

Full Length Research Paper

Comparative analysis of the early growth performance of indigenous *Acacia* species in revegetating Trojan Nickel Mine tailings in Zimbabwe

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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 *Acacia* sp. namely *Acacia gerrardii*, *Acacia karroo* and *Acacia polyacantha* established on nickel 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 vernier caliper respectively and survival was determined at the end of a six-months period. A completely randomized block design with 12 treatments replicated three times was used. Survival and relative growth rates in height and RCD (RGR_h and RGR_d), were tested for significant differences among treatments through analysis of variance using SPSS for Windows Version 15.0 (2006). Overall, there were no significant 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 that all the three species can be used in revegetation of nickel mine tailing dumps.

Key words: Indigenous, *Acacia*, nickel tailings, survival, growth performance, amendments.

INTRODUCTION

Mine wastes represent the highest proportion of waste produced by industrial activity, with billions of tons being produced annually (Bell, 1998). A major negative legacy of the mining industry is dereliction of land which is mainly caused by surface extraction of minerals and the disposal of waste products from mineral workings in the form of waste rock piles or mine dumps and tailing ponds (Bell, 1996). In the case of metalliferous mining, high volumes of waste are produced because of the low concentration of metal in the ore deposit. Historically, mine waste has been disposed of at the lowest cost, often with considerable environmental impacts, for example the disused Rein gold mine in Bindura where the tailing dump was just left bare.

Tailing dumps usually yield extremely harsh conditions to the surrounding environments. Large quantities of waste materials, high pollutant concentration of the mined metal and associated metals (Wild, 1993), and severely infertile soils (Bradshaw, 1997; Bradshaw and Hutt, 2001) are the legacies of this type of industry. In many instances, the dumps have been abandoned in a highly disturbed condition, with limited or no rehabilitation treatment (Gardner, 2001). These heavily impacted lands are almost completely devoid of vegetation leading to soil erosion and off-site remobilization of pollutants including acid-rich wastewaters, generally referred to as acid mine drainage (AMD) or acid rock drainage (ARD). Acid mine drainage originates from accelerated oxidation of iron pyrite (FeS_2) and other sulphidic minerals as a result of exposure of these minerals to both oxygen and water (Mikli, 2001; Johnson and Halberg, 2005). For a detailed discussion of acid mine drainage remediation options

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refer to (Johnson and Halberg, 2005).

The revegetation of tailing dumps is made difficult due to the fact that the sites are composed of freshly crushed rock. Plant growth is hindered by limited access to essential mineral nutrients due to slow soil forming processes. In addition, the tailing material contains phytotoxic chemical elements like Hg, Pb, Cd, Cu, nickel Ni and cobalt Co (McBridge, 1994). The elements may be anthropogenically added during the mining process for example, mercury use of mercury in extraction of gold (Hylander et al., 2007) or they may be associated with the mineral being mined. Nickel 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 and Redente, 2002). The natural process of re-colonization by pioneering and stress-tolerant species is extremely slow and sometimes 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. Top soil was then applied on tailings coupled with 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 as a thin layer.

In Africa, mine tailings have been treated with vegetation. The use of vegetation has a triple effect on mine tailings: (1) it protects the tailings material from both water and wind erosion, (2) it reduces the amount of water entering the spoil heaps through consumptive use, especially in tropical climates where evapotranspiration is relatively high, and (3) it lowers oxygen concentration due to both root and microbial respiration thus reducing AMD. Eucalypts, an exotic fast-growing tree, has been used in gold mining tailings (Mulizane et al., 2005). However, the use of exotic plants (*Eucalyptus* spp., Australian Acacias and Firs) often has the following shortcomings: failure to return the land to its natural state (Murdoch et al., 1997); high cost of establishment and relatively low adaptation to low moisture and nutrient levels. A paradigm shift from applying exotic to indigenous vegetation could prove beneficial.

