Revegetation of sand mines in the Seringveld Conservancy

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Synopsis

Mining of sand in South Africa is rapidly growing to sustain an increasing demand for sand for building purposes. Although mining of sand is regulated by environmental legislation, such as the National Environmental Management Act 107 of 1998[1], previous bad mining practices have left areas of land degraded and vulnerable to erosion. This study was conducted in the Seringveld Conservancy, where mining of sand has left the landscape with a degraded and unsightly appearance, and where little rehabilitation of the original vegetation has taken place.

The aim of the study was to develop rehabilitation techniques for the degraded mined soils on two sand mines, Boekenhout Sand and Krokodil Sand, and to develop an overall strategy of revegetation by regenerating key plant species. Techniques for regenerating indigenous tree species cover, using modified mined sludge if topsoil is not available, were used to develop a practical and cost-effective strategy to be used in revegetation. A comparative trial was used to cultivate indigenous tree species in different soil mixtures.

The study is important as it provides new information on the rehabilitation and revegetation of sand mined areas in the Seringveld Conservancy. This study will determine if alternatives could be used to replace topsoil on mined areas where none is available. The study is needed to determine whether revegetation of the mined areas would be possible using indigenous plant species that are difficult to grow.

The overall results indicate that replacing topsoil was successful for various modified soil mixtures that could sustain the growth of indigenous vegetation on the sand mines. Different indigenous tree species require different modified soil mixtures for successful propagation. A revegetation strategy was developed to complement and enable the rehabilitation of the mined areas in the Seringveld Conservancy.

Keywords

Rehabilitation, revegetation, Seringveld, sand mines, Burkea africana, topsoil, germination trials.

Introduction

Sand mining and land degradation in the Seringveld Conservancy

Sand mining causes the destruction of existing vegetation and the underlying soil profile[2]. After mining has started, the original landscape is disturbed, ecosystems are removed and ecological functions are destroyed[3]. As a result, several changes occur in the physical soil properties (permeability, water holding capacity and soil texture), chemical soil properties (pH, organic matter and salinity) and biological soil properties (microorganisms and micro-fauna)[4]. This results in the loss of soil organic matter[5] and in biological sterility of soil[6].

This article concerns rehabilitation of sand mines in the Seringveld Conservancy, Gauteng Province, South Africa. Sand mines in the Seringveld Conservancy may be classified into two distinct groups for the purpose of evaluating surface rehabilitation. The first category comprises older sand mines, which were operational in the 1980s and which have no saved topsoil for rehabilitation purposes. The second category comprises operational mines that have stored topsoil stockpiles to be used during rehabilitation of mined areas.

The purpose of this contribution is to report on the evaluation of rehabilitation techniques for sand mines, using local soils and soil amendments, and vegetation growth trials of tree species indigenous or endemic to the Seringveld. Two sand mines, Krokodil Sand and Boekenhout Sand, were selected as case studies, representative of the two mine types. Comparative studies have been undertaken to investigate the potential and cost-effectiveness of rehabilitating the two sand mines using locally available soils and soil amendments. The growth trial involves five dominant tree species, cultivated for one growth season in a shade-house setting on the mine. The findings of the trials are incorporated into a short guideline document for practical guidance in mine rehabilitation practice.

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Vegetation in mine rehabilitation

Revegetation is the process of vegetation establishment and care, as part of the process of reclamation, rehabilitation or restoration[8]. The biggest challenge of rehabilitation is to establish a sustainable ecosystem that is self productive and able to survive without continued anthropogenic interventions (irrigation, fertilization or re-seeding)[9]. After the mining of a landscape has ceased, processes of self restoration are often slow (decades) and the final community of plants may not be the most desirable[10].

Revegetation may be achieved by three main techniques, namely planting of trees and shrubs, direct seeding, or by self-regeneration[11]. The availability of topsoil is a major consideration in revegetation. Topsoil needs to be used wisely to achieve successful revegetation[12]. Topsoil set aside during the first stages of mining may need to be amended for use during rehabilitation. Various materials, such as construction fill, agricultural residues or mining sludge, could serve as sources of nutrients and soil property modifiers. Analysing the chemical properties of the soil can be helpful in directing possible soil amendments and guiding species selection[13]). A well-prepared site will provide the most suitable conditions for plant germination, survival and to promote long-term revegetation success.

Study area

The two selected sand mines, Boekenhout Sand and Krokodil Sand, are located in the Cullinan District of Gauteng Province, approximately 30 km north-east of Tshwane and 12 km north-west of Cullinan. Both sand mines are located inside the Seringveld.

Geology and soils

The sand mined on Boekenhout Sand and Krokodil Sand is underlain by quartz, grindstone, scale and conglomerates of the Waterberg system[14,15]. Topsoil is mostly unavailable on portions of Krokodil Sand and previous mining activity left the landscape on which mining took place disturbed, degraded and aesthetically unpleasing. Boekenhout Sand has stockpiled topsoil available for rehabilitation purposes. Topsoil on unmined areas, comprising the top ~150 mm, is not noticeably different from the sandy subsoils of the Seringveld Conservancy.

Vegetation

The natural indigenous vegetation of the Seringveld region is described as Central Sandy Bushveld (SVcb12)[16], comprising tall *Terminalia sericea and Burkea africana* woodlands as dominant species. *Burkea africana* is known colloquially as wild syringa from which the name Seringveld is derived. Dominant indigenous trees identified in an ecological survey by Crafford[17] are *Terminalia sericea* (Silver terminalia), *Burkea africana* (Wild seringa), *Acacia spp*., Mundulea *sericea* (Cork bush) and *Combretum* species.

Methodology

The experimental work of this project comprised four activities: (i) sampling and chemical analysis of soils; (ii) selection and preparation of soil mixtures; (iii) germination trials for tree species selection; and (iv) growth trials and trial plantings of selected species.

Soil sampling

Soil samples were taken: five samples from Boekenhout Sand (four subsoil and one topsoil) and five from Krokodil Sand (all subsoil). Analysis was done for macro- and micro-nutrients P, K, Ca, Mg, Cu, Fe, Mn and Zn, by the Department of Plant Production and Soil Science, University of Pretoria, to determine the amounts of inorganic fertilizers needed to restore the mined soils to a state suitable for revegetation. The standard Bray 1 Extractable P method[18] was used to extract phosphorus from the soil samples. Fe, Mn, Cu, and Zn were determined by inductively coupled plasma atomic emission spectrophotometry (ICP-AES). Ca, Mg, and K were determined by atomic absorption spectrophotometry (AAS).

