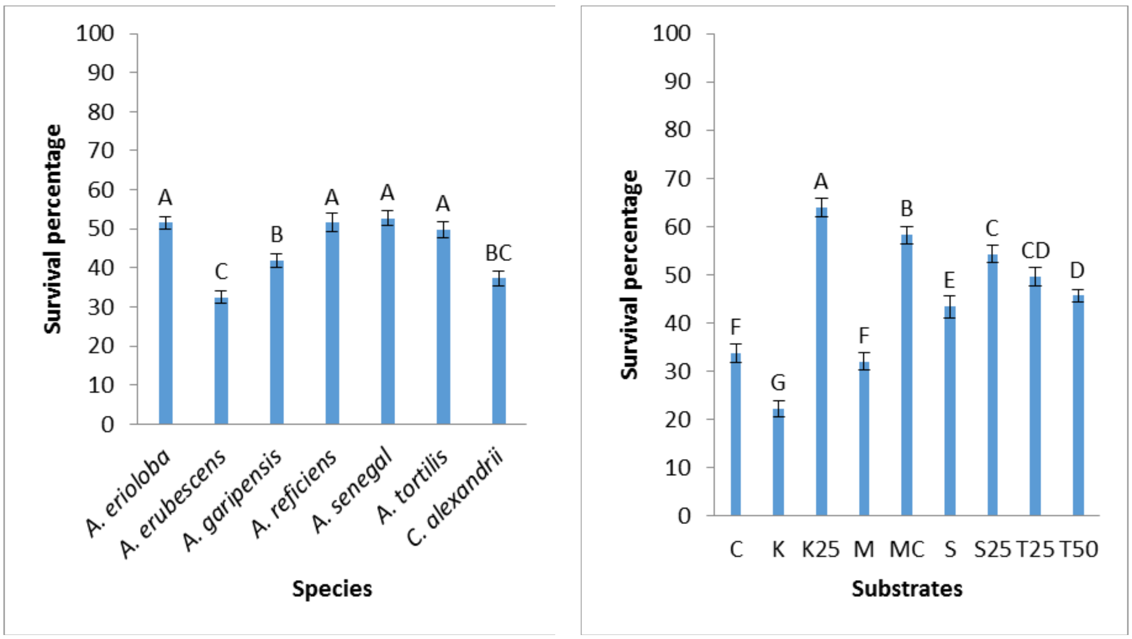
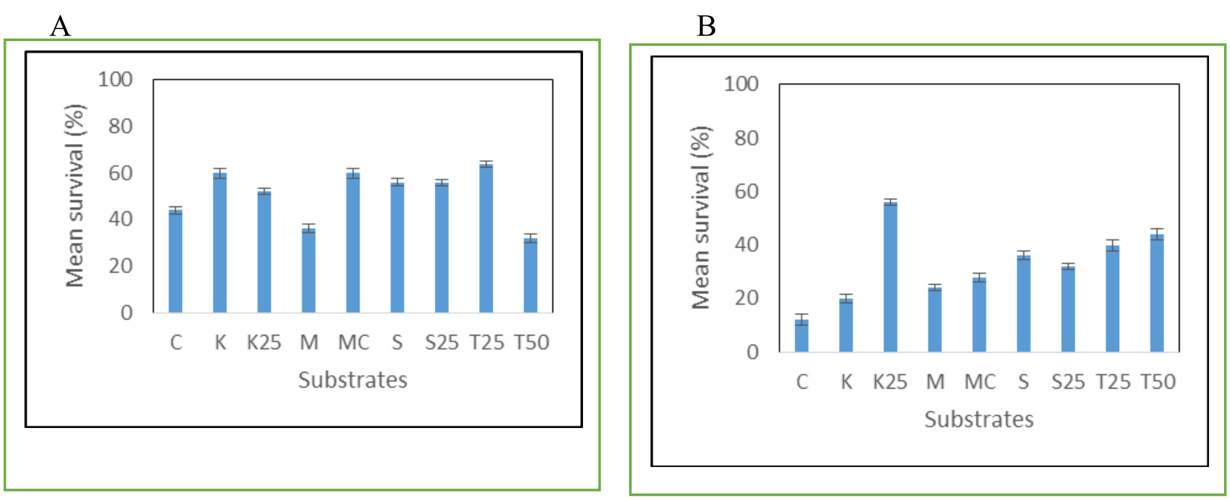
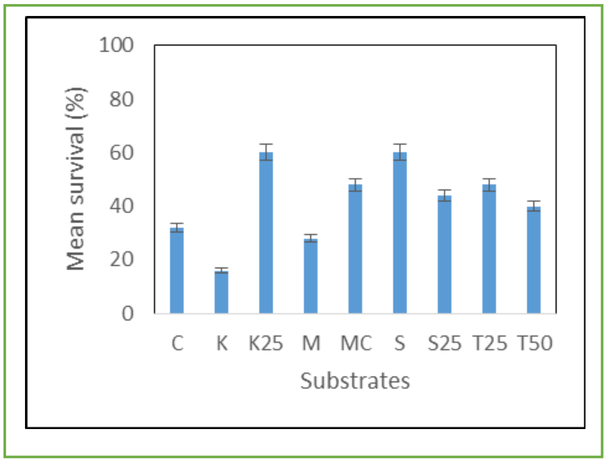


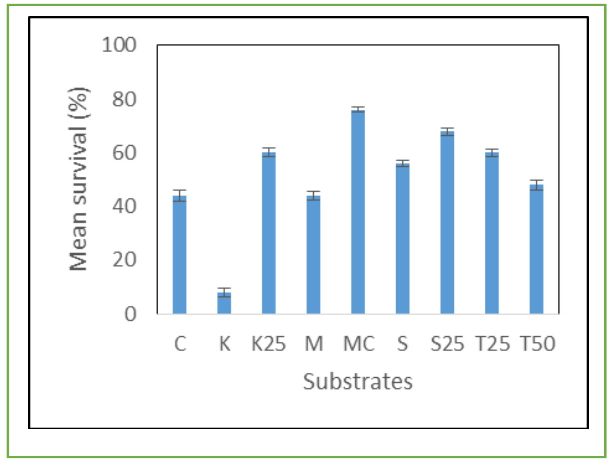
Figure 8. A) Mean survival percentage of all seedlings across all seven species and B) mean survival across all nine substrates, 40 months after transplanting the seedlings at the experimental site (Navachab Gold Mine, Namibia). (Bars are standard errors of the mean, different lowercase letters indicate significant difference among means within entry)