According to Sarrailh and Ayrault (2001), the importance of using indigenous species besides their environmental importance is to meet the livelihoods and cultural needs of local communities who depend on forest products and services. *Acacia* spp. are among the most important pioneer species in the Southern African region (Spicer et al., 2005). The growth of these trees facilitates the enhancement of soil properties such as structure, porosity, moisture retention, and erosion resistance. They also modify extreme soil temperatures that adversely

affect macro/micro soil organisms, moderates the effects of leaching through the addition of bases to the soil and have been used successfully, to reclaim saline and alkaline soils. In addition, *Acacia* species are well adapted to hot climates, different soil types, and variable annual rainfall (150 to 1200 mm) (Hamad and Kamal, 2006). According to Nair (1993), *Acacia* spp. have deep roots that can reach water and minerals, that would otherwise be lost to the system, and are involved in soil nutrient recycling via leaf fall that enhances and facilitates the growth of other plants. The rate of litter fall and decomposition are important factors for future growth and establishment of vegetation by 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, restoring soil fertility and may accelerate the natural regeneration of mine spoils. In addition, their ability to fix nitrogen from the air with the aid of symbiotic bacteria (rhizoid) that live in their roots promotes soil nitrogen enrichment (Spicer et al., 2005). Although the idea of using indigenous species in revegetation of tailing 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 early growth performance of three *Acacia* spp. under different tailing dump amendments.

MATERIALS AND METHODS

Description of the study area

Insingisi tailings (17.18S; 31.18E) dump site (Figure 1) is located 2 km north-west of the Trojan Nickel mine concentrator plant in Zimbabwe. The area lies at an altitude of 1070 m above sea level and it has the capacity to hold 37 mega tonnes of tailings. Benches are incorporated into the outer slope as the wall is raised, so as to increase slope stability. Its north-facing slope has an angle of 26° with an increasing rate of 8 m/yr. A floating decant system is used to return water back to the concentrator plant. The weather 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°C. Figure 2 shows the rainfall distribution during the 2007/08 season.

Geologically, the area is typically a greenstone configuration composed mainly of basaltic rocks (komatiitic/tholeitic basalts, and gabbro) coupled with banded iron formations and volcanic tuffs. The ore mainly consist of Pyrrhotite (Fe, Ni) S with associated nickel bearing Pentlandite ((Fe, Ni)₉S₈) and Polydymite (Ni₃S₄) minerals. Pyrite (FeS₂) and Chalcopyrite (Cu, Fe) S₂ are also found (Trojan Mine, 2007). The surrounding vegetation is typical Miombo woodlands (Figure 1) dominated by *Brachystegia* (*Brachystegia spiciformis* and *Brachystegia boemii*) and *Julbernardia* (*Julbernardia globiflora*) genera. Other species include *Diplorinchus condilocarpus*, *Terminalia sericea*, *Acacia polyacantha*, *Acacia gerrardii*, *Albizia antunesiana*, *Faurea rochetiana*, *Combretum molle*, *Combretum imberbe*, *Bauhinia thonningii*, *Bauhinia petersiana*, *Flacourtie indica*, *Launea edulis*, *Strychnos spinosa* and