Soil mixtures and comparative trials

Various mixtures were prepared, based on three different soils. To derive an amended soil from the poorer quality subsoils of the Krokodil Sand mine, for which no original topsoil had been retained, a strategy suggested by Randel and Wilreker[19] was adapted, namely to use fine silt material from washed sand (referred to as sludge), generally regarded as a waste by-product, as a medium to be mixed with sub-soil.

Topsoil was collected from Boekenhout Sand. Degraded subsoil was collected from Krokodil Sand (on portions where no topsoil was available). The third soil base for evaluation was sludge from sand washing operations on Boekenhout Sand. Ratios of fine washings to subsoil were in the range 1:3 to 1:1. As a further amendment, chicken manure from a nearby chicken farm was collected as a low-cost fertilizer to be blended into trial mixtures. The three collected soils and fertilizer were mixed into various combinations according to the design indicated in Figure 1. In total, seven soil mixtures were used.

Germination trials

Only tree species were considered for germination trials. Selection of tree species for the vegetations trials were based

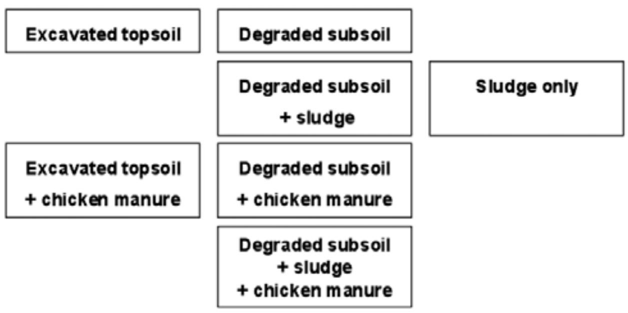

Figure 1—Experimental design containing the various soil mixtures used in the comparative trial experiment

on an ecological survey carried out as part of the Environmental Management Plan development of the targeted mines[17]. From the identified indigenous tree species occurring on the sand mines, ten were chosen for germination trial: *Acacia karroo, Acacia caffra, Burkea africana, Combretum zeyheri, Mundulea sericea, Peltophorum africanum, Strychnos pungens, Terminalia sericea, Rhus leptodictyaa* and *Rhus lancea*. The four most successful species from this trial were selected for use in the subsequent comparative growth trial. Although difficulty to germinate and cultivate, Burkea africana was selected, as it is the dominant species in the Seringveld.

These 5 species were used in germination trials. The germination trials were conducted on the mine Boekenhout Sand, where a shade-house was built to house the experiment. Three equal groups of ~100 seeds per species were used to perform pre-germination treatments. The first group was soaked for 12 hours in tap water. The second group of seeds was placed in boiling water, where after they were left to soak for 12 hours. After soaking, the seeds were planted out in bags containing topsoil from Boekenhout Sand Mine. The third group of seeds was scarified using sanding paper and immediately planted into bags containing topsoil. Seeds were planted by pressing the seed lightly into the moistened soils and covered with 2 to 3 mm of soil. Germination success was taken as the seedling progressing to the stage of establishing a primary root and the emergence of the first leaf pair.

Growth trials and trial plantings of selected seed

Once the best germination method had been determined (boiling water pre-treatment except for *Burkea africana*) the growth trials commenced. Twenty seeds of each of the five selected species were planted in each of the seven soil mixtures (Figure 1). The experimental matrix thus comprised a 7 x 5 matrix, for 35 species x soil combinations, with 20 repetitions of each combination (700 seeds altogether). For the comparative growth trials, up to a maximum of ten of the most vigorous specimens were retained for each combination.

The planting of seeds for the growth trials was planned for late summer, coinciding with the anticipated germination time for the chosen species and coinciding with the onset of expected sustained summer rainfall. Planting in fact took place in the last week of December 2007. However, in early January heavy rainfall (more than 100 mm) resulted in many of the seedling bags becoming saturated (specifically those containing high sludge and chicken manure fractions). The emerging seedlings in sludge and in the degraded mined land, sludge and chicken manure mixtures were lost. To continue with the experiment, it was necessary to plant a further set of test seeds.

Due to limited availability and delays in seed procurement, a second planting to recover from this setback took place on 1 March 2008, rather late in the season. Results reported in this work are based on both the first planting in December (referred to as the summer planting) and from the second planting in March (referred to as the autumn planting). The seedlings were cultivated in the shade-house (now protected by a plastic rain shield) for a period of six months, with growth measurements recorded at seven to fourteen day intervals. The period of regular measurements spanned the end of the growth season (~40 days), the winter senescence period (~70 days), and the onset of the new spring growth season (~50 days). Measurements were terminated at this stage.

Results

Soil sample analysis

Results from analyses of soils for minor and trace elements are presented in Table I (the single Boekenhout topsoil sample, five Boekenhout Sand samples and five Krokodil Sand samples). The needed amendment percentages of major nutrients, needed to bring the samples to similar concentrations to the reference topsoil, were calculated from these soil analyses.

Table I

Concentrations of macro and micro nutrient elements contained in the sampled soils and an analysis to determine the amount of amendments needed for rehabilitation of the sands

	P (mg kg^{-1})	K (mg kg^{-1})	Ca (mg kg^{-1})	Mg (mg kg^{-1})	Cu (mg kg^{-1})	Fe (mg kg^{-1})	Mn (mg kg^{-1})	Zn (mg kg^{-1})
Boekenhout topsoil	18.80	66.00	119.00	42.00	0.27	40.59	23.52	0.42
Boekenhout average	4.1	17.8	55.8	39.5	0.3	24.2	11.9	0.21
Std dev.	3.0	3.3	26.4	28.4	0.1	31.1	7.2	0.16
% Std dev.	75%	19%	47%	72%	50%	128%	61%	76%
Sand: soil ratio	0.22	0.27	0.47	0.94	0.97	0.60	0.50	0.50
Amendments needed (mg kg^{-1})	14.7	48.2	63.2	2.5	0	16.39	11.62	0.21
Krokodil average	3.10	20.80	41.20	18.20	0.16	26.45	8.62	0.18
Std dev.	1.58	11.19	24.13	9.28	0.14	26.11	7.39	0.18
% Std dev.	51%	54%	59%	51%	83%	99%	86%	101%
Sand: soil ratio	0.16	0.32	0.35	0.43	0.60	0.65	0.37	0.43
Amandments needed (m kg^{-1})	15.7	45.2	77.8	23.8	0.14	14.14	14.9	0.24

Averages, standard deviation and percentage standard deviation of the element concentrations of the samples from Boekenhout Sand and Krokodil Sand are presented in Table I. The topsoil sample (referred to below as soil) is used as a control, which is presumed to contain elements and nutrients in concentrations appropriate for the indigenous tree species growing in the Seringveld. The sand:soil ratios were used to indicate the element fraction percentage needed to amend the soil. In Table I, it can be seen that when compared to the topsoil sample, both mines mostly need the three macro nutrients P, K and Ca and the two micro elements Mn and Zn. The table illustrates a high variability in the nutrient concentrations in the sands, ranging from 19% to 100%. Because of the high variability of the elements in the sands, soil amendments cannot be specified as an exact recipe - amendments recommended are approximate requirements.

