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An investigation of the bioaccumulation of chromium and uranium metals by *Cynodon dactylon*: A case study of abandoned New Union Gold Mine Tailings, Limpopo, South Africa

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Mine waste, including tailings is generally outlined as one of the largest environmental concern which faces defunct mines in South Africa and New Union Gold Mine is no exception. These tailing contain heavy metal such as chromium (Cr) and uranium (U) which poses enormous threat to the environment even at small quantity. The study focuses mainly on bioaccumulation of Cr and U in soil by *Cynodon dactylon,* an indigenous grass. The grass and soil sample were collected at New Union Gold Mine and Ka-Madonsi Village at Malamulele, Limpopo Province, South Africa. The concentration of Cr and U were determined with a Thermofischer ICP MS. The research findings indicate that the range in the levels of Cr and U at mine tailings dam A were 152.60 to 196.12 mg/kg and 0.51 to 0.92 µg/gm, respectively. The ranges in the levels of Cr and U at mine tailings dam B were 151.34 to 229.67 mg/kg and 0.85 to 1.06 µg/g, respectively. The levels of Cr and U at the control site were 81.31 mg/kg and 0.73 µg/g. The pH of mine tailing dam A was 3.23 to 3.34 and for tailing dam B were, 3.25 to 3.29 making both tailing acidic while for the control site, it was slightly alkaline at 7.56. The bioconcentration and translation factors of *C. dactylon* were variable but were dependent on pH conditions. Thus, *C. dactylon* was able to bioaccumulate toxic metals Cr and U from the mine tailings making them potential phytoremediation agent for the rehabilitation of exposed mine tailings. This is important in covering the mine tailings since any exposed part of mine tailings is liable to water and wind erosion. Thus, Cr and U may be exported to external environment such as aquatic ecosystem and neighboring rural communities with negative impacts.

Key words: Phytoremediation, chromium, uranium, indigenous grass, dysfunctional mine tailings

INTRODUCTION

Mining is the breaking up and extraction of minerals of economic importance from the earth's crust for human-kind's benefit. It incorporates auxiliary operations like transportation of ore as well as downstream processing of minerals or ore dressing called beneficiation and the disposal of waste (tailings). The last operation results in

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serious environmental and health problems since these tailings contain toxic metals and cyanide residues and may affect communities living nearby. The degree of impacts depends on the scale of mining, mining methods employed and chemicals used to extract the important minerals (Ogola, 2002). According to Ma et al. (2001), phytoremediation can be an essential tool because it is cheap, environmental friendly and long lasting for remediation of the contaminated sites. Bioaccumulation of toxic metals by indigenous grass species from the contaminated site can be a remedy for decreasing the environmental hazard posed by toxic metals on the environment (Conesa et al., 2006; Mulugisi et al., 2009). Toxic metals originating from abandoned gold mine tailings may have a huge impact on the environment and human health (Wong et al., 1999).

According to Zayed and Terry (2003), chromium (Cr) is considered the most hazardous to animals and plants due to its high solubility, morbidity, toxicity as well carcinogenic and mutagenic properties. However, among the Cr species that are commonly known, are the trivalent chromium (Cr^{3+}), an essential element to living organisms and hexavalent form Cr^{6+}, which is toxic (Cheunga and Gua, 2007).

In light of the hazardous nature of chromium, WHO (2011) has issued provisional guideline value of 50 µg/L for total Cr in drinking water. Due to unregulated disposal of mine tailings from New Union Gold Mine, Cr may increase the ecological risk to surface water, sediment, soil and groundwater and it is increasingly becoming environmental and health issue. Han et al. (2002) reported that the cumulative Cr production was estimated to be 105.4 million ton globally in 2000 and has been rapidly increasing since the 1950s.

The use of plants as phytoremedial agents has gained a lot of attention worldwide for its ability to clean up contaminated soil. The use of plants can be a remedy of contaminated soil because of its affordability and environmental friendly. The use of plants for potential toxic metal removal from soil is environmentally sound and low in cost (Schnoor, 1997). The uptake of Cr by plants maybe via carriers of essential ions such as sulphate (Oliveira, 2012) and sulphate is a major contributor anion to acid mine drainage (Sam and Beer, 2000). Thus, the soil factors such as pH and electrical conductivity are able to influence the mobility and availability of chromium such that the Cr^{3+} is the dominate form in acidic conditions ($pH < 4$) experienced at New Union Gold Mine tailings (Mulugisi et al., 2009; Wuana and Okieimen, 2011).

