Scientia Africana, Vol. 15 (No. 2), December 2016. Pp 148-159
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PHYTOEXTRACTION TRIALS OF CADMIUM AND LEAD CONTAMINATED SOIL USING THREE WEED SPECIES

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Received: 22-08-16
Accepted:12-10-16

ABSTRACT

Study on the phytoextraction of cadmium (Cd) and lead (Pb) artificially contaminated soil using 3 weed species (Ageratum conyzoides, Syndrella nodiflora and Cleome rutidosperma) was carried out at the Centre for Ecological Studies, University of Port Harcourt. A Randomized Complete Block Design consisting of 2 sets of contamination treatments designated as Cd(T) and Pb(T) with 3 phytoextraction applications for each set. Cd(T) and Pb(T) were contaminated with 100 mg of Cd and Pb in 4 kg soil respectively. There was also a control with pollution but no phytoextraction application for each set. After 13 weeks of phytoextraction trials, results showed percentage reductions in soil Cd in Ageratum conyzoides (35.8%), Syndrella nodiflora (45.1%) and Cleome rutidosperma (55.3%); and Pb was Ageratum conyzoides (68.7%), Syndrella nodiflora (27.3%) and Cleome rutidosperma (24.8%). The plant concentration factor (PCF) for Cd was Ageratum conyzoides (0.39), Syndrella nodiflora (0.73) and Cleome rutidosperma (1.15) and; Pb was Ageratum conyzoides (1.96), Syndrella nodiflora (0.32) and Cleome rutidosperma (0.31). The mobilization ratio for Cd was Ageratum conyzoides (0.91), Syndrella nodiflora (0.88) and Cleome rutidosperma (0.90) and; Pb was Ageratum conyzoides (1.06), Syndrella nodiflora (0.77) and Cleome rutidosperma (0.57). Therefore, Cleome rutidosperma and Ageratum conyzoides are good phytoextraction plants for Cd and Pb respectively. Also Ageratum conyzoides can be regarded as accumulator for Pb with mobilization ratio > 1 while Cleome rutidosperma and Syndrella nodiflora are Cd and Pb excluder plants.

Key words: weed species, contamination, heavy metals, phytoextraction, *Ageratum conyzoides*, soil.

INTRODUCTION

The rise in industrialization and consumption of industrial-processed products has led to increase contamination of the environment with toxic substances such as heavy metals. McGrath *et al*. (2001) reported that heavy metals affected over 1,400,000 sites in Europe. Heavy metal pollution can be defined as the introduction of heavy metals into the environment in quantities that causes alteration in the physical, chemical and biological systems of the environment with detrimental effects on microorganisms, plants, animals and man.

Heavy metals are not totally biologically insignificant as most of them are needed for normal biological functioning as micro-nutrients; but when the quantities exceeded the normal requirement, they become pollutants. Beyersmann and Hartwig, (2008) observed that the dose and mode of exposure, oxidation state and complex form may make some metals that are indispensable to plant to be toxic. The most important characteristic of heavy metals as pollutants is that they cannot undergo biodegradation and persist in the environment for many years but can also bioaccumulate and biomagnify in living organisms. Heavy metals get into the environment through human activities such as mining, refining; electroplating, municipal wastes and burning (knox *et al.*, 1999; Gisbert *et al*., 2003; Liu *et al*., 2005).

Cadmium (Cd) and lead (Pb) are heavy metals with no known biological importance. Cd as a non-redox metal is highly phytotoxic. It induces lipid profile changes (Quariti, 1997). It also affects an enzyme (H^+-ATPase) associated with membranes (Fodor *et al*., 1995); and photosynthesis (Siedlecka and Baszynsky, 1993). Pb contamination exists in an insoluble form in the upper surface of the soil and it is highly immobile and subsequently absorbed by plants and animals via food chain. Sources of Pb contamination include paints, municipal sewage, and burning of leaded gasoline (Gisbert *et al*. 2003)

Following the ecological consequences associated with heavy metals pollution, remediation of contaminated environment becomes inevitable. Since natural attenuation may not be applicable due to non biodegradability of these heavy metals; phytoremediation has emerged as a viable alternative for the removal of these contaminants from soil or water. Phytoremediation is the use of higher plants for the *in-situ* removal/reduction of contaminants from soil or water. This technology is based on the premise that plants possess the ability to degrade, contain or transfer contaminants (Cunningham *et al*., 1996) thus, making the contaminated environment less toxic or free from the contaminants. Phytoextraction (a form of phytoremediation) is a containment approach adopted by plants to remove contaminants (mostly metals) from the soil or water and accumulate them in their above-ground biomass. These plants demonstrate high level of tolerance without showing metal toxicity syndrome (Cardwell *et al*., 2002). Certain factors such as soil conditions, plant species and the heavy metal type may affect the accumulation of metals by plants (Barman *et al*. 2001; Spinoza-Quinones *et al*., 2005). More than 500 species of plants have been proven with demonstrated ability to hyperaccumulate heavy metals (Kramer, 2010). On the other hand, some plants reduce the heavy metal content in the soil and maintain the metal content (concentration) in the shoot at low level irrespective of the external concentration of the metal. These set of plants are called metal excluder plants. *Polyalthia longifolia* has been identified as a typical Pb excluder plant (Tanee and Amadi, 2016).

