REFORESTATION AND LANDSCAPING ON MINE TAILINGS – A STEP FORWARD IN MINE CLOSURE

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ABSTRACT

South Africa is one of the countries in which the greatest impact of mining on the environment is seen (DEAT, 2005). The environmental impacts are obvious and need to be addressed during each phase of environmental planning especially in mine closure. The environmental impacts of mining are, in general, increased concentrations of heavy metals and changes of pH in both impacted soils and especially in water streams. Mining processes coupled with weather conditions can affect the agricultural and forestry sector by impacting water quantity and water and soil quality.

This research showed that sustainable reforestation on tailings is possible with the indigenous tree species *Searsia lancea* (L.F.) F.A. Barkl. also known as *Rhus lancea* or *Karee* and the non- indigenous tree *Casuarina equisetifolia*. In a laboratory trial 250 trees were planted with both types of tailings, gold and platinum tailings and natural soil. The addition of different organic fertilizers – woodchips, sewage sludge and an organic medium – as a nutrient source and soil ameliorant, allowed the indigenous and alien tree species to grow despite the high levels of contamination. Samples of the different treated soil types were tested for macro-, micro-elements by analysis (straight water analysis, inductively coupled plasma mass spectrometry (ICP-MS)) and biological activity was measured by dehydrogenase at the Eco-Analytica Laboratory (North-West University).

The analysis on soil macro- and micro-elements and the biological activity showed the highest improvement in soil quality on platinum tailings with woodchips and on gold tailings with matured sewage sludge with both tree types. Even the content of heavy metals in both gold and platinum tailings could be lowered by iron exchange and uptake by plants. Also the micro-biological activity in the soil approved an increase in total soil quality.

This research showed that for a period of 5 to 10 years the tailings can be used for reforestation and landscaping even when re-mining has to take place afterwards. During reforestation aeolian dust pollution will be avoided, carbon credits can be claimed and renewable primary products will be created.

1. INTRODUCTION

Most areas on mining properties in South Africa are changed from their natural occurrence. Acidification of soil (Hupfer,2006), high polluted water and waste water (Hatting, 2003), changing of vegetation (Bodenstedt, 1997) and loss of soil quality (van Rensburg, 2004, Claassen, 2006) are results of this industry. Ground water from gold production processes which is transferred to the surface is highly polluted with Ca, Mg, K, Na, SO_4, NO_3, NH_4, Cl, Fe, Mn and Zn.

The earth's crust naturally contains sulphide minerals that can oxidise and generate acidic water when broken by explosives or during naturally occurring rock breakage by tectonic movements and seismic events. This phenomenon is called acid mine drainage (AMD) or acid rock drainage (ARD) and is generated by a combination of chemical reactions and biological processes whereby pyrite is converted to sulphates and iron oxy-hydroxides (Barnes, 1968, Neculita, 2007). The sludge produced during the acid mine water (AMD) neutralization with calcium carbonate ($CaCO_3$) must be pre-treated separately because of its hazardous content and also has special disposal requirements (Maree, 2004). This sludge and unusable tailings materials are deposited on mine tailings storage facilities. To make the tailings aesthetically acceptable and beneficial in relation to future mine closure plans reforestation as a bio mass resource and landscaping was chosen as a possible solution .

2. MATERIALS AND METHODS

Quality of Mining Tailings

Mine tailings material is typified by low pH in gold tailings, high pH in platinum tailings and high EC. The gold tailings had a high EC of 3.05 [mS/cm] and a low pH of 3.75 at the beginning of the trial (table 1, table 2). Concentrations of the elements Ca, Mg, SO_4, NO_3, Mn, Cu and Zn were also high. The platinum tailings were similar in composition to the gold tailings but had a pH of 7.34 and an EC of 1.24 [mS/cm] at the beginning of the trial (table 1, table 2). The concentrations of the elements Ca, Mg, Na, SO_4, Cl, and Mn were also of concern. In this type of substrate plants struggle to survive because low concentrations of essential nutrients and high concentrations of phytotoxic substances. Before and after the application of different fertilizers the soil/substrate quality was analyzed for macro-, micro-elements by straight water analysis and inductively-coupled-plasma mass-spectrometry (ICP-MS).