The phosphorus needed to amend the soil to the same intensity as in the topsoil sample would require a 14.7 mg kg^{-1} improvement for Boekenhout Sand and 15.7 mg kg^{-1} for Krokodil Sand on average (Table I). Recommendations for use of commercial inorganic fertilizer amendments were calculated as an application of 0.50 tons ha^{-1} fertilizer, in the form of superphosphate 10.5 (Omnia Fertilisers®). The price of superphosphate (fertilizers) was R4 000 per ton (2008 prices). The cost implications for Boekenhout Sand and Krokodil Sand of this amendment can be calculated simply as: Cost = Area × Application rate × Cost per ton. The resultant cost estimate for the recommended phosphorus amendment using synthetic fertilizers is R440 000 per mine.

Table I reveals that 48.2 mg kg^{-1} potassium (K) amendment will be needed on Boekenhout Sand and 45.2 mg kg^{-1} on Krokodil Sand on average to correspond to the amount of potassium available in the topsoil sample. Recommendations for use of potassium (K) were 114 kg ha^{-1} for the soil on both sand mines. The amendment of potassium is accomplished by adding K_2SO_4 to the soil, at a cost of R5 500 per ton (2008 prices). Using the formula above, the cost of potassium amendment would be R138 000 per mine.

Because of the high cost of the artificial fertilizers, the author and the sand mine manager decided to replace the superphosphate and K_2SO_4 with locally sourced chicken manure, which contains P_2O_5, K_2O and N_2. P_2O_5 and K_2O breaks up to release phosphate and potassium into the soil for plant absorption. This strategy is much cheaper and considered more environmentally friendly than use of synthetic fertilizers.

There is on average a factor 0.4 Ca deficiency in the subsoil compared to the topsoil sample. Boekenhout Sand and Krokodil Sand need 63 mg Ca kg^{-1} and 78 mg Ca kg^{-1} augmentation respectively to resemble the amounts present in the topsoil sample. An additional 800 kg ha^{-1} of lime would be sufficient to supply the amounts necessary to repair the soil. Lime is inexpensive, with a cost of R150 per ton. Mn amendments suggested for the soil is 15 kg ha^{-1} for the factor 1.5 deficiency. It was agreed to add small quantities of Mn amendment at a cost of R5 600 per ton, for a total cost of R37 000 for both mines.

Plants need small quantities of micronutrients. Micronutrients are presented in Table I as Cu, Zn, Mg and Fe. Cu and Zn are trace elements and soil amendments will be done using $CuSO_4$ and $ZnSO_4$ respectively. Only 2 kg ha^{-1} of $CuSO_4$ amendment is suggested for both Boekenhout Sand and Krokodil Sand. 11 kg ha^{-1} $ZnSO_4$ will be used in the soil of Boekenhout Sand and 6 kg ha^{-1} for Krokodil Sand. Mn and Fe will not be added into the soil as the minor amendments suggested are irrelevant for this study.

Germination trial

Three seed pretreatment techniques were tested in a qualitative trial: hot water soaking after boiling, cold water soaking at room temperature, and scarification. The four successful species were *Acacia caffra, Acacia karroo, Mundulea sericea* and *Peltophorum africanum*. For *Burkea africana*, germination was successful using the scarification technique, with a germination rate of 70%.

Comparative growth trial

Comparative growth trials were conducted to measure the performance of growth for the five species in different soils against a control. The two best performing species out of the five planted were *Acacia karroo* and *Peltophorum africanum*. Both these species had a high germination and survival rate and will be used in determining the characteristics of the soil mixtures. The graphs presented in this section show a comparison of the growth pattern of the species in the soils. Time steps on these graphs represent successive measurements, at intervals from 7 to 14 days. The time axis is thus not continuous, even although for ease of legibility of the graphs the various parameters are plotted as continuous lines. It should be noted that the survival rate is represented as percentages, whereas the rest of the measurements are presented as [mm] of growth. Leaf count is represented as a factor of ten to clearly illustrate the relationship between leaf count, height and width.

Acacia karroo

Figure 2 and Figure 3 represent comparable results obtained by the growth of *Acacia karroo* in seven soil mixtures, including the topsoil from Boekenhout Sand. The results obtained for *Acacia karroo* is from the summer and autumn planting periods and will be discussed in the remainder of the section.

Figure 2 and Figure 3 clearly illustrate 100% survival for six of the seven soil mixtures used in the trials. Only 80% of *Acacia karroo* germinated in the sludge (Figure 3b). The summer planting took place on 26 December 2007 and measurements commenced. After germination in around two weeks time, heavy rain and floods caused a portion of the seedlings in the growth trials to drown. Most soil mixtures containing mixed sludge and chicken manure caused a clogging of the growth medium and resulted in drainage problems.

Figure 2 illustrates the average growth of the species that survived from the summer planting. Because of the flooding of the shade-house, the time axis starts only at 80 days after