Despite advances made in this technology (phytoremediation) in the developed world, little is been done in developing countries like Nigeria where pollution problem is on the increase. Secondly, many breakthroughs in the field of phytoremediation has been associated with the use of foreign plant species but not much work has been done in Nigeria especially in the Niger delta using the indigenous plant species despite the rich biodiversity, hence the thrust of this study.

Ageratum conyzoides, L (commonly called goat weed), *Syndrella nodiflora* (L) Gartn (common name: Nodeweed) and *Cleome rutidosperma*, DC (common name: spider plant or purple cleome) are herbaceous weeds commonly found on agricultural areas, roadsides and planted forests. The use of these plants in this study will provide a clue on good uses of these plants because of their abundance. It will also widen our scope of plants that can be used in phytoremediation (phytoextraction) of heavy metal contaminated soil.

MATERIALS AND METHODS

Experimental site

The study was undertaken at the experimental field at the Centre for Ecological Studies, University of Port Harcourt located within the tropical rain forest belt of Nigeria on Latitude 4^o 65` N and Longitude 7$^o$ 5` E. The area experiences two distinct seasons (dry and rainy). The area is also noted for high temperature and high relative humidity, which are characteristics of the equatorial region. The experiment was set up under transparent shade to allow light penetration but prevent direct rainfall into the set-ups.

Sources of materials and preparation

Loamy soil was collected at a depth of 0 – 10 cm (surface soil) from a fallow land beside Department of Gas Engineering, University of Port Harcourt. The soil was collected in bulk, homogenized properly and taken to the experimental site for bagging. The bags used were obtained from Agricultural Development Programme (ADP), Rumudomaya, Port Harcourt. The bags were not perforated so as to prevent leaching of the contaminants from the bags. 4 kg of soil was weighed into each bag.

The heavy metals used were obtained in their salt form from Bernaco Enterprises Nig. Ltd. Port Harcourt. $CdSO_4$. $8/3H_2O$ and $Pb(NO_3)_2$ were used to obtained Cd and Pb respectively. 10 g of each metal salt solution was dissolved in 1 litre of distilled water to obtain 6.256 g/l and 4.4394 g/l for Pb and Cd respectively as its equivalent of 100 mg concentration.

The 3 weed species used for the phytoextraction were *Ageratum conyzoides*,L. *Syndrella nodiflora*; (L) Gaertn. and *Cleome rutidosperma*, DC. Young seedlings of these weed species were collected from the vicinity of the Centre for Ecological Studies. They were raised in nursery for two weeks before transplanting into the experimental pots (bags). Seedlings of equal size, vigour and age were used to ensure similar conditions.

Experimental design

The Randomized Complete Block Design (RCBD) was used for the experiment. This consist of 2 sets (blocks) designated as Cd(T) and Pb(T). Each set comprises 20 bags (plots). Each bag of Cd(T) was contaminated with 100 mg of Cd while each bag in Pb(T) set was contaminated with 100 mg of Pb. The set-up was allowed to stand for one week. After the one week, each of Cd(T) and Pb(T) was separated into 4 groups of 5 replicates designated as Cd (T_1, T_2, T_3, T_4) and Pb (T_a, T_b, T_c, T_d). Three (3) seedlings each of *Ageratum conyzoides* L, *Syndrella nodiflora*, (L) Gaertn. and *Cleome rutidosperma*, DC were transplanted into T_1 and T_a; T_2 and T_b; T_3 and T_c respectively. T_4 and T_d received no planting (control). The experiment was monitored for 13 weeks. Watering was done three times a week with 300 ml of distilled water per plot. The experimental plots were devoid of weeds by handpicking any visible weeds.

Sample Analysis

Soil samples were collected after contamination but before transplanting of the weeds and at the end of the experiment (13 week after planting). Soil sample from each treatment/bag was collected and taken to the Laboratory for determination of heavy metals (Cd and Pb) concentration. The phytoextraction plants were carefully harvested from the soil without damaging the roots. The shoot of each plant was separated from the root by cutting and were taken to the Laboratory for Cd and Pb contents analyses.

