



Remediation of Chromium(VI) Containing Wastewater Using *Chrysopogon zizanioides* (Vetiver Grass)

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Remediation of heavy metal contaminated soil and water has been investigated through various methods, most of these have been shown to be expensive and sometimes result in the generation of toxic sludge. In situ methods such as phytoremediation have therefore been explored for their green, economical and less environmentally disruptive advantages. This study investigates the use of vetiver grass in the remediation of chromium(VI) from wastewater. The grass is known to grow in both soil and water. The efficiency of the vetiver grass in the removal of Cr(VI) was examined using 2 L solutions of varying concentrations. The initial concentrations of Cr(VI) chosen for the study were 5 ppm, 10 ppm, 30 ppm and 70 ppm. In a seven (7) week period, 87 % reduction in Cr(VI) concentration was observed in the 5 ppm bucket, while 51 % Cr(VI) removal was measured in the 10 ppm bucket. The 30 ppm bucket had a removal efficiency of 28 % in 5 weeks and 12 % removal efficiency in 4 weeks was measured in the 70 ppm bucket. The absorption of chromium was higher in the roots than the leaves at 5 ppm and 10 ppm, whereas it was higher in the leaves than in the roots at 30 ppm and 70 ppm. The results show the potential of vetiver grass in phytoextraction of chromium and its hyperaccumulator potential for other heavy metals.

1. Introduction

High concentration of heavy metals are detected in industrial wastewater as a result of anthropogenic activities (Akpor, 2014). These heavy metals are known to be toxic even at low concentrations (Tchounwou et al., 2012). Conventional wastewater treatments such as biological and chemical processes are widely used as secondary treatment processes; however, some contaminants are not easily removed (Zia et al., 2013). The most common heavy metals present in wastewater include lead, chromium, cadmium and copper (Gautam et al., 2014). The leather tanning industry is one of the oldest industries from which chromium is produced (Pietrelli et al., 2019). Chromium(VI) is the most toxic and bioavailable form of chromium due to its high mobility (Gomes et al., 2017). It is mutagenic, carcinogenic and causes acute effects such as stomach bleeding, cramps, kidney damage, and liver damage (Teklay, 2016).

Various techniques have been investigated for the removal of Cr(VI) from wastewater such as ion exchange, precipitation, adsorption and filtration membrane (Chen et al., 2018). Recently, there has been research into the development of efficient, cost effective and environmentally friendly methods in the remediation of heavy metals (Ali et al., 2013). One of this emerging green technology is known as phytoremediation. It is the use of certain plant species in the cleaning of contaminated soils and water (Lone et al., 2008). One of the plant species identified for its phytoremediation potential is vetiver grass.

The use of vetiver grass as a hyperaccumulator has been under continuous investigation due to its tolerance to high levels of heavy metals (Truong and Baker, 1998). Vetiver grass is effective in its uses because of its dense root system which can grow up to about 7 m (Oshunsanya and Aliku, 2017). The metals are absorbed by means of channels, transporters and pores in the plasma membrane of the root, they are then stored in the roots and/or transported to the stem and leaves (Baker et al., 1994). The absorption of heavy metals may continue until it is harvested. As much as vetiver grass can be used to decontaminate wastewater, it can also be used in the recovery of precious metals.

The aim of this study is to confirm the efficacy of vetiver grass for the phytoremediation of Cr(VI)

2. Experimental

2.1 Materials and methods

The vetiver grass was obtained from Hydromulch (Pty) Ltd (Johannesburg, South Africa). Potassium chromate (K_2CrO_4) was used to prepare simulated wastewater Cr(VI) solutions. A stock solution of 1,000 ppm chromium(VI) was prepared using 3.74 g of (K_2CrO_4) mixed with water in a 1,000 mL volumetric flask. All the other solutions were then prepared using this stock solution. 1,5-diphenylcarbazide mixed with acetone was used to make a DPC solution which acted as an indicator in the presence of 1 N sulfuric acid to determine the concentration of Cr(VI).

2.2 Experimental methods

The vetiver grass was left to acclimatise in water for two weeks before the commencement of the experimental procedure. The grasses were small and had short roots upon arrival, therefore, to promote root and shoot growth a mixture of 7:14:14 N: P: K macronutrients was added to the water. After 2 weeks, the grass was taken out of the water, washed with running tap water and rinsed using distilled water to remove any pollutants that may affect the experimental procedure. Each bucket contained 2 vetiver slips supported using polystyrene to enable floating in water.

