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BIOACCUMULATION POTENTIALS OF SELECTED TREE SPECIES IN HEAVY METAL CONTAMINATED SOIL

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Abstract
Bioaccumulation potentials of some selected tree species (*Tectona grandis*, *Gmelina arborea, Shorea roxburghii, Terminalia ivorensis* and *Terminalia superba*) were assessed from heavy metal contaminated soils in a screen house study. The experiment was a 3 × 5 factorial treatment laid out in Completely Randomized Design. The factors were three levels of contamination (control, double permissible and triple permissible) and five tree species. Data collected include; physical and chemical properties of the soil and metal accumulation in roots, stems and the leaves of the tree species. These were subjected to analysis of variance, while, significantly different means were separated using Duncan Multiple Range Test ($P \leq 0.05$). The results at 16 months after transplanting (MAT) showed that, *S. roxborghi* at the control level significantly ($P \leq 0.01$) accumulated more Mn (76.38mgkg^{-1}) in its stem compared to other species. A significant level of Pb (0.006mgkg^{-1}) was also obtained in the leaves of *Terminalia ivorensis* at triple contamination level, while, *Gmelina arborea* accumulated highest concentrations (7.55mgkg^{-1}) in its stem at the control level compared to other species. Moreover, highest accumulation of Cu (7.65mgkg^{-1}) was obtained in *Terminalia ivorensis* at triple contamination level. Meanwhile, there was no significant difference between Zn and Cd accumulated in the leaves, stems and roots of the tree species throughout the period of investigation. *Terminalia ivorensis*, therefore, has been found to possess a high metal accumulation potential especially at toxic contamination levels compared to other species considered.

Keywords: Bioaccumulation, Contamination, Heavy metals, Phytoremediation, Tree species

Introduction

Heavy metals are naturally found in soils, and plants use them in minute quantities as essential metabolites. In recent years, anthropogenic activities have resulted in enormous increase in both type and concentration of heavy metals in the soils(Mahmood and Malik, 2014). For instance, the discharge of contaminated industrial effluents coupled with atmospheric deposition poses a great threat to ecological integrity of the developing countries. Certain heavy metals could be toxic even at low concentrations and could affect crop production (Yi *et al.*, 2011). Up till now, various physical and chemical remediation methods are been used for the restoration of polluted soils of limited areas, which are usually very expensive (Sarma, 2011). In addition, most of these methods have adverse effects on the properties of the soils, while, rendering the soil useless for plant growth (Danh *et al*., 2009). Phytoextraction is an emerging technology that has received significant scientific and commercial attention because of its elegance and the vast areas of contaminated soils that could be covered (McGrath and Zhao, 2003). Notably, continuous phytoextraction requires perennial and easily manageable plants that could accumulate large amounts of metal pollutants in their aerial tissues, while, producing high biomass (Maric *et al*., 2013). However, very few available hyperaccumulators meet these criteria (Baker *et al*. 2000). As an alternative to herbaceous hyperaccumulators, fast-growing, metal-accumulating woody plants have been considered as potential candidates for the development of feasible phytoextraction (Puschenreiter *et al*., 2010). Trees are perennial long-living plants, having a large surface area compared to other groups of plants. Because of their large size and longer persistence, they have unique adaptability and large accumulation potential to environmental xenobiotics. Much to their advantage, trees have large canopy area and extensive root and

shoot system to accumulate and store a significant amount of heavy metals. Compared to other life forms, accumulation potential of tree species for heavy metals is less studied. This is mostly due to its long period of growth and slow growing rates compared to grasses and crop plants. Consequently, the study of overall performance of trees with respect to metal accumulation becomes necessary in order to select useful species for phytoremediation practice. In view of these, five tree species were evaluated in this study for their phytoremediation potentials in contaminated soils.