Cd and Pb in the samples (Soil and plants) were determined by Atomic Absorption Spectrophometry (varian spectral AA-250 plus) after digestion on an electrothermal plate for 15 minutes using perchloric and nitric acids.

Plant concentration factor (PCF) also known as Transfer factor and; Mobilization ratio (MR) or translocation factor were also calculated according to the methods of Augustynowicz *et al*. (2014) and Ye *et al*. (2014) respectively using the following formulae

$$\text{PCF} = \frac{concentration\ of\ metal\ in\ plant}{concentration\ of\ metal\ in\ soil}$$

$$\text{MR} = \frac{concentration\ of\ metal\ in\ shoot}{concentration\ of\ metal\ in\ root}$$

Statistical Analysis

Mean and standard error mean (SEM) were calculated from the data obtained. Analysis of variance and Least Significance Difference (LSD) were used to separate means using SPSS data analysis version 20.

RESULTS

Results showed varying degree of heavy metal reduction in soil using the three plant species as phytoextraction species. There was also variation in the accumulation of the heavy metals by the three plant species.

Significant (p=0.05) reduction in soil Cd was observed in phytoextracted with the 3 species as compared with the control. That is, the control recorded the higher Cd content than the remediated soil (Fig. 1). Highest soil Cd reduction (53.30%) was observed in *Cleome* sp phytoextracted soil followed by *Syndrella nodiflora* (45.12%) while *Ageratum conyzoides* recorded the least (35.83%).

In the Pb contaminated soil, significant reductions were also observed in the soil phytoextracted with the 3 weed species as compared with the control (no phytoextraction). Highest reduction was recorded at *Ageratum conyzoides* phytoextracted soil (68.73%) while there was no significant difference (p=0.05) between reductions in *Syndrella nodiflora* (27.29%) and *Cleome rutidosperma* (24.79%) remediated soils (Fig. 2).

Scientia Africana, Vol. 15 (No. 2), December 2016. Pp 148-159
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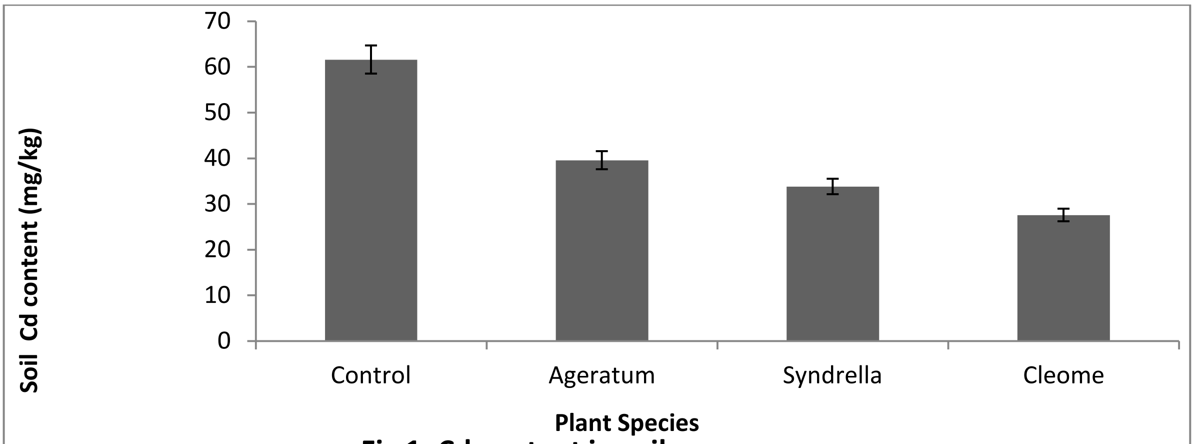