To counter the effect of evaporation, water was topped up to the 2 L mark in each bucket before sampling and the solution was well mixed, with the assumption that during evaporation only water leaves the buckets. The grass was harvested, and this was proceeded by rinsing using running tap water, followed by distilled water. The grass was separated into leaves and roots, the root crowns were not harvested because of the assumption that they are unable to accumulate heavy metals (Ladislas et al., 2013). The roots and leaves were oven dried at 70 °C. The dry roots and leaves were weighed to get the total weight of the harvestable biomass. The dry roots and leaves were ground to powder using a ceramic pestle and mortar. From each plant samples, 0.1 g of roots and leaves was digested using nitric acid and hydrogen peroxide. The mixture was covered, and the digestion was allowed to take place over 48 h. After 48 h the solution was filtered. The filtrate was then analysed for Cr(VI).

2.3 Analytical method

The Cr(VI) concentration in solution was determined using various standard solutions calibrated using a Biochrom WPA Lightwave II UV/Visible spectrophotometer at a single wavelength of 540 µm. The Cr(VI) accumulated in the different parts of the plant samples were analysed using a SPECTRO Analytical Instruments Genesis (ICP-OES) spectrometer.

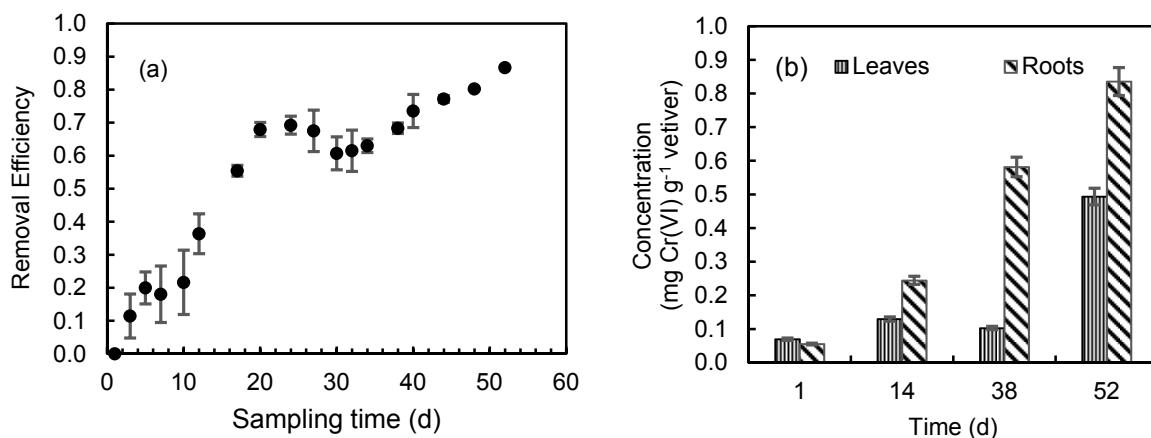


Figure 1: (a) The removal efficiency of Cr(VI) in the 5 ppm solutions, (b) The concentration of Cr(VI) in the root and leaves of vetiver.

3. Results and discussion

3.1 Removal at 5 ppm

Figure 1 shows the Cr(VI) removal efficiency of the grass in the 5ppm solution. Figure 1a shows the results obtained from water samples and Figure 1b shows the results from plant samples. A rapid reduction in Cr(VI)

concentration was observed in the first 20 d (Figure 1a) and thereafter the reduction was gradual. The average rate of reduction in the first 20 d is 0.22 ppm d^{-1} , and thereafter, the rate reduced to 0.094 ppm d^{-1} . A total removal 87 % Cr(VI) was observed at 5 ppm, which corresponds to a removal of 4.35 ppm, reducing the Cr(VI) concentration to the recommended values. The Cr(VI) distribution in the plant is shown in Figure 1b. An increase in Cr(VI) concentration was observed in the plant samples over the experimental period. On day 1, vetiver samples were analysed for Cr(VI) concentration before the commencement of the experiment. More Cr(VI) was found in the roots than in the leaves. This is as a result of restricted heavy metal translocation (Roongtanakiat et al., 2008). A total of $0.49 \text{ mg Cr(VI g}^{-1}$ vetiver and $0.84 \text{ mg Cr(VI g}^{-1}$ vetiver, in the leaves and roots respectively was recovered by the grass in the 5 ppm buckets.