Materials and Methods

Study area and collection of seedlings

The study was carried out at the screen house of the Central Nursery, Department of Sustainable Forest Management (SFM), Forestry Research Institute of Nigeria (FRIN), Jericho hill Ibadan, Oyo State, Nigeria (Latitude 07° 23' 18" N to 07° 23' 43" N and longitude 03° 51' 20" E to 03° 53'43"E). The climate is West African monsoon which is characterized by wet and dry season (bimodal rainfall distribution), wet season begins in April and continues through October with the mean annual rainfall of 1548.9 mm; and lasts approximately for 90 days. The mean maximum temperature is 31.11C, minimum 22.76C and the relative humidity is 71.8% (FRIN, 2018).

Soil sampling and analysis

A composite soil sample (0 – 15) was made by combining several sub-samples collected randomly from uncultivated site of Arboretum in FRIN. The soil was air-dried at room temperature and sieved with a 2mm sieve after which it was analyzed for physical and chemical properties. Particle size distribution was determined by the hydrometer method (Bouyoucos, 1951). Soil pH was determined using a Glass electrode pH meter (Rent Model 720) in distilled water according to Thomas (1996) at 1:2 soil /water ratio. Organic carbon was measured by the wet combustion method (Walkley and Black, 1934). Total Nitrogen concentration was determined by Macro-kjeldahl method according to Bremner (1996); Exchangeable Ca, Mg, K and Na were extracted with neutral normal ammonium acetate buffer according to Helmke and Sparks (1996). K and Na were determined using Flame Photometer (Gallenkamp Model FH 500) and exchangeable Ca and Mg by Atomic Absorption Spectrophotometer (AAS).

Experimental design and treatments

The heavy metals; lead (Pb), zinc (Zn), copper (Cu), cadmium (Cd) and manganese (Mn)) used for the experiment were obtained from the Soil Laboratory, Bioscience Department, FRIN. Three months old seedlings of about 30cm heights of *Tectona grandis*, *Gmelina arborea, Shorea roxburghii, Terminalia ivorensis* and *Terminalia superba* were obtained from the Central Nursery of FRIN. Ten kilogram (10kg) soil was weighed into a 12cm × 18cm Polythene bags and were contaminated with the heavy metals and left to equilibrate for one week, after which the seedlings of the selected tree species were transplanted into the pots and watered to field capacity. The metals were added to the soil as water soluble salts in aqueous solutions. Thus Cd was added as $Cd(NO_3)_2.4H_2O$, Pb as $Pb(CH_2COO)_2.2H_2O$, Cu as $CuSO_4.5H_2O$, Zn as $Zn(NO_3)_2.6H_2O$ and Mn as MnO_4. The experiment was laid out in a 3 × 5 factorial treatment in Completely Randomized Design. The factors comprised three levels of contamination (control, double permissible- and triple permissible) and five tree species (*Gmelina arborea, Tectona grandis, Terminalia superb, Shorea roxborghi and Terminalia ivorensis*). The treatments were replicated three times with 8 pots per replicate giving a total of 360 experimental units. The levels of contamination were: Level 1= Control (No external addition), Level 2: Cd = 0.006 g/kg, Cu = 0.2 g/kg, Pb = 0.4 g/kg, Zn = 0.6 g/kg, Mn = 6 g/kg of heavy metal and Level 3: Cd = 0.009 g/kg, Cu = 0.3g/kg, Pb = 0.6 g/kg, Zn = 0.9 g/kg, Mn = 9 g/kg of heavy metals (WHO, 1996).

Heavy metal analysis

Three seedlings per treatment were selected for a destructive sampling at 4 months interval after transplanting and partitioned into leaves, stem and roots. The fresh weight were measured with the aid of an electric weighing balance and thereafter oven dried at 65°C for 48 hours after which the dried weight was taken and then milled using Arthur-Thomas grinding Machine. One gram of each sample was digested in di-acid mixture consisting of nitric acid and perchloric acid in 3:1 ratio and filtered with Whatman filter paper. The filtrate was used for the analysis of heavy metals (Cd, Pb, Cu, Mn and Zn) using Atomic Absorption Spectrophotometer (Buck Scientific Model 210 VGP).

Statistical analysis

Data obtained for metals accumulated in various tree species were subjected to analysis of variance using Statistical Analysis System (SAS, 1999), while mean separation was done with Duncan Multiple Range Test (DMRT) at 5% level of probability.

