Bioaccumulation of Toxic Metals by Hyparrhenia Grass Species: A Case Study of New Union Gold Mine Tailings and Makhado Town, Limpopo, South Africa

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Abstract The study was on the bioaccumulation of Mn, As and Cd metals by Hyparrhenia grass species from selected sites: New Union Gold Mine tailings and along Makhado Town tarmac road. The mean levels of toxic metals in mine tailings were: Mn (341.27 mg/kg); As (53.75 mg/kg) and Cd (0.77 mg/kg) and from tarmac road soils were: Mn (162.32 mg/kg); As (50.52 mg/kg) and Cd (8.22 mg/kg). The level of toxic metals in different sections of Hyparrhenia grass growing on mine tailings soil. The Mn results: roots (301.91 mg/kg); stem (25.17 mg/kg); leaves (73.20 mg/kg) and flowers (38.75 mg/kg); As: roots (20.55 mg/kg); stem (4.83 mg/kg); leaves (3.62 mg/kg); flowers (10.72 mg/kg) and Cd: roots (0.83 mg/kg); stem (0.31 mg/kg); leaves (0.58 mg/kg); flowers (0.27 mg/kg). The grass growing close to tarmac road were: Mn roots (25.04 mg/kg); stem (231.28 mg/kg); leaves (224.84 mg/kg) and flowers (52.56 mg/kg); As: roots (8.49 mg/kg); stem (4.60 mg/kg); leaves (4.73 mg/kg) and flowers (5.42 mg/kg) and Cd: roots (0.18 mg/kg); stem (0.35 mg/kg); leaves (1.07 mg/kg) and flowers (7.72 mg/kg). The bioaccumulation coefficient of Hyparrhenia grass at tarmac road and mine tailings for As, Mn and Cd was variable and but is a hyperaccumulator for Mn. There were high levels of toxic metal levels (mean) in the soil and grass samples and followed this order: Mn > As > Cd. The presence of these toxic metals in the flowers is a major cause for concern since it implies that there is a danger to other organisms such as bees and small birds that visit for pollen and seed. Hyparrhenia grass is an indigenous grass species that is suitable for accumulation of toxic metals and soil stabilization and can grow in adverse pH conditions of 3.46 (mine tailings) and 5.16 (tarmac road).

Key Words Environmental hazard, toxic metals, indigenous grass, bioaccumulation

Introduction

The expanding industries and corresponding increases in population particularly in developing countries such as South Africa, toxic metal pollution is becoming common. There are documented cases of metal toxicity have been reported including in mining, heavy industries, agriculture, tarmac roads and municipal wastes (Groundwork 2003; Heath *et al.* 2009). In South Africa the pollution started with Industrial Age including abandoned mine tailings where heavy (toxic) metals were released and transported into the environment (Naicker *et al.* 2003; Moja 2007).

The metals such as Mn, Zn and Cu when present in little amounts are important elements in the soil and plants, but then turn out to be toxic when they are in excessive level (Moja 2007). The metals (including Zn, As, Mn, Cu, Pb, Cd) are well-known for their widespread occurrence around mine tailings dams (Conesa *et al.* 2006). The toxic metal contaminations are of significant environmental concern because they are non-biodegradable and can accumulate in the soil with far reaching impacts on biological systems including soil microorganism, other soil biota, groundwater and surface water (Okunola *et al.* 2007). The study of Odiyo *et al.* (2005) showed that there was a positive correlation of heavy metals along tarmac roads in Thohoyandou and progressively was reduced in vegetation and soils away from the road.

The studies of Ogola *et al.* (2009), Mothetha (2009) and Mulugisi *et al.* (2009) did not evaluate the toxic metals As, Cd which are emerging pollutants. During intensive rainfall these metals may transported to the nearby environment and contributed to surface water and groundwater pollution. In addition to this, toxic metals pose a long term effect to local ecosystems. The general objective of this study was to demonstrate the feasibility of using Hyparrhenia grass species to bioaccumulate or remove toxic metals in the contaminated soil environment. The specific objectives were: to analyze the toxic metal content of the different sections of Hyparrhenia grass species (root, stem, leave and flower) that were growing at mine tailings and tarmac road; to analyze toxic metals in soil and also compare the accumulation of toxic metals in the Hyparrhenia grass species and to determine the pH of soil at the study areas.

