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Comparative Assessment of Indigenous and Exotic Tree Species for Phytoremediation of Heavy Metal-Contaminated Soils in Southwest Nigeria.

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ABSTRACT
The growth and overall health of a tree can be negatively impacted by various contaminants and the specific concentration at which these effects occur can differ from one tree species to another, as well as between different contaminants. This study aimed to explore the phytoremediation potential of Tectona grandis, Gmelina arborea, Shorea roxburghii, Terminalia ivorensis, and Terminalia superba in soils contaminated with heavy metals from the Forestry Research Institute of Nigeria (FRIN) in Ibadan, Oyo State, and Ijebu-Igbese in Ogun State. The heavy metals analyzed included copper, zinc, manganese, lead, and cadmium. The soil was contaminated at three different levels: double the permissible level (twice the tolerable limit in soil) with cadmium at 0.006 g/kg, copper at 0.2 g/kg, lead at 0.4 g/kg, zinc at 0.6 g/kg, and manganese at 6 g/kg; triple the permissible level (three times the tolerable limit) with cadmium at 0.009 g/kg, copper at 0.3 g/kg, lead at 0.6 g/kg, zinc at 0.9 g/kg, and manganese at 9 g/kg; and a control group with no contamination. Particle size analysis revealed that the soil was loamy sand with a pH range of 5.69 to 6.44. Gmelina arborea exhibited significantly greater height (176.00 cm) and collar diameter (29.78 mm) compared to the other species, while Terminalia ivorensis produced a higher number of leaves. In conclusion, Gmelina arborea seems to demonstrate a greater tolerance to higher levels of contamination than the other species studied, indicating that it may have a natural ability to adapt to adverse conditions.

Keywords: Contamination, heavy metals, permissible levels, soil, tree species.

Introduction

In recent years, there's been a growing focus on the serious issue of environmental contamination caused by a wide range of chemical pollutants, particularly heavy metals (Alengebawy *et al.*, 2021). Interestingly, some plant species have shown the ability to survive and thrive in soils that are heavily tainted with heavy metals such as Zinc (Zn), Copper (Cu), Lead (Pb), Cadmium (Cd), Nickel (Ni), Chromium (Cr), and Arsenic (As) (Baker, 1987). These heavy metals find their way into our environment from both natural processes and human activities (Zwolak *et al*., 2019). They not only contaminate our food sources but also accumulate in agricultural products and seafood through pollution in water, air and soil (Rai *et al.,* 2019). It's been widely reported that industries play a significant role in releasing these pollutants into our surroundings (Chen and Chen, 2001).

Understanding how metals distribute between soil and plants is crucial for evaluating their environmental impact (Mansur, 2015). The pollution caused by heavy metals has become a pressing global concern that demands our attention. Typically, soils contaminated with these metals lack a healthy vegetation cover, either because the metals are toxic or due to ongoing physical disturbances like erosion (Yan, 2020). Identifying plants that can effectively bio accumulate these metals is quite challenging. This is due to the many interactions that can occur between plants and soil, such as relationships with beneficial soil microorganisms and variations in root structure, as well as specific habitat needs like nutrient levels and water requirements. The greater tolerance seen in trees might suggest an evolutionary adaptation to these conditions. Therefore, selecting the right tree species is essential for successful phytostabilization or metal phytoextraction (Saba *et al*., 2015).

Woody trees are often seen as a boon for the environment. They have this amazing ability to transport and fix mineral elements in their tissues, which makes them great for cleaning up harmful heavy metals that can accumulate in water and soil [Al-Sayaydeh, 2022]. These trees are particularly favored for long-term wastewater resource management because they produce a lot of biomasses. Different species of woody trees vary in how well they bio accumulate and adapt to high levels of heavy metals concentrations in their tissues [Alahabadi *et al.,* 2017].

Using tree species for phytoremediation not only helps clean up contaminated sites but also supports ecological restoration. So, choosing tree species that can produce a lot of biomasses, accumulate metals effectively, tolerate metal toxicity and adapt to various environments can really boost the success of phytoremediation efforts (Sarwar *et al.*, 2017). This study aimed to assess the phytoremediation potential of *Tectona grandis, Gmelina arborea, Shorea roxburghii, Terminalia ivorensis, and Terminalia superba* with a view to finding the species that best accumulate and improving soil contaminated with heavy metals.

MATERIALS AND METHODS

Experimental set up and soil characteristics

The research 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 in Ibadan, Oyo State, Nigeria. It falls within the coordinates ranging from 07° 23' 18" N to 07° 23' 43" N and 03° 51' 20" E to 03° 23' 43" E. This area experiences a bimodal rainfall pattern, with the wet season running from April to October, accumulating an average annual rainfall of 1548.9 mm over about 90 days ref. The average maximum temperature is 31.1°C, while the minimum is 22.76°C and with an average relative humidity of 71.8% (FRIN, 2018).