Fig 1: Cd content in soil

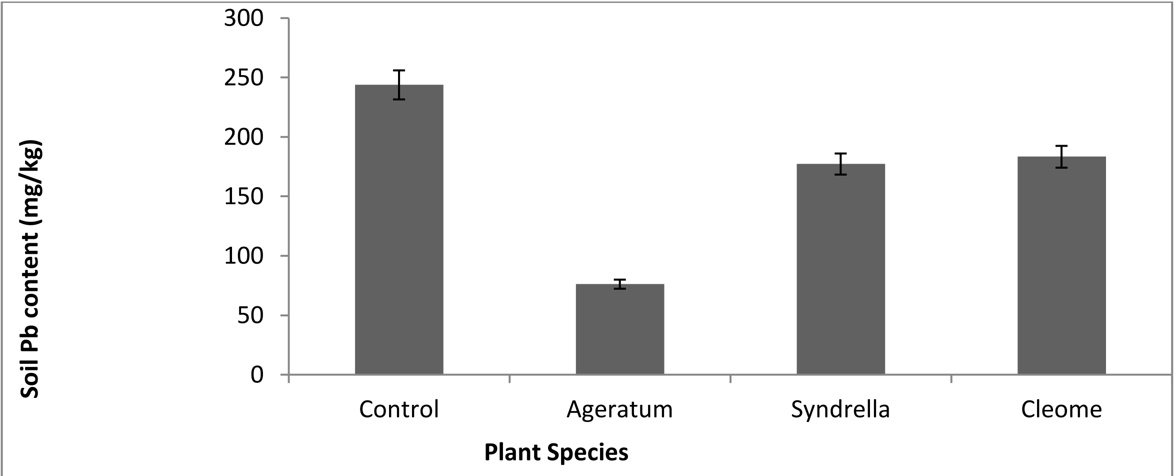

Fig 2: Pb content in soil

Fig. 3 shows the accumulation of Cd in the shoots of the three plants (*Ageratum conyzoides, Syndrella nodiflora* and *Cleome rutidosperma*) used in the phytoextraction trial. *Cleome rutidosperma* recorded the highest accumulation of Cd in the shoot as compared with the other 2 plants. The least accumulation was observed in *Ageratum conyzoides* (p=0.05). Also the accumulations of Pb in the shoots of the 3 phytoextracted plants were significantly different. *Ageratum conyzoides* accumulated the highest Pb in the shoot while *Syndrella nodiflora* recorded the least accumulation (Fig. 4).

