Phytoremediation Using Ornamental Plants in Removing Heavy Metals from Wastewater Sludge

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Abstract. Phytoremediation is a low cost and effective soil treatment option for metal reclamation compared to the conventional method which are very expensive and can cause disturbance to the soil. This research examined the ability of ornamental plants namely, hibiscus (*Hibiscus Rosa-Sinensis*) and rose (*Rosa sp.*) to absorb heavy metals in the wastewater sludge. The objectives of this study were to determine the optimum heavy metals uptake from wastewater sludge using ornamental plants and to determine the overall distribution of heavy metals in the plant parts. The sludge was taken from Mawar wastewater treatment plant that is located at UiTM Shah Alam and treatment was conducted for a period of 30 days. Plants were exposed to the various percentage of sludge amendments in soil (0% - control, 10% - treatment A, 25% - treatment B, 50% - treatment C, 75% - treatment D and 100% - treatment E) for 30 days. The concentration of Fe, Mn, Zn and Cu were measured in each part of plants (roots, stems, leaves). Highest heavy metals removal was in the order of Fe>Mn>Zn>Cu with the treatment of 100% sludge. Root contained the highest concentration of heavy metals in the plant parts. While in comparison between the plants, rose removed more heavy metals as compared to the hibiscus plant.

Keywords: Phytoremediation, ornamental plants, municipal, sewage sludge, heavy metals

1. Introduction

Municipal sludge is a semi-solid by product produced during the wastewater treatment and consists primarily of a mixture of non-toxic organic compounds (organic matter), inorganic compounds, toxic metals, and persistent organic pollutants (POPs), such as polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), and phthalic acid esters (PAEs) [1], [2], [3]. Although several options for the sludge management does currently exist that includes for example anaerobic digestion, composting and incineration in combination with energy recovery [4], in most cases, the sludge management from the treatment plants is proves to be more expensive than liquid treatment [5].

One feasible option is to use the sludge as a soil conditioner due to its high concentration of organic matter [6]. However, concerns pertaining to the heavy metals in the sludge and its removal needs to be considered. Thus, the use of a green approach like phytoremediation to remediate the heavy metals in the sludge could be used as a valuable tool to improve the sludge quality with a more economical and
environmentally friendly approach [7]. Several approaches to sewage sludge phytoremediation have been attempted in recent years. The most common green remediation approach is the application of sewage sludge in extracting or stabilizing the metals using ornamental [8] and bioenergy crops [9], [10]. Although the application of sewage sludge in agriculture can improve soil fertility, these approaches always require a certain amount of “dilution” of the sludge with another substrate (e.g. soil). Only a few tests exist in the literature where phytoremediation was evaluated directly on the local Malaysian ornamental plants like the hibiscus (Hibiscus rosa sinensis) and the rose (Rosa sp.) plants using the municipal sewage sludge. Thus, the objectives of this study were to determine the overall distribution of heavy metals in the plant parts and to determine the optimum heavy metals uptake from wastewater sludge using ornamental plants.

2. Experimental Works

To evaluate the effect of the ornamental plants, namely, hibiscus (Hibiscus Rosa-Sinensis) and rose (Rosa sp.), in the removal of heavy metals from wastewater sludge, experimental pots were conducted for a duration of 30 days. Experimental analysis and laboratory work were done in the Faculty of Applied Science, Universiti Teknologi MARA (UiTM) Shah Alam. Wastewater sludge used was obtained from the Mawar Wastewater Treatment Plant, Universiti Teknologi MARA (UiTM) Shah Alam. A total of 24 seedlings for each hibiscus and rose plants of approximately same size with a ± 5 cm was planted in a plastic pot with the diameter of 15 cm for each pot. These samples were divided and labelled according to six different treatments with four replicates: A - Control (100 % soil), B (75 % soil + 25 % sewage sludge), C (50 % soil + 50 % sewage sludge), D (25 % soil + 75 % sewage sludge), E (10 % soil + 90 % sewage sludge) and F (100 % sewage sludge).

Plant analysis was done using rapid wet digestion. While all soil sludge samples were sieved with 2mm sieve and digested using wet digestion method in accordance with the standard methods for examination of water and wastewater [11]. Then, heavy metals analysis was done using Inductive Coupled Plasma-Optical Emission Spectroscopy (ICP-OES) [12].

The percent of removal efficiency of each heavy metal was calculated as follows:

\[
\text{Removal Efficiency} (%) = \left(1 - \frac{C_f}{C_i}\right) \times 100
\]

Where \(C_i\) is the initial concentration of heavy metal (mg/Kg) and \(C_f\) is the final concentration of heavy metal (mg/Kg).

3.0 Results and Discussion

The concentration of heavy metals in the plant parts which were planted with the wastewater sludge after the experimental period (30 days) is shown in Table 1. For copper (Cu), the minimum concentration, 0.02 mg/Kg was found in the stem of hibiscus under the control condition and the maximum concentration, 9.50 mg/Kg was found in the roots of rose under the 100% sludge condition. Also, zinc (Zn) recorded minimum concentration of 0.12 mg/Kg in the stem of hibiscus under the control condition and 50% soil sludge condition. While the highest concentration of Mn, 116.10 mg/Kg was found in the roots of rose plant under 100% sludge condition. Iron (Fe) was found at its minimum concentration, 0.36 mg/Kg in the hibiscus leaf under the 10% soil sludge mixture, while the maximum concentration, 218.50 mg/Kg was found in the roots of rose plant under 100% soil sludge mixture.
Results indicated significant inter-cultivar variation with respect to anatomical attributes like the alterations in root, stem, and leaf ([13], [14]). Plant’s interior can be considerably influenced by environmental variations. The anatomical alterations can be used to assess plant tolerance and survival to environmental stresses [15]. Hence the response among species varies in terms of the metal uptakes and translocation to the aboveground plant tissues. For instance, due to the thicker anatomy of the hibiscus plant the metal uptake were lesser as compared to the rose plant [16].