3.2 Removal at 10 ppm

Figure 2 presents the results obtained in buckets which had an initial concentration of 10 ppm. The rate of chromium (VI) uptake in 10 ppm was faster than at 5 ppm. The highest removal efficiency at 10 ppm was found to be 51 % as seen in Figure 2a, which corresponds to a reduction of about 5.1 ppm.

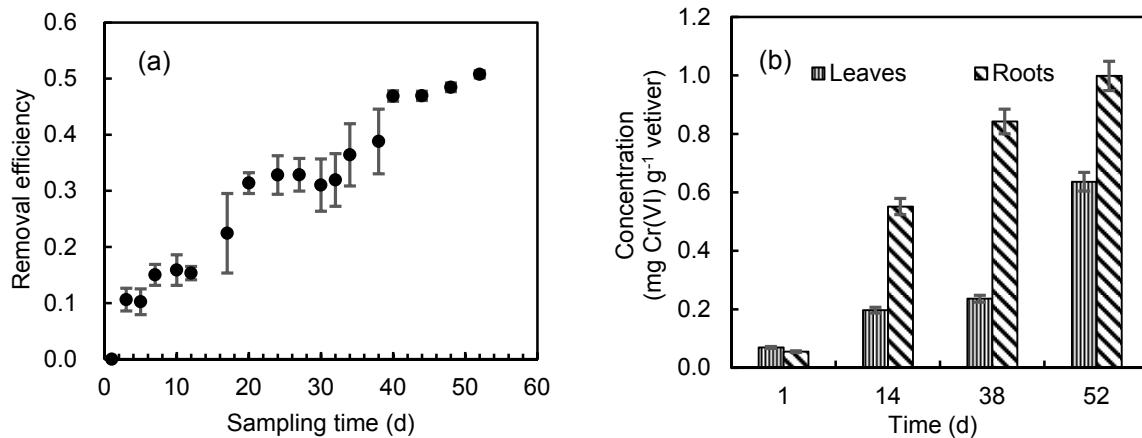


Figure 2: (a) The removal efficiency of Cr(VI) in the 10 ppm solutions, (b)The concentration of Cr(VI) in the root and leaves of vetiver

A similar observation as that obtained from the plant samples in 5 ppm solution was obtained from plant samples in 10 ppm buckets. More Cr(VI) was adsorbed in the roots than in the leaves (Figure 2b). The vetiver in the 10 ppm buckets accumulated more Cr(VI) than the vetiver in the 5 ppm buckets. A total of $0.64 \text{ mg Cr(VI g}^{-1}$ vetiver and $1.00 \text{ mg Cr(VI g}^{-1}$ vetiver was obtained in the leaves and roots respectively. No visible difference was observed between the grass in the 5 ppm and 10 ppm buckets (Figure 4). The grass showed great resilience under these conditions.

3.3 Removal at 30 ppm

At higher concentrations the growth of the grass was hindered and stressed as shown in Figure 4. Figure 3 shows the results obtained from the 30 ppm Cr(VI) samples. A removal efficiency of 28 % (8.4 ppm) from the solution was obtained after 38 d (Figure 3a). After 38 d the grass in the 30 ppm solution dried up and it was harvested.

More Cr(VI) was found in the leaves than in the roots after 38 d (Figure 3b). This is different from what was observed at 5 ppm and 10 ppm from which more Cr(VI) was found in the roots than in the leaves. Accumulation of $1.45 \text{ mg Cr(VI g}^{-1}$ vetiver, was found in the leaves and $0.934 \text{ mg Cr(VI g}^{-1}$ vetiver, was obtained in the roots.

3.4 Removal at 70 ppm

At a higher Cr(VI) concentration of 70 ppm the obtained results from the water samples were oscillatory. Multiple sampling was performed to confirm the obtained results. The average results obtained at 70 ppm are shown in Figure 5. The removal efficiency was lower, at only 11.5 % (Figure 5a). Vetiver reduced Cr(VI) concentration by 8.05 ppm, which is lower than the reduction found in 30 ppm solutions. From grass samples in Figure 5b, more Cr(VI) was obtained in the leaves than in the root which corresponds to the results at 30 ppm.