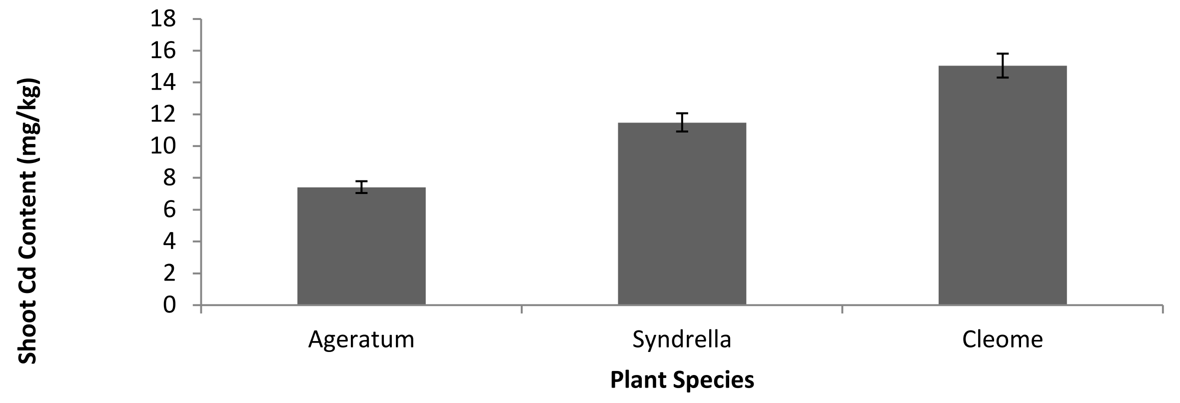

Fig.3: Cd content in Shoot

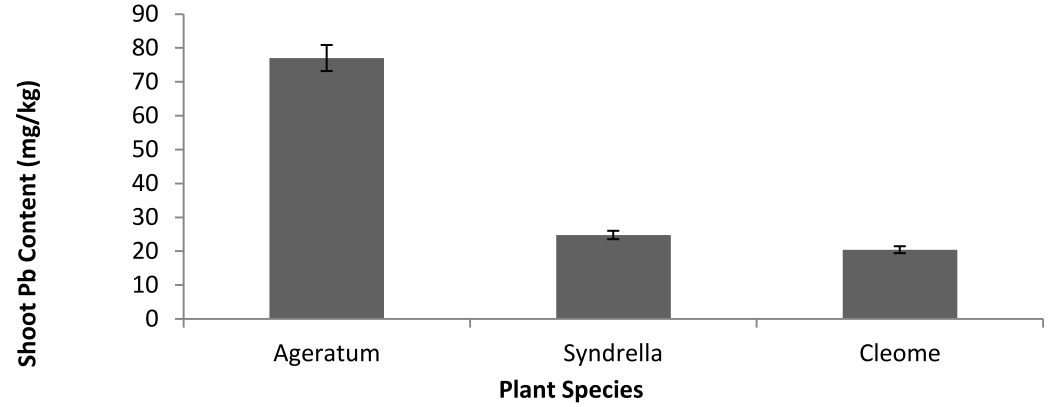

Fig 4: Pb content in shoot

The accumulations of the heavy metals (Cd and Pb) in the roots of the 3 phytoextraction plants are as shown in Fig. 5 and 6. Result showed that the root of *Cleome rutidosperma* absorbed and accumulated more Cd than the roots of *Ageratum conyzoides* and *Syndrella nodiflora*, while *Syndrella nodiflora* accumulated more than *Ageratum conyzoides* (Fig. 5). The concentration of Pb in the roots was highest in *Ageratum conyzoides* followed by *Syndrella nodiflora* and *Cleome rutidosperma*; but there was no significant (p=0.05) difference in the Pb concentration in roots between *Syndrella nodiflora* and *Cleome rutidosperma* (Fig. 6).

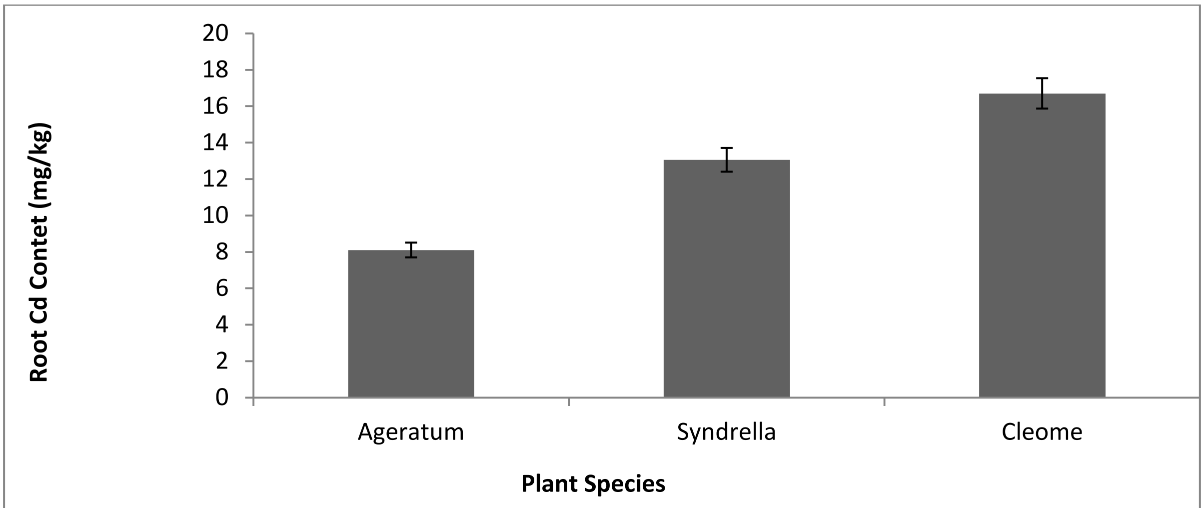

Fig 5: Cd content in Root

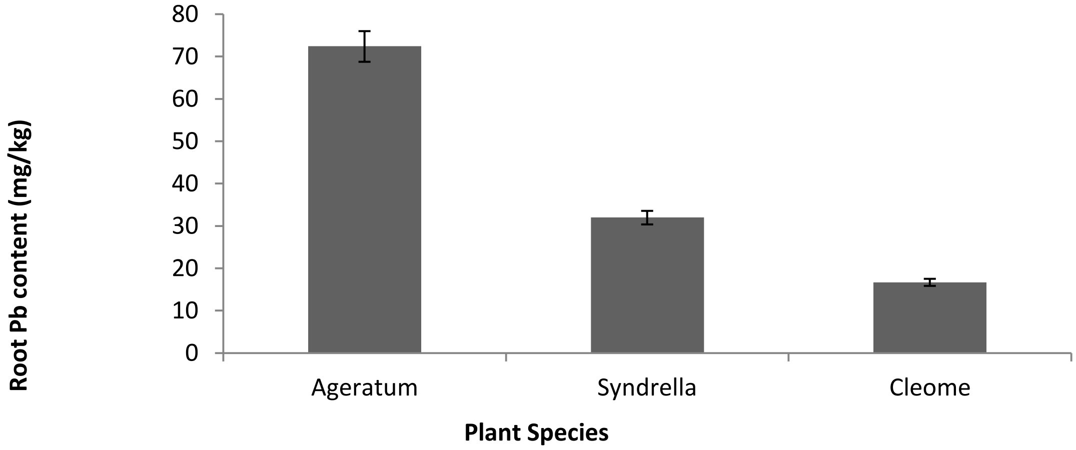

Fig 6: Pb content in root

The plant concentration factor (PCF) or Transfer factor of Cd contaminated soil for the 3 plants showed that *Ageratum conyzoides* and *Syndrella nodiflora* had PCF values of less than one (1) with the exception of *Cleome rutidosperma* which had PCF value greater than 1. In Pb contaminated soil, it was only *Ageratum conyzoides* that recorded a PCF value greater than 1 while the PCF of the other 2 plants were less than 1(Table 1).