C



D



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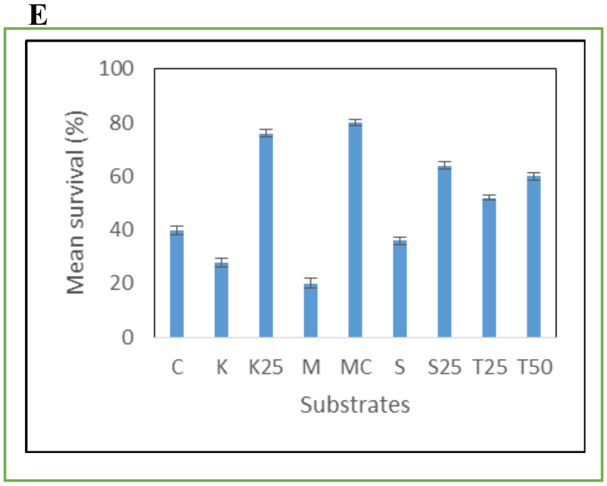
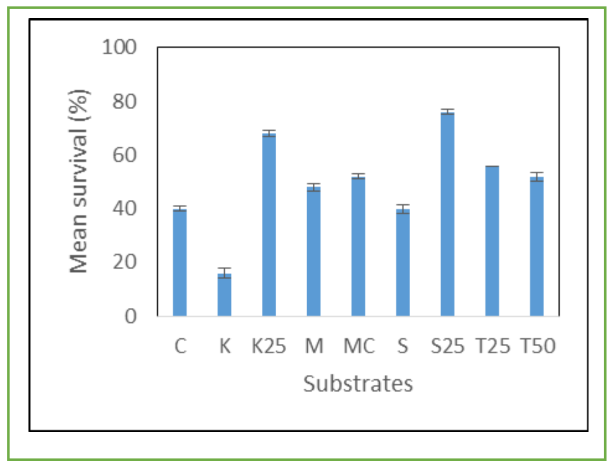


F



G

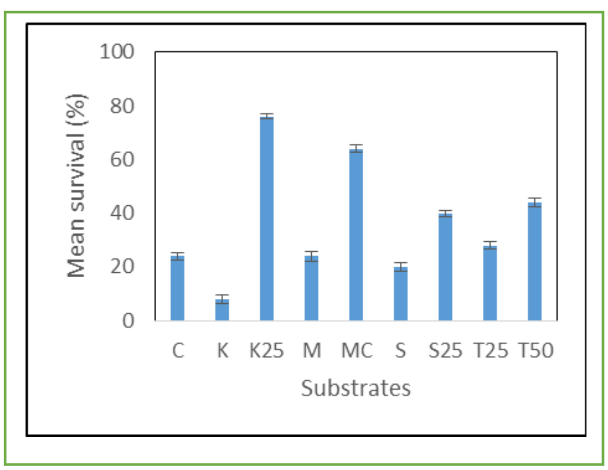


Figure 9. Survival performance of all species in different substrates 40 months after transplant at the experimental site (Grid A) Navachab Gold Mine, Namibia. (Bars are standard errors). Species are: A) *Acacia erioloba* B) *Acacia erubescens* C) *Adenolobus garipensis* D) *Acacia reficiens* E) *Acacia senegal* F) *Acacia tortilis* G) *Catophractes alexandri*

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 3). It also showed that there was no significant interaction between substrates and species in determining the growth of seedlings (Table 3).

The average growth of all the seedlings for all the species across all the substrates was 888cm in the fortieth month, and the seedlings showed a general increase in vegetative growth (cumulative stem length increase) from 2 months to 40 months (Figure 10). Increased growth in seedlings was observed in all the species every month (Figure 11 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 4257 cm in the fourtieth month. This was followed by *Acacia senegal*, *Acacia tortilis* and *Acacia erioloba* respectively. The lowest growth was recorded in *Catophractes alexandri* followed by *Acacia erubescens* (figure 12).

Acacia erioloba grew best in K, and it grew poorest in S (Figure 13a). *Acacia erubescens* grew best in K25 and poorest in M. *Acacia senegal* grew best in K and K25, and poorest in S. *Acacia reficiens* grew best in K and poorest in S. *Acacia tortilis* grew best in M and poorest in S. *Catophractes alexandri* grew best in K and poorest in K25 (Figure 13 a-f). *Adenolobus garipensis* recorded its highest growth in S (Schist) and its poorest in K (Figure 13g). Figure 13 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 3. Results of GLM for seedling growth (cumulative stem length) 40 months after transplanting at the experimental site (Grid A), Navachab Gold Mine

Model: quasi Poisson, link: log

Response: Growth

	Df	Deviance	Resid. Df	Resid. Dev	F	Pr(>F)	
NULL			314	630756			
Substrate	8	16270	306	614486	3.3524	0.001143	**
Species	6	416058	300	198428	114.3026	0.000010	***
Substrate:Species	48	38747	252	159681	1.3306	0.085093	.