Fertilizer

As fertilizers three different types were used as growth medium for cultivation of the experimental plants:

1. Sewage sludge, aged for an average of six months.
2. Woodchips, created by mulching of underground supporting struts after blasting. These woodchips contain, in addition to high concentrations of plastics residue from explosives, high concentrations of nutrients necessary for the growth of plants.
3. An organic medium, a mixture of *Casuarina equisetifolia* leaves and *Eliote* bark.

All fertilizers were used to maximize the affinity to obtain the best binding, related to the lyotrophic series (conversion preference, $Al^{3+} \approx H^{+} >> Ca^{2+} > Mg^{2+} >> K^{+} \approx NH^{4+} > Na^{+}$, Scheffer, 2002) and to store the required nutrients. All fertilizers have different influences on soil quality and tree vitality because of the content and variety of available and essential nutrients.

Tree Types - Searsia Lancea and Casuarina Equisetifolia

In order to use plants which can stand the high phytotoxic contamination and survive in the polluted tailing, the beech species *Casuarina equisetifolia* and *Searsia lancea,* family of Anacardiaceae were chosen. Investigations of *Casuarina equisetifolia* showed a high heavy metal tolerance, and applications of Zn, Cd and Pb generally increase growth. On the other hand, the absorption of N, P, K, Ca and Mg were increased by Zn application (Aly, 2002). Forty-eight trees with a height of about 60 cm were planted in different tailings material from gold and platinum mines as well as in natural soil.

The indigenous (South African) tree species *Searsia lancea* was selected as a resistant tree which establishes easily. *S. lancea* can adapt well to different soils including those that are poorly drained (Van Wyk, 1997). *S. lancea* is a small to medium sized evergreen tree that usually grows to a height of 7 m and a width of 7 m but can be larger depending on environmental factors. One hundred and forty-four trees with a height of about 120 - 150 cm were planted in different tailings material from gold and platinum mines as well as in natural soil.

Microbiological Activity - Dehydrogenase Activity

Microbiological activity was determined by testing for dehydrogenase activity using the INT-method (INT = iodonitrotetrazolium chloride) after von Mersi (1991). The method is based on the incubation of soil with the substrate iodonitrotetrazolium chloride (INT) at 40°C for 2 hours followed by colorimetric estimation of the reaction product iodonitrotetrazolium chloride-formazan (INF) spectrophotometrically at 464 nm against the blank. The amount of metabolised substrate per time and amount of protein was measured. Dehydrogenase activity is expressed as µg INF g^{-1} dwt 2 h^{-1} (INFµg/(g*2h)) and calculated according to the following equation:

$$INF(\mu g g^{-1} dwt 2h^{-1}) = \frac{S_1 - S_0}{dwt}$$

with:
S_1 = INF (in µg) of the test
S_0 = INF (in µg) of the control
2h = 2 hours incubation time
dwt = dry weight of 1g moist soil

3. RESULTS

Visual Differences in Plant Growth

After only two weeks of growth in the ameliorated mine tailings material a difference between the Casuarina could easily be visually detected. Casuarina growing in pure gold tailings material (gold soil) showed signs of die-back possibly due to the elemental content in the slimes material. Yellow-red discolouration on the lower fifth of the trunk indicated stress related to nutrient overdose and non-ideal growth conditions. The same symptoms, but more pronounced, were detected on the lower quarter of the Casuarina growing in platinum tailings (platinum soil). The control unpolluted soil had no visual signs of negative influence on the growth of the trees. Unlike of the trees growing in pure mine tailings material, the Casuarina in the soil mixed with 20% organic fertiliser showed better growth visually. Indicators were fewer discolorations on the trunk, fresh and full green colour of the leaves and faster growth. After 4 weeks the discoloured leaves dropped off and all trees showed a better growth with only few signs of stress. The mortality rate in each soil trial varied from 0% in platinum soil over 17% in gold (2 of 12 plants) and 8% (1 of 12 plants) in control soil.