Results and Discussion

Soil properties

The results of the soil analysis revealed that the soil used belongs to textural class sandy loam according to USDA textural classification, Ditzler *et al*., 2017 (Table 1). The pH of the soil was 6.4 indicating slightly acid. The organic carbon and the total nitrogen were 19.2 and 1.7g/kg respectively, which were within the critical range for the soil as recommended by Njoku *et al*. (2009). The exchangeable K and Ca were 0.07cmol/kg and 4.41cmol/kg respectively, and Magnesium 0.44 cmol/kg. These were found below the critical limit according to Wuana and Okieimen (2011); Manganese, iron, Cadmium and lead were 223, 159.14, 0.62 and 75mg/kg respectively, while zinc and copper were 82 and 3mg/kg. The available phosphorus (2.60 mg/kg) was very low compared to 20-40mg/kg recommendation (Zhan *et al.,* 2015).

Table 1: Pre-planting physical and chemical properties of the soil

Properties	Quantity
Sand (g/kg)	82.20
Silt (g/kg)	3.70
Clay (g/kg)	14.10
Texture	Sandy loam
pH	6.4
Organic carbon (g/kg)	19.20
Nitrogen (g/kg)	1.70
Available P (mg/kg)	2.60
Exchangeable K (cmol/kg)	0.07
Ca (cmol/kg)	4.41
Mg (cmol/kg)	0.44
Zn (mg/kg)	82.00
Cu (mg/kg)	3.00
Mn (mg/kg)	223.00
Fe (mg/kg)	159.14
Cd (mg/kg)	0.62
Pb (mg/kg)	75.00

Metal concentrations

The results of Mn accumulated in different parts of the tree species across the contamination levels are presented in Table 2. It was observed that there was no significant difference in the accumulation of Mn at 4 MAT. However, at 8 MAT, the interactive effect was significant ($P < 0.05$) with the *Terminalia superba* at the control having the highest concentration of Mn in its root (4.145 $mgkg^{-1}$) compared with the other tree species. This was also observed at 12 and 16 MAT. Furthermore at 16 MAT, *Shorea roxborghi* significantly ($P < 0.01$) accumulated more Mn (76.38 $mgkg^{-1}$) in its stem compared to the other tree species at the control level. This revealed that the increase in concentration of the Mn, has led to a decline in the accumulation potential of the tree species. This implies that as the contamination increases, less manganese was accumulated in the stem of the tree species. It was also observed that the stem was able to accumulate more of Mn concentration than the root part of the plant which is in agreement with the assertion of Page and Feller (2005) who noted that Manganese generally tends to accumulate predominantly in the plant shoots than in the roots. Mn content remarkably varied across plant species, growth stage and different organs and ecosystems. Normally, Mn content in plants varies from 10 to 100 mg/kg; below 10 and above 200 mg/kg, Mn deficiency/toxicity occurs and plant physiological processes are compromised (Zhao *et al*., 2012). Metal accumulation in plants in most instances, are those capable of having bioconcentration levels of the pollutants in their tissues above that of the contaminated media (Erakhrumen, 2014).

Copper is an essential element for plant growth, it occurs in many enzymes of oxidation–reduction reactions (Kabata-Pendias and Pendias, 1993). There was no significant difference in the accumulation of copper in the leaf, stem and root of the tree species across different levels of contamination at 4, 8 and 12 MAT (Table 3). However, there was an interaction effect in the stem and the root at 16 MAT with *G. arborea* having significantly higher accumulation of Cu (13.14$mgkg^{-1}$) at control. There was also a significant difference ($p < 0.05$) in the root at triple contamination level with the *T. ivorensis* having the highest accumulation of Cu (7.65$mgkg^{-1}$); indicating that *T. ivorensis* has a very high accumulation potential of Cu at a very high contamination level compared with the other species considered. This could be as a result of the ability of the root to uptake the Cu^{2+} ions which is the bioavailable form of Cu in the soil which is facilitated by reduction reaction. This is in line with Das and Maiti (2007) who conducted a field study in an abandoned copper mine tailings (Rakha mine, Jharkhand, India), to find out accumulation of metal levels; Cu accumulation in the root parts was found even more than 1000mg/kg dry weight (DW), which suggests an exclusion strategy for metal tolerance widely existed in them. Thus, establishment of this species on heavy metal contaminated soil can be a safe method to stabilize the Cu metal. This also corroborated the assertion that there are differences in heavy metal accumulation and storage in actively growing tissues of plants (Majid *et al*., 2011). For instance, Majid *et al*. (*ibid*) reported higher Cu absorption in roots than stems of various plants. In fact, Cu accumulation ability depends on many other factors; for example, Cu accumulation increased with seedling age, the optimum growth stage of the plants enhanced the maximum Cu uptake on account of a much higher transpiration rate, which enhances metal uptake (Mleczek *et al*. 2010).

