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ASSESSMENT OF GERMINATION AND EARLY GROWTH PERFORMANCE OF THREE TREE SPECIES (GERRARDI, A. KARROO AND A POLYCANTHA) ON MINE TAILINGS DAM: A CASE STUDY OF FREDA REBECA MINE

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DEDICATION

I dedicate this research project to my parents .

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I want to thank God Almighty for his grace and favour towards the completion of my research. I also want to acknowledge and thank my project supervisor for his guidance and supervision throughout my research project..Finally I extend my thanks to all the lectures at the Faculty of Agriculture and Environmental Science, Department of Natural Resources Management

ABSTRACT

Indigenous acacia species are preferred in mine dump revegetation because of their ability to colonize hostile environments, enhance soil fertility and meet the livelihood and cultural needs of local communities. This study compared early growth performance of three indigenous A*cacia* species namely *A. gerrardii*, *A. karroo* and *A. polyacantha* established on Gold Mine tailings amended with top soil, sewage sludge, and compound fertilizer.Growth performance in height and root collar diameter (RCD) were measured monthly using a meter rule and a veneer caliper respectively and survival was determined at the end of a six-month period. A completely randomized block design with 12 treatments replicated three times was used. Survival and relative growth rates in height and RCD (RGRh and RGRd), were tested for significant differences among treatments through analysis of variance using SPSS Package.Overall, there were no significance differences (P>0.05) in survival among the *Acacia* species but variation in survival (P>0.05) was observed among amendments. Species growth performance also varied (P > 0.05) among amendment materials and across species. It was concluded all the three species can be used in revegetation of nickel mine tailings dumps under similar conditions.

KEYWORDS: Survival, Growth Performance, Amendments.

Contents

CHAPTER 1

INTRODUCTION

1.1 Background to the study

Tailings dams are hydraulic structures that are created to store large quantities of mine waste (Neina et al., 2019; Gitari et al., 2018; Ginocchio et al., 2017; Pak & Nabipour, 2017; Wang et Fal., 2014) and can be either a retention dam or raised embankments . A single tailings dam can cover several square kilometres and the dam walls can be tens of meters high (Schoenberger, 2016). Once the dam is taken into use, the materials disposed into the dam are in a slurry-based form (Wang et al., 2014), consisting of solid sediments and fluid waste water (Shamsai et al., 2007) as well as heavy metals and sulphides (Chileshe et al.,2019; Kaninga et al., 2019; Ngulube et al., 2016). Tailings dams often consist of fine-grained material ranging from 625 mm to 2 mm (Edraki et al., 2014; Kossoff et al., 2014), depending on the parent rock and are homogenous. Common characteristics of tailings are high bulk density, compaction due to the fine soil texture and low infiltration rate (Ginocchio et al.2017; Mensah, 2015; Titshall et al., 2013; Wong, 2003), and a low water holding capacity (Ginocchio et al., 2017; Shi et al., 2016; Ssenku et al., 2014).

Tailings dumps usually yield extremely harsh surroundings, including large quantities of waste materials, high concentrations of pollutants of the mined metal and the associated metals (Wild, 1993), and severely infertile soils (Bradshaw, 1997; Bradshaw and Huttl, 2001). In many instances, the dumps have been abandoned in a highly disturbed condition, with limited or no rehabilitation treatment (Gardner, 2001). These destroyed lands are almost completely devoid of vegetation due to serious pollution, and eventually produce severe soil erosion and off-site pollution.

The re-vegetation of tailing dumps is made difficult due to the fact that the dumps are composed of freshly crushed rock, which lacks essential mineral nutrients for plant growth and contains phyto-toxic chemical elements. Gold mine tailings are particularly infertile (generally deficient in N, P and K), and high in toxic elements (Ni, Mg) and very vulnerable to erosion (Winter

Sydnor and Redente, 2002). The natural process of re-colonization by pioneer species is extremely slow and sometimes simply does not happen. Revegetation efforts by the mining industry started in 1965, (Gardner, 2001) and used to be done in a rudimentary nature without any amendments being applied to the tailings. Later on top soil was applied on tailings and an arbitrary amount of organic fertilizer but the trees generally grew very poorly and many were uprooted and toppled by wind as a result of nutrient deficiency (Gardner, 2001). Under current practices, direct return of top soil is favored as it enhances the return of viable seeds, nutrients, organic matter and beneficial soil micro-organisms. To maintain these important soil properties at the surface, the topsoil is stripped and returned in as thin a layer as possible. Most efforts to counter the effects of tailings dumps in the past have been based on fast-growing exotic trees such as eucalypts (Mulizane et al., 2005). However, the use of exotic plants (Eucalyptus, Australian Acacias and Firs) often has the following shortcomings: failure to return the land to its natural state (Murdoch Eaton et al., 2017); high cost of establishment; and relatively low adaptation to low moisture and nutrient levels. According to Sarrailh and Ayrault (2001), those involved in rehabilitation projects have increasingly come to recognize the importance of using indigenous species not only for environmental reasons but also to meet the livelihoods and cultural needs of local communities who depend on forest products and services. Acacia species are among the most important pioneer species in the Southern African region (Spicer et al., 2005). The growth of indigenous trees facilitates the enhancement of soil properties such as soil structure, porosity, and moisture retention and erosion resistance. They also modify extreme soil temperatures that adversely affect vegetation growth and soil organisms and moderate the effects of leaching through the addition of bases to the soil surface and they have been used successfully to reclaim saline and alkaline soils.