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

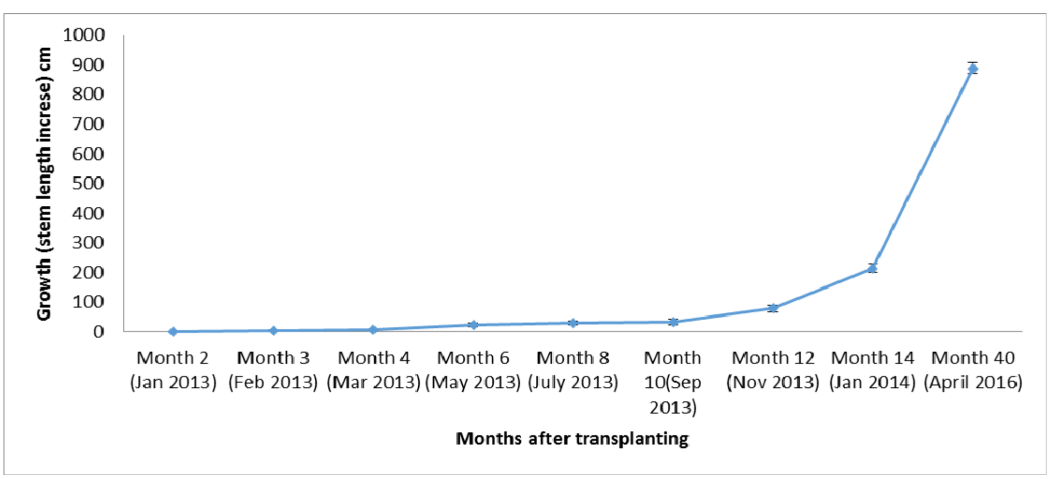


Figure 10. Average growth (cumulative stem length) of all seedlings across all the substrates at the experimental site (Grid A, Navachab Gold Mine) from the second to the fortieth month

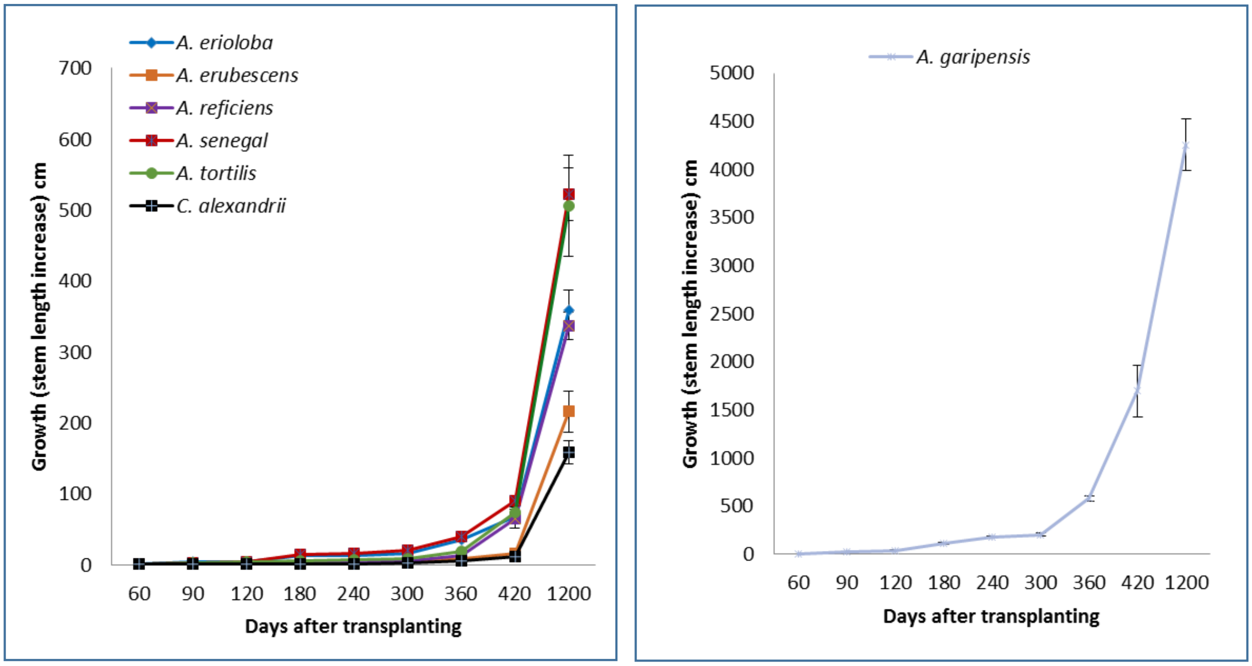


Figure 11. Average growth of seedlings across all the substrates for the six species (A) and for Adenolobus garipensis (B) from 2 months to 40 months after transplanting at Grid A experimental site, Navachab, (Bars are standard errors).