Zinc is an essential element to plants and studies have shown that total zinc concentration in plant tissues increases as zinc supply increases in both tolerant and non-tolerant genotype plant (Murray *et al*., 2000). Table 4 showed no significant difference in the accumulation of Zn in the leaf and root of the tree species considered throughout the period of investigation. However, there were significant difference ($p < 0.01$) in the contamination main effect in the stem at 12 and 16 MAT. *S. roxborghi* at triple contamination at 12 MAT

accumulated the highest Zn, while *G. arborea* had the highest Zn accumulation at Control level among the different tree species considered at the 16 MAT.

Cadmium showed no significant difference in the accumulation of Cd in the leaf, stem and the root of the different tree species considered throughout the period of investigation (Table 5). However, all the species demonstrated a similar response in accumulation of Cd in their stems which was progressive in nature across the contamination levels throughout the period of observation. Cadmium is potentially toxic to both plants and animals and has no essential biological function, and its excessive concentration is undesirable (Nabulo *et al*., 2011). The uptake and distribution of trace metal, especially cadmium varies from species to species, this may be associated with the differences in ability of plant to control the movement of trace metals from xylem to phloem, and via the phloem to other parts of the plant (Singh *et al*., 2011). Studies have shown that increased cadmium application to zinc deficient plant tends to decrease plant zinc concentration, but in plant with adequate zinc supply, zinc concentration are either not affected or increased by cadmium (McBride, 2007).

Lead has a long soil retention time and can stay in the soil for about 150 to 5000 years (Shaw, 1990). Therefore, the probability for this metal to be absorbed will become higher. It does not naturally occur in the plants and can be very toxic if being consumed in high dose (Tuzen, - 2003). Table 6 however showed that the accumulation of Lead was not significant at 4, 8 and 12 MAT, but at 16 MAT, there was a significant difference in accumulation of Pb in the leaf at contamination ($p < 0.05$) and species ($p < 0.01$) main effects, while there was interaction effect ($p < 0.05$) in the Pb accumulated in the stem. *T. ivorensis* significantly accumulated Pb in the leaf (0.006mg/kg) at the triple contamination level, while *G. arborea* accumulated highest concentrations at the control level (7.55mg/kg) in the stem compared to other species. This is in contrast with findings of Das and Maiti (2007), which stated that accumulated metals were mostly retained in root tissue indicating that an exclusion mechanism for metal tolerance widely exists in them. Retention of some metals more than toxic level in the above ground tissues of some plants suggests the presence of internal metal detoxification and tolerance mechanisms in them. *T. grandis* also showed a very good potentials because it has accumulated most of the metals from the soil into the plant tissues in accordance with the study conducted by Blaylock *et al*. (1999) at a lead-contaminated site in Trenton, New Jersey, where through phytoremediation; the average surface soil Pb concentration was reduced by 13%.