Materials and Methods

Study and sampling areas

The Hyparrhenia grass samples and mine tailings soils were collected from the New Union Gold mine tailings dam (longitude 23°01'24"S, latitude

30°43'36"E) and from Makhado town road which lies between 23º03' S longitude and 29º54' E, is along Verbena road close to corner Hlanganani and Verbena roads in New Town suburb of Makhado Town.

pH determination and analysis of heavy metal content of mine tailings and grass samples

The collected samples (mine tailings and grass) were sealed in plastic sachets, labeled with date of sampling and then these were processed following the procedure that was used by Mulugisi *et al.* (2009). The flame Varian Spectra AA 220/880 spectrophotometer was used to measure the levels of Mn and Cd in the samples. A graphite-furnace was then used to measure the levels of As in the samples.

Data analysis

The analytical raw data was processed as per procedure of Mulugisi *et al.* (2009) and statistical analysis was carried with single factor ANOVA.

The bioaccumulation factor (BF) for roots, stem and leaves (ratio between metal level in roots, stem, leaves and metal in soil expresses the ability of the plants to accumulate metals from the soil (Conesa *et al.* 2007). Bioaccumulation Factor for plants was calculated as follows (Li *et al.* 2007).

Bioaccumulation factor (BF) = mean plant concentration (mg/kg)/mean soil concentration (mg/kg)

Results and Discussion

The pH of soil samples at Makhado Town road and New Union Gold Mine tailings

The pH of the soil samples at mine tailings was found to be 3.46 (highly acidic) and the tarmac road was 5.16 (slightly acidic). Soil pH normally plays a vital function in metal bioavailability to plants. According to Odiyo *et al.* (2005) toxic metals are regularly more soluble and leach out in acidic pH. The pH results at tarmac road are in agreement with the study of Odiyo *et al.* (2005) in Thohoyandou Punda Mari tarmac road which had a pH of 6.6, which is slightly acidic. The pH results are also in agreement with the study that was done in along the tarmac road in Kaduna, Nigeria which has recorded the pH of 6.2, which was is slightly acid (Okunola *et al.* 2007).

The distribution of metals in mine tailings and tarmac road

The soil samples were analyzed and showed that the soil samples collected at New Union Gold Mine tailings and Makhado Town (tarmac road) had high levels of toxic metals (Mn and As) except Cd which was low in concentration (Table 1). The ANOVA test showed that the Mn and Cd values were significantly difference ($p < 0.0$) between the mine tailings and tarmac road. The ANOVA test showed that the As values were not significantly different ($p > 0.0$) between the mine tailings and tarmac road. This may indicate the major contribution of Mn originating from the mine tailings. The major contributor for Cd was from the tarmac road. In the absence of any major industry in Makhado Town (tarmac road), the high levels of Mn, As and Cd may be due to petroleum products such as lubricating oils and/or old tyres that are frequently used, and the rough surfaces of the roads which increased the wearing of tyres or the underlay rock material that used to compact the tarmac road (Okunola *et al.* 2007).

The research findings are in agreement with the studies of Okunola *et al.* (2007) and Mulugisi *et al.* (2009) who found almost similar levels of these toxic metals in an urban tarmac road and mine tailings respectfully. The study by Ogola *et al.* (2009) observed high concentration of Mn (up to 112.87 mg/kg) in the soil at Makhado Township which was lower compared to this study.