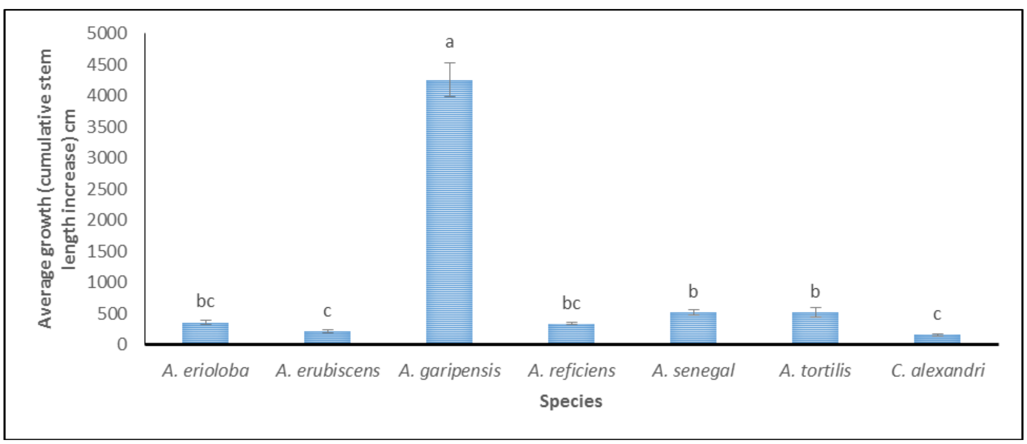
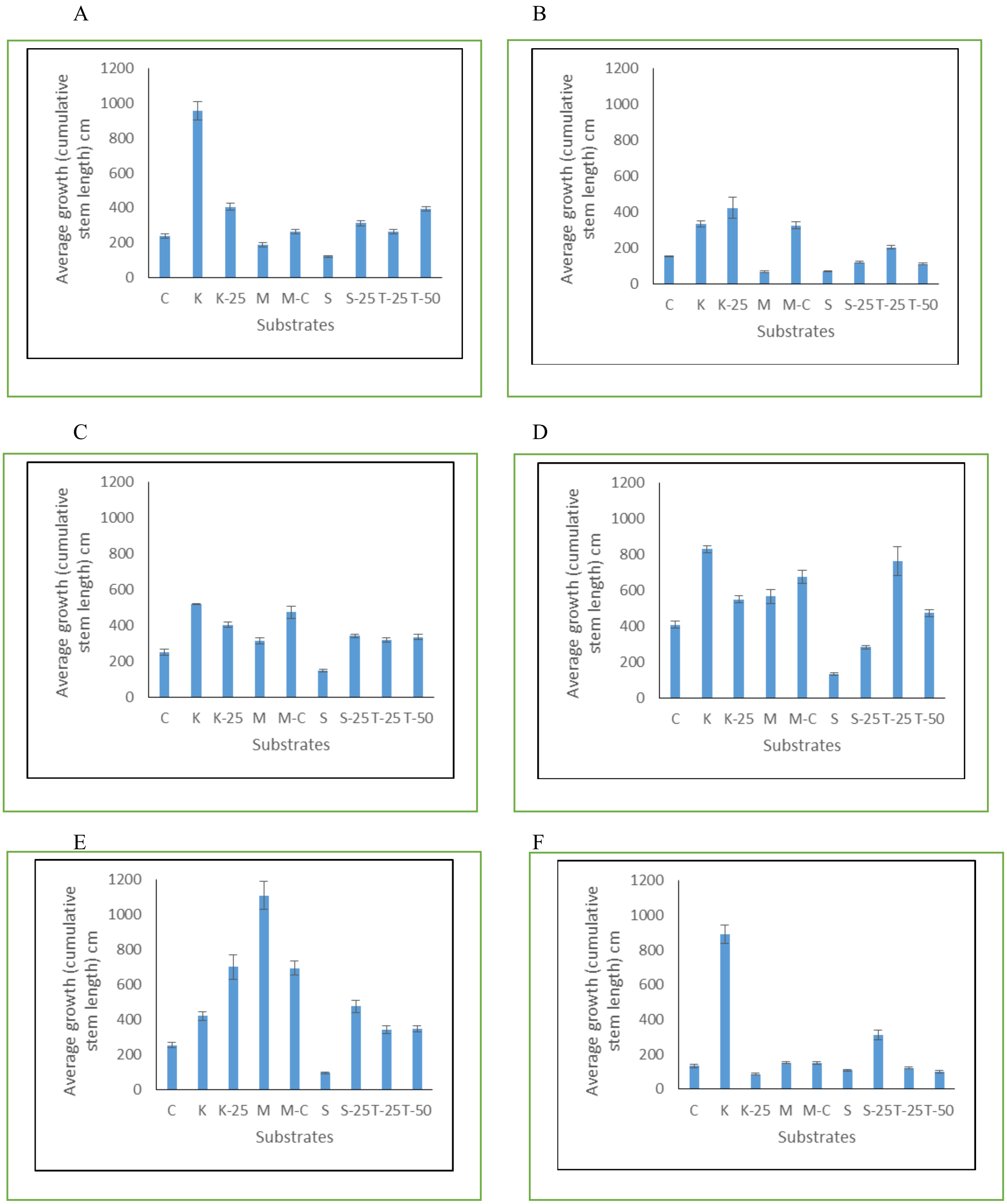


Figure 12. Average growth (cumulative stem length increase) of seedlings in all seven species 40 months after transplanting at the experimental site (Navachab Gold Mine, Namibia). Bars are standard errors; different lowercase letters indicate significant difference among means within the entry.


A
Average growth (cumulative stem length) cm
0 200 400 600 800 1000 1200
C K K-25 M M-C S S-25 T-25 T-50
Substrates
B
Average growth (cumulative stem length) cm
0 200 400 600 800 1000 1200
C K K-25 M M-C S S-25 T-25 T-50
Substrates
C
Average growth (cumulative stem length) cm
0 200 400 600 800 1000 1200
C K K-25 M M-C S S-25 T-25 T-50
Substrates
D
Average growth (cumulative stem length) cm
0 200 400 600 800 1000 1200
C K K-25 M M-C S S-25 T-25 T-50
Substrates
E
Average growth (cumulative stem length) cm
0 200 400 600 800 1000 1200
C K K-25 M M-C S S-25 T-25 T-50
Substrates
F
Average growth (cumulative stem length) cm
0 200 400 600 800 1000 1200
C K K-25 M M-C S S-25 T-25 T-50
Substrates

G

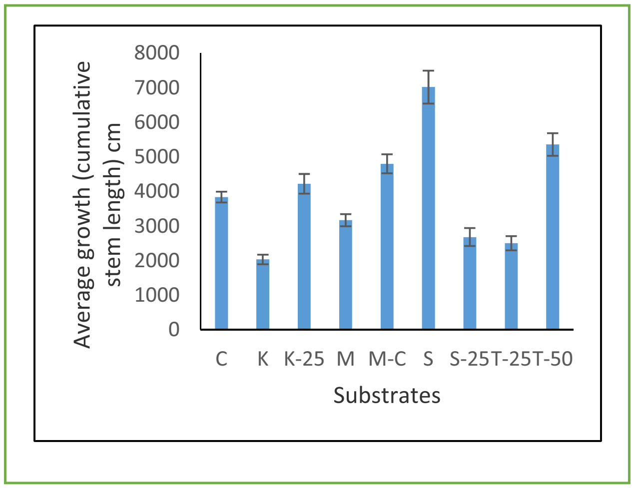


Figure 13. Growth (cumulative stem length increase) of all the 7 species compared in different substrates at forty months after transplant at Grid A, Navachab Gold Mine, (Bars are standard errors of the mean). Species are: A) *Acacia erioloba* B) *Acacia erubescens* C) *Acacia reficiens* D) *Acacia senegal* E) *Acacia tortilis* F) *Catophractes alexandri* G) *Adenolobus garipensis*

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 and lowest in M. Phosphorus was highest in S25 and MC and lowest in T50. Sodium, potassium and magnesium were highest in S and lowest in M. Calcium was highest in S25 and lowest in M. The highest sand content was recorded in K and highest clay content was recorded in S25. (Table 4).