Table 2: Mean concentration of manganese (Mn) in Leaf, Stem and Root (mg/kg)

Treatment	4 MAT			8 MAT			12 MAT			16 MAT		
	Leaf	**Stem**	**Root**	**Leaf**	**Stem**	**Root**	**Leaf**	**Stem**	**Root**	**Leaf**	**Stem**	**Root**
Control												
T. grandis	0.051	0.100	0.077	0.088	0.730	0.385	0.072	0.740	1.155	0.252	8.850	2.079
G. arborea	0.035	0.400	0.393	0.070	1.150	1.625	0.205	4.430	2.797	0.242	4.990	5.034
T. superba	0.071	1.000	0.891	0.156	1.160	4.145	0.294	3.730	12.436	0.041	23.800	22.385
S.roxborghi	0.205	0.250	0.190	0.098	2.530	1.193	0.063	6.370	3.580	0.095	76.380	6.444
T. ivorensis	0.048	0.250	0.698	0.006	2.540	3.488	0.030	3.380	10.463	0.468	21.310	18.833
Conta 2												
T. grandis	0.037	0.090	0.310	0.071	0.930	0.369	0.256	1.150	1.106	0.041	0.140	1.991
G. arborea	0.051	0.150	0.770	0.205	1.500	0.420	0.008	1.620	1.260	0.280	0.190	2.268
T. superba	0.008	0.250	0.260	0.048	2.500	0.754	0.056	0.850	2.263	0.070	0.100	4.073
S.roxborghi	0.061	0.020	0.015	0.045	0.190	0.293	0.269	1.920	0.880	0.239	12.950	1.584
T. ivorensis	0.092	0.190	0.193	0.083	1.900	0.905	0.005	1.70	2.715	0.399	10.450	4.887
Conta 3												
T. grandis	0.053	0.320	0.435	0.098	3.200	2.177	0.156	4.340	6.530	0.101	5.400	11.754
G. arborea	0.070	0.110	0.272	0.037	1.140	0.385	0.077	1.170	1.155	0.259	2.680	2.079
T. superba	0.167	0.020	0.025	0.031	0.220	0.197	0.040	2.240	0.590	0.002	2.880	1.062
S.roxborghi	0.073	0.110	0.146	0.006	1.140	0.272	0.253	2.800	0.815	0.140	3.670	1.467
T. ivorensis	0.248	0.400	0.783	0.050	4.030	3.188	0.273	3.720	9.565	0.167	12.450	17.217
F sig. (Conta)	ns	ns	ns	ns	ns	*	ns	**	*	ns	**	*
F sig. (Species)	ns	ns	ns	ns	ns	ns	ns	**	ns	ns	**	ns
F sig.(Interaction)	ns	ns	**	ns	ns	*	ns	ns	*	ns	**	*

= p<0.05, ** = p<0.01, ns = not significant. Conta 1= Control, Conta2 = Cd = 6.0 mg/kg, Cu = 200 mg/kg, Pb = 400 mg/kg, Zn = 600 mg/kg, Mn = 6,000 mg/kg, Conta 3 = Cd = 9.0 mg/kg, Cu = 300 mg/kg, Pb=600 mg/kg, Zn=900 mg/kg, Mn=9,000 mg/kg. Conta= Contmination level; MAT= Months after transplanting

Table 3: Mean concentration of copper (Cu) in Leaf, Stem and Root (mg/kg)

Treatment	4 MAT			8 MAT			12 MAT			16 MAT		
	Leaf	Stem	Root	Leaf	Stem	Root	Leaf	Stem	Root	Leaf	Stem	Root
Control												
T. grandis	0.005	0.020	0.015	0.027	0.110	0.076	0.003	1.090	0.226	0.006	13.140	0.406
G. arborea	0.004	0.090	0.101	0.001	0.900	0.503	0.008	1.270	1.510	0.017	0.520	2.718
T. superba	0.002	0.090	0.073	0.003	0.780	0.365	0.299	1.590	1.095	0.006	0.190	1.971
S.roxborghi	0.003	0.010	0.012	0.007	0.120	0.058	0.025	1.240	0.175	0.004	0.150	0.315
T. ivorensis	0.002	0.010	0.014	0.001	0.090	0.072	0.003	0.900	0.215	0.034	7.170	0.387
Conta 2												
T. grandis	0.006	0.240	0.012	0.002	2.370	0.058	0.006	2.760	0.175	0.006	0.330	0.315
G. arborea	0.005	0.010	0.014	0.003	0.110	0.070	0.001	1.130	0.208	0.021	0.140	0.374
T. superba	0.001	0.010	0.014	0.002	0.070	0.070	0.005	0.750	0.210	0.002	0.090	0.378
S.roxborghi	0.001	0.010	0.010	0.001	0.100	0.143	0.023	1.050	0.428	0.018	0.130	0.770
T. ivorensis	0.026	0.010	0.010	0.003	0.080	0.050	0.001	0.840	0.150	0.047	5.150	0.270
Conta 3												
T. grandis	0.040	0.010	0.023	0.001	0.150	0.113	0.003	1.480	0.340	0.004	1.920	0.612
G. arborea	0.002	0.010	0.021	0.003	0.080	0.376	0.032	0.770	1.129	0.019	3.770	2.032
T. superba	0.031	0.010	0.009	0.001	0.100	0.126	1.241	1.000	0.378	0.023	01.000	0.680
S.roxborghi	0.004	0.090	0.043	0.001	0.890	0.328	0.020	1.800	0.985	0.002	2.200	1.773
T. ivorensis	0.021	0.070	0.283	0.008	0.730	1.416	0.023	1.630	4.248	0.031	4.700	7.646
F sig. (Conta)	ns	ns	ns	ns	ns	ns	ns	ns	*	ns	ns	*
F sig. (Species)	ns	ns	ns	ns	ns	*	ns	ns	ns	ns	**	ns
F sig.(Interaction)	ns	ns	**	ns	ns	ns	ns	ns	ns	ns	*	*