As tailings are created during extraction of minerals and metals, the soils are young and lack cohesion (Asensio et al., 2018) and have limited organic matter (Titshall et al., 2013; Cooke & Johnson, 2002) and microbial activity (Ginocchio et al., 2017; Shi et al., 2016; Ssenku et al., 2014), can be acidic and contain elevated levels of heavy metals (Chileshe et al., 2019; Shi et al., 2016; Lottermoser, 2010; O'Dell et al., 2007).

The rate of litter fall and decomposition of acacia species are important factors for the future growth and establishment of vegetation through regulating the microbial activity in the soil (Raman and Madhoolika, 2003). Accordingly Spicer et al. (2005) added that these species attain satisfactory growth and produce sufficient biomass which is able to speed up the site occupancy by surface stabilization, restore soil fertility and may accelerate the natural regeneration of mine spoils.

In addition, Acacia species are well adapted to hot climates and a wide range of soil types and annual rainfall (150-1200 mm), (Hamad and Kamal, 2006). They are often described as hardy because they can tolerate droughts and water logging, infertile and highly saline or alkaline soils (ADEH, 2003). Acacias are generally fast growing and grow particularly well on bare ground. One of their most valuable attributes as described by Spicer et al. (2005) is their ability to fix nitrogen from the air with the aid of symbiotic bacteria (rhizoid) that live in their roots and enrich the soil with nitrogen. Although the idea of using indigenous species in re-vegetation of tailings dumps is now widely accepted,(Mulizane et al. 2005) highlighted the need for continued investigation into their establishment and growth performance. Therefore, the objective of the study was to compare the growth rate and germination rate.

1.2 Problem Statement

Rehabilitation of disturbed areas is often hindered by low seed germination and poor seedling establishment (Abari et al., 2012). Distribution and abundance of plants could be associated with variations in seed germination and seedling recruitment between various habitats and environmental conditions (Souza & Fagundes, 2014). As already mentioned, disturbed environments could negatively affect all aspects of reproductive biology. Range expansion of plants requires successful germination and seedling establishment (O'Connor, 2015).In this study, A gerrardii, A. karroo and A. polyacantha were used in the field to assess their growth performance during the reclamation and redevelopment of polluted and degraded soils.

1.3 JUSTIFICATION

These species has received justification from recent studies on plant communities of metal contaminated areas. Surveys of plant species surviving in long term heavy metal contaminated environments have revealed that these species constitute a dominant portion of the populations in these communities hence having potential for phytoremediation. These species exhibiting great environmental plasticity, with the ability to grow in impoverished or marginal soils and to accumulate high quantities of heavy metals and they has been applied as a hyper-accumulator plant for bioremediation of fly ash dumps elsewhere .

The three selected tree species have characteristics that were hoped to enhance the phytoremediation of polluted and degraded soils. The tree species are locally known to be resistant to draught and termites, fast growing and produce vast amount of seeds. They are also capable of enhancing nitrogen fixation, hence improving soil fertility of the nutritionally impoverished tailings and pyrite soils. By growing very fast the new vegetation cover will minimize soil erosion and lixiviation of hazardous heavy metals to aquifers or river systems by controlling direct rainfall impacts on bare soils and promoting the retention of water within the rhizosphere. Plant growth requirements are key components that determine the growth and survival of introduced species.