Table 4. Soil physical and chemical properties of the nine substrates

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 /kg)	3	2	43	3	0	41	3	1	1
Sodium (mg/kg)	171	72	73	9	51	36	65	81	3
Potassium (mg/kg)	141	62	92	68	72	75	106	60	61
Magnesium (mg/kg)	289	213	205	47	124	171	168	133	50
Calcium (mg/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

Survival of *Acacia senegal*, *Acacia tortilis, and Catophractes alexandri* was significantly and positively correlated with conductivity. Calcium was positively and significantly correlated with the survival of *Adenolobus garipensis*, *Acacia reficiens,* and *Acacia senegal*. Sodium and Magnesium were significantly and positively correlated with the survival of *Adenolobus garipensis* and negatively and significantly correlated with the growth of almost all the other species. Calcium carbonate equivalent was also positively and significantly correlated with the survival of most of the species. Sand was negatively and significantly correlated with the survival of *Adenolobus garipensis* (Table 5 a-b).

Table 5. A) Survival and B) Growth of each species correlated with various soil properties

A

		A. erioloba	*A. erubescens*	*A.garipensis*	*A. reficiens*	*A.senegal*	*A. tortilis*	*C.alexandri*
Conductivity (mS/m)	Pearson Correlation	.026	.650	.559	.643	**.844****	**.792***	**.711***
	Sig. (2-tailed)	.947	.058	.118	.062	.004	.011	.032
	N	9	9	9	9	9	9	9
Organic carbon (% m/m	Pearson Correlation	-.220	.253	-.033	-.031	.000	-.022	-.157
	Sig. (2-tailed)	.569	.511	.933	.936	1.000	.955	.687
	N	9	9	9	9	9	9	9
Organic matter (% m/m	Pearson Correlation	-.070	.516	.228	.305	.440	.359	.262
	Sig. (2-tailed)	.857	.155	.555	.425	.235	.343	.496
	N	9	9	9	9	9	9	9
Phosphorus (mg /kg)	Pearson Correlation	.390	-.121	.157	.578	.550	.453	.362
	Sig. (2-tailed)	.299	.757	.686	.103	.125	.221	.338
	N	9	9	9	9	9	9	9
Sodium (mg /kg)	Pearson Correlation	.219	.339	**.749***	0.38081	0.12865	.191	.034
	Sig. (2-tailed)	.572	.372	.020	.312	.742	.623	.931
	N	9	9	9	9	9	9	9
Potassium (mg /kg)	Pearson Correlation	.446	.191	.524	.284	-.090	.023	-.294
	Sig. (2-tailed)	.229	.622	.147	.460	.817	.952	.442
	N	9	9	9	9	9	9	9
Magnesium (mg /kg)	Pearson Correlation	.286	.077	**.667***	0.5685	0.26042	.271	.064
	Sig. (2-tailed)	.455	.843	.050	.110	.499	.481	.870
	N	9	9	9	9	9	9	9
Calcium (mg /kg)	Pearson Correlation	.232	.465	**.741***	**.736***	**.777***	.605	.544
	Sig. (2-tailed)	.548	.208	.022	.024	.014	.085	.130
	N	9	9	9	9	9	9	9
Sand (%)	Pearson Correlation	-.298	-.554	**-.700***	-.575	-.449	-.429	-.183
	Sig. (2-tailed)	.435	.122	.036	.106	.225	.249	.638
	N	9	9	9	9	9	9	9
Silt (%)	Pearson Correlation	.267	.547	**.689***	.566	.437	.412	.176
	Sig. (2-tailed)	.488	.128	.040	.112	.239	.271	.651
	N	9	9	9	9	9	9	9
Clay (%)	Pearson Correlation	.572	.522	**.678***	.555	.488	.531	.224
	Sig. (2-tailed)	.107	.150	.045	.121	.182	.141	.563
	N	9	9	9	9	9	9	9
% CaCO3 equivale	Pearson Correlation	.150	.648	.562	**.709***	**.932****	**.779***	**.794***
	Sig. (2-tailed)	.699	.059	.115	.032	.000	.013	.011
	N	9	9	9	9	9	9	9
Infiltration rate	Pearson Correlation	-.166	**-.677***	-.400	-.345	-.329	-.430	-.371
	Sig. (2-tailed)	.669	.045	.287	.363	.388	.248	.325
	N	9	9	9	9	9	9	9

*. Correlation is significant at the 0.05 level (2-tailed).

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

B

		A. erioloba	*A. erubescens*	*A.garipensis*	*A. reficiens*	*A.senegal*	*A. tortilis*	*C.alexandri*
Conductivity (mS/m)	Pearson Correlation	-.142	.126	.183	.118	-.270	-.075	-.325
	Sig. (2-tailed)	.715	.747	.637	.763	.483	.849	.394
	N	9	9	9	9	9	9	9
Organic carbon (% m/m	Pearson Correlation	-.040	-.299	.033	-.136	.231	-.313	-.208
	Sig. (2-tailed)	.919	.435	.934	.728	.549	.413	.591
	N	9	9	9	9	9	9	9
Organic matter (% m/m	Pearson Correlation	-.080	-.054	.007	.059	.242	-.189	-.321
	Sig. (2-tailed)	.837	.889	.986	.881	.531	.627	.400
	N	9	9	9	9	9	9	9
Phosphorus (mg /kg)	Pearson Correlation	-.128	.090	-.106	.310	-.105	.143	.036
	Sig. (2-tailed)	.743	.817	.786	.416	.788	.713	.926
	N	9	9	9	9	9	9	9
Sodium (mg /kg)	Pearson Correlation	-.484	-.248	**.683***	**-.728***	**-.757***	**-.657**	-.427
	Sig. (2-tailed)	.187	.521	.043	.026	.018	.044	.251
	N	9	9	9	9	9	9	9
Potassium (mg /kg)	Pearson Correlation	-.372	-.407	.442	-.591	-.484	-.596	-.168
	Sig. (2-tailed)	.325	.277	.233	.094	.187	.090	.666
	N	9	9	9	9	9	9	9
Magnesium (mg /kg)	Pearson Correlation	-.607	-.305	.581	**-.673***	**-.731***	**-.658**	-.477
	Sig. (2-tailed)	.083	.426	.101	.047	.025	.054	.195
	N	9	9	9	9	9	9	9
Calcium (mg /kg)	Pearson Correlation	-.415	.049	.413	-.251	-.401	-.512	-.542
	Sig. (2-tailed)	.267	.900	.269	.515	.284	.159	.132
	N	9	9	9	9	9	9	9
Sand (%)	Pearson Correlation	.393	.219	-.415	.400	.340	.594	.441
	Sig. (2-tailed)	.295	.571	.267	.286	.371	.092	.234
	N	9	9	9	9	9	9	9
Silt (%)	Pearson Correlation	-.405	-.234	.429	-.413	-.331	-.597	-.462
	Sig. (2-tailed)	.280	.544	.249	.269	.385	.090	.211
	N	9	9	9	9	9	9	9
Clay (%)	Pearson Correlation	-.195	-.022	.181	-.190	-.371	-.448	-.142
	Sig. (2-tailed)	.615	.955	.642	.624	.325	.227	.715
	N	9	9	9	9	9	9	9
% CaCO3 equivale	Pearson Correlation	-.167	.309	.053	.242	.038	.001	-.408
	Sig. (2-tailed)	.667	.419	.892	.530	.923	.997	.275
	N	9	9	9	9	9	9	9
Infiltration rate	Pearson Correlation	.013	-.091	-.089	-.228	-.077	-.343	.066
	Sig. (2-tailed)	.973	.816	.821	.555	.845	.366	.865
	N	9	9	9	9	9	9	9

