Manganese and vanadium uptake by *Cynodon Dactylon* grass species: A case study in New Union gold mine tailings, Limpopo, South Africa

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Abstract

Environmental hazards originating from abandoned mines are on the increase worldwide, including South Africa. Here, we report the manganese and vanadium uptake by *Cynodon dactylon*, which was found thriving at abandoned New Union Gold Mine tailings, Limpopo province, South Africa. The Mn and V concentrations were determined with a Thermofischer ICP MS. The total average Mn and V uptake by *C. dactylon* were 689.45 µg/g and 91.99 µg/g and controls were 426.55 µg/g and 55.56 µg/g respectively. It appears that the Mn and V uptake by *C. dactylon* was beneficial, since Mn is a micronutrient element that is essential to plant growth and V is an essential element, which mimics phosphorus uptake. *C. dactylon*, is a suitable phytoremedial agent for exposed acidic mine tailings.

Keywords: indigenous grass, phytoremediation agent, manganese and vanadium toxicity; water sources

Introduction

Human development has led to enormous scientific and technological advancement. Globalisation however raises new challenges, in the environmental protection and conservation (Bennett et al. 2003). Governments around the world recommend an environment free from harmful contamination for its citizens; nonetheless the demand for a country's economy surpasses the demand for safe natural environment. Paradoxically, it is the economic, agricultural and industrial developments that are often associated with polluting the environment (Ikhuroria and Okiemen 2000). Since the establishment of industries, soil pollution has increased severely. According to Nriagu (1996), about 90 % of the emission of heavy metals caused by humans has occurred since 1900 AD; it is now well known that anthropogenic activities result into substantial accumulation of heavy metals in soil on a global scale. Industrial activities like mining, smelting, refining, manufacturing process cause environmental exposure of heavy metals (Nrianga 1996). With gold mine tailings, acid mine drainage (AMD) is a problem which leads to the mobility and hence availability of heavy metals to the environment (Sam and Beer 2000). The heavy metals are deposited into the environment and are then bioaccumulated by living organisms and transferred to the food chain (Dembitsky 2003; Manohar et al. 2006).

In the northern limb of the Giyani Greenstone Beltis the abandoned New Union Gold Mine is found.Characteristic for the area is the Achaean granite, which is invaded by older and highly metamorphosed quartzite banded iron formation, amphibolites and schist. These rocks are considered similar to those found in the lower part of the Onverwacht Group in Barberton Mountain Land (Potgieter and De Villiers 1986). The occurrence of gold mineralization is controlled spatially by the presence of folding; consequently gold is concentrate in folded hinges. The belt formerly known as Sutherland Greenstone Belt is in the northeast trending features, which is about 15 km wide and 70 km long, it is aligned with the Pietersburg Greenstone Belt. Predominantly the gold is found in quartzite, schist, amphibolites and banded ironstone in contact with granite gneiss where the schist dips towards the gneiss (Potgieter and De Villiers 1986).

ATSDR (2009) stated that the deliberate exposure to high levels of vanadium in air may results in lung damage, nausea, mild diarrhea and stomach cramps. The same study also showed that animals ingesting vanadium resulted in reduced levels of red blood cells, increase in blood pressure and mild neurological effects. Many living organisms, including humans, require manganese as an essential element. It is necessary for proper functioning of some enzymes (super oxide dismutase) and the activation of others. Manganese deficiency in humans appears to be unusual because it is present in many common foods (ATSDR 2000). The health effects from over-exposure of manganese depend on the route of exposure, the chemical form, the age at exposure and an individual nutritional status. Nervous system has been determined to be the primary target with neurological effects generally observed, irrespective of the route of exposure. The convincing evidence from occupation studies in humans showed that inhalation exposure to high levels of manganese compounds can result in neurological effects (Rodier 1995).