1.4 Aim

To compare early growth performance of three mentioned species

1.5 Objectives

- To determine the growth performance of the three species
- To compare the growth in height, basal diameter of the species

1.6 Research Hypotheses

Ho -The risk of tree depletion has no significant effects on the population status of the mentioned species

H1 -Storage conditions of seeds have no significant effects on germination.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Gold mining activities in Kilembe that lasted for close to 30 years from 1956 to 1982 generated an enormous volume of cobaltiferous pyrite wastes to the tune of 1.13 million metric tonnes that were stockpiled near Kasese town, 11 km east of the mines (Tusiime, F.M. et al 2007). Flotation tailings to the tune of 15 million metric tonnes were dumped in various areas in Kilembe valley in which the fast flowing River Nyamwamba is located (Pohl, W. et al 2009) . In total there are four tailings dams in the area. The cobaltiferous pyrite wastes and the tailings dams have remained acidic and devoid of vegetation for the last 30 years. The acid mine drainage emanating from these wastes has over the years polluted the nearby ecosystems without any mitigation measures instituted leading to wide spread environmental pollution in Queen Elizabeth Conservation Area (QECA)(Tusiime, F.M. et al 2007) and old Kilembe Copper Mining Area.In QECA the acid mine drainage from the wastes scarred and damaged shallow rooted vegetation creating bare ground over a large area, now popularly referred to as the pyrite trail, originally covering a total area of about 150 hectares and a distance of about 11 km to Lake George .Mitigation of the pollution most especially after closure of mining areas is still a global challenge most especially in the developing world due to the exorbitant costs involved when conventional techniques such as leaching of pollutant, vitrification, electro-kinetic treatment, excavation and off-site treatment are deployed (Barceló, J. et al. 2003). Such methods are expensive and technically limited to small areas. Amongst the various strategies adopted for removal of toxic heavy metals from the contaminated sites, phytoremediation has emerged as an economical, eco-friendly and aesthetically acceptable technology in the recent years (Vangronsveld, J. 2012) . It is a technique that involves the use of plants and soil microbes for removal and cleaning of pollutants from the soil including heavy metals.

Among the plants used in phytoremediation, trees are preferred to the shallow rooted plants because of their ability to treat the contaminants at greater depths, as their roots have the potential to penetrate more deeply into the ground. However, their success largely depends on their establishment and growth performance on sites to be remediated. In another study, one naturalized leguminous tree species Leucaena leucocephala (Lam.) De Wit.(Family Fabaceae), one exotic leguminous tree species Senna siamea (Lam.) H. S. Irwin & Barneby (Family Fabaceae) and one non leguminous fast-growing tree species Eucalyptus grandis W. Hill ex Maid (Family Myrtaceae) were used in the field to assess their growth performance during the reclamation and redevelopment of polluted and degraded soils. Selection of the legumes has received justification from recent studies on plant communities of metal contaminated areas. Surveys of plant species surviving in long term heavy metal contaminated environments have revealed that legumes constitute a dominant portion of the populations in these communities (Weia, G. et al.2013) hence having potential for phytoremediation. Eucalyptus grandis is a tree species exhibiting great environmental plasticity, with the ability to grow in impoverished or marginal soils and to accumulate high quantities of heavy metals (Ocampo, J.A.2004) while Senna siamea has been applied as a hyper-accumulator plant for bioremediation of fly ash dumps elsewhere (Jawarkar, A.A. 2009)

The three selected tree species have characteristics that were hoped to enhance the phytoremediation of polluted and degraded soils. The tree species are locally known to be resistant to draught and termites, fast growing and produce vast amount of seeds.(Joel etal 2019) Senna siamea and Leucaena leucocephala are legumes capable of enhancing nitrogen fixation, hence improving soil fertility of the nutritionally impoverished tailings and pyrite soils. By growing very fast the new vegetation cover will minimize soil erosion and lixiviation of hazardous heavy metals to aquifers or river systems by controlling direct rainfall impacts on bare soils and promoting the retention of water within the rhizosphere.

Plant growth requirements are key components that determine the growth and survival of introduced trees (Suresh, N. 2010) in a phytoremediation process. However, mine spoil habitats are nutritionally impoverished; characterized by low nitrogen mineralization rates, low phosphate availability, low soil organic matter, poor soil structure, compacted sub-soil, poor drainage and low water holding capacity(King, J.A. 1988). Like any other plant species, reduction of soil phytotoxicity is a precondition for growth of legumes on highly metal contaminated sites .Limestone and compost have been reported to improve substrate fertility by increasing plant nutrients and organic matter content, and neutralizing acidity (King, J.A.1988)On the basis of being abundant and locally available, limestone and compost were selected for the study. Limestone was added to neutralize the acidity while compost was to improve upon the water-holding capacity and the impoverished nutritional status of the soils or tailings respectively. The main purpose of soil amendments was initially to facilitate the establishment of the test trees before growing on their own abilities beyond the treat soil layers.Comparatively, scanty information is available on the response of many woody species commonly used in ecological restoration as compared to the grass species. Similarly, there is no information on the field performance of Leucaena leucocephala, Senna siamea and Eucalyptus grandis in the phytoremediation of tailings and mine wastes polluted soils that are characterised with heterogenous distribution of heavy metals as in this study area.