Winde et al. (2004) reported that in South Africa, uranium (U) was recovered from gold ore production and this U production peaked to 7200 tons in 1980 but has since ceased. However, annual gold ore beneficiation has ensured that approximately 6000 tons of U is deposited on mine tailings in South Africa (Winde et al., 2004). The study of Cowart and Burnett (1994) reported high levels of radioactive and heavy metals in mine tailings that originated from gold and uranium mining activities. Winde et al. (2004) went further to study the U migration from gold mine tailing into the groundwater and contamination of surface water sources. Winde (2010) reported that neutrotoxic effects of U to learners and gold miners had the potential to affect academic performance and lower their performance. Winde et al. (2004) also stated that there was potential high risk since the communities relied on untreated surface water sources for their drinking purposes.

The people who consume water contaminated by U may suffer from kidney pro-blems (failure) and even cancer (Winde et al., 2004). Exposure to such toxic metal may have serious health problems on humans especially children and old people because of their weakened immune system and to the environment (Au et al., 1998). WHO (2011) has promul-gated a U provisional guideline of 30 µg/L in drinking water. The mobility and availability of U is dependent on a number of soil factors such as pH, redox potential, soil moisture levels and microbial activity with the uranyl ion being stable in aqueous solutions of $pH < 2.5$ (Gavrilescu et al., 2009).

According to Mulugisi et al. (2009), five indigenous grass species, *Cynodon dactylon*, *Cyperus esculentus, Hyperthermia tamba, Hyperthermia hirta* and *Paspalum dilatum* were analyzed for their absorption of heavy metals in mine tailings at New Union Gold Mine, Malamulele and Limpopo Province, South Africa. Other plants species such as *C. dactylon* which were grown on the soil contaminated by toxic metals have the ability to accumulate huge amount of toxic metals in their tissues without symptoms of toxicity (Padmavathiamma and Li, 2007). Soleimani et al. (2009) observed that *C. dactylon* was able to accumulate Mn metal both in roots and shoots. Manganese was found to be accumulated in the root (63 mg/kg) and shoot (36 mg/kg) of *C. dactylon* growing in natural top soil (Maiti and Jaiswal, 2008). According to the studies above, it is shown that *C. dactylon* can be regarded as hyperaccumulator because of its ability to absorb greater than one (>1) mean metal concentration.

Mulugisi et al. (2009) demonstrated that *C. dactylon* grass species was able to bioaccumulate heavy metals, Mn (up to 225.5 mg/kg); Cu (up to 41.5 mg/kg); Zn (41 mg/kg); Pb (up to 4.5 mg/ kg); Co (up to 2.5 mg/kg) and accumulated less (1 mg/kg) of Cd on mine tailings soils at New Union Gold Mine, South Africa. A study was done by Saraswat and Rai (2009) to evaluate the phytoextraction potential of six different plant species for Cr, Zn and Cd removal under laboratory conditions. The study show that *C. dactylon* was able to exhibit maximum bioaccumulation for Cr. However there are limited studies on the bioaccumulation potential of Cr and U uptake by *C. dactylon* grass species under field conditions. The general objective of this study was to assess the bioaccumulation of total Cr and U by *C. dactylon*. The specific objectives were: to determine the contribution of