Unlike the Searsia growing in unaltered mine tailings material, the trees in the tailings mixed with matured sewage sludge as fertiliser showed better growth visually in both gold and platinum tailings. Indicators of this were fewer discolorations on the leaves, fresh and full green colour of the leaves, faster growth and fuller growth of the treetop. The total mortality rate in each group of ameliorants varied from 2% in the control soil, to over 25% in the gold tailings and only 4% in platinum soil.

In all trials the Searsia growing in tailings with matured sewage sludge added as an ameliorant had a vital appearance and looked healthy, fresh and green after the first two months and continued so until the end of the six month trial. Searsia growing in soil ameliorated with woodchips had a similar appearance. In the gold tailings the Searsia were smaller, with less dense leaf structure and brown-yellow leaves and 5 deaths.

Discolouration of both trees leaves indicates detoxification of excess amounts of elements. The plant assimilates the toxins in the leaves before the leaves are abscised, therefore detoxifying the plant. After only a few weeks the discoloured leaves dropped off and all trees showed a better re-growth with fewer signs of stress.

Differences in Soil Quality

The use of pre-treated fertiliser with *Casuarina* in polluted soil indicates an improved soil quality after only one month of plant growth. The elements Na, SO_4, NO_3 and NH_4 in the treated gold and platinum soil in particular were significantly reduced. In addition in the gold soil the elements Fe, Mn, Zn and B were also significantly reduced (table 1). A total reduction of elements could be shown by a decrease in the electrical conductivity (EC) of 39% in the treated platinum soil. In this application the organic medium had the ability to exchange and bind the elements by the lyotrophic series.

The use of pre-treated fertiliser with *Searsia* in polluted tailings showed an improvement in soil quality after only two months of plant growth. The elements Na, Mg, PO_4, Cl, NO_3 and NH_4 in the treated gold and platinum soil in particular were significantly reduced. In addition in the platinum soil the elements Ca and SO_4 were also significantly reduced (table 2). A total reduction of ionic compounds could be shown by a decrease in the electrical conductivity (EC) of 97% in the platinum tailings treated with woodchips and 38% in gold tailings treated with matured sewage sludge.

Table 1. Quality change in soil chemistry with *Casuarina*

Macro-elements											
Sample	**Time frame**	Ca	Mg	K	Na	PO_4	SO_4	NO_3	NH_4	Cl	HCO_3
		ppm									
Control Soil + organic medium (Csz)	start	70.54	27.95	32.06	14.02	0.00	72.95	346.60	3.61	13.28	0.61
Control Soil + organic medium (Csz)	after 1 month	42.08	20.17	21.50	24.37	0.00	107.59	138.89	0.13	27.29	9.15
Control Soil (Cc)	start	132.66	45.21	55.91	5.75	0.00	119.12	605.16	9.16	9.22	6.10
Control Soil (Cc)	after 1 month	67.33	31.84	29.71	21.15	0.00	91.26	305.68	0.78	30.14	1.22
Gold Soil + organic medium (Gsz)	start	350.68	95.03	3.91	28.74	0.00	1260.33	24.24	1.37	13.72	0.61
Gold Soil + organic medium (Gsz)	after 1 month	352.69	76.80	7.04	26.44	0.00	1169.07	10.23	0.32	24.69	1.22
Gold Soil (Gc)	start	448.87	31.84	0.39	6.44	0.00	1210.38	20.50	1.48	4.85	0.00
Gold Soil (Gc)	after 1 month	394.37	44.72	1.95	22.76	0.00	1148.90	7.98	1.15	24.24	0.00
Platinum Soil + organic medium (Psz)	start	120.23	38.16	35.97	40.92	0.00	439.96	5.55	0.04	34.27	100.68
Platinum Soil + organic medium (Psz)	after 1 month	44.09	35.24	22.29	36.55	0.00	231.51	0.88	0.20	32.93	94.57
Platinum Soil (Pc)	start	185.96	47.39	40.66	36.78	0.00	632.09	23.25	0.27	43.73	61.02
Platinum Soil (Pc)	after 1 month	60.92	51.53	31.28	40.46	0.00	340.06	8.84	0.45	40.63	94.57