2.2 Seed storage conditions as determinants of longevity

Seed germination is defined as hydration of the seed leading to emergence of the embryonic radicle and shoot (Bewley et al., 2013). Maintaining seed viability over extended periods in storage is necessary for preserving the genetic integrity of plants.Successful seed storage conditions help in preserving the genetic integrity of many tree species for long periods. Seed longevity in storage exemplified by initial viability, freedom from fungal and insect attack, seed maturity, physiological deterioration, and mechanical damage is determined by factors like moisture content of seeds, nature of seeds, temperature and relative humidity (Rajjou et al., 2008). On the basis of storage behavior, three kinds of seed are recognized which are orthodox, recalcitrant and intermediate seeds (Berjak and Pammenter, 1997). Recalcitrant seeds are sensitive to chilling, are highly hydrated and they cannot withstand intensive desiccation (Bustam, et al., 2021). seed behavior is orthodox thus can retain its viability for several years under appropriate storage conditions (Orwa et al., 2009)

2.3 Seed moisture content

Seed moisture is the most crucial component in sustaining germination rate during storage, because it is the principal factor influencing all cellular processes (Bonner et al., 2008). The metabolism rates of both orthodox and recalcitrant seeds could be decreased by maintaining the seedlings in a dry condition at cold temperatures. True orthodox seeds maintained at low moisture content of between 5-10 % can be stored comfortably at nearly any temperature compared" to recalcitrant seeds. Therefore, seed moisture content "at the time of storage determines how low the temperature can be set for seed storage. Orthodox seeds can be exposed to sub-zero temperatures, while recalcitrant seeds cannot. Orthodox seeds can be stored for a few years at temperatures as low as -20°C" (Ellis et al., 1992) and (Ellis and Hong, 2006).

2.4 Seed storage temperature and relative humidity

The ideal storage temperature for seeds is approximately 14 degrees with a relative humidity of slightly less than 40 %. Most refrigerators have high relative humidity and hold a temperature of approximately 14.2oC (Bharat et al., 2012). Seeds stored in a refrigerator should be kept in containers that are tightly closed to keep the humidity levels low. Orthodox seeds will sustain survivability better when hardened to low content of moisture of roughly 4¬8 percent and then preserved in an environment in which humidity is regulated, than when preserved in equilibrium with ambient air humidity (Zhang et al., 2021). Cool condition is mostly favorable for storage of orthodox seeds.Long-term conservation of gene resources of orthodox agricultural seeds is at atemperature of less than -20o C and a moisture content of approximately -6oC to 16oC. Previous study shows that half-life is doubled for seeds dried to equilibrium and thereafter to approximately -20oC in waterproof containers under long-term gene bank (Ellis, 1996).

2.5 Factors responsible for germination of seeds

The longevity oforthodox seeds, also referred to as drying-tolerant seeds is thus determined by" content of moisture (MC) and temperature. Previous research indicates that "factors responsible for poor germination of Melia volkensii during storage" have been attributed to both physiological and physical factors (Milimo and Hellum, 1989).It is documented that farmers have used various traditional technologies to break seed dormancy to enhance propagation of Melia volkensii. These methods include: scarification procedure which is done by burning of the nuts. Nuts that are regurgitated by goats are usually used by farmers to raise seedlings (Mwamburi, 2005). Additionally,there are other methods that are used by farmers for instance splitting or cracking of the nuts and sowing of them in troughs" (Kidundo 2018).

CHAPTER 3

METHODOLOGY

3.1 DESCRIPTION OF THE STUDY AREA

Freda mining talings (19.18 S; 32.18E) dump is located 2 km north-west of the Freda Rebecca mine concentrator plant, in Zimbabwe. The dump lies at an altitude of 1070 m above sea level. It is found in agro-ecological region which is characterized by a tropical climate with distinct wet and dry seasons. Brief convectional thunderstorms and drizzle mark the wet season (November to March). Average annual rainfall is 800 mm and the average annual temperature is 28 0C. Geologically, the area is typically greenstone configuration consisting of mainly basaltic rocks with komatiitic basalt, tholeitic basalt, gabbro, banded iron formations and volcanic tuffs. The ore mainly consist of Pyrrhotite (Fe, Ni) S. Associated with pyrrhotite are two gold bearing minerals, namely Pentlandite.The ore also consist of Pyrite (FeS2) and Chalcopyrite (Cu, Fe) S2. The vegetation is typical miombo woodlands dominated by Brachystegia (B. spiciformis and B. boemmii) and Julbernadia (J. globiflora) genuses. Other species include Diplorinchus condilocarpon, Terminalia sericea, Acacia polyacantha, A. gerrardii, Albizia antunesiana, Faurea rochetiana, Combretum molle, C. imberbe, Bauhinia thonningii, B. petersiana, Flacourtia indica, Launea edulis, Strychnos spinosa and Vanguerina infausta.