Today, *C. dactylon* has a variety of uses, from hay, pastures, and lawn grass and has been used all over the world for soil stabilization projects for preventing soil erosion. *C. dactylon* adapts well in wide range of climates, from rainy tropics to arid land and in irrigated areas (Holm et al. 1977). *C. dactlyon* grows well in a variety of soil types, fertile, sandy to silt soils, alluvium, heavy clay to acidic and alkaline types (Holm et al. 1991; Carey 1995; Anderson 1999; Mulugisi et al. 2009). This grass has been discovered to be highly tolerant to extreme soil conditions, including low pH, and heavy metal concentration (Truong and Baker 1988). *C. dactylon* is a creeping grass that spread over large areas, and may tolerate pollution by trace elements (Smith et al. 1998). *C. dactylon* grass is due to its morphological and physiological characteristiceffective in erosion and sediment control (Greenfield 1989). Revegetation of gold mine tailings is important for long term stability of land surface. Though studies have been done on metal accumulation by *C. dactylon* grass species at New Union Gold Mine Tailings, South Africa, none have been carried out on which sections of the native grass are examined for its metal accumulation. The specific objectives were to analyse the content of two toxic metals (Mn and V) in different sections of *C. dactylon* grass species (root, stem, rhizome and leaves) and to compare the metal accumulation in *C. dactylon* grown on mine tailings and on a control site. Then the soil pH and electrical conductivity measurements were used to represent metal mobility and bioavailability.

Methods

C. dactylon and soil samples were collected from New Union Gold mine tailings that were located near kaMadonsi village at Malamulele in Limpopo province, South Africa (Figure 1). Grab soil samples were collected from the top profile (0 to 20 cm depth).

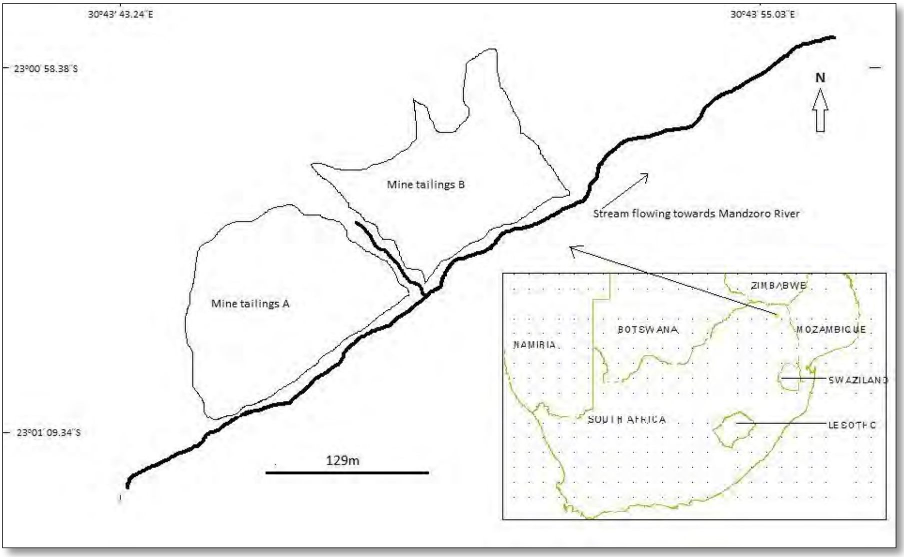

Figure 1 *The location of New Union Gold Mine tailings.*

Sample preparation

All samples were processed as per procedure of Mulugisi et al. (2009).

Metal Analysis

After acid digestion of mine tailings and grass, the samples were sent to ARC Institute of Soil, Water & Climate in Pretoria for metal analysis. For analysis of Mn and V a Thermofischer ICP MS Model X Series II was used.

Preparation for pH and Electrical Conductivity (EC)

To measure pH and EC, 50 ml deionized water was added to 50 g soil or tailings. After mixing for 5 seconds with a stirring rod the mixture was allowed to settle. After 30 minutes the pH and EC were determined using the CYBERSCAN CON 500 calibrated as per manufacturer instructions.

Data Analysis

Factors for bioconcentration and translocation were determined using the procedure described by Hazrat et al. (2010). Heavy metal concentrations in mine tailings and control samples were compared using MS Excel single factor Analysis of variance (ANOVA) at a significant level of $p < 0.05$.

Results and Discussion

Phytoextraction of Vanadium

Figure 2 shows the bioaccumulation of V in the different parts of *C. dactylon*. In *C. dactylon* that grew on the mine tailings the V concentration was significantly higher ($p < 0.05$) than in plants that grew on the control site. This is in agreement with the study of Onder et al. (2007) who reported that the tolerable level of V in *C. dactylon* grass was 50 µg/g. The differences in the levels of V in the tissues of *C. dactylon* might be attributed to the differences in soil pH and electrical conductivities (Table 1).