Table 2 shows the Mobilization Ratio (MR) or Translocation Factor in the 3 phytoextraction plants for the two metals. Results showed that it is only *Ageratum conyzoides* that recorded a mobilization ratio of value greater than 1 in Pb contaminated soil. All other plants showed Mobilization ratio (MR) of less than 1 for the two heavy metals (Cd and Pb) polluted soil.

Table 1. Plant Concentration Factor (PCF) or Transfer factors of the three weed species

Weed species	**Plant Concentration Factor (PCF)**	
	Pb	**Cd**
Ageratum conyzoides	1.96	0.39
Cleome rutidosperma	0.31	1.15
Syndrella nodiflora	0.32	0.73

Table 2. Mobilization Ratio or Translocation factor of the three weed species

Weed species	**Mobilization Ratio (MR)**	
	Pb	**Cd**
Ageratum conyzoides	1.06	0.91
Cleome rutidosperma	0.57	0.90
Syndrella nodiflora	0.77	0.88

DISCUSSION

Plants have different mechanisms of tolerating and accumulating metals in their biomass leading to the concept of hyperaccumulators, accumulators and excluders. In hyperaccumulators, metals are accumulated in the above-ground parts (shoot and leaf) of the plant (0.01- 1%) of the dry weight (Kramer, 2010; van der Ent *et al*., 2013) while in excluders, the metal level of the shoot is kept at constant low level irrespective of the external concentration level of the metal. Briat and Lebrun (1999) identified three major principles that are involved in metal tolerance in plants. These are (1) regulating metal uptake by root of plants by preventing overload (2) creating a mechanisms for the maintenance of non toxic forms of metal at the intracellular level and (3) Detoxification of oxygen radicals by the production of antioxidant enzymes.

Results showed that the 3 weed species differ in their ability to absorb and accumulate Pb and Cd in their biomass and subsequent translocation into their above-ground parts. *Cleome* sp and *Ageratum* sp significantly reduced more than 50% of Cd and Pb respectively, from the contaminated soil while *Syndrella* sp had less than 50% reduction for the two metals. This is an indication of the plants preference for accumulation of different metals. In other words, a plant may effectively accumulate one metal but inefficient for another metal. The observed variation in their accumulation ability might be due to combination of factors such as plant species and plant traits; and other physicochemical, physiological and morphological mechanisms of metal retention in the plant tissues (Favas *et al*., 2016). This goes to show that the ability of the 3 plants to manipulate the rhizosphere for the acquisition of metals and other nutrients from the soil differs. Other factors such as pH, temperature, the cation exchange capacity (CEC), and organic matter content of the soil may also contribute to the differential absorption (Msaky and Calvet, 1990; Salim *et al*., 1993).

The absorption and subsequent accumulation of metals by the plants has been shown to be dependent upon the degree of metal contamination in the soil (Caldwell *et al*., 2012). The size and type of root system have also been observed as one of the causes of differential absorption of metals by plants (Prasad, 2007; Nakbanpote *et al*., 2016). For instance, plants with fibrous adventitious roots covered with numerous root hairs may create a high surface area for absorption than plant without such root characteristics (Nakbanpote *et al*., 2016). Thus, it may be deduced that the structure and architecture of root systems have important role to play in plant adaptation to water, nutrients and metals absorption/accumulation (Staňová *et al*., 2012).

Results showed differences in metal concentrations in the shoot and root of the 3 plant (weed) species. *Cleome* sp showed highest concentration of Cd and *Ageratum* sp showed highest concentration of Pb in both their roots and shoots. This showed that C*leome* sp and *Ageratum* sp possess Cd and Pb metals accumulating characteristics, respectively, than *Syndrella* sp suggesting the action of physiological barriers. Liao *et al*. (2000) observed that Xylem sap pH and redox potential can affect the types, amount and movement of metals ions in the xylem while Clemens *et al.* (2002) report that membrane transport proteins mediated this xylem loading process.