= p<0.05, ** = p<0.01, ns = not significant. Conta 1= Control, Conta2 = Cd = 6.0 mg/kg, Cu = 200 mg/kg, Pb = 400 mg/kg, Zn = 600 mg/kg, Mn = 6,000 mg/kg, Conta 3 = Cd = 9.0 mg/kg, Cu = 300 mg/kg, Pb=600 mg/kg, Zn=900 mg/kg, Mn=9,000 mg/kg. Conta= Contmination level; MAT= Months after transplanting

Table 4: Mean concentration of zinc (Zn) in Leaf, Stem and Root (mg/kg)

Treatment	4 MAT			8 MAT			12 MAT			16 MAT		
	Leaf	**Stem**	**Root**	**Leaf**	**Stem**	**Root**	**Leaf**	**Stem**	**Root**	**Leaf**	**Stem**	**Root**
Control												
T. grandis	0.621	0.450	0.357	1.282	1.390	3.565	0.913	1.550	3.365	0.035	18.610	1.143
G. arborea	0.584	0.240	0.380	0.599	2.350	3.803	0.049	2.680	3.087	1.457	3.630	0.031
T. superba	0.649	0.240	0.283	0.640	0.950	2.832	0.962	2.040	0.944	1.249	0.250	0.016
S.roxborghi	0.016	0.160	0.506	0.018	1.590	5.060	0.054	1.720	1.687	0.661	0.210	0.012
T. ivorensis	0.025	0.150	0.579	0.556	1.450	5.791	1.263	1.590	1.930	0.683	11.700	0.013
Conta 2												
T. grandis	0.361	1.000	0.349	0.649	2.080	3.490	0.272	2.320	1.163	1.594	0.280	1.033
G. arborea	2.100	1.410	0.080	0.016	1.630	0.802	1.160	3.170	1.427	1.520	0.380	2.264
T. superba	0.260	0.720	0.593	0.025	1.880	5.930	0.603	2.050	1.977	1.305	0.250	0.343
S.roxborghi	1.152	0.610	0.426	0.359	1.100	4.260	0.681	1.380	1.420	1.403	0.170	0.446
T. ivorensis	1.517	0.520	0.343	0.032	2.070	3.430	0.703	2.890	1.143	1.812	11.330	0.516
Conta 3												
T. grandis	1.847	1.370	3.595	0.260	2.450	35.945	0.683	4.180	11.982	0.630	5.130	0.632
G. arborea	0.661	0.090	0.174	1.150	0.900	1.738	0.044	1.090	0.579	1.257	6.610	0.015
T. superba	1.143	0.360	0.423	0.328	4.340	4.233	0.035	4.200	1.411	0.029	4.890	1.269
S.roxborghi	0.023	0.100	0.348	0.651	1.040	3.475	0.058	4.580	1.158	0.705	5.530	0.010
T. ivorensis	0.381	0.280	0.830	0.033	2.800	8.300	0.286	3.040	2.767	0.013	11.140	0.028
F sig. (Conta)	ns	ns	ns	Ns	ns	Ns	ns	**	ns	ns	**	ns
F sig. (Species)	ns	ns	ns	Ns	ns	Ns	ns	ns	ns	ns	ns	ns
F sig.(Interaction)	ns	ns	ns	Ns	ns	Ns	ns	ns	ns	ns	ns	ns

