Rehabilitation on Gold Tailings Disposal Facilities: Quo Vadis?

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ABSTRACT

Gold tailings disposal facility rehabilitation in South Africa has been in a way controversial in terms of final solutions and sustainability. Low rainfall (< 500 mm per annum), acidic conditions and steep side wall slopes (± 33°) make rehabilitation extremely difficult.

AngloGold decided to follow a scientific approach towards rehabilitation of mine spoils and to evaluate and research the different products, materials and techniques to improve existing and develop new methods with respect to: -

- Stabilising slopes by means of flattening
- Chemical stabilisers to minimise dust and water pollution
- Irrigation methods to improve water efficiency
- Lime requirements and application methods to neutralise the acidic spoils
- Intensive grass and tree species selection to establish on the tailings disposal facilities.
- Different planting methods for trees to increase the survival rate
- Alternative land use for tailings disposal facilities

This paper will describe the results of this research work and the practical applications. The results of the experiments were so relevant and cost effective that some of these have already been put into practice at other sites.

1. INTRODUCTION

Because gold tailing deposits are eroded by water and wind causing pollution, the mining industry is under considerable pressure to achieve high standards in the rehabilitation of tailing deposits. The basic philosophy of erosion control in the rehabilitation of tailings deposits is to protect the surface against the action of water and wind forces either by rock-cladding or by biological means (vegetation cover). At present the establishment of a good vegetation cover is considered the preferred solution.

Gold tailings have a high acid potential, a low fertility and poor physical properties. Stabilising it with vegetation requires liming, fertilisers and organic matter additions, scaled to match the severity of conditions. Although there are broad philosophies and methodologies in the rehabilitation of gold tailings facilities the finer points of rehabilitation are "competitive secrets". The only way to get the right answers is through research.

In the mid 1990's when rehabilitation of decommissioned tailings storage facilities in the Welkom area, Free State, South Africa started, AngloGold (at the time

Freegold) set aside FS South 6 for research purposes to specifically address aspects of rehabilitation. EnviroGreen made a proposal for a research project with the following objectives: -

- To improve or optimise existing rehabilitation techniques and methods to such an extent that the ultimate results are more economical and sustainable.
- To find new stabilising and rehabilitation techniques that are more reliable, economical and sustainable than the existing ones.

The different experiments conducted can be grouped in six main categories.

2. MAIN CATEGORIES OF RESEARCH WORK

2.1 *Protection of the Surface against the Action of Water and Wind Forces.*

2.1.1 *Physical and Chemical Methods*
Three experiments were done in this group, namely rock cladding (four trials) and chemical soil stabilisers (six different chemical substances).

2.1.2 *Biological Methods*
Two windbreak experiments were conducted. One with five different grass species as windbreaks on the perimeter walls and the other with different trees and shrubs on side slopes.

2.1.3 *Slope Flattening*
The north facing slope of FS S6 was flattened to 18° and vegetated. This project was done by AngloGold's Environmental Department.

2.2 *Methods of Rehabilitation and Amelioration.*

Eight different methods of rehabilitation (leaching, leaching with horizontal lime trenches, elementary amelioration, minimum cultivation with topsoil, optimum amelioration, optimal amelioration with drip irrigation, optimal amelioration with impact sprinkler, and dry land) are in the process of evaluation. This project is a joint venture between AngloGold, the Water Research Commission of South Africa and EnviroGreen.

The experiments on different methods of amelioration focused on types and amounts of lime, fertilisers and compost (49 trials in total).

2.3 *Seeding and Germination*

The investigations include seed mixtures, mulch application (rates and types), surface covering, timing of seeding, influence of aspect, and nitrogen fixers in legumes (78 trials in total).

2.4 *Evaluation of New Species (grasses and trees)*

Fifteen alternative grass species and twelve tree species were evaluated (46 trials).

2.5 *Trees*

Fifteen different tree species, three sapling sizes and eight different planting methods were investigated (31 trials in total).

2.6 *Land Use*

The cultivation of 23 different vegetables was evaluated.

3. ISSUES, RESULTS AND DISCUSSION

Several techniques and methods for the establishment of vegetation on gold tailings are in use by different rehabilitation and mining companies with different levels of success. The main categories of the research work were used to address the common problem (issues) experienced in the rehabilitation of gold tailings

Issue 3.1 ***Protection of the Surface against the action of Water and Wind Forces***

3.1.1 *Temporary Stabilisation of Tailings*

Only one experiment with six different chemical stabilisers was conducted. The final conclusion is: -

- Polymer chemical stabilisers are not suited for use on gold tailings with high salt contents.