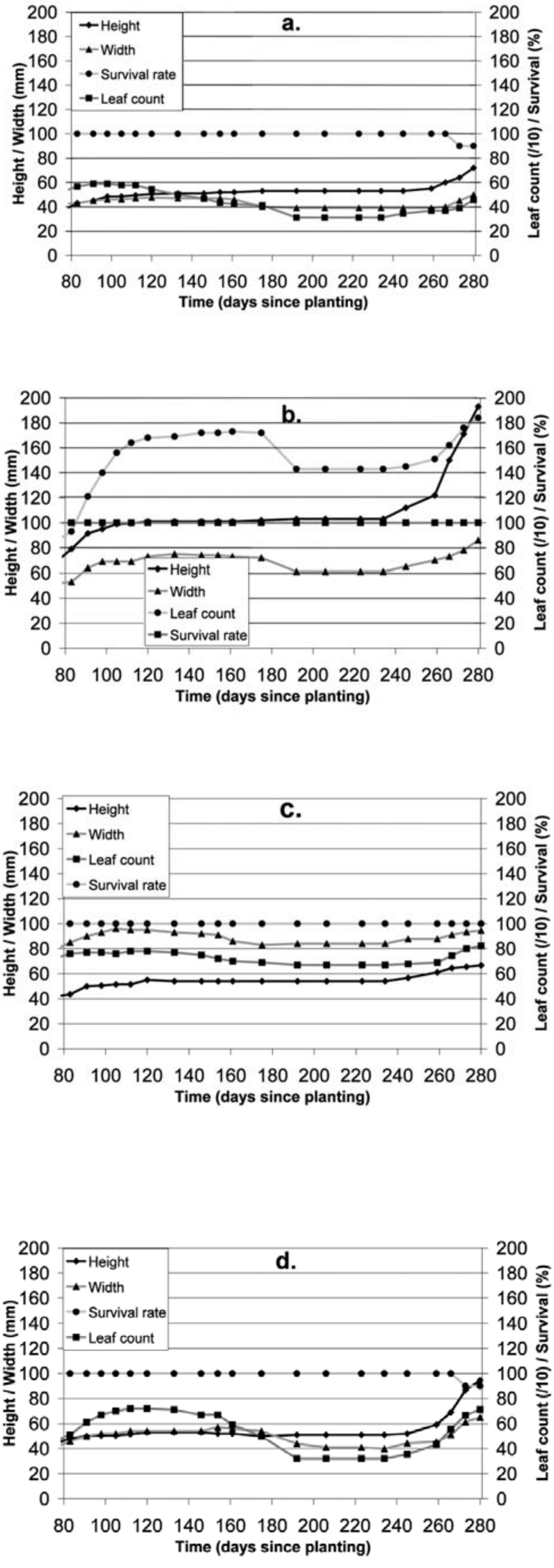

Figure 2—Growth of Acacia karroo from the summer planting: (a) Topsoil (b) Topsoil and chicken manure (c) Degraded mined land (d) Degraded mined land and sludge

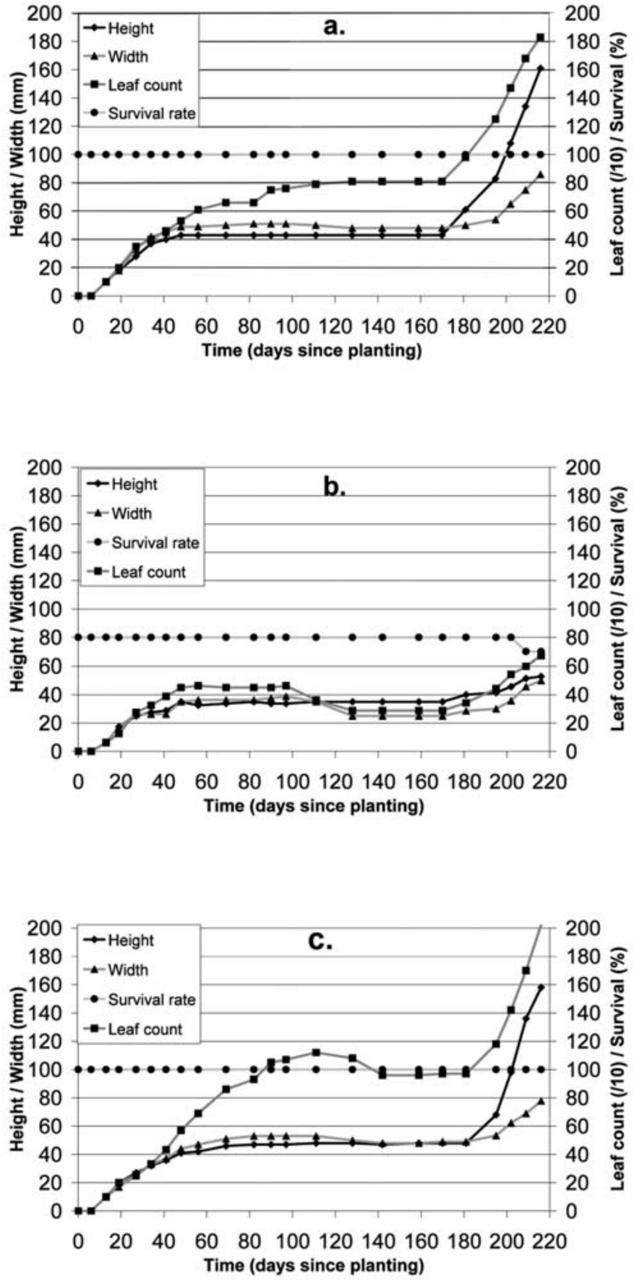

Figure 3—Growth of Acacia karroo from the autumn planting: (a) Degraded mined land and chicken manure (b) Sludge (c) Degraded mined land, sludge and chicken manure

germination from when the first measurements were done. The plant growth in height, width and leaf count follows an expected seasonal pattern. Growths progressed until 160 days after planting, corresponding to the start of the winter months. After 240 days (since planting), the height increased again to indicate growth in the new growth season.

Plant width and leaf count decreased in the winter months (from around 140 days since planting) and stabilized 190 days after planting. The new growth season started from 230 days after planting. When compared to topsoil (Figure 2a), a substantial amount of growth took place when chicken manure was mixed with topsoil (Figure 2b).

After the rain and partial flooding of the growth trial, the autumn planting took place on 1 March 2008. Seedlings from the topsoil and chicken manure; sludge; and degraded mined land and sludge mixtures were replanted (Figure 3).

Figure 3 illustrates the average growth for the *Acacia caffra* seedlings planted in the autumn planting. 100% germination was achieved for the topsoil and chicken manure mixture; and the degraded mined land, sludge and chicken manure mixture. Sludge had an 80% germination success.

The degraded mined land and chicken manure mixture (Figure 3a) had a similar growth pattern to the degraded mined land, sludge and chicken manure mixture (Figure 3c). Both of these mixtures illustrate extensive growth patterns far higher than the growth of topsoil when compared to the period from 80 days after planting to the end of the trials (Figure 3). Degraded mined land, sludge and chicken manure (Figure 3c) had the overall best leaf count for species planted in the autumn planting, which is a direct resulted from application of chicken manure to the soil.

Peltophorum africanum

When focusing on soil mixtures not containing chicken manure, results indicate that degraded mined land and sludge mixture (Figure 4b) displayed an overall better growth pattern of average height, width and leaf count of seedlings than the topsoil control (Figure 3a) from 80 days since planting to the end of the trials.