3.2 DESCRIPTION OF THE RESEARCH SITE

Freda mining tailing is a valley dump which has the capacity to hold 40 mega tonnes of tailings. Benches are incorporated into the outer slope as the wall is raised so as to increase slope stability.

3.3 Germination and viability experiments

Mature ripe fruits of the tree species were collected by the researcher and depulped by removing the outer fleshy part using a plank of wood to while placing them on stone. After depulping the fruits, the nuts obtained were dried and were put on a groove carved out on a wooden plank and cracked open using a knife and hammer (Kamondo" et al., 2016).

The germination materials were divided into three lots . The nuts were cleaned in water and sun-dried for 5 days in preparation for seed extraction. The dry seed sub lots were also sun-dried for three days to a moisture content (MC) of 6 % that was determinedby oven drying at 103°C for 24 hours (Ellias et al., 1990). The moisture content wascalculated by subtracting the dry weight of seeds from the initial/wet weight of" seeds multiplied by one hundred (100.Dry seeds were used for initial germination in 3 replicates of 100 seeds each as per International Seed Testing Association germinationn protocol (ISTA, 2012). During test for germination, seeds were compressed and decontaminated in a solution of 5 grams of a fungicide Ridomil Gold fungicide (Metalaxyl-M and S-isomer) in 1 litre of distilled water. The seeds were later soaked in cold water (4oC) for 12 hours and finally rinsed with 1 % sodium hypochlorite solution. The coat of seeds was split longitudinally utilizing arazor blade that was decontaminated. "Seeds were germinated in plastic containers using fine sterilized clean river sand as the substrate (Dolor, 2009). The seeds were covered with a layer of sand drenched with" fungicide (Muok et al., 2010). The number of germinated seedlings was daily recorded for a period of 10 days. Once scored, the sprouted seedlings were retrieved using a pair of tweezers to confirm the daily counts were for newly propagules.

In order to test the storage conditions' effect on germination of the three mentioned species, seeds and nuts were stored under different conditions and tested for germination at an interval of 2months after storage. The experimental conditions were room temperature (30oC) and in refrigerator at -20°C; under each temperature condition seeds and nuts were stored in sealed or plastic containers that are uncapped. The germination materials "were tested for their germination in intervals. (Bharat, 2012; Probert, 2007). Each germination test consisted 3 replicates each with 25 seeds or nuts. Thus, the experimental design was three factorials arranged in a completely randomized design.

Germination was recorded for a period of 10 days..In order to test the storage conditions' effect on germination of the seeds and nuts were stored under different conditions and tested for germination at in intervals after storage. The experimental conditions were room temperature (30oC) and in refrigerator at -20°C; under each temperature condition seeds and nuts were stored in sealed or plastic containers that are uncapped. The germination materials were tested for their germination in intervals (Bharat, 2012; Probert, 2007).

3.4 EXPERIMENTAL DESIGN

A completely randomized block design with 3 blocks was used. The blocking factor was position on the slope. There were two treatment factors namely tailing amendments and tree species. Tailing amendments had four levels which are top soil (1230 g per tree;12 300kg/ha), sewage sludge (1300 g per tree; 13 000kg/ha), compound D fertilizer (N: P_2O_5: K_2O: S; 7:14:7:6.5) applied at a 50g per tree (88.2 kg/ha) rate (Hill, 1977), and the untreated control.(Lambert, et al. 1985)states that applications of up to 22 000 t/ha sewage sludge usually furnish the needed nutrients without causing toxicity and 45 000 t/ha or more, lower the survival and growth rate of pines. Tree species were A. gerrardii, A. karroo and A. polyacantha.

3.5 CHARACTERISTICS OF TAILINGS AND AMENDMENTS

The tailings were alkaline with an average pH ($CaCl_2$) of 8.0 for the 0 to 20 cm depth and 8.1 for the 20 to 40 cm depth and are fine-sandy in texture. The soils used were medium sandy clay with an average pH ($CaCl_2$) of 6.7. The non-stock piled top soil was collected from the area surrounding the tailings dump. As for the treated sewage sludge, it had a coarse sandy texture with an average pH ($CaCl_2$) of 2. The sludge was treated at the Fredda Rebecca Mine sewage works Plant and stock piled for some years. Compound D fertilizer (N: P_2O_5: K_2O: S; 7:14:7:6.5) was used in this research.

3.6 NURSERY

Acacia gerrardii and A. polyacantha seeds were collected locally. Acacia karroo seeds were collected in the Midlands Province (1 430 m altitude; 643 mm mean annual rainfall; 28 0C mean annual temperature) and these were sown on the 31st of October 2007. The seeds were pre-treated by boiling them in water followed by soaking in hot water overnight (Donald and Jacobs, 1993). Free-draining, workable, sandy loam topsoil collected from underneath established acacia species was used as growth media. Sowing depth was 1.5 cm. The seedlings were watered once everyday for a period of 8 weeks. Thereafter, the watering period was gradually reduced to progressively harden the seedlings. Besides watering, nursery tending included weeding and root pruning.