3.1.2 *Biological Methods*

Best species for windbreaks on slopes. Two were conducted: -

- Grass wind-breaks on slopes
- Tree and shrub wind-breaks on slopes

The results are: -

- Of the four species evaluated only *Pennisetum macrorum* (Hippo grass) and *Hyperhenia hirta* (Thatch grass) survived after five years.
- Trees and shrubs were planted in a close grid pattern on the slope to minimise wind erosion, but they are still too small to be evaluated.

3.1.3 *Slope Flattening*

The objectives of this experiment were the following: -
To determine: -

- Cost implications
- Mechanical soil preparation and amelioration
- Vegetation sustainability
- Water run off and erosion

The results were the following: -

- Costs compare favourably with conventional methods. Initially higher due to civil engineering costs, but lower vegetation and maintenance cost.
- Flatter slopes allow the use of less labour intensive sprinkler irrigation systems.
- No excessive erosion after abnormally high rainfall.
- 18° too steep, 15° ideal.

Issue 3.2 ***Methods of Rehabilitation and Amelioration***

3.2.1 *Converting the tailings chemically, physically and biologically into a proper growth medium.*

The following experiments were conducted to find a solution for this issue.

- Mulch, compost and other types of surface cover
- Fertilisers
- Amelioration with and without lime
- Different methods of chemical amelioration

The results obtained are: -

- The addition of compost improves the chemical and biological properties of the tailings, but not the physical properties with respect to water-holding capacity. Compost has the same neutralising effect as lime in the medium term (3-4 years). Microbial activity is enhanced with the addition of compost, but as the vegetation cover develops the effect of compost on microbial activity diminished. Mushroom compost and sewage sludge were found to be the best type of compost tested. See Figures 3.2.1 and 3. 2. 2

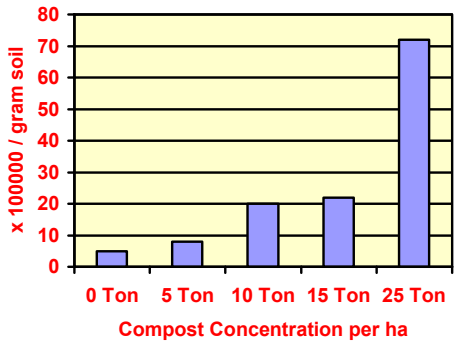

Figure 3. 2.1 Microbial Activity at different compost concentrations

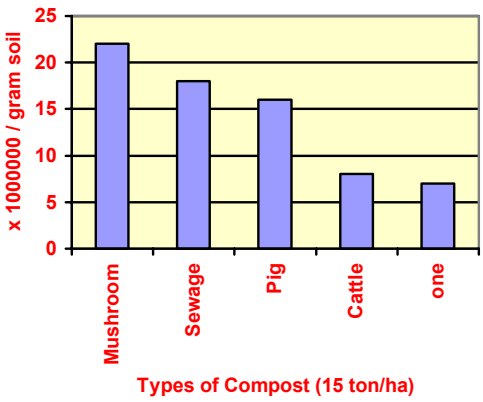

Figure 3.2.2 Microbial Activity at different compost sources

- The results obtained indicate that the amounts of fertilisers normally applied are excessive. The amounts of fertilisers applied to increase the phosphate status can be decreased by more that 50%. It was found that potassium leaches easily and therefore potassium fertilisers should be applied in smaller quantities and more frequently.
- Addition of lime does neutralise the acidity, but the amount of lime in reserve to neutralise potential acidity was not determined. Most of the lime treated plots have a high pH (more than 8.5) at present (3 –4 years after amelioration). See Table 3.2.3.

3.2.2 *Utilising Irrigation Water Efficiently*

One experiment was conducted and is still ongoing. The preliminary results are as follows: -

- Generally, excess amounts of water are applied. The leaching fraction of the non-leaching methods was 25% compared to the leaching requirement of 10% to prevent salt build up.
- The results of cone penetration test indicate that the depth of surface preparation is less than 20cm
- Drip irrigation causes a build up of salts because the leaching requirement could not be met
- After two years, lucerne now dominates the irrigated plots seeded with climax grass.