The only difference between the degraded mined land and chicken manure mixture (Figure 5a) and the degraded mined land, sludge and chicken manure mixture (Figure 5b) is the addition of the sludge waste product which resulted in a marginal better growth than in (Figure 5a).

Burkea africana

Burkea africana was chosen in the growth trials to establish if these species could be grown from seed, and if so, in which of the seven soil mixtures. The results for the summer planting of *Burkea africana* seedlings are presented in Figure 6. A 100% germination of *Burkea africana* was achieved through the scarification techniques used for germination. Growth progressed until 230 days after planting where after most seedlings died. The reason for this is not fully understood and forms part of objections for further studies.

For *Burkea africana* in topsoil (Figure 6a) and the topsoil and chicken manure mixture (Figure 6b), a few surviving seedlings were recorded after winter (around 240 days since planting). This represents only 20% survival in topsoil and 10% in the topsoil and chicken manure mixture.

Seedlings from the autumn planting also indicated a good germination rate of 100%. Little growth occurred in the winter months (around 100 days since planting). The degraded mined land and chicken manure mixture (Figure 7a) and the degraded mined land, sludge and chicken manure mixture (Figure 7c) both illustrated reduced numbers in survival from 170 days after planting and all seedlings died before the end of the trials. Seedlings planted in mine waste sludge (Figure 7b) revealed a 30% survival rate at the end of the trial period.

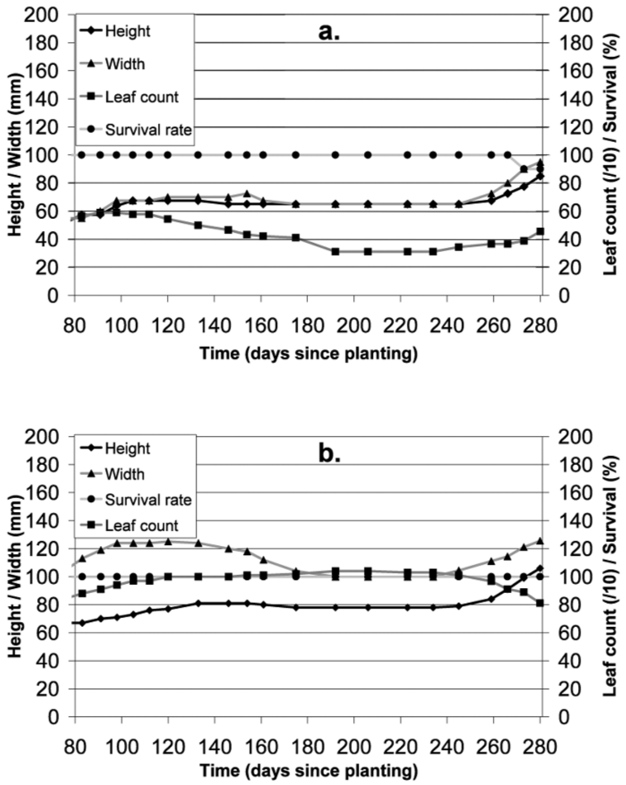

Figure 4—Growth of *Peltophorum africanum* from the summer planting: (a) topsoil (b) degraded mined land and sludge

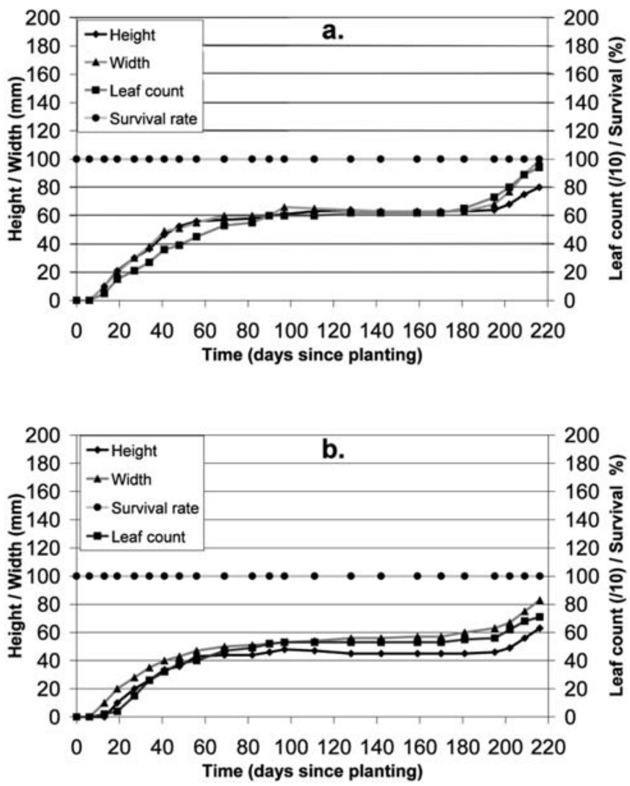

Figure 5—Growth of *Peltophorum africanum* from the autumn planting: (a) degraded mined land and chicken manure (b) degraded mined land, sludge and chicken manure