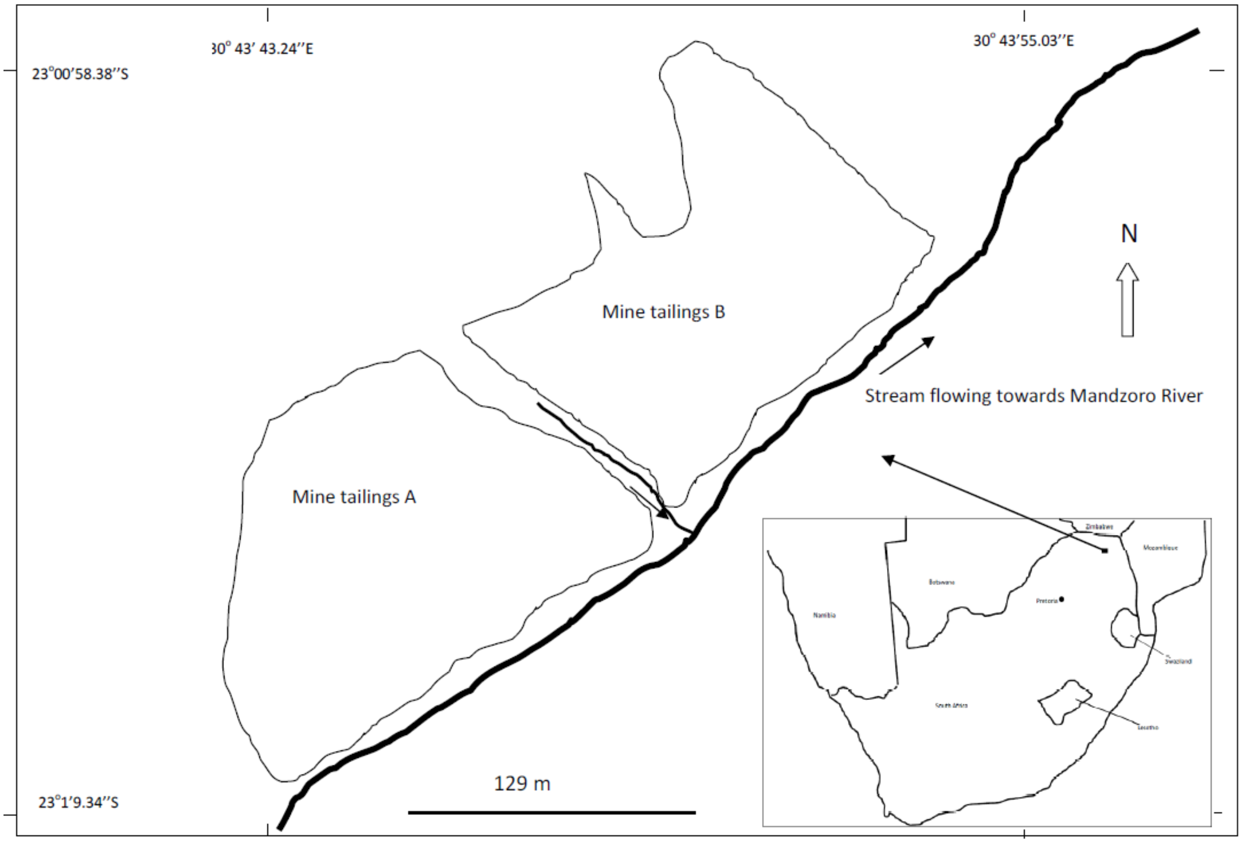

Figure 1. The location of the study area.

pH and electrical conductivity (EC) to the solubility and mobility of total Cr and U metals; to determine the distribution of total Cr and U in different sections of *C. dactylon* grass species (roots, stem, rhizome and leaves) and to determine the distribution of Cr and U in the mine tailings.

MATERIALS AND METHODS

Sample collection and preparation

Mine tailings and grass samples were collected from both tailings Dam A and B. The tailing (soil) and *C. dactylon* grass samples were collected at the following geographical coordinates. A1, A2, B1, B2 and controls were collected at 23°01'05"S and 30°43'50"E, 23°00'59"S and 30°43'53"E, 23°01'06"S and 30°43'47"E, and 23°01'04"S and 30°43'45E", and 23°00'10.3"S and 30°42'9.9E, respectively (Figure 1). The soil samples were collected from the top profile 0 to 20 cm for both control and mine tailings. The grass and tailing samples were then processed as per procedure of Mulugisi et al. (2009).

Determination of pH and electrical conductivity

The pH and conductivity analysis was based on the procedure of Sampanpanish et al. (2006), where an aliquot of 50 g of mine tailings/soil was mixed with 50 mL of de-ionized water (1:1 w/w). The contents were stirred for 5 s with a stirring rod and the pH and EC were then simultaneously determined for each sample using the CYBERSCAN CON 500 after calibration as per manufacturer instructions.

The analysis of metal content by ICP MS

The metals total chromium (^{52}Cr) and uranium (^{238}U) in the mine tailings, control samples and grass samples were analysed in duplicate with an Inductively Coupled Plasma Mass Spectrometer (Thermofischer ICP MS Model, X Series II; ARC Institute of Soil, Climate and Water, Pretoria). The instrument was able to measure more than 40 elements, including ^{52}Cr and ^{238}U, at a detection limit of 0.01 ppb. The instrument was calibrated using the US EPA method 6020A. Analysis was automatic, and data acquisition and processing was controlled by instrument software. The results were expressed as mg per kg and or µg/g.

Data analysis

The analytical raw data was processed as per procedure of Mulugisi et al. (2009) and statistical analysis was carried out with Microsoft Excel, single factor ANOVA at a significance level of $p <$ 0.0. The bioconcentration factor and translocation factors were calculated as per procedure of Hazrat et al. (2012). The bioconcentration factor (BCF) and translocation factor (TF) data was then log transformed and then analysed for Pearson correlation coef-

Table 1. The levels of total Cr in mine tailings, control site and grass.

Sample site	Parameter	Total Cr content (mg/kg)	*Cynodon dactylon** (mg/kg)
Mine tailings A	Range	152.6 to 196.1	379.2 to 519.0
	Mean	174.4 ±30.8	449.1 ± 98.9
Mine tailings B	Range	151.3 to 229.7	314.5 to 518.5
	Mean	190.5 ± 55.4	416.5 ±144.2
Control site	Range	80.1 to 82.6	36.4 to 36.9
	Mean	81.3± 1.3	36.6 ± 0.3

*The sum of total Cr in different plant sections of the grass.