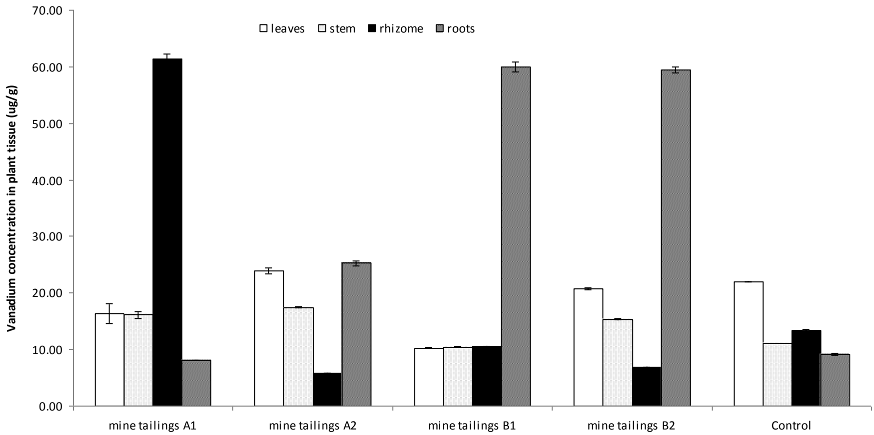

Figure 2 *Phytoextraction of Vanadium by C. dactylon (SD; n = 3).*

The pH of the mine tailings was low probable due to oxidation processes of pyrite and other sulphide minerals exposed to atmospheric oxygen and water (Sam and Beer 2000). Soil pH plays a significant role in potential toxic metal bioaccumulation, bioavailability, toxicity, and leakage capability to surrounding areas particularly during heavy rain season (summer time) (Abou-Shanab et al. 2007).

Table 1 *pH and EC of Soil Sample at New Union Gold Mine Tailings*

Parameter	**Mine Tailings**				**Control**
	A1	**A2**	**B1**	**B2**	
pH	3.55 ± 0.04	3.49 ± 0.01	3.62 ± 0.01	3.66 ± 0.04	7.59 ± 0.15
EC (µS/cm)	1717 ± 26	1982 ± 8	1568 ± 7	1987 ± 13	543 ± 1

In Australia, *C. dactylon* grass has been successfully used in the rehabilitation of highly acidic gold mine tailings with a pH of 2.7 (Truong and Baker 1998).The Australian study concurs with our research findings where *C. dactlyon* was able to grow in adverse pH conditions that exist at New Union Gold mine tailings (Table 1) The soil electrical conductivity (EC) is the ability of the soil water to carry an electrical current. This can be used to determine the amount of nutrients available for plants. Compared with the control, the electrical conductivity of tailings dam A and B were three to four times higher(Table 1). Electrical conductivity that ranges from 200 and 1200 μS/cm is suitable for the plant growth (http://www.fao.org/docrep/T0667E/t0667e05.htm). Soils with EC below 200 μS/cm has not enough nutrients available to the plant and could perhaps show a sterile soil with little microbial activity. An EC above 1200 μS/cm may indicate too much high salt fertilizer or salinity problem from lack of drainage. The electrical conductivity of the mine tailings in New Union Gold Mine was very high (Table 1). With such high electrical conductivity, it is not possibly for many plant species to grow, but the unique physiological characteristic of *C. dactylon* grass allows it to thrive under such adverse conditions.

Phytoextraction of Manganese

Figure 3 shows the bioaccumulation of Mn in the different tissues of *C. dactylon*. In the leaves and rhizome of *C. dactylon* that was growing on the mine tailings the Mn concentration was not significantly different ($p > 0.05$) from the control site. Mn is an essential element in plants that is required for effective leaf functioning, biosysnthesis of chlorophyll and is involved in the photosynthesis process in water-splitting system of photosystem II (Millaleo et al., 2010). However the Mn content of stem and roots of *C. dactylon* was significantly similar ($p < 0.05$) between the mine tailings and control site. The differences in the levels of Mn in the tissues of *C. dactylon* might be attributed to the differences in soil pH and electrical conductivities (Table 1). Mulugisi et al. (2009) showed that the total Mn uptake by *C. dactylon* was in the range 111 to 334 mk/kg (mine tailings A) and 147 to 333 mg/kg (mine tailings B) which concurs with our research findings for total sum of Mn in different tissues (Figure 3). The research was also in line with the study of Madejón et al. (2006) in South Spain (mine spill) which recorded concentrations of Mn in different sections of *C. dactylon* of (up to 885 μg/g); although this was slightly lower than concentrations found in this study.