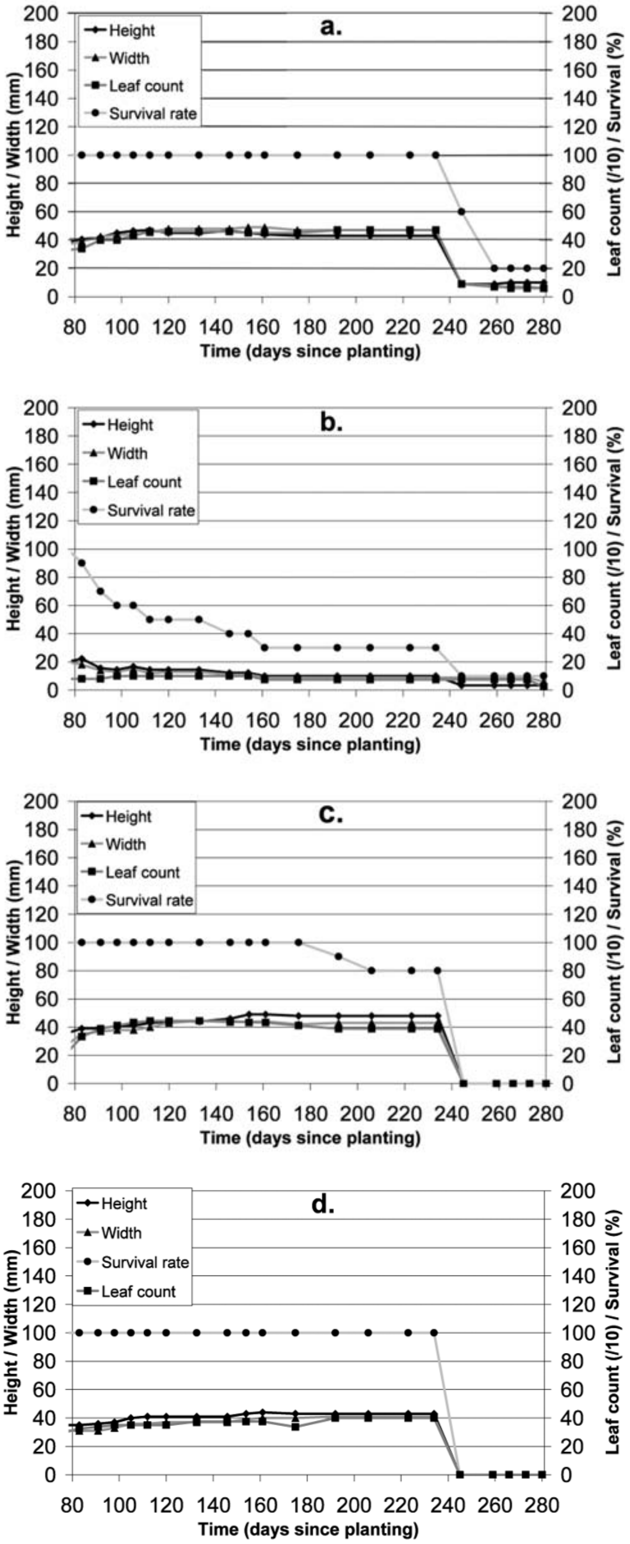

Figure 6—Growth of *Burkea Africana* from the summer planting: (a) topsoil (b) topsoil and chicken manure (c) degraded mined land (d) Degraded mined land and sludge

Standard deviation

Standard deviation was used to measure the dispersion of data around the mean value of the height measurements of *Peltophorum africana* (Figure 8) from the summer planting. When a trend line is drawn, the figure indicates the typical

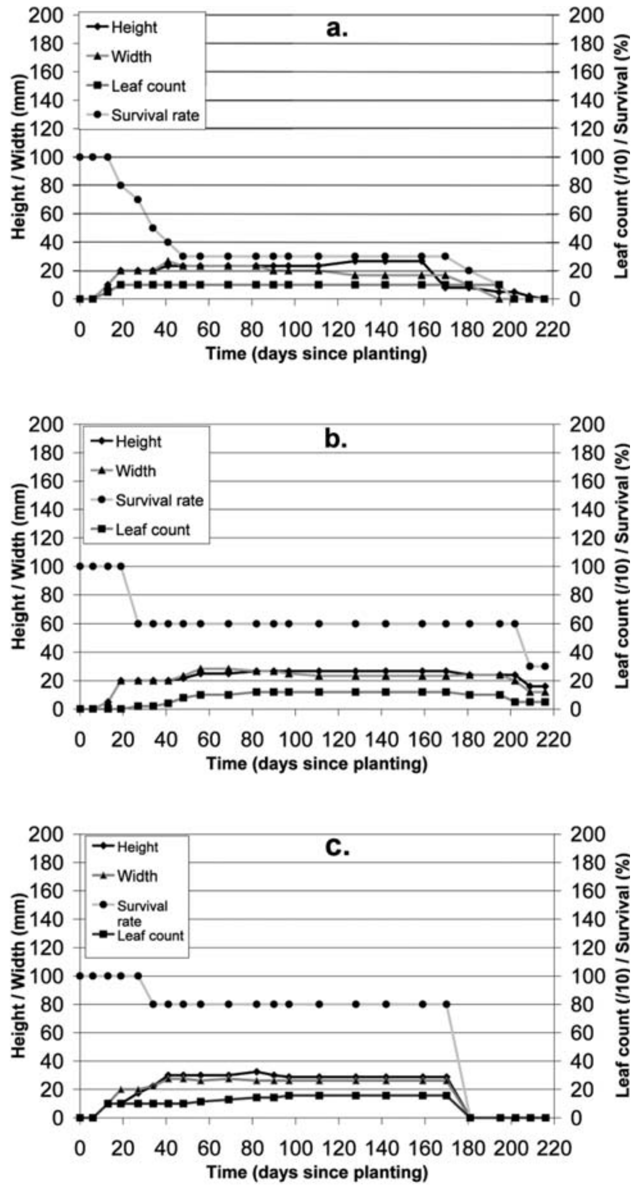

Figure 7—Growth of Burkea africana from the autumn planting: (a) Degraded mined land and chicken manure (b) Sludge (c) Degraded mined land, sludge and chicken manure

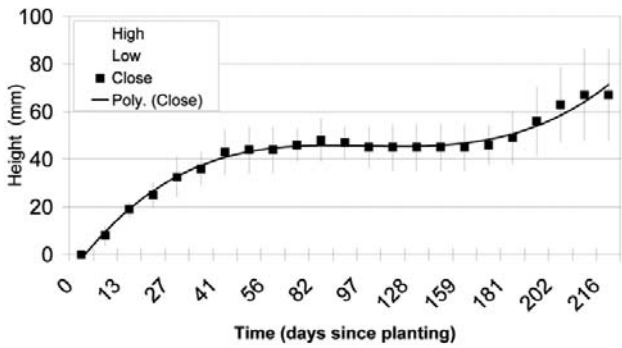

Figure 8—Standard deviation of the mean height measurements from *Peltophorum africanum*

Table II

The overall germination and survival rate percentage

	Percentage germination / survival rate (%/%)				
	Acacia caffra	*Acacia karroo*	*Peltophorum africanum*	*Mundulea sericea*	*Burkea africana*
Topsoil	20/100	100/100	100/40	100/0	100/20
Topsoil and chicken manure	0/0	100/100	100/100	100/80	100/10
Degraded mined land and chicken manure	0/0	100/100	100/100	30/66	100/0
Degraded mined land	0/0	90/100	100/100	100/40	100/0
Degraded mined land and sludge	60/67	100/100	100/100	100/100	100/0
Sludge	0/0	80/100	100/100	100/90	100/30
Degraded mined land, sludge and chicken manure	0/0	100/100	100/100	100/80	100/30

*The gray shading indicates the success of germination and survival from best (light) to worst (dark)

seasonal growth pattern experienced by most of the plants in the growth trials. The mean is indicated by green squares. High/low lines indicated on the figure represent the maximum and minimum standard deviation from the mean. The high intensity of measurements taken through out the growth trials resulted in a lower standard deviation.