Cd and As have no known biological functions to plants and animals and are harmful to human health and the environment even in low level due to their persistence high toxicity and bioaccumulative character (Padmavathiamma and Li 2007; Meza-Figura *et al.* 2009). Furthermore, Mn, Cd and As in soil could be transported to, dispersed to, and accumulated in plants and animals, and then passed through the food chain to human beings as the final consumer (Liu *et al.* 2006). Mn is an essential element in plant growth but excessively high levels of Mn in soil can inhibit plant growth (Liu *et al.* 2006).

Toxic metals concentration in different sections of Hyparrhenia grass

The level of Mn, As and Cd were determined in the different section of Hyparrhenia grass (roots,

Table 1 *Total Mean concentration (mg/kg) of toxic metals in the soil samples*

	Mine tailings				Tarmac road			
	mean	SD	Min	Max	Mean	SD	min	Max
As	53.75	2.82	51.75	55.74	50.52	1.00	49.82	51.23
Mn	341.27	5.48	337.39	345.14	162.32	5.57	158.38	166.26
Cd	0.77	0.45	0.77	0.78	8.22	0.91	7.58	8.86

Mean & SD (standard deviation) n = 2

***Table 2** Mean metal concentration (mg/kg) in different section of Hyparrhenia grass*

	Mine tailings						Tarmac road					
	As		Mn		Cd		As		Mn		Cd	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Root	20.55	7.85	301.91	4.63	0.83	0.32	8.49	2.61	25.04	0.78	0.18	0.03
Stem	4.83	4.22	25.17	0.86	0.31	0.32	4.60	0.77	231.28	1.64	0.35	0.07
Leaves	3.62	0.60	73.20	2.02	0.58	0.53	4.73	2.04	224.84	21.76	1.07	0.03
Flowers	10.72	9.52	38.75	0.97	0.27	0.17	5.42	0.00	52.56	3.36	7.72	0.24
Total Mean	39.72		439.03		1.99		23.24		533.72		9.32	

Mean & SD (standard deviation) n = 2

stem and leave and flowers) at the mine tailings and tarmac road (Table 2).

Accumulation of heavy metals in different sections of Hyparrhenia grass

The levels of Mn in different section of Hyparrhenia grass were different in both study areas (Table 2). It was observed that Hyparrhenia grass at mine tailings was able to bioaccumulate high levels of Mn in the roots in comparison to tarmac road. The ANOVA test showed that the Mn values were significantly difference ($p < 0.0$) between the Hyparrhenia grass bioaccumulative capacity in the mine tailings and tarmac road sites. The different in accumulation of Mn levels in the soil by Hyparrhenia grass in this study is probably due to differences in pH of the two soils, tarmac road (5.16) and mine tailings (3.46). However, this study recorded high levels of Mn in the leaves and stem of Hyparrhenia grass that was growing at tarmac road. Generally, most of heavy metals are less available to grasses under near alkaline conditions, than under acid conditions (Okunola *et al.* 2007). The research findings are in agreement with the study of Madejón *et al.* (2002) who reported high levels of Mn in leaves (up to 1500 mg/kg) in plants (pasture grass). From visual observations at mine tailings showed cattle dung was present and this implies that they may be consuming the grass. If this is case it means that the metals are accumulating in their bodies and may have long term impact on their health.

The levels of arsenic in different section of Hyparrhenia grass were different in both study areas (Table 2). The ANOVA test showed that the As values were significantly not different ($p > 0.0$) between the soil samples and the Hyparrhenia grass bioaccumulative capacity in the mine tailings and tarmac road sites. The research findings show that the As levels in the Hyparrhenia grass are in agreement with the study of Teng *et al.* (2008) which has reported the increased levels of heavy metals in the grasses as results of the increased levels of heavy metals in the mine tailings. The research findings are in agreement with the study of Truong (1999) who reported high levels of As level in the roots of Vetiver grass (Vetiveria zizanioides) (up to 185 mg/kg) and low in the stem (up to 9.6 mg/kg). The recommended levels of As levels in grasses for livestock is 50 mg/kg (Madejón *et al.* 2002). Furthermore, the same authors also reported even low levels of As in grasses can be detrimental to health of the grass grazers in the long term.