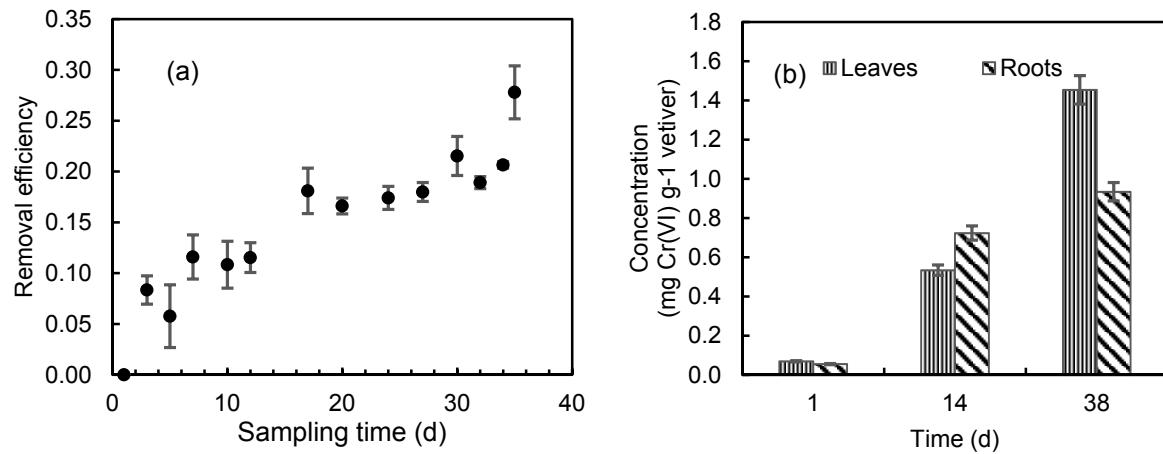


Figure 3: (a) The removal efficiency of Cr(VI) in the 30 ppm (b) The concentration of Cr(VI) in the root and leaves of vetiver.

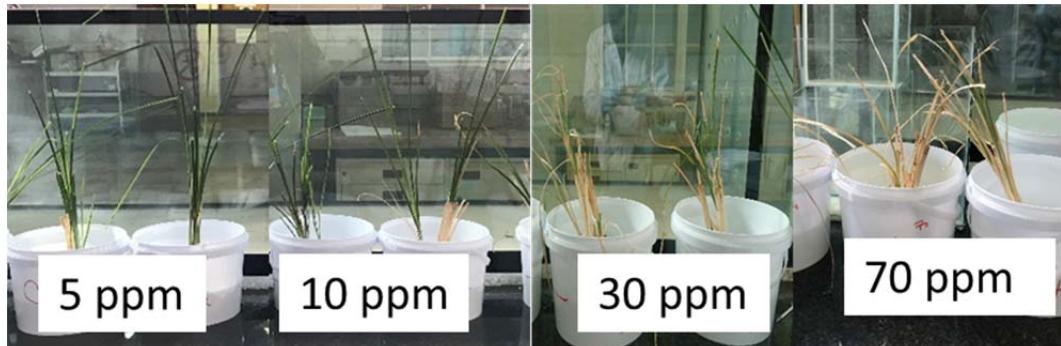


Figure 4: Vetiver in 5 ppm, 10 ppm, 30 ppm and 70 ppm Cr(VI) solution

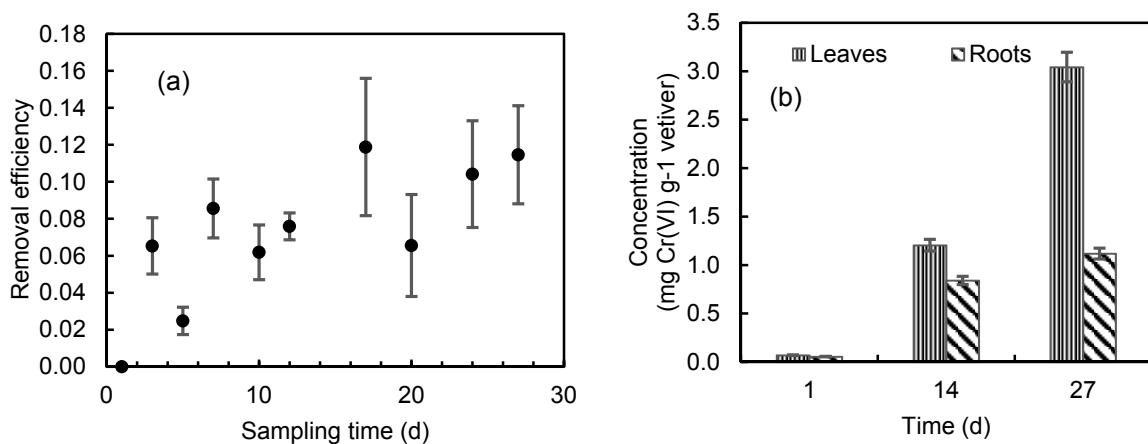


Figure 5: (a) The removal efficiency of Cr(VI) in the 30 ppm solutions, (b) The concentration of Cr(VI) in the root and leaves of vetiver.