Excluder and accumulator plants can be empirically distinguished on the basis of the Plant concentration factor (PCF) (also known as Transfer factor or bioconcentration factor) Augustynowicz *et al*., 2014; Chen *et al*., 2015; Trotta *et al*., 2006; Zhuang *et al*., 2007), and of the translocation factor (TF) or Mobilization ratio (MR) (Rahman *et al*., 2014; Ye *et al*., 2014) Results showed that *Ageratum* sp had a Transfer factor of 1.96 and Translocation factor of 1.06 for Pb while the other plants (*Cleome* sp and *Syndrella* sp) had values < 1. Plant with PCF and Translocation factor > 1 can be regarded as accumulator while those < 1 can be called excluder plants (Macnair, 2003; Trotta *et al*., 2006). Hence, *Cleome rutidosperma* and *Syndrella nodiflora* can be classified as Cd and Pb excluder plants while *Ageratum conyzoides* can be regarded as Pb accumulator plant.

The results from the study have demonstrated the ability of the 3 tested weed species (*Cleome rutidosperma, Syndrella nodiflora* and *Ageratum conyzoides*) in their Pb and Cd accumulations. Significant reductions in both Cd and Pb were recorded in the contaminated soil as compared with the control (no phytoremediation). The reduction gradient was as follows: Cd: *Cleome rutidosperma* (55.3%) > *Syndrella nodiflora* (45.1%) > *Ageratum conyzoides* (35.8%) and; Pb was *Ageratum conyzoides* (68.7%) > *Syndrella nodiflora* (27.3%) > *Cleome rutidosperma* (24.8%). Thus, *Ageratum conyzoides* and *Cleome rutidosperma* were found to be effective phytoextraction plants especially in Pb and Cd polluted soil, respectively. On the basis of their PCF and MR, *Ageratum conyzoides* can be classified as accumulator plant while *Cleome rutidosperma* and *Syndrella nodiflora* as excluder plants.

REFERENCES

Augustynowicz, J., Tokarz, K., Baran, A. and Plachno, B.J. (2014). Phytoremediation of water polluted by thallium, cadmium, zinc and lead with the use of macrophyte, *Callitriche* *cophocarpa. Arch. Environ. Contam. Toxicol.*, 66: 572-581.

Barman, S.C., Kisku, G.C., Salve, P.R., Misra, D., Sahu, R.K., Ramteke, P.W. and Bhargava, S.K. (2001). Assessment of industrial effluents and its impact on soil and plants. *Journal of Environmental Biology*, 22: 251-256.

Beyersmann, D. and Hartwig, A. (2008). Carcinogenic metal compounds: Recent insight into molecular and cellular mechanisms. Archives of Toxicology, 82(8): 493- 512.

Briat, J.F. and Lebrun, M. (1999). Plant responses to metal toxicity. *CR Acad. Sci. III* 322: 43-54.

Caldwell, E.F., Duff, M.C., Ferguson, C.E., Coughlin, D.P., Hicks, R.A. and Dixon, E. (2012). Biomonitoring for uranium using stream-side terrestrial plants and macrophytes. *J. Environ. Monit.*, 14: 968-976.

Cardwell, A.J., Hawker, D.W. and Reenway, M.G. (2002). Metal accumulation in aquatic macrophytes from southeast Queensland, Australia. *Chemosphere*, 48: 653-663.

Chen, G., Liu, X., Brookes, P.C. and Xu, J. (2015). Opportunities for phytoremediation and bioindication of arsenic contaminated water using a submerged aquatic plant: *Vallisneria natans* (lour) Hara. *Int. J. Phytoremediation*, 17: 249-255.

Cunningham, S.D., Anderson, T.A., Schwab, A.P. and Hus, F.C. (1996). Phytoremediation of soils contaminated with organic pollutants. *Advanced Agronomist*, 56: 55-114.

Clemens, S., Palmgren, M.G. and Krämer, U. (2002). A long way ahead: Understanding and engineering plant metal accumulation. *Trends in Plant Sciences*, 7: 309-315.

Favas, J.C. Pratas, J., Mitra, S., Sarkar, S.K. and Venkatachalam, P. (2016) Biogeochemistry of uranium in the soil-plant and water-plant systems in an old uranium mine. *Science of the Total Environment*, 568:350–368.

Fodor, E., Szabo-Nagy, A. and Erdei, L. (1995). The effects of cadmium on the fluidity and H^+-ATPase activity of plasma membrane from sunflower and wheat roots. *J. Plnt Physiol.*, 147: 87-92.

Gisbert, C., R. Ros, A. de Haro, D.J. Walker, M. Pilar-Bernal, R. Serrano and J.N. Avino. (2003). A plant genetically modified that accumulates Pb is especially promising for phytoremediation. *Biochemical and Biophysical Research Communications*, 303: 440-445.

Kramer, U. (2010). Metal hyperaccumulation in plants. *Annu. Rev. Plant Biol.*, 61: 517-534.