Table 2. The levels of U in mine tailings, control site and grass.

Sample site	Parameter	U content (µg/g)	*Cynodon dactylon** (µg/g)
Mine tailings A	Range	0.51 to 0.92	2.92 to 5.41
	Mean	0.72 ± 0.29	4.17 ± 1.76
Mine tailings B	Range	0.85 to 1.06	5.77 to 6.94
	Mean	0.95 ± 0.14	6.36 ± 0.83
Control site	Range	0.68 to 0.78	1.71 to 1.83
	Mean	0.73 ± 0.05	1.77 ± 0.09

*The sum of total Cr in different plant sections of the grass.

Table 3. pH and EC of New Union Gold Mine Tailings and controls.

Parameter	Mine tailing**				Control**
	A1*	A2*	B1*	B2*	
pH	3.34 ± 0.02	3.25 ± 0.07	3.29 ± 0.09	3.29 ± 0.03	7.56 ± 0.01
EC (µS/cm)	1378 ± 59	1568 ± 15	1962 ± 39	1815 ± 6	266 ± 4
Significance difference (p) value	P= 0.00	P = 0.00	P = 0.00	P = 0.00	

*Not significance different ($p > 0.05$); **significance different ($p < 0.05$); Standard error show standard deviation (n = 2).

ficient at significance level at $p < 0.05$ and 0.01 using statistical software SPSS 19.0.

RESULTS AND DISCUSSION

The concentration of total Cr and U in mine tailings, soils and grass samples

The levels of total Cr and U were determined in the abandoned New Union Gold Mine tailings, control site and the indigenous grass, *C. dactylon* (Tables 1 and 2). The total Cr levels in the mine tailings were higher than the background levels (controls) by a factor of two. The total Cr in the mine tailings were in excess of the South Africa soil quality standard of 80 mg/kg (Aucamp, 2000). The indigenous grass, *C. dactylon* was able to bioaccumulate more of the total Cr as indicated in Table 1 in comparison with the control grass by a factor of 11 (a factor of 12.5 for mine tailings A and 11.5 for mine tailings B).

The U levels in the mine tailings were similar to the background levels (controls). The indigenous grass, *C. dactylon* was able to bioaccumulate more of the U as indicated in Table 1 in comparison with the control grass by a factor of 2 (a factor of 2.4 for mine tailings A and 3.6 for mine tailings B). The U content in the New Union Gold Mine tailings was lesser (1.0 µg/g) than the reported U content (2.70 ± 0.03 µg/g) of an abandoned uranium mine tailings in Hungary (Mihucz et al., 2008). The U content in the mine tailings exceeded the South Africa soil quality standard of 80 mg/kg and U has the potential to contaminate the water sources (Aucamp, 2000).

The ability of *C. dactylon* to bioaccumulate more Cr and U might be linked to the mobility and bioavailability of Cr and U as a result of the acidic conditions that were present at the mine tailings (Table 3) (Sampanpanish et al., 2006; Abou-Shanab et al., 2007).