Micro-elements and other data								
Sample	**Time frame**	Fe	Mn	Cu	Zn	B	pH	EC
		ppm						*(mS/cm)*
Control Soil + organic medium (Csz)	start	0.15	0.52	0.03	0.02	0.15	4.66	0.75
Control Soil + organic medium (Csz)	after 1 month	0.29	0.03	0.02	0.02	0.00	5.80	0.54
Control Soil (Cc)	start	0.10	2.43	0.03	0.03	0.01	4.72	1.26
Control Soil (Cc)	after 1 month	0.12	0.06	0.02	0.00	0.00	4.88	0.77
Gold Soil + organic medium (Gsz)	start	0.13	7.26	0.04	0.58	0.12	4.58	2.70
Gold Soil + organic medium (Gsz)	after 1 month	0.08	0.85	0.03	0.23	0.05	4.71	2.52
Gold Soil (Gc)	start	0.23	9.83	0.34	1.07	0.02	3.74	2.57
Gold Soil (Gc)	after 1 month	0.06	3.49	0.05	0.44	0.00	4.34	2.47
Platinum Soil + organic medium (Psz)	start	0.01	0.04	0.04	0.00	0.08	7.16	1.19
Platinum Soil + organic medium (Psz)	after 1 month	0.34	0.04	0.03	0.00	0.00	7.46	0.73
Platinum Soil (Pc)	start	0.02	0.05	0.03	0.01	0.01	7.18	1.58
Platinum Soil (Pc)	after 1 month	0.02	0.02	0.02	0.00	0.03	7.67	0.99

Table 2. Quality change in soil chemistry with *Searsia*

Macro-elements											
Sample	**Time frame**	Ca	Mg	K	Na	PO_4	SO_4	NO_3	NH_4	Cl	HCO_3
		ppm									
Control Soil + woodchips (CWC)	start	115.42	33.05	63.73	14.02	0.00	105.67	502.23	8.17	28.72	6.10
Control Soil + woodchips (CWC)	after 2 month	43.28	15.80	21.11	38.62	0.00	203.65	0.70	0.13	45.38	9.15
Control Soil + woodchips (CWC)	after 6 month	7.21	3.16	11.34	5.98	1.11	34.58	2.48	0.79	6.74	18.30
Control Soil + sewage sludge (CSH)	start	69.74	40.83	56.69	17.01	14.41	116.24	456.35	39.47	27.30	15.25
Control Soil + sewage sludge (CSH)	after 2 month	90.98	60.03	32.84	62.53	41.49	222.86	280.88	0.40	86.86	6.10
Control Soil + sewage sludge (CSH)	after 6 month	6.01	1.70	5.08	2.53	9.65	10.57	4.96	0.61	2.32	6.10
Control Soil (CCO)	start	144.68	43.02	47.31	13.10	0.00	88.38	642.98	8.46	27.30	6.10
Control Soil (CCO)	after 2 month	24.45	12.64	8.21	28.74	0.53	106.63	14.88	0.04	34.66	21.36
Control Soil (CCO)	after 6 month	2.81	1.22	2.74	1.84	2.37	12.49	1.25	0.43	0.98	6.10
Gold Soil + woodchips (GWC)	start	446.07	84.10	3.52	29.66	0.00	1,453.42	24.12	2.58	27.04	0.00
Gold Soil + woodchips (GWC)	after 2 month	352.29	47.39	10.95	18.16	0.00	1,034.59	7.56	0.72	23.06	12.20
Gold Soil + woodchips (GWC)	after 6 month	422.02	11.18	8.99	6.90	0.00	1,081.66	7.01	0.52	2.68	0.00
Gold Soil + sewage sludge (GSH)	start	401.58	70.73	8.21	17.24	1.90	1,505.29	11.34	87.02	17.13	0.61
Gold Soil + sewage sludge (GSH)	after 2 month	321.43	69.03	3.52	20.00	0.00	1,036.51	30.21	1.23	16.31	15.25
Gold Soil + sewage sludge (GSH)	after 6 month	367.11	13.61	2.35	4.14	0.17	938.53	6.84	0.81	1.70	0.00
Gold Soil (GCO)	start	464.10	70.73	0.39	17.70	0.00	1,429.40	18.02	2.20	16.57	0.00
Gold Soil (GCO)	after 2 month	424.43	38.16	4.30	27.36	0.00	1,176.76	11.65	0.76	27.30	6.10
Gold Soil (GCO)	after 6 month	435.65	9.72	4.69	7.82	1.64	1,094.15	5.95	1.10	2.53	0.00
Platinum Soil + woodchips (PWC)	start	340.66	149.23	104.39	245.99	0.00	1,081.66	268.48	0.40	548.81	33.56
Platinum Soil + woodchips (PWC)	after 2 month	58.51	59.06	25.02	65.98	0.00	347.74	1.17	0.47	92.89	88.47
Platinum Soil + woodchips (PWC)	after 6 month	10.42	3.65	7.82	4.37	0.08	10.57	0.41	0.22	2.34	61.02
Platinum Soil + sewage sludge (PSH)	start	72.14	86.28	38.32	93.34	39.22	402.50	97.97	14.52	152.80	64.07
Platinum Soil + sewage sludge (PSH)	after 2 month	34.47	33.05	13.68	34.71	1.76	139.29	22.94	0.32	52.47	91.52
Platinum Soil + sewage sludge (PSH)	after 6 month	5.61	3.40	3.91	1.61	2.81	5.47	6.20	0.16	1.67	27.46
Platinum Soil (PCO)	start	81.76	54.44	22.68	74.95	0.00	350.63	78.36	0.60	115.15	36.61
Platinum Soil (PCO)	after 2 month	32.86	37.92	15.64	52.88	0.00	185.40	8.55	0.67	98.20	42.71
Platinum Soil (PCO)	after 6 month	8.82	2.19	5.08	1.61	0.07	2.88	1.24	0.25	0.59	48.81