Table 1 Concentration of heavy metals in plant parts after experimental period

| Type of plants | Percent of wastewater sludge |
|---------------|-----------------------------|
|               | Control | 10% | 25% | 50% | 75% | 100% |
|               | Leaf | Stem | Root | Leaf | Stem | Root | Leaf | Stem | Root | Leaf | Stem | Root | Leaf | Stem | Root |
| **Cu (mg/Kg)** |       |     |      |     |     |      |     |     |      |     |     |      |     |     |      |
| Rose          | 2.50  | 1.40| 12.70| 2.40| 7.40| 3.30  | 2.60| 9.10| 8.90  | 2.70| 1.00| 7.40  | 2.10| 1.00| 4.40  |
| Hibiscus      | 0.06  | 0.02| 0.05 | 0.04| 0.07| 0.04  | 0.06| 0.05| 0.06  | 0.07| 0.05| 0.07  | 0.07| 0.05| 0.07  |
| **Zn (mg/Kg)** |       |     |      |     |     |      |     |     |      |     |     |      |     |     |      |
| Rose          | 65.60 | 42.20| 109.80| 31.90| 4.40| 47.50 | 42.10| 120.80| 83.50| 37.70| 46.40 | 84.00| 64.10| 55.80| 46.00 |
| Hibiscus      | 0.25  | 0.12| 0.18 | 0.25| 0.23| 0.40  | 0.23| 0.16| 0.40  | 0.07| 0.07| 0.07  | 0.07| 0.05| 0.07  |
| **Mn (mg/Kg)** |       |     |      |     |     |      |     |     |      |     |     |      |     |     |      |
| Rose          | 7.50  | 16.80| 98.40 | 8.20 | 7.40| 10.00 | 8.90 | 70.20 | 85.20| 13.40| 7.20  | 85.80| 25.60| 7.90  | 20.00 |
| Hibiscus      | 0.32  | 0.10| 0.16 | 0.22| 0.23| 1.00  | 0.18| 0.24| 0.59  | 0.13| 0.11| 0.14  | 0.11| 0.09| 0.13  |
| **Fe (mg/Kg)** |       |     |      |     |     |      |     |     |      |     |     |      |     |     |      |
| Rose          | 4.80  | 45.20| 58.40 | 5.20| 5.23| 101.00| 4.90| 12.87| 126.60| 9.60| 6.50| 163.70| 14.80| 14.00| 66.70 |
| Hibiscus      | 0.46  | 2.93| 6.08 | 3.08| 3.03| 10.10 | 0.39| 3.27| 12.87 | 3.50| 3.50| 3.27  | 3.50| 3.50| 3.27  |

Figure 1 and Figure 2 show the plant removal efficiency of heavy metals after the treatment of 30 days. In agreement to the results from Table 1, rose plant removes more heavy metals as compared to the hibiscus plant. Details on the metal removal efficiency are as follows.
In Figure 1, for Cu removal, rose plant recorded highest percentage removal efficiency, 47.31%, at treatment E (100% sludge), while the lowest removal efficiency, 1.43% at treatment A (10% soil sludge). Hibiscus recorded the highest percentage removal, 13.61%, at treatment E (100% sludge) and lowest percentage removal, 1.32%, at treatment B (25% soil sludge).

While, for Zn removal, rose plant recorded highest percentage removal efficiency, 54.85%, at treatment E (100% sludge), while the lowest removal efficiency, 12.09% at treatment A (10% soil sludge). Hibiscus recorded the highest percentage removal, 28.24%, at treatment E (100% sludge) and lowest percentage removal, 4.05%, at treatment B (25% soil sludge).

In Figure 2, for Mn removal, rose plant recorded highest percentage removal efficiency, 67.45%, at treatment E (100% sludge), while the lowest removal efficiency, 9.98% at treatment A (10% soil sludge). Hibiscus recorded the highest percentage removal, 18.51%, at treatment E (100% sludge) and lowest percentage removal, 11.33%, at treatment C (50% soil sludge).

While, for Fe removal, rose plant recorded highest percentage removal efficiency, 85.16%, at treatment E (100% sludge), while the lowest removal efficiency, 32.90% at treatment A (10% soil sludge). Hibiscus recorded the highest percentage removal, 24.07%, at treatment E (100% sludge) and lowest percentage removal, 12.37%, at treatment B (25% soil sludge).
**Conclusion**

In this study and from the obtained results, it can be concluded that highest heavy metals removal was in the order of Fe>Mn>Zn>Cu with the treatment E (100% sludge). Root contains the highest concentration of heavy metals in the plant parts. While in the removal of heavy metals from the wastewater sludge amongst ornamental plants, rose plant can remove more heavy metals as compared to the hibiscus plant.

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