3.7 PLANTING

Seedlings were transplanted.. They were planted in 15cm deep and 10 cm diameter pits. The tailings amendment materials were placed in the pit and the seedling planted. For fertilizer, localized placement was used with 50 g being placed around the seedling during planting. Localised placement reduces the amount of contact between soil particles and the fertilizer nutrient, thus minimizing the opportunity for adverse fixation reactions (Brady and Weil, 1999).

3.8 DATA COLLECTION

Growth rate was determined by counting the total number of surviving saplings in each bed . Ten seedlings per bed were monitored for growth in height and root collar diameter (RCD) throughout the growth period. Growth in height and RCD were measured using a height rod and veneer calipers respectively. Height was taken as the distance along the axis of the true stem between the root collar and the tip of the tree (Husch et al., 2003).

3.9 DATA ANALYSIS

Data collected were entered into Microsoft Excel spreadsheets (2019) for subsequent statistical procedures.Growth rate determination Survival percentage of each species was calculated as the number of trees surviving by the end of the experiment divided by initial tree number multiplied by 100. To ensure conformity to normal distribution, survival data was arcsine transformed using excel before statistical analysis. Absolute percentages were used for presentation purposes of the analyzed data. Sapling growth was evaluated as the mean relative growth rates in height (RGRh) and RCD (RGRd) over the total growth period using the formulae for classic plant growth analysis.

3.10 Germination tests

Germination data for stored nuts and extracted seeds were compared using the t test at 5 % level of significance using "a two-way ANOVA to analyze the effects of seed storage treatments and seed storage time. The treatments used were seeds stored either as extracted seeds or nuts" at a temperature of 30o C and 20oC in closed and open containers. In this study seed storage time was 2 months. "At P <0.05, germination means were separated using Fisher's least significant difference test. At confidence interval of 95 %, the germination trend of extracted seeds and nuts that were stored at different environmental conditions and in different containers was" tested using a t test.

CHAPTER 4

RESULTS

Table 4.1: Relative growth performance of A. gerrardii

Added material	**Relative growth rate mean of height(%)**	**Relative growth rate mean of basal diameter**
Top soil	0.73	0.72
S. sludge	0.01	0.04
Fertiliser	1.31	1.14
control	0.70	0,68

Table 4.2:Relative growth performance of *A. karroo*

Added material	**Relative growth rate mean of height(%)**	**Relative growth rate mean of basal diameter (%)**
Top soil	1.86	0.93
S. sludge	0.97	0.34
Fertiliser	2.57	1.47
control	1.89	0.93

Table 3:Relative growth performance of A. polyacantha

Added material	**Relative growth rate mean of height(%)**	**Relative growth rate mean of basal diameter (%)**
Top soil	0.51	0.08
S. sludge	0.28	0.57
Fertiliser	0.29	1.04
control	0.30	0.42

A. GERRARDII

Relative growth rates in height and RCD for *A. gerrardii* were significantly different throughout all amendments except for trees on top soil and the control. *A. gerrardii* established on fertilizer amendment exhibited the highest RGRh and RGRd and conversely the least significant RGRh and RGRd on sewage sludge amendment.

A. KARROO

In terms of RGRh *A. karroo* exhibited the same trends as *A. gerrardii*. There were significant

differences throughout all amendments (in RGRd in which species performance was as follows: fertilizer>topsoil>control>sewage sludge.

A.POLYACANTHA

All *A. polyacantha* established on all the amendments had similar performance in RGRh except trees on top soil and sewage sludge with the former outperforming the latter. In terms of RGRd, trees on the top soil and the fertilizer, and trees on top soil and sewage sludge had similar performances . However, trees on the top soil and fertilizer performed better than the control.

Table 4.4:Mean survival percentages under different tailings amendments for *A gerrdii*

Amendment material	**Mean survival %**
Top soil	100
S. sludge	71.11
Fertiliser	100
control	100
Overall (%)	**92.78**

Gerrardii established on sewage sludge recorded a lower survival percentage compared to other amendments. There were no significance differences in overall survival among the three *Acacia* species. Survival percentages under top soil amendment and control were better than those under sewage sludge and fertilizer.

