Research Article

Cadmium removal from aqueous solutions using Macaranga peltata: a potential plant for phytoremediation

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Received 11 June 2015; Revised 21 September 2015; Accepted 27 September 2015; Published 2 January 2016

Abstract

The concentration of heavy metals in the environment is increasing at an alarming rate due to the high rate of industrialisation and intensive agricultural practices over the past few decades. Since most of the heavy metals are persistent and toxic in nature, they significantly reduce agricultural productivity and pose severe threat to human beings through food chain contamination. In recent years, phytoremediation has gained considerable attention as a solar driven green technology for the removal of heavy metals. In the present study we examined the Cadmium (Cd) removal potential of Macaranga peltata – one of the woody species emerging in early successions - found very common in Kerala. The experiment was conducted in batch mode for a period of 20 days in three different concentrations of Cd (0.5, 1.5, and 2.5 mg/L) in two different mediums (distilled water and 10% Hoagland nutrient solution). The percentage removals of Cd by M. peltata from three treatments in distilled water were 98, 93 and 89% respectively, where as in the case of Hoagland nutrient medium it was 90, 89 and 82% respectively. The results show higher removal efficiency in distilled water as compared to Hoagland nutrient medium. The analysis of the plants revealed that most of the Cd was accumulated in the roots followed by stem and leaf. Cd accumulation also affected the chlorophyll content of the plant at higher concentrations. The study shows that M. peltata is a promising plant for the phytoremediation of Cd. Since most of the earlier studies on phytoremediation were carried out using smaller plants with less biomass production and growth rate, the use of M. peltata – one of the fastest growing tree species in the present study receives special attention.

Keywords: Phytoremediation, Rhizofiltration, Wastewater treatment, Heavy metals, Cadmium
1. Introduction

The rapid industrialization in developing countries with an enormous and increasing demand for heavy metals has resulted into high anthropogenic emission of these pollutants into the environment (Bindu et al., 2010). Since heavy metals are non-degradable, the contamination of water bodies and soil by these metals causes a serious environmental problem, threatening human health, crop productivity and biodiversity. Among the heavy metals Cadmium is one of the most toxic metal along with mercury and arsenic. The natural sources of Cd include volcanic activity, ocean sprays and forest fires. The anthropogenic activities such as mining, smelting, coal combustion, refineries, iron and steel industries, disposal of industrial effluents and sewage sludge as well as application of phosphate fertilizers contribute significant quantities of cadmium into the environment. The industrial uses of cadmium are widespread and increasing in electroplating, paint pigments, plastics, alloy preparation, mining, ceramics and silver-cadmium batteries (Voletsy 1990). Toxicity of Cd may result from its binding to sulhydryl groups of proteins leading to inhibition of activity or disruption of structure, disturbance of cellular redox control (Schutzendubel et al., 2002), and/or inducing the production of reactive oxygen species (Romero-Puertas et al., 2004).

The removal of heavy metals from the environment to protect people and other living organisms deserves top priority. The conventional methods that are being used to remove heavy metal ions from wastewater include chemical precipitation, ion-exchange, membrane filtration, electro-chemical treatment, and adsorption. However, technologies for the removal of heavy metals from the soil are limited to soil washing, soil leaching, excavation and dumping in landfills etc. All these techniques face serious limitations such as high cost and intensive labour apart from the destruction of soil quality and soil microflora (Ali et al., 2013). In this context low cost, environmental friendly and sustainable technologies like phytoremediation are more preferred over the other technologies in developing countries.

Green plants play a positive role in the removal of pollutants from the environment and accomplish their detoxification by various mechanisms (Bindu et al., 2008; Arunbabu et al., 2015). The concept of phytoremediation (as phytoextraction) was suggested by Chaney (1983). It is a novel, cost-effective, efficient, environment - and eco-friendly, in situ applicable, aesthetically pleasing and solar-driven remediation method. It takes advantage of the plants and their associated rhizospheric microorganism’s natural abilities to take up, accumulate, stabilize and/or degrade contaminants from the environment (Abbasi and Ramasamy 1999; Singh et al., 2003; Bindu et al., 2008).

Despite many years of research and experiments, the application of phytoremediation for the removal of heavy metals is still in its infancy. The commercialization of this technology depends upon the selection of suitable plant species to treat the heavy metals. Most of the earlier studies on phytoremediation were carried out using smaller plants with less biomass production and growth rate, which limits its application at the field scale. Hence the present investigation was carried out with the objective to study the ability of M. peltata - one of the early successional woody species found very common in Kerala, India in removing Cd from wastewater.