Heavy metal salts used for the study were sourced from the Soil Laboratory within the Bioscience Department of FRIN. The metals were introduced to the soil in the form of their water-soluble salts as aqueous solutions. Specifically, Cd was added as Cd $(NO_3)2{\cdot}4H_2O$, Pb as $Pb(CH_2COO)_2{\cdot}2H_2O$, Cu as $CuSO_4{\cdot}5H_2O$, Zn as $Zn(NO_3)_2{\cdot}6H_2O$, and Mn as MnO_4. We used three-month-old seedlings of *Tectona grandis*, *Gmelina arborea*, *Shorea roxburghii*, *Terminalia ivorensis*, and *Terminalia superba*, all approximately 30 cm tall, sourced from the Central Nursery of the SFM Department at FRIN. The selection of these plant species was intentional, aiming to avoid using agricultural or fruit crops as phytoaccumulators or phytoextractors, which could inadvertently enter the food chain and pose risks to health. The topsoil for this study was collected from the Arboretum at FRIN and the Ijebu-Igbese waterside in Ijebu-Ode, Ogun State, Nigeria.

Sample preparation and routine analysis

The soil sample was air-dried at room temperature for 48 hours and then passed through a 2 mm sieve. Physical and chemical properties were analyzed which includes determination of particle size distribution using the hydrometer method (Bouyoucos, 1951). To measure the soil pH, we used a glass electrode pH meter (Rent Model 720) in distilled water, following the method outlined by Thomas (1996) at a 1:2 soil-to-water ratio. Available phosphorus was assessed using the Bray-I method as described by Kuo (1996). We measured organic carbon through the wet combustion method (Walkley and Black, 1934) and converted it to organic matter by multiplying the organic carbon values by a factor of 1.724, as per Jackson's procedure reported by Sparks (1996). The total nitrogen concentration was determined using the Macro-Kjeldahl method according to Bremner (1996). For exchangeable calcium, magnesium, potassium, and sodium, were extracted using neutral normal ammonium acetate buffer, following Helmke and Sparks (1996). Potassium and sodium were measured using a Flame Photometer (Gallenkamp Model FH

500), while exchangeable calcium and magnesium were analyzed with an Atomic Absorption Spectrophotometer (AAS), Bulk Scientific Model – 210 VGP.

The air-dried soil was ground with a rolling pin on a grinding board to break down any lumps into smaller particles, then sieved it again with a 2 mm sieve to remove any materials that couldn't pass through. We weighed out a 10 kg soil sample using a balance and placed it in 12 cm × 18 cm polythene bags. The soil was then contaminated with five selected heavy metals and left to equilibrate for a week, three-month-old seedlings of selected tree species with equal height were transplanted, into the pots and ensured they were watered to field capacity with regular watering. Plant height (cm), collar diameter (mm), leaf production, and the dry matter of the root, stem, and leaf starting from two months after transplanting (MAT) of the seedlings were assessed.

Treatments and experimental design

The study was designed as a 3 × 5 factorial experiments using a Completely Randomized Design, replicated three times with 8 pots for each replicate, resulting in a total of 360 experimental units across the two different soil locations. The experiment looked at three levels of contamination: no contamination, double the tolerable limit, and triple the tolerable limit (which we referred to as Control, double permissible, and triple permissible levels). Additionally, five tree species were examined: *Gmelina arborea, Tectona grandis, Terminalia superb, Shorea roxburghii, and Terminalia ivorensis,* five heavy metals were introduced: Lead (Pb), manganese (Mn), zinc (Zn), copper (Cu), and cadmium (Cd), to the soil at three different levels. The levels were as follows: Control had no contamination; Double permissible included Cd at 6.0 mg/kg, Cu at 200 mg/kg, Pb at 400 mg/kg, Zn at 600 mg/kg, and Mn at 6,000 mg/kg; and Triple permissible had Cd at 9.0 mg/kg, Cu at 300 mg/kg, Pb at 600 mg/kg, Zn at 900 mg/kg, and Mn at 9,000 mg/kg (Denneman and Robberse 1990).

Stasistical data analysis

Data collected were analyzed using Statistical Analysis System (SAS) version 8 (1999); Analysis of Variance (ANOVA) was performed to established significant effects and Duncan Multiple Range Test (DMRT) was used to compare treatment means at 5% level of probability.