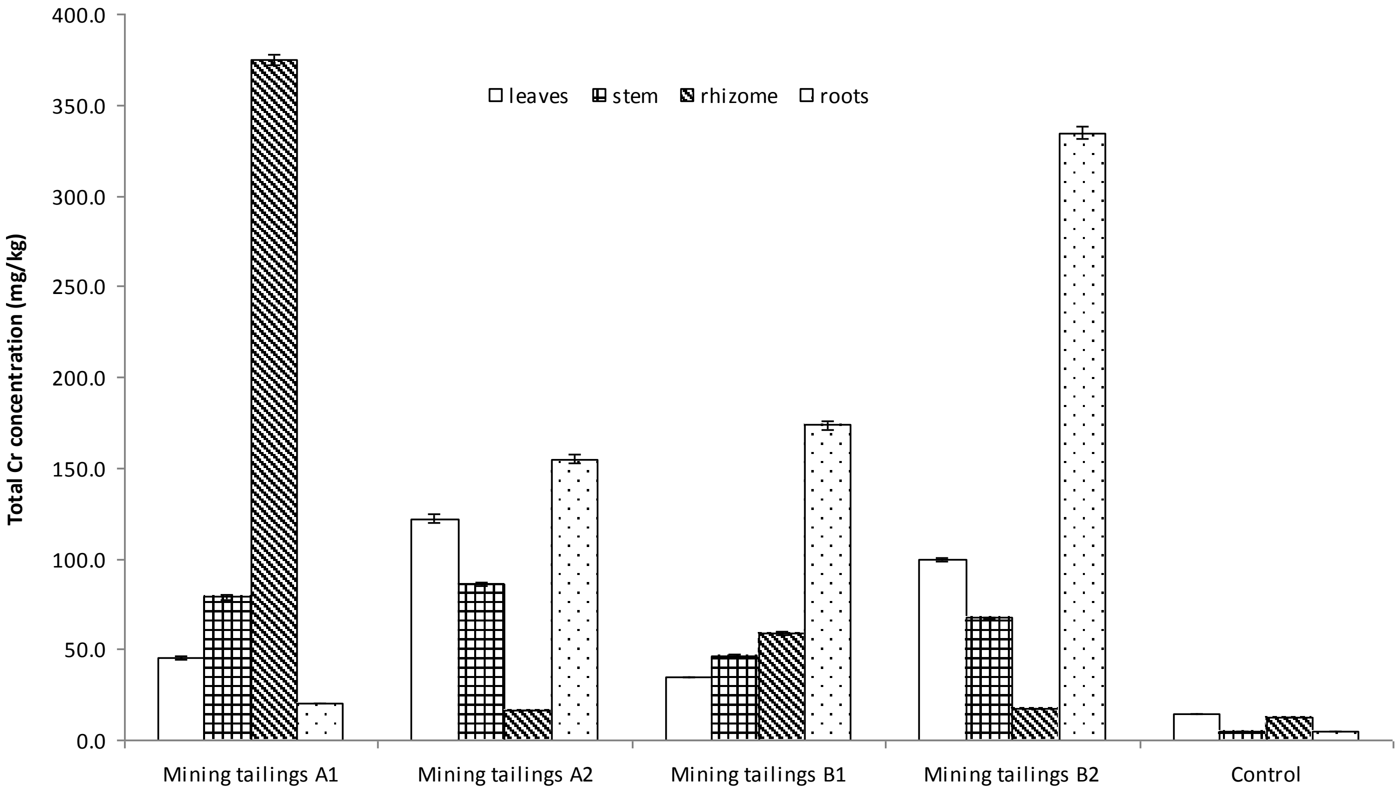

Figure 2. The uptake of total Cr by different tissues of *C. dactylon* grass. Error bars show standard deviation (n = 2).

The uptake of total chromium and its distribution in different tissues of *C. dactylon*

The research findings show that the metals, total chromium (Cr) and uranium (U) were present in the mine tailings, control site and the native grass, *C. dactylon* (Figures 2 and 3). The grass, *C. dactylon* that was growing on the mine tailings accumulated more of total Cr in comparison with the control site (Figure 2) and was significantly different ($p < 0.05$). The reason why grass accumulated more total Cr than the control grass was probably due to low pH of the mine tailings in comparison with the control site where the pH was almost alkaline (Table 1). It is possible that the total Cr content originated from the mine tailings and was taken up by *C. dactylon*. Also, the low pH and high electrical conductivities probably contributed to mobility and bioavailability of total Cr to *C. dactylon*. Abou-Shanab et al. (2007) reported that soil pH plays a significant role in metal uptake by plants.

The accumulation of total Cr in different tissues of *C. dactylon* grass was variable between the mine tailings and the control site (Figure 2). *C. dactylon* grass that grew in mine tailings A1 accumulated the total Cr in different tissues, the accumulation order was rhizome > stem > leaves > roots. The total accumulation of Cr in different tissue of *C. dactylon* was 519.1 mg/kg for mine tailings A1. For mine tailings A2, the following level of Cr was accumulated in different tissues of *C. dactylon* grass, the highest was in roots > rhizome > stem > leaves. The overall total accumulation of Cr of different tissue of *C. dactylon* grass was 314.6 mg/kg for mine tailings A2. *C. dactylon* grass that grew in mine tailings B1 accumulated the following level of Cr in its different tissues, roots > leaves > stem > rhizome. The total accumulation of Cr for mine tailings B1 in different tissue of *C. dactylon* grass was 379.0 mg/kg. In mine tailings B2, different level of Cr was accumulated in different tissues of *C. dactylon* grass, the highest level was in roots > leaves > stem > rhizome. The total accumulation of Cr for B2 in different tissues of *C. dactylon* grass was 518.6 mg/kg. In the control site, the following level of Cr was accumulated, the highest was in leaves > rhizome >roots > stem. The total accumulation for Cr at the control site for different tissues of *C. dactylon* was 36.7 mg/kg.