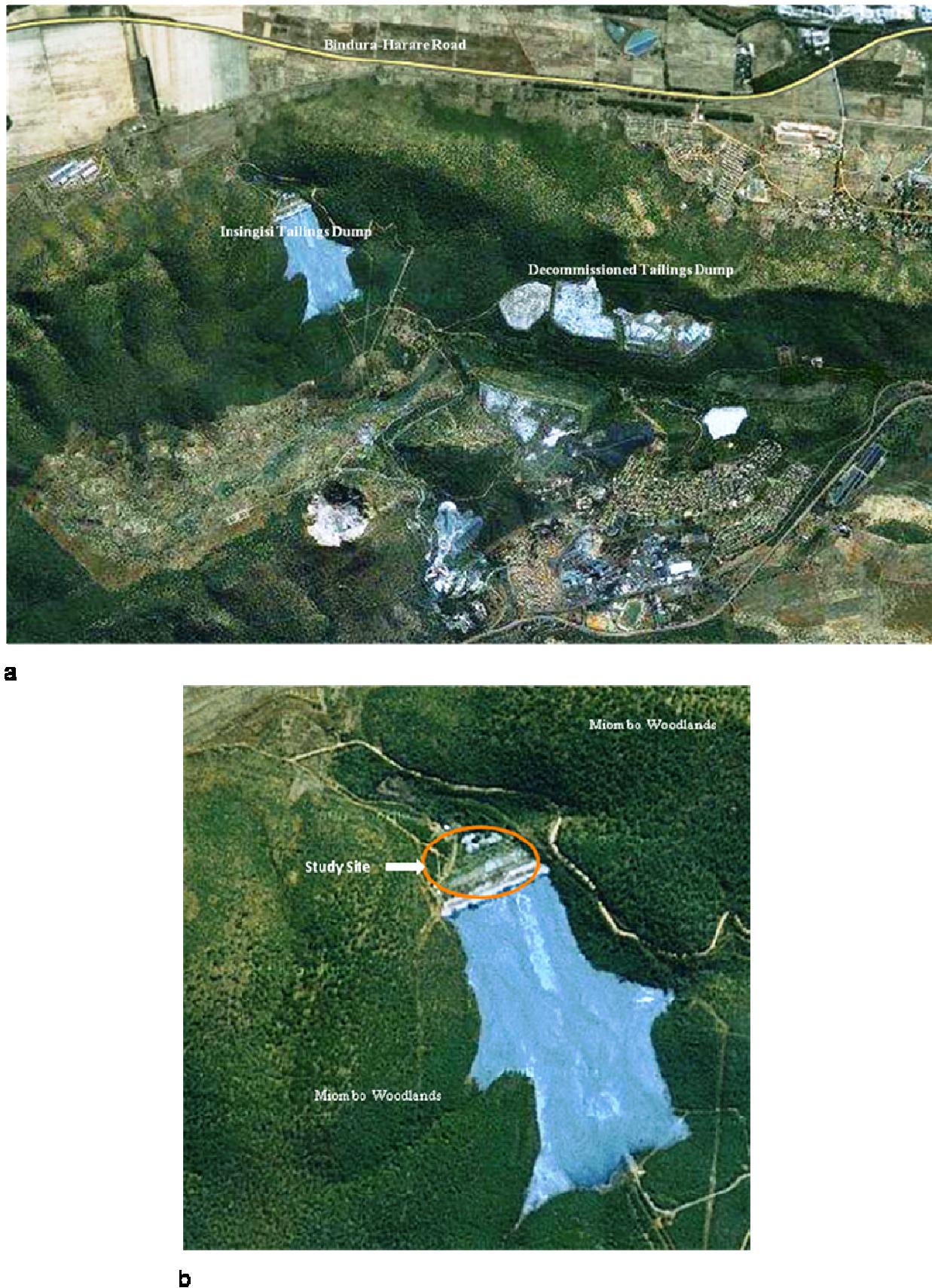


Figure 1. (a) Satellite image of Trojan Nickel Mine and (b) Insingisi Tailings Dump where the research was done.

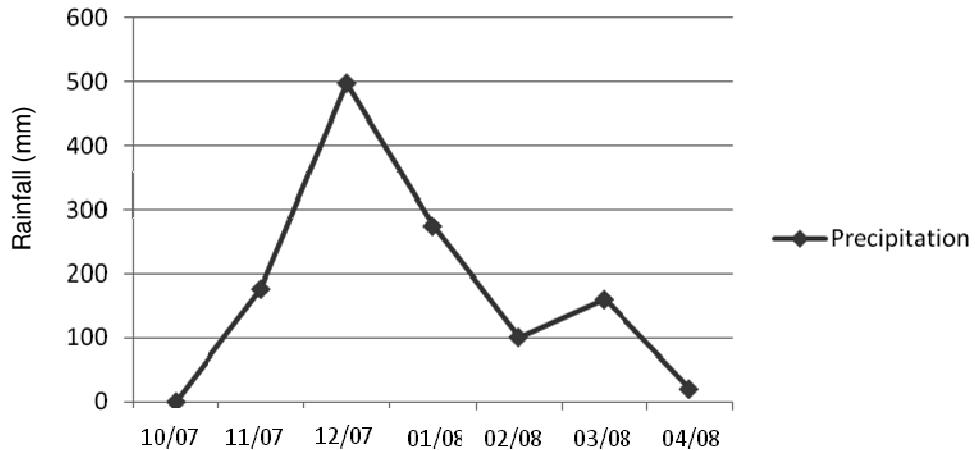


Figure 2. Rainfall distribution from October 2007 to April 2008 in Bindura District.