Micro-elements and other data								
Sample	**Time frame**	Fe	Mn	Cu	Zn	B	pH	EC
		ppm						*(mS/cm)*
Control Soil + woodchips (CWC)	start	0.11	1.81	0.02	0.02	0.00	4.74	1.12
Control Soil + woodchips (CWC)	after 2 month	0.64	0.06	0.02	0.00	0.03	5.69	0.57
Control Soil + woodchips (CWC)	after 6 month	1.89	0.31	0.10	0.13	0.15	5.93	0.13
Control Soil + sewage sludge (CSH)	start	0.47	1.01	0.02	0.01	0.06	5.71	1.13
Control Soil + sewage sludge (CSH)	after 2 month	0.19	0.09	0.05	0.02	0.07	5.20	1.31
Control Soil + sewage sludge (CSH)	after 6 month	1.91	0.29	0.14	0.19	0.30	5.23	0.08
Control Soil (CCO)	start	0.24	0.49	0.02	0.01	0.00	4.90	1.31
Control Soil (CCO)	after 2 month	2.10	0.04	0.04	0.01	0.09	6.23	0.38
Control Soil (CCO)	after 6 month	1.74	0.39	0.11	0.15	0.19	5.68	0.05
Gold Soil + woodchips (GWC)	start	0.32	12.99	0.47	2.87	0.00	3.86	3.14
Gold Soil + woodchips (GWC)	after 2 month	0.01	1.20	0.03	0.03	0.00	6.70	2.26
Gold Soil + woodchips (GWC)	after 6 month	0.45	0.67	0.02	0.09	0.00	4.29	2.26
Gold Soil + sewage sludge (GSH)	start	0.10	12.43	0.05	1.59	0.00	4.54	3.20
Gold Soil + sewage sludge (GSH)	after 2 month	0.04	0.68	0.04	0.03	0.01	6.47	2.27
Gold Soil + sewage sludge (GSH)	after 6 month	0.10	0.42	0.01	0.10	0.03	4.42	1.98
Gold Soil (GCO)	start	0.36	12.93	0.54	2.89	0.00	3.75	3.05
Gold Soil (GCO)	after 2 month	0.05	1.55	0.05	0.06	0.00	5.25	2.56
Gold Soil (GCO)	after 6 month	0.00	1.87	0.05	0.17	0.04	4.32	2.31
Platinum Soil + woodchips (PWC)	start	0.21	0.11	0.03	0.02	0.00	6.86	4.28
Platinum Soil + woodchips (PWC)	after 2 month	0.02	0.03	0.04	0.02	0.00	7.66	1.13
Platinum Soil + woodchips (PWC)	after 6 month	1.90	0.10	0.14	0.02	0.06	7.70	0.13
Platinum Soil + sewage sludge (PSH)	start	0.06	0.07	0.00	0.00	0.16	7.53	1.65
Platinum Soil + sewage sludge (PSH)	after 2 month	0.00	0.00	0.00	0.00	0.00	7.74	0.63
Platinum Soil + sewage sludge (PSH)	after 6 month	1.74	0.04	0.03	0.02	0.03	7.12	0.08
Platinum Soil (PCO)	start	0.06	0.02	0.00	0.00	0.05	7.34	1.24
Platinum Soil (PCO)	after 2 month	0.00	0.02	0.01	0.00	0.00	7.34	0.75
Platinum Soil (PCO)	after 6 month	1.80	0.10	0.07	0.01	0.10	7.38	0.09