Overall germination and survival comparison of soils

The overall germination and survival rated are presented in Table II. The table is presented in different shades of grey to distinguish the species and soil mixtures with the best resulting percentages. The shading clearly determines that *Acacia karroo* and *Peltophorum africanum* are the best suited species for cultivation in the different soils presented in Table II.

The performance of the different species in the soil mixtures was analysed to determine the possibility of using one or more of the soil mixtures of the growth trial as a replacement for topsoil. Table II represents the five different species and the seven soil mixtures. The topsoil and chicken manure; and the degraded mined land and sludge mixture were the overall best performing soils in the trial. Topsoil was the third ranked soil where after the degraded mined land, sludge and chicken manure mixture; and sludge had the same survival pattern.

A revegetation strategy for two sand mines in the Seringveld Conservancy

The area included in the revegetation strategy consists of two different sand mines. Because of similarities in the revegetation strategies of the two mines, a single plan with variations will be developed. Where necessary, distinction will be made between the two mines and will be indicated accordingly. The revegetation strategy will be discussed under the headings illustrated in Figure 9.

Removal of topsoil and subsoil

Topsoil is the most important factor in revegetation and should receive substantial attention in rehabilitation strategies.

Boekenhout sand

Topsoil should be removed by bulldozers and stored separately on the mining site. Topsoil should be stored out of the way of mining activities and should be covered with vegetation to stop erosion. If self establishment does not occur, it is advisable to plant fast growing vegetation on the topsoil heap to bind the soil.

Krokodil sand

Krokodil Sand is a degraded mine left by previous mining activities. Not all portions of Krokodil Sand have available topsoil for revegetation purposes. Therefore little topsoil is

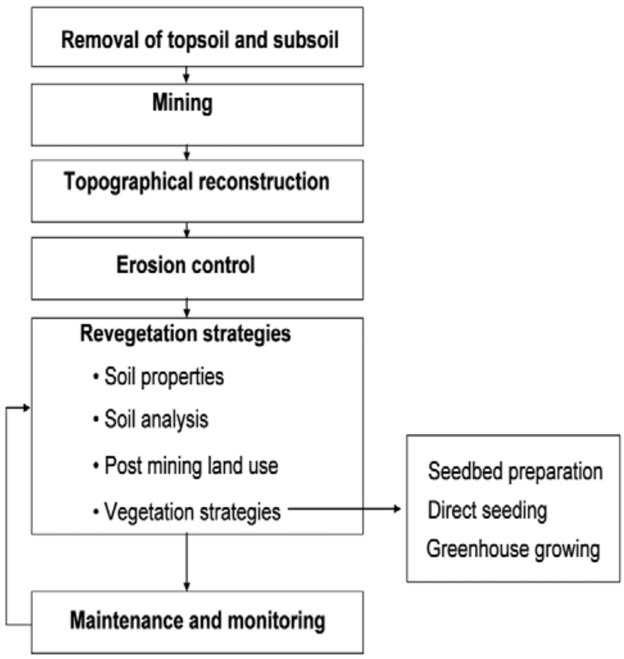

Figure 9—Steps to be taken in the revegetation strategy for Boekenhout and Krokodil Sand

*Chicken manure is available from nearby farms in sufficient quantity and at no charge other than the cost of transport available for rehabilitation on the portions previously mined on Krokodil Sand. The upper layer of the remaining soil will be stripped and piled as it may contain seed and organic matter built up through the years since initial exposure.

Mining

Sand mining will takes place on both mines using bulldozers and front end loaders. Mining activities should stop before the water table is reached to prevent the formation of dams on the mine and to prevent extracting the surrounding underground water source.

Topographical reconstruction

Firstly the holes dug by excavators will be smoothened at the edges to give a topographical flowing effect. The topsoil, which contains the seed bank and organic matter that could aid in revegetation process, should be returned. Chicken manure* should be worked into the topsoil as fertilizer to maximize growth of a new vegetation cover that will be established in further steps of the revegetation plan. Topsoil will not always be available for reconstruction. Degraded mined land should be mixed with sludge from sand washing and used as artificial topsoil to aid in vegetation growth.

Erosion control

Because the soil on the two sand mines has a sand nature and the permeation factor is high, surface runoff is reduced. Nevertheless, some mitigation is necessary to prevent possible erosion. Vegetation establishment will most likely be chosen over mulching and netting because of the small incline of the slopes and the sandy nature of the topsoil, which seldom forms crusts.

Revegetation strategies

Determination of the soil properties

Soil properties are determined through sampling soils in the designated revegetation area. Samples should be taken at the same depth for all samples. The samples should be mixed together, using a standard soil sampling method, and one master sample should be taken for laboratory analysis[20].

Soil analysis

Soil nutrient analysis is available through external laboratories (e.g. University of Pretoria Agricultural Department). The soil analyses will guide the types and amount of fertilizer required to amend the soils for the selected plant types

Chicken manure should be sourced from local chicken farms and worked into the soil. Fertilizers should be worked into the soil well before the revegetation process is initiated to prevent the fertilizing agents from burning the plants.

Post-mining land use

It is important at this stage to know the post-mining land use planned for the area to be revegetated. This will largely determine the plant species to be grown on this land. Boekenhout Sand and Krokodil Sand will be converted into a wildlife game farm when mining is completed and therefore the use of indigenous vegetation is indicated.

Seedbed preparation

Soil amendments such as lime, organic material and fertilizers should be added to the soil to achieve the optimum growing results.

Direct seeding

Direct seeding should be done using a seed mix developed for the mining area, and should contain indigenous grass and tree species. Seeding is mostly successful for grass species, while trees and shrubs should be cultivated in a controlled environment before they are planted out in the field.

Shade-house growing

Young tree and shrub seedlings should be cultivated in a controlled environment. Species that are fast growers should be chosen in preference to slower growing species, but where many trees are planted, slower growing species should be used in the mix.

Boekenhout Sand will cultivate many of the indigenous species in their own shade-house and where possible, will buy tree species from indigenous tree cultivators. *Burkea africana* will be grown by Wildflower Nursery to an age of three years for the Boekenhout Sand and Krokodil Sand revegetation plan.

Maintenance and monitoring

Watering and fertilizing of trees should continue until the trees are strong enough to survive without human aid. Monitoring should take place on regular time intervals to establish if the revegetation strategy was successful. Any trees that did not survive the transplanting process should be replaced. Soil sampling and analysis should be done every five years to monitor the development of the soil and need for supplementary fertilization.