<u>Issue 3.3</u> Seeding and Germination

3.3.1 *Temporary stabilisation of tailings directly after seeding*

Two experiments were conducted: -

- Mulch and other types of surface cover
- Type and concentration of mulch

The results obtained are: -

- The best germination was found with two bales/100m² (± 40 kg/100m²)
- Decomposed mulch is better than fresh mulch
- Seed with homogenous shade (ecomat and bidum) germinates better than those only partly covered with mulch.

3.3.2 *Seeding Methods and Germination*

Three experiments were conducted: -

- Seeding methods
- Summer climax grass seeded in autumn
- Effect of slope aspect on germination

The results are: -

- Wheat seed must be covered, but covering of grass seed with tailings is not recommended.
- Climax grass seeded in autumn did not germinate well.
- The rate of germination is faster on west facing slopes than on south facing slopes.

Issue 3.4 ***Evaluation of New Species (grasses on slopes and flats)***

Species selection for local climatic conditions.
Two experiments were conducted: -

- New grass species on slopes
- New grass species on flats

Results: -

- Of the 16 grass species evaluated the only species that performed excellently on slopes were : *Chloris gayana* (Rhodes grass), *Cynodon dactylon* (Couch grass), *Polypogan monspeliensis* (Annual beard grass), and *Erogrostis curvula* (Weeping love grass)
- Of the 17 grass species evaluated on the flat areas, the only species that are still performing well, four years after establishment are: *Chloris virgata* (Feather-top chloris), *Lolium perenne* (Rye grass), *Hyparrhenia hirta* (Thatch grass), *Digitaria erianta* (Common finger grass) and *Anthephora pubescens* (Wool grass). (Table 3.4.1)

Issue 3.5 ***Evaluation of Tree Species and different Planting Methods***

Of the 13 tree species evaluated, the following trees performed exceptionally well: *Rhus pendulina* (White karee), *Acacia melanoxylon* (Blackwood), *Eucalyptus viminalis* (Eucalyptus), *Dodonaea viscosa* (Sand olive), *Casuarina equisetifolia* (Beefwood) and *Combretum erythrophyllum* (River bush willow).

Issue 3.6 ***Other Land Uses for Tailings Storage Facilities***

One experiment, to evaluate the cultivation of vegetables on tailings storage facilities was conducted. The experiment on trees could also be used to recommend some alternative land use on tailings facilities.

- Cabbages, radishes, spinach and tomatoes can be produced successfully on tailings dams without any radiation or heavy metal hazard (23 different vegetables were tested). (See table 3.6).
- Some trees e.g. some eucalyptus species and *Acacia melanoxylon* (Blackwood) can be established on tailings storage facilities successfully for commercial purposes.

4. CONCLUSIONS

The objectives of the project were: -

- To improve or optimise existing rehabilitation techniques and methods to such an extent that the ultimate results are more economical and sustainable.
- To find new stabilising and rehabilitation techniques that are more reliable, economical and sustainable than the existing ones.

The extent to which each of these objectives was achieved will be described separately.

Objective 1

(a) ***Improve or optimise existing rehabilitation techniques.***
The biological rehabilitation of gold tailings consists of different links: surface preparation (no cultivation, partial cultivation, intensive cultivation etc.), amelioration (lime, compost, fertilisers, leaching etc.), seeding (seeding mix, seeding rate, seed burial etc.), irrigation (type, frequency, amount etc.) and succession management. Improving any of these

links will strengthen the rehabilitation chain and reduce risks.

A variety of rehabilitation actions were investigated and those that led to significant improvement or optimising include: -