Table 1. Research design.

Part of slope	Treatments											
	PTS	KF	GTS	KC	GC	KSS	PC	KTS	PF	PSS	GSS	GF
Upper slope	PTS	KF	GTS	KC	GC	KSS	PC	KTS	PF	PSS	GSS	GF
Mid slope	GTS	KSS	GSS	PC	KC	PF	PTS	GC	GF	KTS	PSS	KF
Lower slope	PF	PC	KF	GC	GSS	PTS	PSS	KSS	GF	KTS	KC	GTS

GTS = *A. gerrardii* on top soil, GSS = *A. gerrardii* on sewage sludge, GF = *A. gerrardii* on fertilizer, GC= *A. gerrardii* control, KTS= *A. karroo* on top soil, KSS= *A. karroo* on sewage sludge, KF= *A. karroo* on fertilizer, KC= *A. karroo* control, PTS=A. *polyacantha* on top soil, PSS=A. *polyacantha* on sewage sludge, PF= *A. polyacantha* on fertilizer, PC=A. *polyacantha* control.

Vangueria infausta. The tree canopy is open and there is little under-storey vegetation. Dominant grasses are *Hyparrhenia filipendula*, *Hyparrhenia dissoluta*, *Hypertherbia dissolute*, *Brachiaria brizantha*, *Pogonatheria squarrosa*, *Craspedorchis rhodesiana* and *Eragrostis* species.

Experimental design

A completely randomized block design (Table 1) 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 (1 230 g/tree, 12 300 kg/ha), sewage sludge (1 300 g/tree, 13 000 kg/ha), compound D fertilizer (N: P₂O₅: K₂O: S; 7:14:7:6.5) applied at a 50 g/tree (88.2 kg/ha) rate (Hill, 1977), and the untreated control. The untreated control was the tailings material without amendment. 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*, *Acacia karroo* and *A. polyacantha*.

This resulted in 12 treatment combinations replicated 3 times and randomly distributed to 36 plots with each plot having 15 planting stations with 1 m in row and inter row spacings. Survival percent was determined at the end of the six months period by counting the total number of surviving saplings in each plot. Ten seedlings per plot were monitored for growth in height and root collar diameter (RCD) at monthly intervals. These parameters 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).

Characteristics of tailings and amendments

Samples of tailings and tailing amendments were analyzed at the Scientific and Industrial Research and Development Centre (SIRDC) laboratory in Harare. The tailings, which had been recently deposited (about two to five months before transplanting) were alkaline with an average pH (CaCl₂) of 8.0 for the 0 to 20 cm depth and 8.1 for the 20 to 40 cm. These tailings had no natural vegetation growing on them. The soils used were medium sandy clay with an average pH (CaCl₂) 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 (CaCl₂) of 2. The sludge was treated at the Trojan Nickel Mine sewage works Plant and stock piled for five years. The sewage consisted of industrial and domestic wastes. Compound D fertilizer (N: P₂O₅: K₂O: S; 7:14:7:6.5) was used in this research. The chemical constituents of the tailings and the amendments are shown in Table 2a.

Nursery

A. gerrardii and *A. polyacantha* seeds were collected locally. *A. karroo* seeds were collected in the Midlands Province (1 430 m altitude; 643 mm mean annual rainfall; 28°C 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 every day for a period of 8 weeks. Thereafter, the watering period was gradually

Table 2a. Characteristics of tailings and amendment materials.