Differences in Microbiological Activity

During the experiment with *Casuarina* the total biological activity was reduced to about 57% on average in all different polluted and fertilized soil types. The benefit of the organic medium is a higher microbiological activity initially and after 4 weeks. The biological activity in platinum soil with fertiliser is, after one month, better with 39.76 [INF µg/(g*2h)] than the initial biological activity of untreated soil - 32.73 [INF µg/(g*2h)] (figure 1).

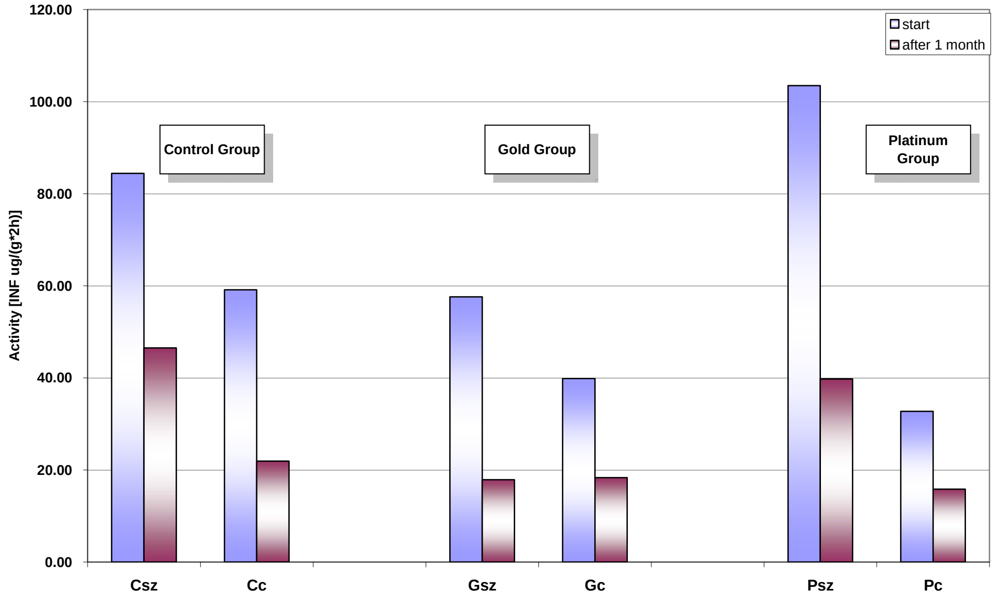

Figure 1. Quality change of microbiological activity in the different soil types ameliorated with the organic medium and *Casuarina*