- Mulch – the optimum amount of mulch was found to be two bales per 100 m² (± 40 kg/100 m²)
- Fertilisers – the amounts of fertilisers applied are generally in excess. Less phosphate fertilisers are needed to increase the phosphate status to acceptable levels. For example 400 kg Supers per ha are more than enough compared to the 900 kg/ha applied normally. Potassium was also applied at too high rates that led to high leaching losses. The better alternative is to apply less potassium fertiliser, but more frequently. It was found that conventional fertilisers are more cost effective than slow releasing fertilisers. However, the slow-releasing fertilisers are a better alternative to use for the establishment of trees on gold tailings.
- Compost – the actual amount to apply depends on the salt content of the tailings, but in general the more one can apply, the better. If large quantities are applied (>15 ton/ha) then the amount of fertilisers added should decrease. The application of compost does benefit micro-organisms in the early stages, but as the grass cover improves, the difference in microbial activity between plots with and without compost treatments becomes negligible. Compost does not really improve the water holding capacity of gold tailings if the compost is <10% by volume.
- Seeding – it was found that intercropping of rye grass and lucerne with climax grass, led to the dominance of ryegrass and lucerne within a year or two. The exact reason for this dominance was not established but it is either allelopathy or a combination of the aspect and leaching of potassium. The south facing slope (on which the majority of the experiments were conducted) is cooler and wetter and therefore more beneficial for rye grass. Lucerne, which has a high potassium requirement, can benefit from the potassium leached to lower layers because it has a very deep root system. Intercropping of rye grass and lucerne with climax grass is not recommended, at least not for south and west facing slopes.
- Irrigation – it was found that even the "so called" none leaching methods are leaching methods to some extent due to excessive irrigation. Furthermore, when cutting back on irrigation, the necessary leaching requirement to prevent salt build up is sometimes ignored.
- Trees – an improved method to establish trees on gold tailings was found to be a combination of slow releasing fertilisers and additional auger holes.

(b) ***Economical and Sustainability***

Employing the optimisation and improvement methods, using the appropriate seed mix and amounts of fertiliser will not only reduce risks but will ultimately lower the cost of rehabilitation

Sustainability is a measure of the likelihood that a gold tailings facility rehabilitated to a certain standard will remain physically, chemically, biologically and socially acceptable for a significant period. The introduction of new or modified practices must be made, as in this case, on an experimental scale and their subsequent progress carefully monitored. The experiments were monitored from three to four years, which, is not long enough to make conclusive remarks regarding sustainability at this stage. Furthermore, field validation is necessary to avoid costly mistakes and

to ensure that the work consistently achieves positive results.

It is considered that objective one has been achieved.

Objective 2

New stabilising and rehabilitation techniques that are more reliable and economically feasible

There were only two experiments with aims that fell within this category, namely chemical stabilisers and the cultivation of vegetables on tailings facilities.

It was found that polymer chemical stabilisers should not be used on gold tailings that have a high salt content. These stabilisers are not reliable under high salt conditions.

It was found that cabbages, radishes, spinach and tomatoes could be produced successfully on gold tailings. However, to bring tailings to the same production level as agricultural land would be too expensive but there can be situations (labour, locality, market, excess water, etc.) where the production of vegetables on tailings facilities could be viable. An additional spin off of the project was that the tailings were so well ameliorated and/or transformed by the previous vegetation (vegetables) that the natural grass and herbs established afterwards voluntarily on the site.

5. RECOMMENDATIONS

In conducting the experiments it was found that fairly high qualities of tailings properties and plant quality could be achieved. The question remains, how sustainable is it? For rehabilitation purposes tailings quality can be defined as "the sustained capability of the tailings to accept, store and recycle water, nutrients and energy, to sustain biological productivity and maintaining environmental quality". The definition implies that tailings quality has two parts : an intrinsic part covering the ameliorated tailings inherent capacity for plant growth, and a dynamic part influenced by the management of the rehabilitated tailings facility. In general, a management system would be viewed as sustainable only if it maintains or improves the tailings quality.

Attributes of dynamic tailings quality are subject to change over relatively short time periods. For example, total organic matter may change over a period of years to decades, whereas pH and labile organic matter fractions may change over a period of months to years. In comparison, microbial biomass and populations, nutrient mineralisation rates and macro-porosity can change over a period of hours to days. Thus, maintenance and/or improvement of dynamic tailings quality deals primarily with those attributes or indicators that are more subject to change (e.g. loss or depletion) and are strongly influenced by management practices.

Monitoring has been common place for air and water but not for tailings. With regard to change in tailings quality, standards are needed to assess if the recorded changes are within natural variation or optimum range of tailings attributes in question, or if the changes are related to management practices that may require changes if quality is deteriorating. The interpretation of such changes and the required management response underlines the importance of "experience" and "skill" in the manager. Monitoring is important, but the usefulness of the data will only be realised if it is used in management decisions.

6. QUO VADIS?

This research project of AngloGold's South Africa Region, indicates that through an innovative, scientific approach towards rehabilitation of mine tailings storage facilities, results can be delivered, and there is a way forward for this extremely challenging work.