2. Materials and methods

Saplings of *Macaranga peltata* (Roxb.) Müll.Arg. have been used as the bioagent in the present study. The plant belongs to the genus *Macaranga* and family *Euphorbiaceae*. The plants of uniform size and weight (15 cm height, 5 leaves and 2.0 g fresh weight) were collected from the campus of Mahatma Gandhi University, Kottayam, Kerala. Special attention was given to collect plants without damaging the roots. The plants were washed thoroughly in running tap water to remove any soil/clay particles, and then with distilled water. The plants were then transferred to 75 mL test tubes containing 50 mL of
10% Hoagland nutrient solution and allowed to acclimatize for one week in the laboratory. After acclimatization the plants were transferred to the experimental setup. The experiment was conducted with three different concentrations of Cd (0.5, 1.5 and 2.5 mg/L) in two different growth mediums (Hoagland nutrient solution and distilled water). A set of plants were also run as control without the addition of Cd and another set was run as control without plants. The entire experiment was conducted in the laboratory at room temperature under illumination provided by fluorescents lamps with a light to dark (LD) cycle of 14:10 h (Ignatius et al., 2014, Bindu et al., 2010). Samples of wastewater were collected on 5th, 10th, 15th, and 20th days of the experiment from all the treatments and analyzed for Cd. The plants were harvested at the end of the experiment and changes in biomass and chlorophyll content were determined. The Cd concentration in the root, stem and leaf of each plant was also determined after drying and microwave digestion. The plant samples were digested with a solution of 3:1 HNO₃-HClO₄ (v/v) in a microwave digester (MARS Xpress, CEM corporation, USA). The digested solution was made up to 25 mL in a volumetric flask with distilled water. The concentration of Cd in the samples was determined by Anodic Stripping Voltammetric method using hanging mercury drop electrode of voltammetric trace metal analyzer (797 VA Computrace, Metrohm, Switzerland). From the results of the Cd content in the plant parts, the Bioconcentration Factor (BCF) and Translocation Factor (TF) were computed as follows.

\[
\text{BCF (solution – root)} = \frac{\text{Cd in the root (µg/g)}}{\text{Cd in the solution (µg/L)}}
\]

\[
\text{TF (root - stem)} = \frac{\text{Cd in the stem (µg/g)}}{\text{Cd in the root (µg/g)}}
\]

\[
\text{TF (root - leaf)} = \frac{\text{Cd in the leaf (µg/g)}}{\text{Cd in the root (µg/g)}}
\]

3. Results and discussion

3.1. Percentage removal of Cd

The reduction in Cd concentration from the wastewater during the batch experiment in Hoagland medium and distilled water was monitored during 5th, 10th, 15th and 20th day of the experiment and the percentage removal of Cd was calculated (Fig. 1). The percentage removal of Cd from 0.5, 1.5 and 2.5 mg/L of Cd in Hoagland medium at the end of the experiment was 91, 89 and 82 % respectively and for distilled water it was 98, 94 and 90% respectively. From the experiment it was observed that the Cd removal was higher in the distilled water treatment as compared to the Hoagland medium in all the concentrations studied. It was also observed that a major portion of the Cd removal takes place within 5 days of the experiment in all the treatments (Fig. 1). After the 5th day, Cd removal was observed to be increasing slowly towards the end of the experiment.
Ignatius et al. (2014) also reported very high removal of lead from the solution during the first few days of the hydroponic experiment with *Plectranthus amboinicus*. Dushenkov et al. (1995) reported that the root of the plants has an intrinsic ability to absorb and precipitate heavy metals from solutions which can exceed even 10% of the root dry weight. They also reported that plant roots utilize several mechanisms for the removal of heavy metals such as absorption, intracellular uptake and translocation. Since the Hoagland medium is a balanced nutrient solution for the growth of plants, it contains lots of ions which compete with Cd and that could be the possible reason for the low removal of Cd in Hoagland medium as compared to the distilled water.