The differences in accumulation of total Cr may be attributed to differences in soil pH and electrical conductivity (Table 1) which in turn might influence the mobility and bioavailability of Cr. The differences in total Cr uptake between and within the mine tailings sites may be attributed to the age of the grass shoots. The study of Sampanpanish et al. (2006) in Thailand, at chromium contaminated tannery site, showed that *C. dactylon* young shoots (<30 days) were able to bioaccumulate more

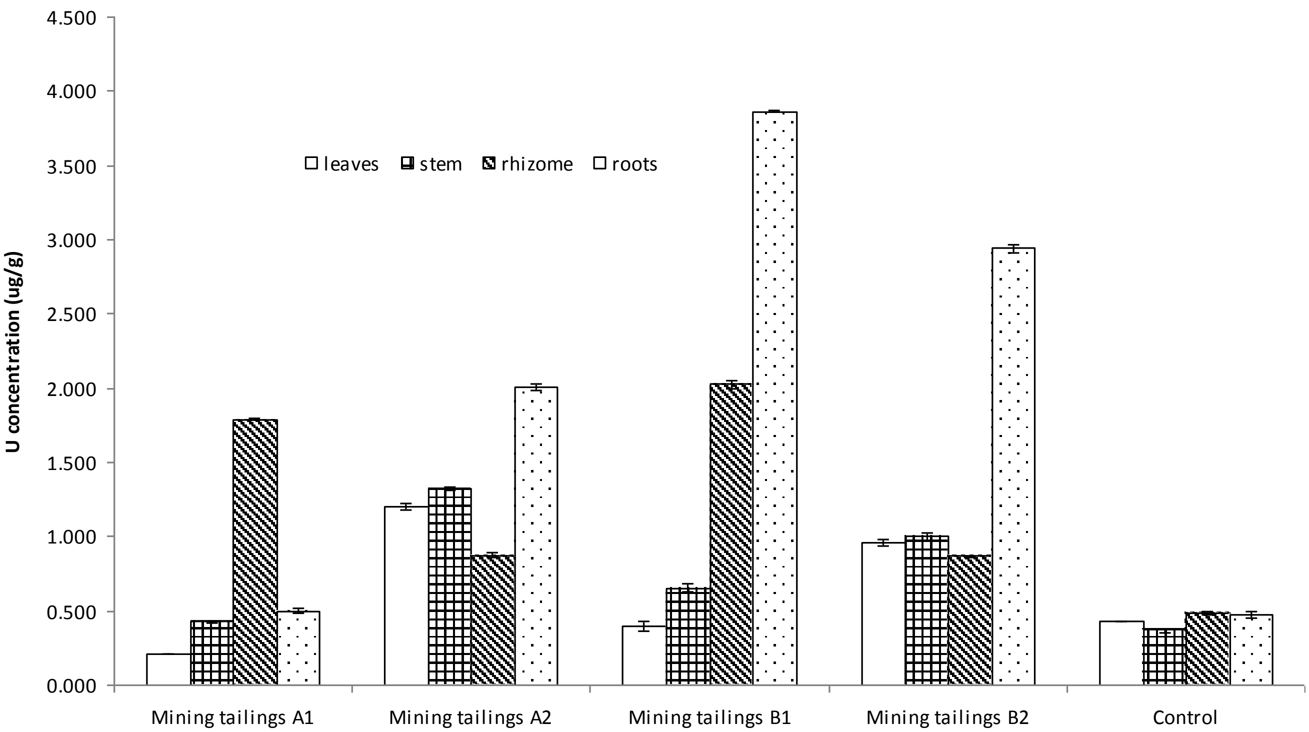

Figure 3. The uptake of U by different tissues of *C. dactylon* grass. Error bars show standard deviation (n = 2).

total Cr in the following accumulation order: roots > stem > leaf. However, for shoots older than (>30 days), the accumulation order was mainly based on the root system as shown by our studies. In our study, the age of the grass was not determined as the grass was collected at random and was found growing at the mine tailings and the control site.

The total Cr content in the mine tailings was less that of the study of Malarkodi (2007) but was higher than the prescribed Cr standards of developed countries of 150 mg/kg at pH < 7. The research findings of total Cr in the mine tailings (Figure 2) were in excess of the South Africa soil quality standard of 80 mg/kg and Cr has the potential to contaminate the water sources (Aucamp, 2000). But the control sample, the total Cr content (81.3 mg/kg) was slightly above the South Africa soil quality standard of 80 mg/kg.

The bioaccumulation of metals by plants is influenced by factors such as soil pH, electrical conductivity and organic content of the soil and nature and chemical form of the metallic element. The research study show that the pH of the mine tailings at New Union Gold Mine was highly acidic, whereas at the control site, the pH was slightly alkaline (Table 3). The research findings are similar to the studies of Aucamp (2000) and Naicker et al. (2003) who reported low acidic conditions at gold mine tailings.