After 27 d of exposure of the plants in the 70 ppm bucket, a concentration of 3.04 mg Cr(VI) g⁻¹ vetiver was obtained in vetiver leaves. However, the concentration in the roots did not increase significantly past

1.00 mg Cr(VI) g⁻¹ vetiver, which is the same as that obtained at 30 ppm. It is clear that at higher Cr(VI) concentrations, more Cr(VI) is translocated to the leaves. This might be the cause of the drying out of the leaves.

Figure 6 shows a correlation between the uptake amount from the Cr(VI) solution and the concentration found in the leaves and the roots at 27 d. It is noticed that the amount of Cr(VI) removed from solution increased with the increase in the initial concentration. Also, a saturation phenomenon is noticed in the roots at 1 mg Cr(VI) g⁻¹. After saturation, more chromium is translocated to the leaves at higher initial Cr(VI) concentration. It can also be seen that at 5 ppm and 10 ppm the amount of Cr(VI) in the roots is higher than the amount in the leaves, and at 30 ppm and 70 ppm, the amount of Cr(VI) is higher in the leaves than in the roots.

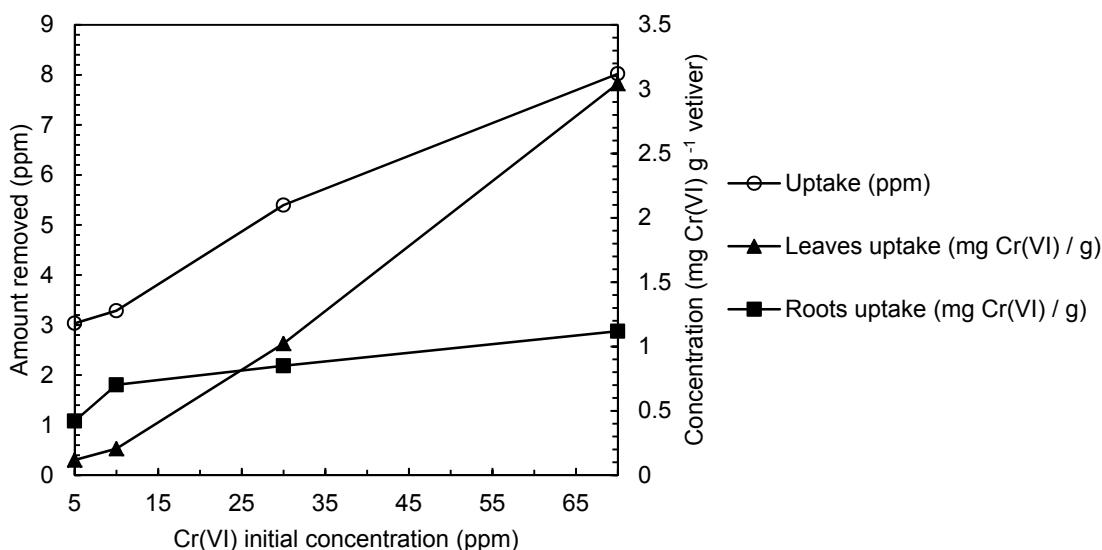


Figure 6: Uptake of Cr(VI) in plants and leaves after 27 d in 5 ppm, 10 ppm, 30 ppm and 70 ppm initial Cr(VI) concentrations

4. Conclusions

Chrysopogon zizanioides was found effective in removing and recovery of Cr(VI) from water. It has the ability to reduce Cr(VI) concentrations to lower than the recommended limits. The rate of removal depends on the concentration of the medium. Vetiver prove to be a good accumulator of heavy metals in phytoremediation due to its ability to accumulate heavy metals in its roots and translocation of the heavy metals to the shoots. Vetiver proves to be highly tolerant at concentrations below 30 ppm and less tolerant at concentrations above 30 ppm.

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