Discussion

Many plants from high sludge and chicken manure containing mixtures were lost due to heavy rainstorms that occurred in January 2008 and replanting took place in March 2008. Two plantings were done and therefore the results are divided into two plantings, starting two months apart. Overwatering appears to have occurred and this would have had a negative effect on the outcome of the experiment. It is suggested that all these factors should be monitored in a controlled environment.

Soil sample analysis

Soil sample analyses lead to identifying deficiencies in the soils to be revegetated. Soil sample analysis revealed that the soil is deficient in phosphorus (P), potassium (K) and calcium (Ca). Soil need to be amended using K_2SO_4 and superphosphate 10.5. It was found that the addition of superphosphate and K_2SO_4 to the soil is costly and the use of chicken manure should be considered as it is an organic fertilizer. Amendments of calcium, magnesium and the micro nutrients should be added to the soil and before any revegetation is done; soil should be analysed again to determine the status of the developed soil.

Germination and growth trial

Germination trials were conducted and it was evident that *Acacia caffra, Acacia karroo, Peltophorum africana, Mundulea sericea* and *Burkea africana* were the best germinating species. The five species were tested to determine their growth rates through a growth trial extending over seven months. The results determined the suitability of using these species in a revegetation strategy and confirmed the suitability of the applied soil modifications needed to sustain growth on areas with no available topsoil. Many important species that were not included in the shade-house trials occur on the two mines and it is recommended that additional species be evaluated for inclusion in revegetation programmes.

The overall best performing species for the growth trial experiment based on its growth performance and survival rate was the *Acacia karroo*. For *Acacia karroo*, supplementing the topsoil is possible on areas where no topsoil is available. *Acacia karroo* grows well in soil amended with chicken manure but can also survive on degraded mine soils.

Peltophorum africanum was the second best performing species out of the seven used in the growth trial. The growth of *Peltophorum africanum* illustrates that the addition of sludge (waste product) to sub-soil can positively enhance growth in the species when this amended mixture is used as a replacement for topsoil.

Germination of *Burkea africana* was conducted successfully but most growth declined and few of the seedlings survived the winter. Growth trials of this species did not yield sustainable growth in any of the amended soils and only a few specimens survived in the sludge and degraded mined land mixtures. The species is known to be difficult to cultivate and therefore more efforts should be made to cultivate and successfully grow these plants. It is suggested that the species should be planted early in the growth season to allow maximum growth to take place before the next winter. This will ensure that the seedlings can grow into stronger plants that would be able to survive the winter senescence. The trial also established that *Burkea africana* should be planted in deeper and higher volume bags to allow space for elongation of the taproot. It is recommended that this species be grown by an established nursery that has control over the amounts of water irrigated onto the plants on a daily basis. Wildflower Nursery has been successful in cultivating these plants and will be used to cultivate *Burkea africana* seedlings on behalf of the mines.

Performance and characteristics of soil mixtures

Topsoil and various mixtures of sub-soils with amendments were evaluated. Topsoil and chicken manure was the most effective soil mixture for the growth of the five endemic plant species in the plant trial. This is to be expected as the topsoil should contain important humus and minerals optimum for plants adapted to these soils and local climate. The chicken manure aided in supplying the plants with additional minerals and nutrients resulting in a better and more effective growth pattern of the five species. However, this mixture did not work for *Burkea africana*, which seems to thrive in low-nutrient soils.

The degraded mined land and sludge mixture was the second most effective mixture. This finding is important in planning the revegetation of the degraded mined areas, as these materials are readily available, while topsoil is in short supply.

Both chicken manure and sludge form sand washing activities are relatively cheap to use in the revegetation strategies of Boekenhout Sand and Krokodil Sand. Available topsoil on Boekenhout Sand can be amended with chicken manure to provide a more advantageous mixture, while degraded subsoil on Krokodil Sand may be mixed with sludge to substitute for missing topsoil. It should be noted that more representative soil sampling will be necessary to reflect more accurately variability in composition of the soils within the mines. Sampling done for the purposes of this article was sufficient for deriving a preliminary costing model. A comprehensive soil survey and associated cost of multiple analyses would have been too expensive for this study.

Revegetation guide

A revegetation guide was successfully compiled in a simple form of procedures to be followed by the workers on the mines. The strategy is likely to initiate environmental awareness among mineworkers and can be used as a guide to vegetate areas disturbed through previous and ongoing mining. The revegetation guide incorporates guidelines for shaping disturbed landscapes for optimal later vegetation. The guideline contains easy to follow directives for mine managers and workers alike. The revegetation guide is focused specifically on the two sand mines concerned in this study and if followed, should ensure successful revegetation.

Conclusion

The revegetation of sand mines in the Seringveld Conservancy with indigenous vegetation can be accomplished successfully by using techniques and procedures developed in this minor dissertation. It is viable for the sand mines to use these strategies and to adopt them into their rehabilitation plans, as use of mine sludge and locally available inexpensive chicken manure are more cost-effective than strategies involving purchased synthetic fertilizers. Soil amendment should be done using chicken manure as a fertilizer for the macro elements needed in the soil (and low cost) and inorganic fertilizers should be used for the balance of the needed minerals. Waste produced by sand washing activities on the sand mines was successfully used in a mixture with subsoil as a substitute where no topsoil was available on previously mined areas.

Five endemic species were successfully germinated and established for the first season of growth in some of the amended soil mixtures. Not all of the tested endemic species evaluated could be germinated and propagated, specifically the locally abundant *Burkea africana*. If needed, *Burkea africana* could be propagated by a specialist indigenous nursery that has experience in propagation of these difficult species and then replanted on the sand mines as part of a revegetation programme.

A revegetation strategy was compiled to assist mining parties of the two sand mines Boekenhout Sand and Krokodil Sand with revegetation strategies.

This project has successfully achieved its two primary aims. Despite the degraded landscape of the Seringveld, this study has demonstrated successful and affordable techniques for regenerating indigenous tree species cover, using amended mine sludge if topsoil is not available, and developed a strategy for rehabilitation projects. This is a major contribution to sand mine rehabilitation in the Seringveld Conservancy. The implementation of the techniques developed will provide opportunity for mining parties to conserve the environment and actively achieve a balanced approach of development. The resulting rehabilitation will contribute towards the Dinokeng Game Reserve initiative by restoring the landscape and ecosystems and by implementing environmentally friendly mining practices.

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