7. REFERENCES (LITERATURE CITATION)

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Table 3.2.1 Layout and Results

Block No.	Treatment	Microbial Activity 1998 ($x10^7$/g)	Microbial Activity 2001 ($x10^7$/g)	Root Development 2001 (cm)	Basal Cover 2000 (%)	Dominant Species 2000
H1	Full lime, fertiliser and compost treatment	4.0	2.9	61	6.3	Climax grass
H2	Only compost treatment	3.8	4.8	62	6.3	Climax grass
H3	Only lime	0.66	2.0	50	4.5	Climax ad pioneer grass
H4	Only fertiliser	0.62	5.1	39	4.0	Pioneer and some climax grass
H5	No treatment	0.0006	0.17	40	<2.5	Pioneer and a few climax grasses

Table 3.4.1 Grass Species – Layout and results

Legend for germination and performance:

G = Germination
Pion - Typical pioneer behaviour
P = Performance

Rating (semi-quantitative)

0 = Very bad
1 = Bad
2 = Reasonably
3 = Good
4 = Very Good
5 = Exceptionally well

Block No.	Grass Species	Germination & Growth Performance of grass after one Year
L-1	*Chrloris gayana*	G5, P5
L-2	*Cyndon dactylon*	G5, P5
L-3	*Polypogon monspeliensis*	G5, P5
L-4	*Eragrostis curvula*	G5, P5
L-5	*Digitaria eriantha*	G3, P1
L-6	*Eragrostic echinochloidea*	G2, P1 (Pion)
L-7	*Themeda triandra*	GO, PO
L-8	*Hyparrhenia hirta*	GO, PO
L-9	*Melinis repens*	G3, PO (Pion)
L-10	*Ennapogon cenchroides*	GO, PO
L-11	*Andropogon eucomus*	GO, PO
L-12	*Chloris virgata*	G4, P1 (Pion)
L-13	*Mulch*	G3, P1 (Pion)
L-14	*Aristida congesta*	G1, P1
L-15	*Heteropogon contortus*	G1, PO
L-16	*Anthephora pubescens*	GO, PO
L-17	*Cenchrus ciliaris*	G1, PO
L-18	*Arunda donax*	G2, P1
L-19	*Sorghum spp*	G3, P2
L-20	*EnviroGreen mix*	G5, P5

Table 3.5.1 Grass Species – Layout and results

Legend for Rating (semi-quantitative)

0	=	Very bad	3	=	Good
1	=	Bad	4	=	Very Good
2	=	Reasonably	5	=	Exceptionally well

Block No.	Tree Species	Growth Performance of trees after one Year (semi-quantitative)
L-5	Apricot	3
L-6	Mulberry	4
L-7	Privet & Acacia karro	4
L-8	Salt bush	5
L-9	Buffalo thorn	2
L-10	White karee	5
L-11	Date palm	3
L-12	Mountain karee	1
L-13	Pepper tree	3
L-14	Blackwood	5
L-15	Eucalyptus	5
L-16	Sand olive	5
L-17	Beefwood	5
L-18	Asparagus	0
L-20	River bush willow	5

Table 3.6 Results of vegetable trails

Common Name	Botanical Name	Germination	Growth potential	Production
Beans	*Phaseolus vulgaris*	2	1	0
Beetroot	*Beta vulgaris*	2	2	0
Black Current	*Ribes nigrum*	3	3	0
Cabbage	*Brassica olevacea*	4	4	5
Carrots	*Daucus carota*	4	4	4
Cauliflower	*Brassica olevacea var. botrytis*	3	3	4
Celery	*Apium graveolens*	2	1	0
Cucumber	*Cucumis sativus*	1	1	2
Eggfruit	*Solanum melongena*	2	1	2
Lettuce	*Lactuca sativa*	3	3	4
Maize	*Zea mays*	2	2	1
Mint	*Mentha spicata*	4	4	4
Potatoes	*Solanum tuberosum*	3	2	3
Pumpkin	*Cucurbita maxima*	3	2	3
Radish	*Raphanus sativus*	5	4	5
Spinach	*Spinacia oleracea*	5	5	5
Sweet melon	*Cucumis melo var reticulatis*	0	0	0
Tomatoes	*Lycopersicon esculentum*	4	3	5
Onions	*Alium cepa*	3	3	3
Green pepper	*Capsicum annuum var grossum*	2	2	2
Parsley	*Pertoselinum crispum*	3	4	4
Gooseberry	Physalis peruviana	3	2	1
Water melon	Citrullus vulgaris	0	0	0