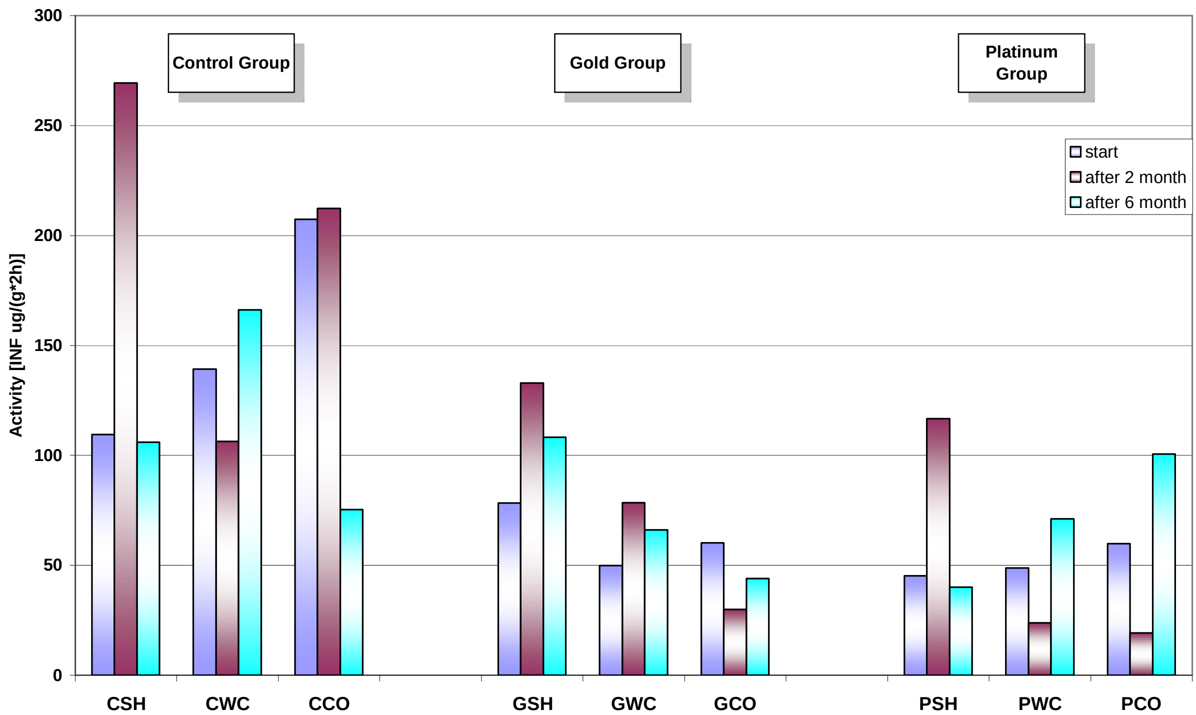

Figure 2. Quality change of microbiological activity in the different soil types ameliorated with sewage sludge, woodchips and *Searsia*

The total microbiological activity in both unaltered tailings and ameliorated soil types was only about one third, on average about 50 [INF µg/(g*2h)], compared to the conditions in natural soil - 110 [INF µg/(g*2h)]. This is the result of the free available inhibitors of microbial growth in the polluted tailings. These substances block the metabolism of the micro-organisms and inhibit total activity. The benefit of the adding ameliorants can be seen in initial higher microbiological activity and a deposit function of the most needed and available nutrients for the micro-organisms after two months. The microbiological activity in gold tailings ameliorated with sewage sludge is, after two month, improved; 78.3 [INF µg/(g*2h)] with sewage sludge and better than the initial microbiological activity of untreated tailings of 60.3 [INF µg/(g*2h)] (figure 2). In platinum tailings the initial microbiological activity in tailings ameliorated with woodchips was 48.7 [INF µg/(g*2h)] before it raised up to 71.1 [INF µg/(g*2h)] after 6 month (figure 2).

4. CONCLUSION

The results in soil quality, microbiological activity and visual impression of both tree types showed that the reforestation on mine gold and platinum tailings was successfully proved. In total the tree type *Searsia* was most improved in platinum soil with woodchips and in gold soil with sewage sludge as an ameliorant. *Casuarina* growing in the organic medium was most effective in platinum soil. These results were also supported by microbiological activity. However, the recommendation for the rehabilitation process of mine tailings both soil types in South Africa is obviously reforestation with the indigenous tree type *Searsia lancea*.

Reforestation and landscaping on low quality mine tailings upgrades the aesthetics of the mining area, controls dust, creates a renewable resource, and improves soil quality. These results represent a valuable contribution to environmental protection by mining companies.