Table 4.5::Mean survival percentages under different tailings amendments for *A. karroo*

Amendment material	**Mean survival %**
Top soil	93.33
S. sludge	60.00
Fertiliser	68.89
control	95.56
Overall (%)	**79.44**

Table 4.6:Mean survival percentages under different tailings amendments for *A. polyacantha*

Amendment material	**Mean survival %**
Top soil	100
S. sludge	91.10
Fertiliser	71.10
control	100
Overall (%)	**90.54**

Table 7:Mean Percentage germination of *A Karoo*

Amendment material	**Mean Germinated %**
Top soil	98
S. sludge	65
Fertiliser	58
control	95
Overall (%)	**79**

Table 8:Mean Percentage germination of *A. gerrdii*

Amendment material	**Mean survival %**
Top soil	97
S. sludge	70
Fertiliser	95
control	98
Overall (%)	**90**

Table 9:Mean Percentage germination of *A. polyacantha*

Amendment material	**Mean germinated%**
Top soil	96
S. sludge	88
Fertiliser	65
control	98
Overall (%)	**86.75**

CHAPTER 5

DISCUSSION

5.1 Species Survival Performance

A polyacantha, A. karroo and A. gerrardii established on the Freda Mine tailings dump survived satisfactorily well. Hamad and Kamal (2006) and ADEH (2003) attribute ability of acacias to survive to their hardiness and adaptability to a wide range of soil types and annual rainfall as well as tolerance to droughts and water logging, low nutrient soils and highly saline or alkaline soils. Survival on top soil amendments and the tailings (control) were not significantly different and the probable reason is that in the initial six months trees were still getting nutrients from the nursery soil they were transplanted with such that the two treatments appear to be similar. Sewage sludge and fertilizer amendment had similar and lower survival of 74.07% and 80.00% respectively which is below the 85% required to avoid blanking. In comparison with the other treatments (top soil and the control), these are low values which according to Lambert, et al. (1985) is a result of low response to sewage sludge application.

The low pH (2.4) of sewage sludge results in increased availability of heavy metals such as Cu, Zn, Fe and Mn which when taken up by the plant adversely affects plant growth and death of plants can be a response to increased concentration within the plant system (Brady and Weil, 2002). In contrast, Corrêa and Mélo Filho (2004) observed that sewage sludge presented a pronounced advantage over composted garbage for plant survival when tree survival of eight Brazilian Savanna tree species ranged from 47 to 87% in 22 months of growth and the best result of 87% of seedling survival was on trees treatewith sewage sludge. In our study low survival under fertilizer amendment may be attributedto physiological stress due to inadequate water supply as the plants were not watered

5.2 SPECIES GROWTH PERFORMANCE

Overall, among the three species, *A. karroo* performed best in RGRh and RGRd respectively this is indicative of its robustness and hardiness under different growing conditions. This concurs with Spicer, et al. (2005) who characterized A. karroo as a fast grower. In addition, Ibrahim et al. (2001) concluded that A. karroo was able to make opportunistic growth at any time. However, in contrast to the results of this study, Hamad and Kamal (2006) reported on moderate or sluggish growth for A. karroo and A. gerrardii in a study done in Saudi Arabia where they grew to 3.7 cm and 4.1 cm stem diameter and 120 cm and 144cm height respectively after a growth period of one year. Although A. polyacantha is one of the fast growing acacias under natural conditions, it had the least RGRh (0.035±0.007 cmcm-1month-1) which contrasts with the tree's growth characteristics (Palgrave, 1983) and observations made by Mulizane, et al. (2005). This can be explained by the fact that since it is mainly adapted to watery places such as on alluvial soils in river valleys (Spicer, et al., 2005), it had difficulties in adapting to tailings conditions. Another reason could be that the tree is prioritizing growth in other dimensions such as lateral growth at the expense of height as a way of adapting to the sloppy area (260) so as to avoid being toppled down by wind. This is evidenced by its RGRd(0.071±0.006 cmcm-1month-1) which is twice higher than RGRh. Brady and Weil (2002) also noted that on sloppy areas, tall trees tend to become short and thick as an adaptation to avoid toppling over.