There was a significant difference between the pH of the control site and mine tailings ($p < 0.05$) and there was no significant difference between the mine tailings A and B ($p > 0.05$). The acidic conditions at the mine tailings were probably due to acid mine drainage (AMD) (Sam and Beer, 2000). Thus, during the weathering process (a continuous event), high concentrations of insoluble ferric hydroxide precipitate $Fe(OH)_3$, dissolved sulphate (SO_4^{2-}) and acid (H^+) are produced. The sulphuric acid produced will seep into adjacent rock or mine tailings and produce secondary reactions that result in heavy metals such as aluminum, manganese, zinc, lead, arsenic and other oxidation products (Sam and Beer, 2000; Mulugisi et al., 2009). In addition to this chemical reaction that produces AMD, the presence of microorganism such as *Thiobacillus ferrooxidans* (Sam and Beer, 2000) accelerates the AMD event. The acidic waters are transported through the subsurface waters by groundwater flow and may become inflows to receiving surface streams. However, if there is sufficient alkalinity, the acidic waters are neutralized but this can be easily overcome when the naturally occurring neutralizing capacity fails and AMD accumulates with pH dropping.

The electrical conductivity (EC) of the tailing samples at New Union Gold Mine tailings was higher than that of the control site (Table 1). There is a significant difference between the EC of the control site and mine tailings ($p < 0.05$). The high EC values of the mine tailings were probably because of the acid mine drainage. Acid mine drainage influences EC to exceed general guidelines of 1200 µS/cm in the tailing dams due to oxidation process of pyrite and sulphide minerals upon exposure to atmospheric oxygen and water (James, 1997). The research findings for the mine tailings are similar to that of Aucamp (2000) who reported electrical conductivity range of 1150 to 1711 µS/cm. Mining activities have extremely large global negative impacts on the environment and the greater part of these impacts are from the mine tailings which are typically described by high level of potential toxic metals, low pH, low nutrients, low water retention capacity and also high electrical conductivity (Mulizane et al., 2005; Conesa et al., 2006).

The uptake of uranium and its distribution in different tissues of *C. dactylon*

The results show that the grass, *C. dactylon* absorbed more of the uranium (U) in mine tailings and the control site, and was significantly different, $p < 0.05$ (Figure 3). Furthermore the accumulation of U in different tissues of *C. dactylon* grass varied between the mine tailings and the control site and also within the mine tailings. This might be explained by the mobility and bioavailability of U due to the acidic conditions that were present at the mine tailings. Under alkaline conditions present at the control site, the U was less mobile and therefore not bioavailable. This is supported by the study of Gavrilescu et al. (2009) who showed that the mobility and availability of uranium was dependent on a number of soil factors such as pH, redox potential, soil moisture levels and microbial activity and the uranyl ion was stable in aqueous solutions of pH < 2.5.

The differences in U uptake between and within the mine tailings sites may be attributed to the age of the grass shoots. The study of Sampanpanish et al. (2006) in Thailand, at chromium contaminated tannery site, showed that *C. dactylon* young shoots (<30 days) were able to bioaccumulate more total Cr in the following accumulation in the order roots > stem > leaf. However, for shoots older than (>30 days), the accumulation order was mainly based on the root system as indicated by our results. The presence of U in the leaves of the indigenous grass may be a potential hazard to animal grazers. The study of Winde (2010) showed that the presence of Cd, which was shown in the mine tailings and *C. dactylon* grass (Mulugisi et al., 2009) may lead to higher levels of U toxicity.

The effects of uranium on human health are not immediate and it may take several years before any adverse consequences are recognized. Au et al. (1995, 1998) investigated whether residents residing near uranium mining operations, who were potentially exposed to toxicants from mining waste, had increased genotoxic effects when compared with people residing elsewhere. The authors found that uranium concentrations in soil samples were significantly higher in the target area than those in the control areas. Thus, the mine tailings have health issue and environmental concern, such as lung cancer, leukemia, stomach cancer and birth defects, to the whole population in the area surrounding the mine (Au et al., 1998).

The negligence of toxic metals resulted in the relocation of toxic metals to the surrounding environment and, contributes to soil contamination, ground and surface water contamination (Liu et al., 2006). Toxic metals contamination in soil is one of the major sources of toxic metals in groundwater and surface water (Fayiga et al., 2004). The contamination of surface and groundwater by toxic metals pose a particular threat to the health of the community and animals around that particular area affected by toxic metals such as radioactive metals, especially to the community that drink this water without any proper treatment (Winde et al., 2004; Bitala and Kweyunga, 2009).