Element	Availability of element	Concentration of element (ppm)			
		Tailings material 0-20cm	Tailings material 20-40cm	TS	SS
Resin P		15.00	34.34	0.00	46.70
Initial N		0.50	0.50	0.75	13.44
As	SA	50.53	52.13	0.82	32.51
B	SA	27.70	25.70	5.37	85.28
Cd	SA	2.13	1.99	0.14	1.44
	RA	0.04	0.05	0.02	0.05
Cr	SA	10.54	3.07	0.00	59.23
	RA	0.00	0.00	0.00	1.79
Co	SA	8.93	8.82	48.05	10.52
	RA	0.80	0.02	0.06	2.63
Cu	SA	74.43	74.65	104.81	201.18
Fe	SA	61838.00	15965.11	ND	27368.71
	RA	513.61	0.27	0.00	1053.36
Mo	SA	0.23	2.50	0.00	1.15
	RA	0.33	0.12	0.00	0.00
Ni	SA	349.62	300.20	430.62	139.37
	RA	0.00	0.00	0.00	115.20
Se	SA	0.28	0.08	0.03	1.58
Zn	SA	7.87	7.12	13.37	20.35
	RA	0.07	0.06	0.20	12.55
Pb	SA	1.30	1.64	1.31	2.15
	RA	0.16	0.14	0.36	0.13
Mn	SA	26.57	42.34	2190.22	6.92
	RA	0.18	0.04	0.21	4.39
Ca	SA	1923.49	1856.30	ND	467.07
Mg	SA	21058.66	24214.63	4722.63	467.39
P	SA	22.38	21.04	4.53	1784.18
	RA	0.00	0.00	0.00	7.82
S	SA	307.92	354.64	69.47	6144.00
	RA	180.28	260.37	38.94	3448.06

TS, top soil; SS, sewage sludge; SA, slowly available; RA, readily available; ND; no data.

Table 2b. Summary of methods used for analysis of tailings and amendments samples.

Parameter	Method
Texture (particle size distribution)	Sieving and hydrometer method (Bouyoucos)
Cation exchange capacity	Saturation with pH 7.0 1M NH ₄ Ac if soil pH > 6.4 and 0.2M NH ₄ Cl if soil pH<6.5. NH ₄ Cl solution is adjusted to 0.4 pH units of the soil.
Exchangeable bases	Extract as above and read using atomic spectroscopy.
Soil pH	1 part soil to 2.5 parts of 0.01M CaCl ₂ or distilled water and shaken for one hour.
Available heavy metals	Extraction with mild extractant (0.01M CaCl ₂) yields information on metals in soil solution that are readily available to plants or pollution status of soils. Shake a 1:10 soil/solution for 2hrs.
Slowly available heavy	Extraction with 0.43 M HNO ₃ yields information on metals in soil solution that are relatively weakly bound (chelated to organic matter) and those adsorbed on soil exchange complex or in soil solution. Shake a 1:10 soil/solution for 2 h.
Available P	An anion exchange resin, Dowex 21K which has a high adsorbing power and good mechanical properties was used for adsorbing phosphates from soils. P adsorbed by resins has been tested as an accurate measure of available P in Zimbabwean soils (Saunders and Meterlerkamp, 1962. International Soil Conference, New Zealand)
Initial N	Inorganic N forms are extracted using 2M KCl. The different forms of inorganic N are estimated by steam distillation method using MgO as alkaline reagent and Devarda alloy as reductant.

reduced to progressively harden the seedlings. Besides watering, nursery tending included weeding and root pruning.

Planting

Seedlings were transplanted on the 14th and 15th of December 2007. The tailing amendment materials were placed in 20 cm deep and 15 cm diameter pits and the seedlings planted at ±12.5 cm depth. For fertilizer, localized placement was used with 50 g being placed around the seedling during planting. Localized placement reduces the amount of contact between soil particles and the fertilizer nutrient, thus minimizing the opportunity for adverse fixation reactions of nutrient elements (Brady and Weil, 1999).