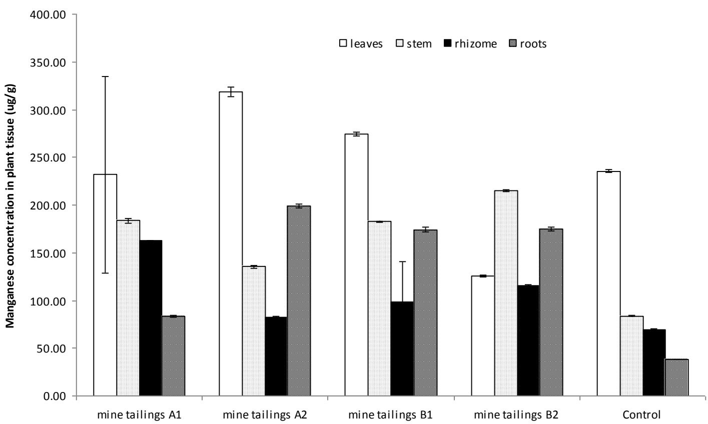

Figure 3 *Phytoextraction of Manganese by C. Dactylon (SD; n = 3).*

Bioconcentration and Translation factors

In Table 2 bioconcentration factors of *C. dactylon* for V and Mn are presented. In the case of V the uptake by *C. dactylon* was higher in rhizome and roots probably due to the direct contact with the contaminated ground. For Mn, the bioconcentration factor was greater than 1 for leaves which probably indicates the essential role played by Mn in photosynthesis process.

***Table 2** Bioconcentration factors (BCF) of C. dactylon for V and Mn*

BCF and metal	Mine Tailings				Control
	A1	A2	B1	B2	
Root_V	0.223	0.668	2.129	1.849	0.148
Rhizome_V	1.694	0.153	0.374	0.211	0.217
Stem_V	0.445	0.461	0.369	0.478	0.180
Leaves_V	0.451	0.631	0.364	0.647	0.356
Root_Mn	0.488	1.452	1.780	1.395	0.153
Rhizome_Mn	0.951	0.604	1.004	0.923	0.281
Stem_Mn	1.074	0.987	1.865	1.715	0.338
Leaves_Mn	1.358	2.321	2.803	1.003	0.951

The translation factors of *C. dactylon* for V and Mn are shown in Table 3. Efficient transport of V and Mn from *C. dactylon* roots to the leaves, stem and rhizome was found, especially in plants grown in mine tailings A1. According to Hazrat et al. (2010), TF values indicate concentration of metals in the root tissues.

***Table 3** Translocation factors (TF) of C. dactylon for V and Mn*

TF and metal	Mine Tailings				Control
	A1	A2	B1	B2	
Leaves_V	2.020	0.945	0.364	0.350	2.401
Stem_V	1.993	0.690	0.173	0.259	1.217
Rhizome_V	7.587	0.229	0.176	0.114	1.460
Leaves_Mn	2.785	1.599	1.575	0.719	6.231
Stem_Mn	2.204	0.680	1.048	1.229	2.217
Rhizome_Mn	1.951	0.416	0.564	0.661	1.839

The mine tailings at New Union Gold Mine may create pollution problems and cause land degradation without vegetation cover. Revegetation of mine tailings is necessary for stabilisation and for minimizing leaching of heavy metals. This process will prevent wind and water erosion of the exposed mine tailings and transportation of heavy metals to the nearby Shingwedzi River which flows toward Kruger National park.

Conclusions

Revegatation of mine tailings generating low pH and high EC was possibly with *C. Dactylon.* Under the adverse conditions *C. dactylon* was also able to accumulate V and Mn from the mine tailings compared to the control conditions. This was evident from BCF and TF values which were greater than one in some cases.

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