= p<0.05, ** = p<0.01, ns = not significant. Conta 1= Control, Conta2 = Cd = 6.0 mg/kg, Cu = 200 mg/kg, Pb = 400 mg/kg, Zn = 600 mg/kg, Mn = 6,000 mg/kg, Conta 3 = Cd = 9.0 mg/kg, Cu = 300 mg/kg, Pb=600 mg/kg, Zn=900 mg/kg, Mn=9,000 mg/kg. Conta= Contmination level; MAT= Months after transplanting

Table 5: Mean concentration of cadmium (Cd) in Leaf, Stem and Root (mg/kg)

Treatment	4 MAT			8 MAT			12 MAT			16 MAT		
	Leaf	Stem	Root	Leaf	Stem	Root	Leaf	Stem	Root	Leaf	Stem	Root
Control												
T. grandis	0.001	0.100	0.003	0.039	0.730	0.013	0.032	0.740	0.181	0.005	8.850	0.326
G. arborea	0.007	0.400	0.001	0.008	1.150	0.005	0.001	4.430	0.015	0.002	4.990	0.027
T. superba	0.007	1.000	0.001	0.003	1.160	0.005	0.003	3.730	0.016	0.003	23.800	0.028
S.roxborghi	0.007	0.250	0.001	0.001	2.530	0.004	0.003	6.370	0.012	0.006	76.380	0.021
T. ivorensis	0.007	0.250	0.002	0.002	2.540	0.008	0.002	3.380	0.024	0.001	21.310	0.043
Conta 2												
T. grandis	0.007	0.090	0.001	0.006	0.930	0.002	0.004	1.15	0.006	0.003	0.140	0.011
G. arborea	0.007	0.150	0.001	0.001	1.500	0.004	0.002	1.620	0.013	0.020	0.190	0.023
T. superba	0.007	0.250	0.002	0.006	2.500	0.009	0.025	0.850	0.028	0.008	0.100	0.050
S.roxborghi	0.007	0.020	0.001	0.004	0.190	0.002	0.003	1.920	0.006	0.004	12.950	0.011
T. ivorensis	0.007	0.190	0.001	0.001	1.900	0.004	0.008	1.780	0.012	0.028	10.450	0.023
Conta 3												
T. grandis	0.007	0.320	0.001	0.004	3.200	0.005	0.003	4.340	0.016	0.008	5.400	0.028
G. arborea	0.008	0.110	0.001	0.002	1.140	0.007	0.006	1.170	0.021	0.023	2.680	0.038
T. superba	0.000	0.020	0.002	0.008	0.220	0.008	0.010	2.240	0.025	0.155	2.880	0.045
S.roxborghi	0.002	0.110	0.001	0.006	1.140	0.005	0.006	2.800	0.016	0.008	3.670	0.029
T. ivorensis	0.004	0.400	0.002	0.003	4.030	0.008	0.002	3.720	0.025	0.001	12.450	0.045
F sig. (Conta)	**	ns	ns	ns	ns	Ns	ns	ns	ns	ns	ns	ns
F sig. (Species)	**	ns	ns	ns	ns	Ns	ns	ns	ns	ns	ns	ns
F sig.(Interaction)	**	ns	ns	ns	ns	Ns	ns	ns	ns	ns	ns	ns

= p<0.05, ** = p<0.01, ns = not significant. Conta 1= Control, Conta2 = Cd = 6.0 mg/kg, Cu = 200 mg/kg, Pb = 400 mg/kg, Zn = 600 mg/kg, Mn = 6,000 mg/kg, Conta 3 = Cd = 9.0 mg/kg, Cu = 300 mg/kg, Pb=600 mg/kg, Zn=900 mg/kg, Mn=9,000 mg/kg. Conta= Contmination level; MAT= Months after transplanting