Data analysis

Survival percentage of each species was calculated as the number of trees surviving by the end of the experiment divided by initial tree number (15) 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 (RGR_h) and RCD (RGR_d) over the total growth period, using the formulae for classic plant growth analysis as shown in Equations 1 and 2 (Fisher, 1921).

$$RGR_h = \frac{\log_e hf - \log_e hi}{t_2 - t_1} \quad [1]$$

Where RGR_h =Relative growth rate in height,

hi = the initial (a month after establishment, ' t_1 ') growths in height,

hf = the final (after ' t_2 ' months) growths in height.

$$RGR_d = \frac{\log_e df - \log_e di}{t_2 - t_1} \quad [2]$$

Where RGR_d =Relative growth rate in RCD,

di = the initial (a month after establishment, ' t_1 ') growths in RCD,

df = the final (after ' t_2 ' months) growth in RCD,

Survival percentages, RGR_h, RGR_d, height and RCD were tested for significance among treatments through one-way analysis of variance (ANOVA) using SPSS for Windows Version 15 (2006). Differences between means were tested using LSD post hoc tests at 5% level of significance. The model for the research is given below:

$$Y_{ijkl} = \mu + \beta_i + T_j + S_k + \beta T_{ij} + TS_{jk} + \beta S_{ik} + \beta TS_{ijk} + e_{ijkl} \quad [3]$$

Where: Y_{ijkl} is the measured variable for the jk^{th} treatment in the i^{th} block (e.g. height)

μ is the overall mean for the site,

β is the effect of the i^{th} block

T_j is the effect of the j^{th} tailings amendment

S_k is the effect of k^{th} Acacia spp.

Table 3. Mean survival percentages under different tailing amendments.

Species (N = 135)	Mean survival (%) ± SD				Overall mean survival (%) ± SE(N = 180)
	Topsoil	Sewage sludge	Fertilizer	Control	
<i>A. gerrardii</i>	100.00±0.00 ^a	71.11±16.78 ^b	100.00±0.00 ^a	100.00±0.00 ^a	92.78±5.55 ^a
<i>A. karroo</i>	93.33±11.55 ^a	60.00±20.00 ^a	68.89±48.23 ^a	95.56±7.70 ^a	79.44±5.55 ^a
<i>A. polyacantha</i>	100.00±0.00 ^a	91.11±7.70 ^a	71.11±34.21 ^a	100.00±0.00 ^a	90.56±5.55 ^a
Overall mean survival (%) ± SE (N= 135)	97.78±6.40 ^a	74.07±6.40 ^b	80.00±6.40 ^b	98.52±6.40 ^a	

Means with common superscripts along each row show no significant differences ($P>0.05$) except for overall species which was down the column. For each amendment material means with common subscripts within a column (excluding overall means) are not significantly different ($P>0.05$).

e_{ijkl} is the random error associated with the plot in block i randomly allocated treatment j.

RESULTS

Species survival performance

A. gerrardii established on sewage sludge recorded a lower ($P<0.05$) survival percentage compared to other amendments (Table 3). There were no significant differences ($P>0.05$) in overall survival among the three *Acacia* species. Survival percentages under top soil amendment and control were better ($P<0.05$) than those under sewage sludge and fertilizer.

Species growth performance

Relative growth rates of *A. gerrardii* in height and RCD were significantly different ($P<0.05$) throughout all amendments except for trees on top soil and the control. Conversely it exhibited the highest and least significant RGR_h and RGR_d on the fertilizer and sewage sludge amendments (Table 4). Similarly, *A. karroo* exhibited the same trends as *A. gerrardii* but there were significant differences throughout all amendments ($P<0.05$)