Bioconcentration and translation in *C. dactylon*

The study of Al-Qahtani (2012) shows that the bioaccumulation of metals by plants is influenced by factors such as soil pH, electrical conductivity and organic content of the soil, and oxidation state of the metallic element. The research findings show that the BCF ratio was variable between the *C. dactylon* grass that grew on mine tailings and the control (Table 4). This BCF variability may be attributed to metal mobility and bioavailability as a result of acidic conditions. Al-Qahtani (2012) stated that neutral to alkaline conditions restrained metal mobility and therefore the metal bioavailability in plant uptake and translocation into plant tissues. Our study show that at the acidic mine tailings, the BCF was less than 1 with exception of the root system which was greater than 1 for mine tailings such as A2 and B2 (Table 4). Also, the alkaline conditions probably contributed to low BCF ratios for the control site. There was no significant correlation between pH > 3.34 for mine tailings A1 and control site; Pearson correlation coefficient of 0.456 at $p > 0.05$ (2 tailed). Whereas, at pH <3.29, there was significant correlation between mine tailings A2 and B1, Pearson correlation coefficient of 0.740 at $p < 0.05$ (2 tailed) and between B1 and B2, Pearson correlation coefficient of 0.861 at $p < 0.01$ (2 tailed). It appears that the bioaccumulation of metals (Cr and U) was influenced by acidic pH <3.29.

The use of translocation factor (TF) indicates the mobility of metal uptake from soil to root, rhizome, shoot and leaves. According to Al-Qahtani (2012), the TF ratio is a suitable pointer to whether the plant is an accumulator, excluder or indicator. Our study shows that there was considerable variation in the TF ratios between the *C. dactylon* grass that grew within the acidic mine tailings and the alkaline control site (Table 5). The research findings show that at the acidic mine tailings, the TF was less than 1 with exception of the root system which was

Table 4. Bioconcentration factors (BCF) of *C. dactylon* for Cr and U.

Parameter	Mine tailing				Control
	A1	A2	B1	B2	
pH	3.34 ± 0.02	3.25 ± 0.07	3.29 ± 0.09	3.29 ± 0.03	7.56 ± 0.01
Root Cr	0.104	1.014	0.756	2.211	0.063
Rhizome Cr	1.910	0.108	0.258	0.113	0.152
Stem Cr	0.402	0.564	0.204	0.445	0.060
Leaves Cr	0.231	0.798	0.152	0.657	0.175
Root U	0.972	2.176	3.661	3.445	0.659
Rhizome U	3.485	0.951	1.918	1.019	0.667
Stem U	0.831	1.435	0.622	1.173	0.519
Leaves U	0.405	1.306	0.375	1.127	0.589

Table 5. Translocation factors (TF) of *C. dactylon* for Cr and U.

Parameter	Mine tailing				Control
	A1	A2	B1	B2	
pH	3.34 ± 0.02	3.25 ± 0.07	3.29 ± 0.09	3.29 ± 0.03	7.56 ± 0.01
Leaves Cr	2.236	0.787	0.200	0.297	2.784
Stem Cr	3.882	0.556	0.270	0.201	0.961
Rhizome Cr	18.448	0.107	0.342	0.051	2.431
Leaves U	0.417	0.600	0.102	0.135	0.892
Stem U	0.855	0.659	0.170	0.223	0.786
Rhizome U	3.586	0.437	0.524	0.689	1.011

greater than 1 for mine tailings such as A2 and B2 (Table 5).

There was significant correlation between pH > 3.34 for mine tailings A1 and control site; Pearson correlation coefficient of 0.906 at $p < 0.01$ (2 tailed) whereas at pH < 3.29, there was significant correlation between mine tailings A2 and B1, Pearson correlation coefficient of 0.833 at $p < 0.05$ (2 tailed) and between B1 and B2, Pearson correlation coefficient of 0.947 at $p < 0.01$ (2 tailed). It appears that the mobility and metal translocation of metals (Cr and U) was influenced by soil pH. The bioaccumulation of U and total Cr by *C. dactylon* has the potential of transferring these heavy metals to animal grazers (cattle and goats) that visit the mine tailings for lavish grass during summer as shown by the study of Mothetha (2009).

Conclusion

The study shows that total Cr and U was present in mine tailings and in the indigenous grass, *C. dactylon*. This was evident from the BCF and TF values which indicate that the *C. dactylon* was able to uptake the metals within the different tissues. The low pH and high electrical conductivity further enhances the mobility and bio-availability of heavy metals for *C. dactylon* uptake. The presence of these heavy metals in mine tailings and grass indicates the potential to contaminate the water sources and the environment bearing in mind that U contamination has long term negative impact due to its radioactivity. For animal grazers, the consummation of *C. dactylon* maybe the route for transfer of the heavy metals from mine tailings to humans. Lastly, *C. dactylon* has the potential to be used as vegetative cover for the exposed mine tailings to prevent water and wind erosion.

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