Knox, A.S., Gamerdinger, A.P., Adriano, D.C., Bollag, J.M. and Frankenberg, W.T. Jr. (1999). Sources and practices contributing to soil contamination. In: *Bioremediation of Contaminated Soils*, Madison, Wisconsin, USA. Agronomy Series, No. 37, Pp 53-87.

Liao, M.T., Hedley, M.J., Woolley, D.J., Brooks, R.R. and Nichols, M.A. 2000.

Copper uptake and translocation in chicory (*Cichorium intybus* L. cv. Grasslands Puna) and tomato (*Lycopersicon esculentum* Mill. cv. Rondy) plants grown in NFT system. I. Copper uptake and distribution in plants. *Plant and Soil*. 221: 135-142.

Liu, X.M., Wu, Q.T. and Banks, M.K. (2005). Effect of simultananeous establishment of *Sedum alfridi* and *Zea mays* on heavy metal contamination in plants. *Int. J. Phytoremediation*, 7(1): 43-53.

Macnair, M. (2003). The hyperaccumulation of metals by plants. *Adv. Bot. Res.*, 40: 63-105

McGrath, S.P., Zhao, F.J. and Lombi, E. (2001). Plant and rhizophere process involved in phytoremediation of metal contaminated soils. *Plant Soil*, 232(1/2): 207 -214.

Msaky, J.J. and Calvet, R. (1990). Adsorption behaviour of copper and zinc in soils: influence of pH on adsorption characteristics. *Soil Science*, 150: 513-522.

Nakbanpote, W., Meesungneon, O. and Prasad, M.N.V. (2016). Potential of ornamental plants for phytoremediation of heavy metals and income generation. In Prasad, M.N.V. (Ed.). *Bioremediation and Bioeconomy*. Elsevier, Armsterdam. Pp 179-217.

Prasad, M.N.V. (2007). Phytoremediation in India. In: Willey, N. (Ed.). *Phytoremediation: Methods and Reviews*. Humana Press, New Jersey. Pp. 435-454.

Quariti, O., Boussama, N., Zarrouk, M. Cherif, A. And Ghorbali, M.H. (1997). Cadmium and copper induced changes in tomato membranes lipids. *Phytochemistry*, 45: 1343-1350.

Rahman, K.Z., Wiessner, A. Kuschk, P., van Afferden, M., Mattusch, J. and Muller, R.A. (2014). Removal and fate of arsenic in the rhizophere of *Juncus effusus* treating artificial waste water in laboratory-scale constructed wetland. *Ecol. Eng*. 69: 93-105.

Siedlecka, A. And Baszynski, T. (1993). Inhibition of electron flow around photosystem in chloroplasts of Cd-treated maize plants is due to Cd-induced iron deficiency. *Physiol. Plant.*, 87: 199-202.

Stanova, A, Durisova, E., Banasova, V., Gurinova, E., Nadubinska, M., Kenderesova, L., Ovecka, M. and Ciamporova, M. (2012). Root system morphology and primary root anatomy in natural non-metallicolous and metallicolous populations of three Arabidopsis species differing in heavy metal tolerance. *Biologia*, 67: 505-516.

Spinoza-Quinones, F.R., Zacarkim, C.E., Palacio, S.M., Obregon, C.L.and Zenattti, D.C. (2005). Removal of heavy metal from polluted river water using aquatic macrophytes *Salvinia* sp. *Braz. J. Physiol*., 35: 744-746.

Tanee, F.B.G. and Amadi, N. (2016). Screening of *Polyalthia longifolia* and *Aloe vera* for their phytoextractability of heavy metals in tropical soil of the Niger Delta. *Journal of Applied Science and Environmental Management*, 20(1): 141-147.

Trotta, A., Falaschi, P., Cornara, L., Minganti, V., Fusconi, A., Drava, G. and Berta, G. (2006). Arbuscular mycorrhizae increase the arsenic translocation factor in the As hyperaccumulating fern: *Pteris vittata* L. *Chemosphere*, 65: 74-81.

van der Ent, A., Baker, A.J.M., Reeves, R.D., Pollard, A.J. and Schat, H. (2013). Hyperaccumulators of metals and metalloid trace elements: facts and fiction. Plant soil, 362: 319-334.

Ye, D., Li, T., Zhang, X., Zheng, Z., Liu, S. and Li, J. (2014). P uptake characteristics and P removal potentials of P*ilea sinofasciata* grown under soil amended with swine manure. Ecol. Eng., 73: 553-555.

Zhuang, P., Yang, Q.W., Wang, H.B., and Shu, W.S. (2007). Phytoextraction of heavy metals by eight plants species in the field. *Water Air Soil Pollut.*, 184: 235-242.