3.2. Metal Accumulation by the plant

The accumulation of Cd by the root, stem and leaf of the plant at the end of the experiment was analysed and the results are presented in Fig. 2. The root accumulated highest concentration of Cd followed by stem and leaf in all the treatments. At 0.5 mg/L Cd treatment, the root accumulated 365.85 mg/kg Cd in Hoagland medium and 390.24 mg/kg Cd in distilled water, whereas at 2.5 mg/L Cd treatment it increased to 2073.17 and 2268.29 mg/kg respectively. The concentration of Cd in the plant increases with increasing Cd in the solution. The accumulation was slightly higher in the treatments with distilled water as compared to the Hoagland medium (Fig. 2). Di Toppi and Gabbrissi (1999) reviewed the response of Cd to higher plants and suggest that the ability of higher plants to take up Cd depends on the concentration and bioavailability of Cd and other elements. It was reported that the uptake of Cd ions is in competition for the same transmembrane carrier with nutrients, such as potassium, calcium, magnesium, iron, manganese, copper, zinc and nickel (Clarkson and Luttge, 1989; Rivetta et al., 1997).
3.3. Bioconcentration Factor (BCF) and translocation Factor (TF)

Bioconcentration factor (BCF) is defined as the ratio of metal concentration in the plant to the initial concentration of metal in the feed solution. The translocation of metals from the roots to aerial parts of the plants is generally expressed as the translocation factor (TF). It indicates the efficiency of the plant in translocating the accumulated metal from its roots to aerial parts. The BCF and TF values obtained for the present study are given in Table 1. The results indicate that the BCF and TF values were less than one in all the treatments. Therefore the plant cannot be considered as a hyperaccumulator of Cd.

Table 1. Bioconcentration factor and translocation factor.

<table>
<thead>
<tr>
<th>Cd conc.</th>
<th>BCF (medium-root)</th>
<th>TF (root-stem)</th>
<th>TF (root-leaf)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Hoagland solution</td>
<td>Distilled water</td>
<td>Hoagland solution</td>
</tr>
<tr>
<td>0.5</td>
<td>0.732</td>
<td>0.780</td>
<td>0.141</td>
</tr>
<tr>
<td>1.5</td>
<td>0.862</td>
<td>0.894</td>
<td>0.067</td>
</tr>
<tr>
<td>2.5</td>
<td>0.829</td>
<td>0.907</td>
<td>0.050</td>
</tr>
</tbody>
</table>

3.4. Changes in biomass and chlorophyll

The changes in chlorophyll and biomass of the plant during the experiment were also monitored. Growth changes are often the first and most obvious responses of plants under heavy metal stress. During the experiment, the biomass of the plants exposed to increasing concentration of Cd shows a decreasing trend, whereas in the control i.e., without Cd the biomass of the plant increased. The chlorophyll content of the plants also decreased at higher concentration of Cd (Fig. 3). It was also observed that the plant shows partial wilting of leaf when exposed to higher concentration of Cd. Bindu et al. (2010) and Ignatius et al. (2014) also observed similar trend of decreasing biomass and chlorophyll content with increasing metal concentration in the solution. Hasan et al. (2007) reported that Cd has inhibitory effects on the growth of Eichhornia crassipes. Stratford et al. (1984) reported that Cd was toxic and caused substantial reduction in E. crassipes growth mainly suppressing development of new roots. However in another study by Phetsombat et al. (2006) it was found that Salvinia cuculla remained healthy at 2 mg/L of Cd exposure.
4. Conclusion

Heavy metal pollution of aqueous and terrestrial environment is a major environmental problem facing the world today. Among the different technologies available for the removal of heavy metals, phytoremediation has definite advantages such as low cost, environmental friendly and high public acceptance. However for the commercialization of this technology, the know-how about the response of plants to heavy metals has to be expanded. Hence the present study investigated the efficiency of the plant Macaranga peltata (Roxb.) Müll.Arg. in removing cadmium from wastewater. The experiment was conducted in two different mediums such as Hoagland nutrient medium and distilled water. The plants showed good removal of Cd from all the treatments. When comparing the performance of plants in Hoagland solution and distilled water, the Cd removal was high in distilled water. But the health of the plant was good in Hoagland medium. The overall results of the study shows that the plant can be used as an efficient bioagent for the treatment of low level Cd contaminated wastewater.

Conflict of interest statement

We declare that we have no conflict of interest.

Acknowledgement

Support from the Department of Science and Technology (DST), Government of India through the DST INSPIRE fellowship to Mr. Arun Babu V has been gratefully acknowledged. The authors also thank DST FIST and DST – PURSE programmes (Govt. of India) for the supports.

References