Table 6: Mean concentration of lead (Pb) in Leaf, Stem and Root (mg/kg)

Treatment	4 MAT			8 MAT			12 MAT			16 MAT		
	Leaf	**Stem**	**Root**	**Leaf**	**Stem**	**Root**	**Leaf**	**Stem**	**Root**	**Leaf**	**Stem**	**Root**
Control												
T. grandis	0.005	0.030	0.023	0.058	0.340	0.116	0.047	0.630	0.348	0.001	7.550	0.626
G. arborea	0.003	0.030	0.026	0.001	0.260	0.130	0.008	0.930	0.391	0.004	2.660	0.703
T. superba	0.003	0.040	0.006	0.005	0.370	0.032	0.091	3.740	0.095	0.001	0.450	0.171
S.roxborghi	0.006	0.050	0.035	0.004	0.480	0.173	0.012	4.860	0.518	0.002	0.580	0.932
T. ivorensis	0.003	0.000	0.011	0.002	0.050	0.053	0.001	0.460	0.158	0.002	4.300	0.284
Conta 2												
T. grandis	0.004	0.010	0.003	0.003	0.020	0.010	0.001	0.240	0.031	0.001	0.030	0.056
G. arborea	0.001	0.020	0.005	0.006	0.040	0.023	0.001	0.370	0.068	0.001	0.050	0.122
T. superba	0.004	0.020	0.007	0.003	0.050	0.034	0.005	0.480	0.103	0.002	0.060	0.185
S.roxborghi	0.003	0.040	0.036	0.001	0.410	0.182	0.002	4.200	0.545	0.003	0.500	0.981
T. ivorensis	0.027	0.010	0.024	0.001	0.090	0.154	0.004	0.920	0.463	0.005	2.470	0.833
Conta 3												
T. grandis	0.008	0.020	0.024	0.004	0.200	0.119	0.005	2.010	0.358	0.003	5.560	0.644
G. arborea	0.002	0.020	0.020	0.002	0.200	0.102	0.058	2.060	0.305	0.003	2.770	0.549
T. superba	0.006	0.020	0.005	0.004	0.170	0.026	0.077	1.700	0.078	0.001	3.250	0.140
S.roxborghi	0.004	0.040	0.032	0.002	0.350	0.159	0.056	3.570	0.478	0.002	5.950	0.860
T. ivorensis	0.001	0.010	0.008	0.006	0.080	0.212	0.001	0.780	0.635	0.006	3.920	1.143
F sig. (Conta)	ns	ns	ns	Ns	ns	Ns	ns	ns	ns	*	**	ns
F sig. (Species)	ns	ns	ns	Ns	ns	Ns	ns	*	ns	**	*	ns
F sig.(Interaction)	ns	ns	ns	ns	ns	Ns	ns	ns	ns	ns	*	ns

= p<0.05, ** = p<0.01, ns = not significant. Conta 1= Control, Conta2 = Cd = 6.0 mg/kg, Cu = 200 mg/kg, Pb = 400 mg/kg, Zn = 600 mg/kg, Mn = 6,000 mg/kg, Conta 3 = Cd = 9.0 mg/kg, Cu = 300 mg/kg, Pb=600 mg/kg, Zn=900 mg/kg, Mn=9,000 mg/kg. Conta= Contmination level; MAT= Months after transplanting

Conclusion

This study revealed that of all the tree species considered under different contamination levels, *Tectona grandis* demonstrated high potential for accumulation of Mn, Cu and Pb in the stem portion of the plant tissues, while, *Terminalia ivorensis* has the highest phytoremediation potential for Cu because of its ability to accumulate this metal especially at the root portion of the plant at a very high contamination level. *Tectona grandis* is therefore, recommended as very good bioaccumulator specie for Mn, Cu and Pb contaminated site, while, *Terminalia ivorensis* is recommended as a good phytostabilisation candidate for Copper. This is as a result of their adaptability to an adversely contaminated condition especially at their early stage of growth.

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