The accumulation of Cd levels in roots, stems, leaves and flowers of Hyparrhenia grass at two different sites were different (Table 2). The ANOVA test showed that the Cd values were significantly different ($p < 0.0$) between the Hyparrhenia grass bioaccumulative capacity in the mine tailings and tarmac road sites with exception of stem and leaves. The higher level of Cd was recorded in the Hyparrhenia grass flowers from tarmac road, while Cd level in the mine tailings was lower. The lower level of Cd in the different section of the Hyparrhenia grass was probably due to the low levels of Cd in the soils (Table 1). The ANOVA test confirmed that the Cd values were significantly different ($p < 0.0$) between the soils, mine tailings and tarmac road. The difference in accumulation of Cd levels in the soil by Hyparrhenia grass in this study is probably due to the effect of pH since the tarmac road was slightly acid (5.16) compared to mine tailings pH which was acidic (3.46). The high levels of Cd in the flowers of Hyparrhenia grass may have a long term negative effect in insects (this include bees, locusts etc) and small birds that might visit or feed on the flower or the seeds.

Bioaccumulation Coefficient of Toxic Metals in Hyparrhenia grass

It appears that Hyparrhenia grass species qualifies for the definition to be a hyper-accumulator for Mn and Cd exclude As in both study areas (Figure 1; Conesa *et al.* 2007). However, Hyparrhenia grass cannot be used as hyper-accumulator of As in this study due to lesser bioaccumulation factor (>1). This aspect of phytoremediation includes the removal of metals through hyper-accumulation and stabilization of soils and binding such that soil erosion is minimized (Conesa *et al.* 2009). The Hyparrhenia grasses at New Union Gold Mine tailings are grazed upon by domestic animals such as goats, sheep, cattle and wild animals such as rab-

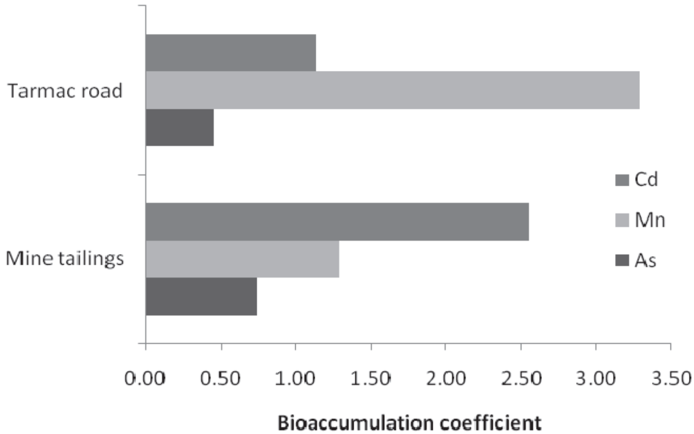

Figure 1 *Bioaccumulation coefficient (BAC) for Cd, Mn and As in the Hyparrhenia grass species growing at New Union Gold Mine tailings and Makhado Town (tarmac road).*

bits and wild dogs that prey on the rabbits as indicated by visual examination of animal droppings at the tailings dams (Mothetha 2009). This may be the transportation route in which the toxic metals are transferred from the mine tailings to mammals and human.

Conclusion

The study showed that they were high levels of toxic metals in Hyparrhenia grass, mine tailings and tarmac road. The soil pH at both study sites was below 7, mine tailings was 3.46 and tarmac road was 5.16. Generally, toxic metals in this study were less available to soil under acidic conditions which is the mine tailings than under Makhado tarmac road. The presence of toxic metals in the Hyparrhenia grass is cause for concern since domestic and wild animal grazer may accumulating these metals and have a long term hazard. Even the small insects such as bees are not spared either since the flowers have high levels of these toxic metals. However the Hyparrhenia grass may be suitable for phytostabilization of mine tailings and preventing toxic metals on tarmac roads from reaching to freshwater bodies.

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