5. REFERENCING

Aly, Ragaa Aly Taha, (2003): Influence of heavy metals zinc, cadmium and lead on growth and uptake of Acacia saligna, Casuarina equisetifolia and Cupressus sempervirens. *Dissertation, Niedersächsische Staats- und Universitätsbibliothek Göttingen.*

Barnes H.L., Romberger, S.B. (1968) *Chemical Aspects of Acid Mine Drainage.* Journal WPCF, 40 (3), pages 371 – 384

Bodenstedt, A., Rottländer, E. (1997): Veränderung von Böden durch anthropogene Einflüsse: ein interdisziplinäres Studienbuch. Deutsches Institut für Fernstudien, Springer, ISBN 3540615563, 9783540615569.

Claassen, S., van Rensburg, L., Jansen van Rensburg, P.J. (2006): *Soil microbial community structure of coal mine discard under rehabilitation.* Water, Air, & Soil Pollution 174:355-366.

Department of Environmental Affairs and Tourism (2005) *State of the environment: How mining affects the environment.* Published online on official web-page

Gisi, U., Schenker, R., Schulin, R., Stadelmann, F.X., Sticher, H. (1997): Bodenökologie. *2. Auflage - Stuttgart; New York: Thieme.*

Hatting, R.P., Lake, J., Boer, R.H., Aucump, P., Viljoen, C. (2003): Rehabilitation of contaminated Gold Tailings Dam Footprints. *WRC Report No 1001/1/03*

Hatting, R.P. (2003): Guidance for the Rehabilitation of contaminated Gold Tailings Dam Footprints. *WRC Report No 1001/2/03*

Hupfer, M. & Kleeberg, A. (2006): *State and Pollution of freshwater ecosystems – Warning signals of a changing environment.* In: Lozan, J.L., Graßl, H., Hupfer, P. & Schönwiese, C.-D. (eds.): Climate Change: Enough Water for all? Wissenschaftliche Fakten in Zusammenarbeit mit GEO. Hamburg 126-132.

Le Bissonnais, Y., Singer, M.J. (1992): Crusting, runoff, and erosion response to soil water content and successive rainfalls. *Soil Science Society of America Bulletin, Volume 56, Issue 6, 1992, pages 1898 – 1903*

Maree, J.P., Streydom, W.F., Adlem, C.J.L., De Beer, M., Van Tonder, G.J., Van Dijk, B.J. (2004): Neutralization of Acid Mine Water and Sludge Disposal. *WRC Report No. 1057/1/04, Water Research Commission, Pretoria.*

Neculita, C.-M, Zagury, G. J., Bussiere, B. (2007) *Passive Treatment of Acid Mine Drainage in Bioreac-tors using Sulfate-Reducing Bacteria: Critical Review and Research Needs.* In: Journal of Environ-mental Quality (J. Environ. Qual.), Volume 36, pp. 1 – 16, ISSN 0047-2425

Pollmann, O., Van Rensburg, L., Lange, Ch., Engel, N. (2008): Soilification: man-made-soil as new resource for agriculture, reforestation and landscaping; *Proceedings "Moving Organic Waste Re-cycling towards Resource Management and for the Biobased Economy", Organic Recovery & Biological Treatment (Orbit), 6th International Conference*, ISBN 3-935974-20-5

Pollmann, O., van Rensburg, L., Wilson, F. (2008): Sustainable Full-scale Rehabilitation of polluted Mine Tailings and Acid Mine Drainage (AMD). *WISA Conference 2008 "The Confluence of the Water Industry" of the Water Institute of Southern Africa (WISA)*, ISBN 978-0-9802623-2-2

Scheffer, F., Schachtschabel, P. (2002): *Lehrbuch der Bodenkunde*. 15. Auflage - Heidelberg; Berlin: Spektrum Akademischer Verlag

Von Mersi, W., Schinner, F. (1991): An improved and accurate method for determining dehydrogenase activity of soils with iodonitrotetrazolium chloride. *Biol Fertil Soils 11:216-220*

Van Rensburg, L, Maboeta, M. (2004): *Rehabilitation of Co-extruded Diamond Tailings Generated at a Diamond Mine: Quantifying Physical and Chemical Properties of Co-disposed Material*. SA J Plant Soil. 21(3): 133-138.

Van Wyk, B., Van Wyk, P. (1997): Field Guide To Trees Of Southern Africa. *1st edition, Cape Town: Struik Publishers.*