The overall order of amendment performance for the three species was as follow (RGRh, RGRd, and growth trends) fertilizer > topsoil = control > sewage sludge. Fertilizer amendment exhibited the highest RGRh, RGRd and growth trends because the application of inorganic compound D fertilizer ensured the availability of vital plant growth nutrients in readily available forms for plant uptake (Brady and Weil, 2002). The results reinforce the recommendation by Brown et al. (1996) for use of fertilizer to increase biomass on reclaimed mine soils. Besides increasing both plant growth and nutrient uptake, the fertilizer stimulates increased cycling of the nutrients, and the nutrient ions taken up by the plant come largely from various pools in the soil and not directly from the fertilizer. The results concur with Hill (1977) who observed a clearly visible response to 50g per tree (88.2kg/ha) of compound D on three mines using Acacia saligna, Casuarina glauca, Eucalyptus camaldulensis, Schinus molle and Casuarina equisetifolia. and Piha et al. (1995) who observed approximately 40% vegetative cover established at the end of the first season in Zimbabwe when a moderate rate of compound fertilizer and leguminous tree species were used. In contrast Hill (1977) observed a depressive effect on biomass production when a combination of compound fertilizer 50g per tree (88.2kg/ha) and single super phosphate; 500g per tree (882kg/ha) was used on Acacia saligna, Casuarina glauca, Eucalyptus camaldulensis, Schinus molle and Casuarina equisetifolia.Relative growth rate in height (RGRh), RGRd and growth trends for topsoil and control were similar showing no differentiation between the two treatments. There was no differentiation because the roots for both treatments are still in the nursery soil such that nochange of growing environment has taken place. This is attributed to the short time period of the research such that the roots had not yet developed long roots that would have moved from the pot soil into the tailings material

Sewage sludge material had the least RGRh, RGRd, and growth trends mainly because of the extremely low pH (2.4) which according to Brady and Weil (2002), results in high mobility of elements such as Zn, Cu, Fe and Mn and the latter two may even be present in high enough concentrations to be toxic to plants which adversely affect plant growth. The relatively high readily available forms of these elements as indicated in Table 1: Fe (1053.36 ppm), Mn (4.39 ppm), Cu (201.18 ppm) and Zn (12.55 ppm) also inhibit development and hinder the production and activity of mycorrhizal fungi which improve plant growth by increasing the uptake of plant nutrients, particularly P (Lambert, et al., 1985). Although P (7.82 ppm) is readily available for plant uptake, the plants are failing to utilize it most probably because of the reduced capability of mycorrhizal fungi. The hindrances on the production and activity of mycorrhizal fungi adversely affects N-fixation (Wild, 1993).

5.3 Seed germination

Overall mean percentage germination was also found to be higher for *gerrdii* seeds (90%), and lower for *karoo* seeds (79%). In addition, the rate of germination was faster for *gerrdii* seeds as compared to *karoo* and *polyacantha* seeds.The higher percentage germination on top soil area compared to the fertiliser and sewage sludge area area was again consistent with Witkowski & Weiersbye (2003) findings where percentage germination for *A. gerrdii* seeds 100% compared to 97%. Witkowski & Weiersbye (2003) explain that this may be due to the seed coat acting as a buffer between the embryo and the saline conditions due to higher tissue content of calcium (Ca) and potassium (K). *Acacia* species have been shown to allocate nutrients differently, especially Ca and K, between the embryo and the testa when established under varying salt conditions (Rehman et al., 2000).

Although a significant difference was shown for percentage germination between the amended areas, the percentage of germination was still shown to be greater than 50% for all areas in this study as well as by Witkowski & Weiersbye (2003). Seed size and number are determined by a wide range of biotic and abiotic selective forces (Esler et al., 1989). Germination is generally closely related to seed size, with the larger seeds having a higher percentage germination compared with smaller seeds (Souza & Fagundes, 2014). This is due to the larger seeds providing seedlings with a higher store of resources (Venable & Brown, 1988).

The percentage of germination when compared to seed size class may be a useful indicator of *A. gerrdii* preferentially allocating limited resources to other plant organs such as its roots to obtain nutrients at depth when growing under stressful conditions (Souza et al 2014). In stressful environments, the essence of resource allocation in a plant is limited so that these will be divided among the plant parts in such a way as to maximise fitness (Witkowski et al 1996). This is seen as an adaptive mechanism in harsh environments (Eriksson, 1999).

(Souza et al,2014) found during an experiment with Fabaceae species, that small seeds had a higher germination percentage and germinated faster when compared to larger seeds. Conversely, El-ahmir et al. (2015) explains that larger seeds generally gain a competitive advantage over the smaller seeds due to their earlier germination. This is consistent with this study where the *gerrdii* seeds were generally larger and had a faster rate of germination than other seeds collected.

CHAPTER 6

6.1 CONCLUSIONS

In conclusion, basing on early survival performance, *A. gerrardii, A. karroo and A. polyacantha* can be used in revegetation of Freda mine tailings dumps under similar conditions since all the tailings amendments resulted in satisfactory survival results. It is also evident from the study that potted seedlings without any amendments are good enough to ensure survival. In terms of growth performance, fertilizer ensured relatively high initial growth. Further study is recommended over a longer observation period so as to ascertain changes in survival and growth performance of the Acacia spp under for the four tailings amendments.

6.2 RECOMMENDATIONS

Further study is recommended over a longer observation period so as to ascertain changes in survival and growth performance of the Acacia under for the four tailings amendments.

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Appendix B

Seed treatment and Seed germination recording


BIOBASE