*. Correlation is significant at the 0.05 level (2-tailed).

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

Based on the CCA results, 90.1% of seedling growth-soil variation was explained by axis 1-2 (Table 6 a). Axis 1 (Eigenvalue: 0.119) accounted 70.1% of variance. Magnesium and sodium (showing the longest arrows) were more correlated with this Axis and therefore closely related to the species (*Adenolobus garipensis*) in that ordination (Figure 14). Axis 2 (Eigenvalue 0.034) accounted for 19.9% of variance. Sand and infiltration rate (showing the longest arrows) was more correlated with axis 2 (Table 6a) and therefore closely related to the species in that ordination (*Acacia erioloba* and *Acacia erubescens*).

In seedling survival, 72.8% of the variance between soil properties and survival of seedlings was explained with axis 1-2. Axis 1(Eigenvalue 0.033) explained 50.5% of the variance and was dominated by CaCO3 and conductivity. This axis was associated with *Catophractes alexandri* and *Acacia tortilis*. Axis 2 (Eigenvalue 0.014) was strongly correlated with sodium, magnesium and potassium (Table 7 b) and associated with *Adenolobus garipensis* and *Acacia erubescens* (Figure 15). It explained only 29.9% of the variance.

Table 6. Results from the CCA analysis for A) Seedling growth and B) seedling survival

A

	Axis 1	Axis 2
Eigenvalues	0.119	0.034
% variation explained	70.113	19.988
Cumulative Percentage	70.113	90.101
Cum.Constr.Percentage	70.113	90.101
Spec.-env. correlations	1	1

B

	Axis 1	Axis 2
Eigenvalues	0.033	0.014
% variation explained	50.575	22.226
Cumulative Percentage	50.575	72.801
Cum.Constr.Percentage	50.575	72.801
Spec.-env. correlations	1	1

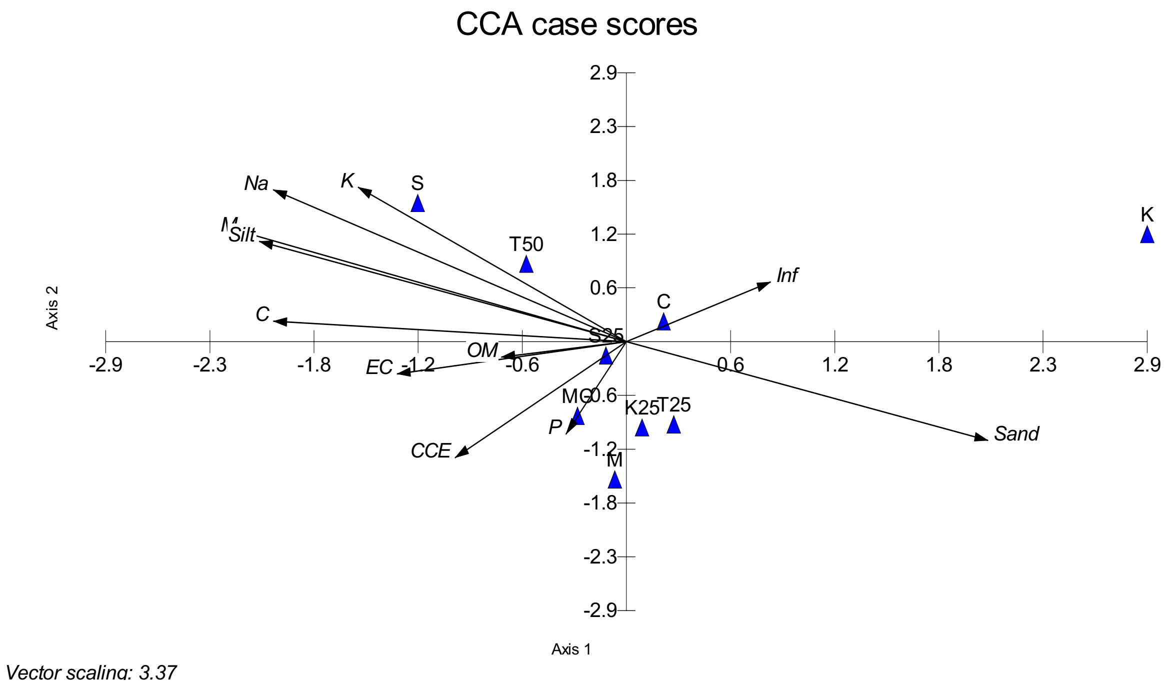
Table 7. Correlations of the environmental variables with the axis 1 and 2 for A) seedling growth and B) seedling survival

A

	Envi. Axis 1	**Envi. Axis 2**
Conductivity (mS/m)	-0.382	-0.104
Calcium (mg /kg)	-0.587	0.066
OM	-0.208	-0.05
Potassium (mg /kg)	-0.446	0.498
Sodium (mg /kg)	-0.588	0.489
Sand (%)	0.602	-0.318
Magnesium (mg /kg)	-0.641	0.355
% CaCO3 equivalent	-0.285	-0.373
Silt (%)	-0.611	0.323
Infiltration rate	0.24	0.192
Phosphorus (mg /kg)	-0.101	-0.298