in RGR_d in which species performance was as follows: fertilizer>topsoil>control>sewage sludge. All *A. polyacantha* established on all the amendments had similar performance in RGR_h ($P>0.05$) except trees on top soil and sewage sludge with the former outperforming the latter. In terms of RGR_d , trees on the top soil and the fertilizer, and trees on top soil and sewage sludge had similar performances ($P>0.05$). However, trees performed poorly in the control. The overall species performance in RGR_h (mean±SE) was as follows: *A. karroo* (0.182 ± 0.007)>*A. gerrardii* (0.062 ± 0.006)>*A. polyacantha* (0.035 ± 0.007). In terms of RGR_d (mean±SE) *A. karroo* (0.092 ± 0.006) performed better than ($P<0.05$) both *A. gerrardii* (0.069 ± 0.006) and *A. polyacantha* (0.071 ± 0.006) which had similar performances ($P>0.05$). There were significant differences ($P<0.05$) between sewage sludge and top soil amendments in terms of RGR_h and RGR_d for all the three *Acacia* species (Table 4). Among the four tailing amendments, fertilizer exhibited the most significantly high RGR_h and RGR_d of 0.133 ± 0.008 $\text{cm cm}^{-1} \text{month}^{-1}$ and 0.127 ± 0.007 $\text{cm cm}^{-1} \text{month}^{-1}$ respectively and sewage sludge had the least RGR_h and RGR_d of 0.041 ± 0.008 $\text{cm cm}^{-1} \text{month}^{-1}$ and 0.031 ± 0.008 $\text{cm cm}^{-1} \text{month}^{-1}$ respectively. The overall order of performance was as follows (RGR_h ; RGR_d) fertilizer

(0.133 ± 0.008 ; 0.127 ± 0.007)>topsoil (0.103 ± 0.007 ; 0.082 ± 0.007) = control (0.095 ± 0.007 ; 0.068 ± 0.007)>sewage sludge (0.041 ± 0.008 ; 0.031 ± 0.008).

DISCUSSION

Species survival performance

A. polyacantha, *A. karroo* and *A. gerrardii* established on the Trojan Nickel Mine tailings dump survived satisfactorily well. Hamad and Kamal (2006) and ADEH (2003) attributed the 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. Survivals on top soil and control amendments were not significantly different. This can be explained by the similarity of the available concentrations of the phytotoxic trace elements which are similar except for Pb (Table 2a). Lead relatively has a lower level of phytotoxicity compared to for example Cu, Ni and Co (McBridge, 1994). The relatively high pH of the tailings material means that, most of the phytotoxic elements are fixed in relatively insoluble complexes. Sewage sludge and fertilizer

Table 4. Species growth performance.

Species (N = 90)	Amendment material	Mean Relative Growth Rate (cm cm ⁻¹ month)	
		RGR _h ± SD	RGR _d ± SD
<i>A. gerrardii</i>	Top soil	0.072±0.073 ^a	0.073±0.064 ^a
	S. sludge	-0.002±0.070 ^b	0.003±0.074 ^b
	Fertilizer	0.114±0.074 ^c	0.131±0.047 ^c
	Control	0.066±0.064 ^a	0.068±0.067 ^a
	Overall± SE	0.062±0.006	0.069±0.006
<i>A. karroo</i>	Top soil	0.186±0.073 ^a	0.093±0.049 ^a
	S. sludge	0.097±0.110 ^b	0.034±0.070 ^b
	Fertilizer	0.257±0.047 ^c	0.147±0.043 ^c
	Control	0.189±0.096 ^a	0.093±0.060 ^d
	Overall± SE	0.182±0.007	0.092±0.006
<i>A. polyacantha</i>	Top soil	0.051±0.040 ^a	0.080±0.057 ^{ac}
	Sewage sludge	0.028±0.043 ^b	0.057±0.074 ^{ab}
	Fertilizer	0.029±0.042 ^{ab}	0.104±0.092 ^c
	Control	0.030±0.047 ^{ab}	0.042±0.051 ^b
	Overall± SE	0.035±0.007	0.071±0.006
Significant difference			
Species		***	*
Media		***	***
Species and media		***	***

Means with common superscripts within each column for each species show no significant differences ($P>0.05$). *** show significant differences ($P<0.001$). *Show significant differences ($P<0.05$).

amendments had similar lower survivals (Table 3) 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 resulted in increased availability of heavy metals such as Co, Ni, Zn, and Mn (Table 2a) which when taken up by the plant adversely affects growth, and death of plants could occur as a response to increased concentration within the plant system (Brady and Weil, 2002). In contrast, Corréa and Mélo (2004) observed that, sewage sludge presented a pronounced advantage over composted garbage for plant survival. Tree survival rates of eight Brazilian savanna tree species ranged from 47 to 87% in 22 months and the best result of 87% of seedling survival was on trees treated with sewage sludge.