B

	Envi. Axis 1	**Envi. Axis 2**
Conductivity (mS/m)	-0.639	0.317
Calcium (mg /kg)	-0.508	0.1
OM	-0.28	0.158
Potassium (mg /kg)	0.305	-0.562
Sodium (mg /kg)	-0.003	-0.39
Sand (%)	0.147	0.224
Magnesium (mg /kg)	-0.065	-0.555
% CaCO3 equivalent	-0.665	0.424
Silt (%)	-0.151	-0.226
Infiltration rate	0.266	-0.11
Phosphorus (mg /kg)	-0.225	0.07



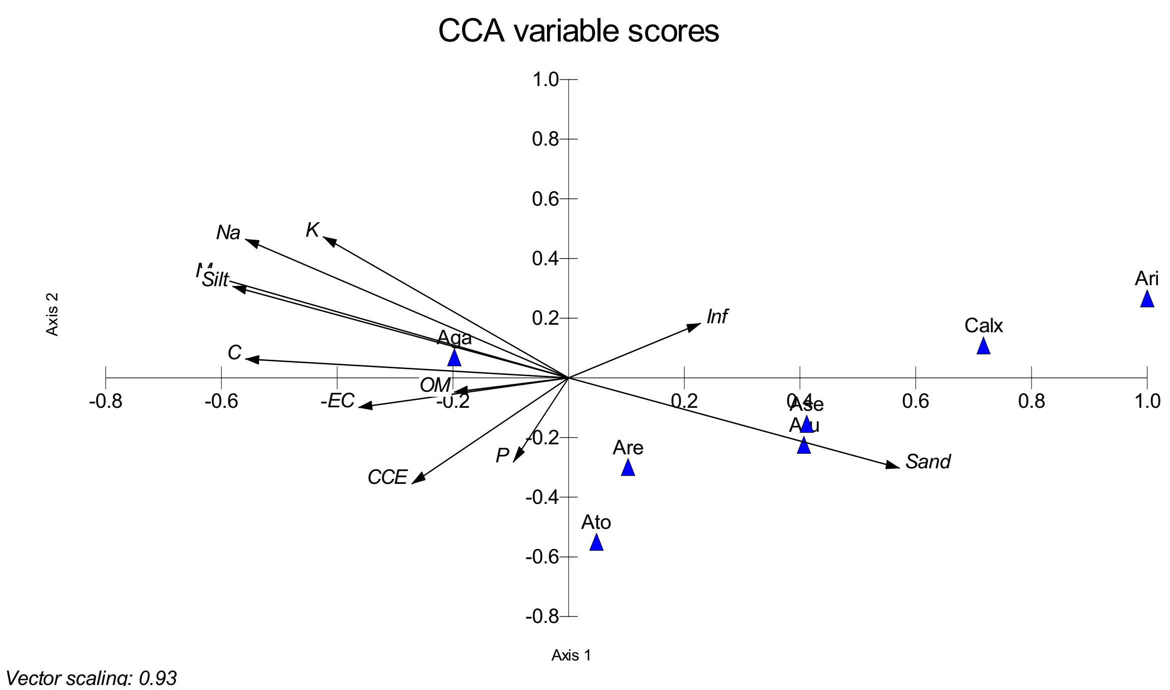


Figure 14. CCA-ordination of species A)growth and B)substrates in relation to soil properties based on Axis 1and 2.