In our study, low survival under fertilizer amendment may be attributed to physiological stress, due to inadequate water supply as the plants were not watered. This is because fertilizer applies nutrients in a more readily available form compared to the other. At early growth stages the root system is not well developed and there will be an excess of nutrients which affects growth,

due to osmotic effects until the growth of the plant is sufficient to absorb part of the early excess and reduce external concentration (Black, 1993). The adverse effects of high osmotic potential in the plant rootzone can be avoided by split application of fertilizers, that is adding fertilizers in smaller quantities at intervals.

Species growth performance

A. karroo performed best in RGR_h and RGR_d (Table 4) this being indicative of its robustness and hardness 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. These observations were made under two different management regimes and also different to the current student implying that, this is an inherent characteristic of *A. karroo*, thus supporting our view that this species is robust. 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 and 4.1 cm stem diameter and 120 and 144 cm 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 RGR_h ($0.035 \pm 0.007 \text{ cm cm}^{-1} \text{ month}^{-1}$) 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 steep slope (26°), so as to avoid being toppled down by wind. This is evidenced by its RGR_d ($0.071 \pm 0.006 \text{ cm cm}^{-1} \text{ month}^{-1}$) which is twice higher than RGR_h . Brady and Weil (2002) noted that on steep slope 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 follows (RGR_h , RGR_d , and growth trends) fertilizer > topsoil = control > sewage sludge. Fertilizer amendment exhibited the highest RGR_h , RGR_d and growth trends because the application of inorganic compound D fertilizer ensured the availability of vital nutrients in readily available forms for plant uptake (Brady and Weil, 2002). Our results reinforce the recommendation by Brown et al. (1996) for use of fertilizer to increase biomass on reclaimed mine soils. Besides increasing plant growth and nutrient uptake, the fertilizer stimulates nutrient cycling not necessarily provided by the fertilizer but by the soil. The results concur with Hill (1977) who observed a clearly visible response to 50 g per tree (88.2 kg/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.

Relative growth rate in height (RGR_h), RGR_d and growth trends for topsoil and control were similar, showing no differentiation between the two treatments. There was no differentiation because the concentrations of available elements are similar under the two treatments (Table 2a). 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. Lower performance by sewage sludge is attributed to 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 2: 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 nutrient uptake, 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 also affects N-fixation (Wild, 1993). These results concur with Lambert et al. (1985) who observed that mycorrhizal trees responded with impeded shoot development of conifers under sewage sludge in Cincinnati, United States.

In contrast Larson (1974) indicated good growth response from sludge (5% N, 3% P and 0.5% K) as well as Corrêa and Mélo (2004) also observed that, sewage sludge presented a pronounced advantage over composted garbage for eight Brazilian Savanna tree species. The variability in performance could be a reflection of variability of chemical characteristics of sewage sludges which is highly dependent on its source. Besides the effects of heavy metals under acidic conditions, nutrient release and retention is affected due to a reduction in cation exchange capacity (Mikli, 2001) which reduces the supply of essential bases Ca, Mg and K, thus reducing plant growth.

CONCLUSIONS AND RECOMMENDATIONS

In conclusion, based on early survival performance, *A. gerrardii*, *A. karoo* and *A. polyacantha* can be used in revegetation of nickel mine tailing dumps under similar conditions, since all the tailing 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. *A. karoo* outperformed both *A. gerrardi* and *A. polyacantha* in terms of RGR_h and RGR_d .

Further study is recommended over a longer observation period, so as to ascertain changes in survival and growth performance of the *Acacia* spp. under the four tailing amendments. We also recommend studying of heavy metal nutrient up-take among the three species.

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