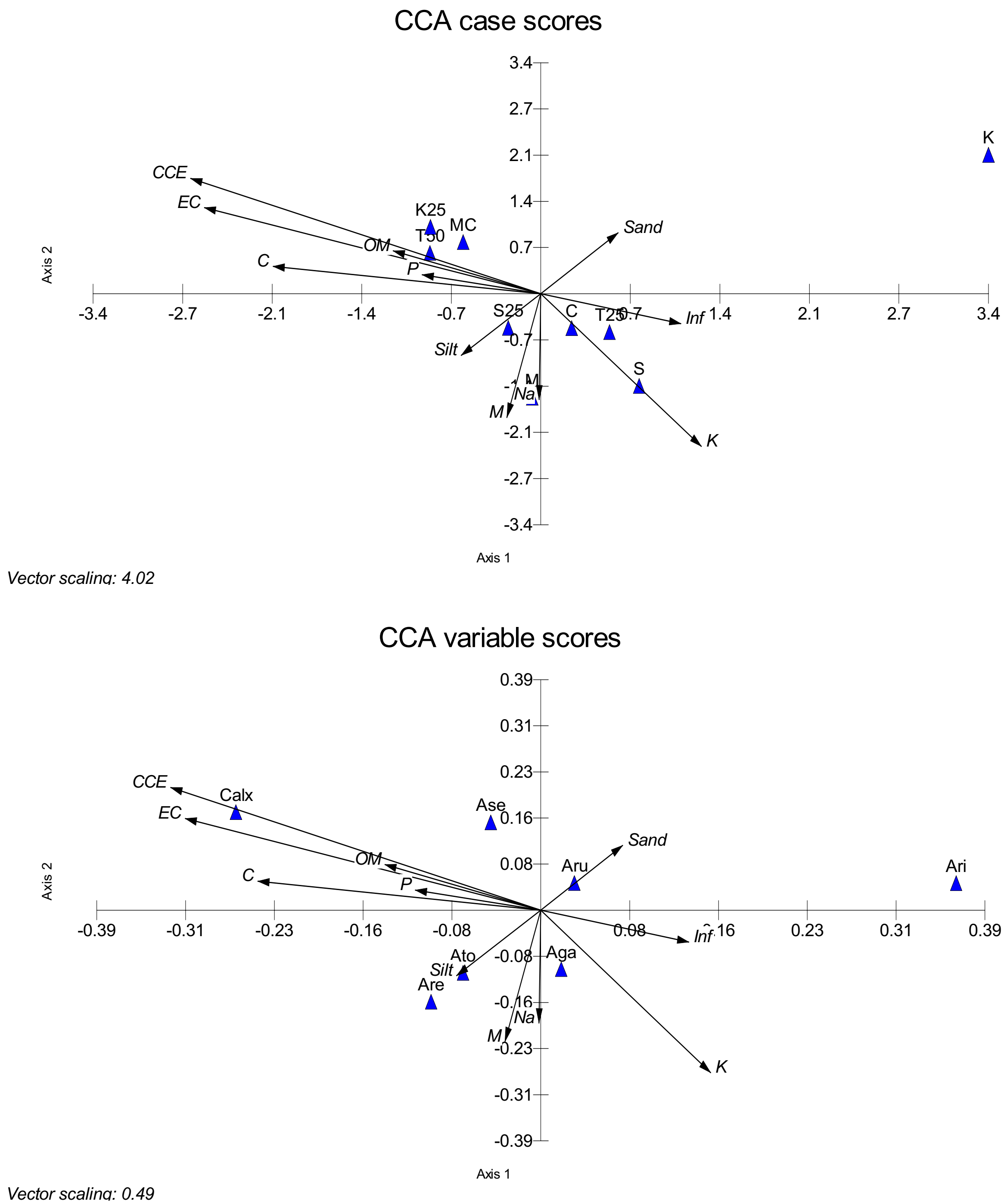


Figure 15. CCA-ordination of species survival and substrates in relation to soil properties based on Axis 1and 2.

Figure 14 and 15 ordination diagram: represents species or substrates, and arrows represent soil properties. The first axis is vertical and second axis is horizontal. Shown also are the projections of the substrates labeled 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*, Aru = *Acacia erubescens*, Ari=*Acacia erioloba*, Ato=*Acacia tortilis* and Aga= *Adenolobus garipensis*. The environmental variables are clay, silt, sand, K=potassium, CCE=Calcium carbonate equivalents, P =Phosphorus, Na=Sodium, Mg=Magnesium, Infil=Infiltration rate, C=Calcium and EC= conductivity, OM=Organic matter.

Discussion

Seedling Survival

In this study, 61% of seedlings were still surviving in the first year. After three years only 45% had survived, and this is despite the dry environment with little or no rain. In dry regions, several studies have shown that survival of seedlings is strongly affected by water stress and drought conditions (Davis et al., 1999; Elfeel & Mohamed, 2011). After establishment, however, seedlings tend to be less affected by abiotic and biotic factors (Davis et al., 1999). In the present study, the surviving seedlings were well developed and reached a large size in three years. The survival of nursery-raised seedlings in some studies has often been poor, and this is attributed to drought and browsing by animals among others. In the present study browsing by animals and drought were also factors. We speculate that moisture stress affected the survival of seedlings, and the nature of the mined substrates posed a challenge to the survival of seedlings.

Percentage survival was highest in *Acacia senegal* followed by *Acacia erioloba, Acacia reficiens,* and *Acacia tortilis* respectively. The species showing the lowest survival was *Acacia erubescens* followed by *Catophractes alexandri.* 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* has 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 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 & Mohamed, 2011; Mensforth, Thorburn, Tyerman, & Walker, 1994; Sun & Dickinson, 1995).

Elfeel & Mohamed (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 a 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) stated that the adaptation of plant species to their biotic and abiotic environment is manifested in their traits. Plant adaptation strategies revealed 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 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 the 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 the lowest survival in the first year and highest growth. After the first year, it still grew exponentially, and its survival remained constant. 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 the establishment. It appears however that the surviving seedlings, once established have a very good chance of survival.

Regarding survival performance in different substrates, the present study indicates that survival was highest in, K-25, followed by MC, S-25 and T-25 and lowest in K, M, and C respectively. Generally, a suitable substrate has both chemical and physical properties that promote growth and survival. Survival of most species was significantly correlated with conductivity, calcium, clay and CaCO3 equivalents. High level of the above-mentioned soil properties were also recorded in K-25, S-25, and MC, 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 other factors 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, these are however still poorly understood.

Joseph, Tom, & Robert (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. Some 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 compositions of salts contributing to the values of EC are actually not known. Dierickx (2009)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 was 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 the material is very coarse, the 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 could also have 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, Sheoran, & Poonia (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 containing a high level of soluble salts.

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 to 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 the 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 the overall performance of species is a major 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 three times better in this substrate than in the rest of the substrates. Schist is also the substrate that recorded 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 & 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 inhibit 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 sand veld (R. 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, Aranibar, Mantlana, & Macko, 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 of 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 survive in rocky substrates.

The highest growth in most of the species was recorded in K25, MC and T25. These substrates also recorded the highest survival of seedlings compared to the rest of the substrates. As we see here, it is the mixed substrates that recorded both high growth and survival compared to pure substrates. As discussed earlier, these substrates were rich in calcium, clay, CaCO3 and conductivity which were also positively correlated and ordinated with the survival of most of the studied species. Perhaps these properties make them preferable to other substrates. According to Chave (2008), certain environmental features prevent the establishment of plants that do not present specific adaptations to the chemical composition of soils, water availability, or light availability. Soils may contain metals toxic to certain plants; other species may be unable to establish in the anoxic soils. In all these cases, species that have not developed particular adaptations to cope with the specific site conditions will be unable to establish.

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 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. 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 wide distributed species such as *Catophractes alexandri* and *Acacia erubescens*.

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. We speculate that differences in individual functional traits clearly underlie species differences in growth and survival of seedlings.

Conclusions

A number of standard factors are considered in making decisions on selecting which species can be used for rehabilitation and revegetation. These 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 of the selected species, germination requirements and how they perform in different substrates. In this study, the above factors were considered. We suggest that we cannot simply match species to habitats based on how widely distributed they are in nature. Mined soils tend to be a poor medium for plant growth due to factors such as lower aggregate stability, poor infiltration rates and reduced water holding capacity. This inhibits the potential for plant growth and establishment. So in selecting the suitable species to use in rehabilitation or restoration projects, it is critical to assess their performance in mined soils. One can then combine the other factors such as their distribution patterns and their germination requirements to select the suitable species.

Many reclamation experiments do soil amendments to accommodate different species. However, we 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. 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

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 the study area. Understanding relationships between mined 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. We speculate that differences in individual functional traits clearly underlie species differences in growth and survival of seedlings.

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