Results

Table I showed the physicochemical properties of soils from FRIN and Igbese Ijebu carried out revealing similar textural class of Loamy sand (Sand: 82.2% and 92.2%, Silt: 3.7 and 1.7% and clay: 14.1 and 6.1% respectively) and the pH of 5.69 was observed in Igbese-Ijebu while that of FRIN was 6.38. The organic carbon and the Total Nitrogen were 1.92 % and 0.17% for the soil from FRIN and 0.84% and 0.073% respectively for Igbese Ijebu soil. The exchangeable K and Ca were 2.13 cmol/kg and 7.31 cmol/kg respectively in Ijebu igbese which was higher than that of the soil of FRIN which were 0.07cmol/kg and 4.41cmol/kg respectively. Magnesium was found to be lower in soil from Ijebu compared to that of the FRIN which was 0.21 and 0.44 cmol/kg respectively. Manganese, iron, cadmium and lead were 223 mg/kg, 159.14 mg/kg, 0.62 and 75 mg/kg respectively in soil from FRIN which was higher than that of the Ijebu which were 16 mg/kg, 95.9 mg/kg, 0.52 mg/kg and 32 mg/kg respectively. Zinc and copper were 184 mg/kg and 4 mg/kg for the Ijebu soil and 82 mg/kg respectively. The available phosphorus in the soil from FRIN was 2.60 mg/kg compared to that of Ijebu which was 2.13 mg/kg, these are very low. Table 2 is Analysis of variance (ANOVA) of heavy metals contamination on height of different species from FRIN. Species interaction showed significant difference on height of tree species planted on soil from FRIN from 2MAT to 12 MAT, *Gmelina arborea* was significantly taller than the other species and increases from 2MAT (62.50 cm) to 10 MAT (1148.00 cm) at double permissible contamination. While at 12MAT, it was significantly higher at control (176.00 cm) compared to other contamination levels. Table 3 shows the analysis of variance (ANOVA) of heavy metals contamination on height of different species from Ijebu-Igbese soil. Heavy metal contamination and species interaction had significant effect ($p > 0.01$) on the height of tree

Table 1: Physico-chemical properties of the soil before planting

Property	Soils from: FRIN	Ijebu-Igbese
Sand (%)	82.2	92.2
Silt (%)	3.7	1.7
Clay (%)	14.1	6.1
Texture	Loamy sand	Sandy
pH	6.38	5.69
Organic carbon (%)	1.92	0.84
Nitrogen (%)	0.17	0.073
Available P (mg/kg)	2.60	2.13
Exchangeable K (cmol/kg)	0.07	1.02
Ca (cmol/kg)	4.41	7.31
Mg (cmol/kg)	0.44	0.21
Zn (mg/kg)	82	184
Cu (mg/kg)	3	4
Mn (mg/kg)	223	16
Fe (mg/kg)	159.14	95.9
Cd (mg/kg)	0.62	0.52
Pb (mg/kg)	75	32

*Significantly lower at *P<0.05,* **Significantly lower at *P<0.01*

Table 2: Analysis of variance (ANOVA) of heavy metals contamination on height of different species from FRIN

Sources	Df	Months after transplanting 2	4	6	8	10	12	14	16
Conta (C)	2	1.03	14.11*	4.99	4.82	5.39	4.84	3.49	0.25
Species (S)	4	6.75**	17.71**	131.93**	201.31**	274.00**	280.12**	292.68**	483.03**
C x S interaction	8	6.61**	4.50	5.87	3.26	1.13	1.58	4.54	13.04
Error	30	1.33	3.32	4.44	4.20	2.66	1.66	3.97	15.89
Total	44								
CV (%)		17.91	20.90	18.33	15.63	11.03	7.97	11.46	19.49

*Significantly lower at *P<0.05,* **Significantly lower at *P<0.01*

Table 3: Analysis of variance (ANOVA) of heavy metals contamination on height of different species from Ijebu-Igbese soil

Sources	Df	Months after transplanting 2	4	6	8	10	12	14	16
Conta (C)	2	365.52**	148.24	141.07	151.09	51.95	5.55	479.76	1607.64**
Species (S)	4	280.76**	1253.055**	2437.98**	3619.63**	5406.16**	8582.16**	8285.94**	7582.55**
C x S interaction	8	164.95	138.24	192.21	331.20	436.01*	507.80**	913.98**	2106.88**
Error	30	55.97	116.83	140.28	180.47	169.42	155.90	214.67	290.77
Total	44								
CV (%)		24.75	25.37	21.15	19.94	16.85	13.94	14.43	14.55

*Significantly lower at *P<0.05,* **Significantly lower at *P<0.01* species planted on soil from Ijebu-Igbese only from 10 MAT to 16 MAT. Table 4 and 5 are also the Analysis of variance (ANOVA) of heavy metals contamination on Collar Diameter of different species from FRIN and Ijebu-Igbese respectively. While Table 6 and 7 are the Analysis of variance (ANOVA) of heavy metals contamination in Leaves of different tree species from FRIN and Ijebu-Igbese respectively. The results revealed significant differences at $p > 0.01$ among the tree species in terms of number of leaves produced in both FRIN and Ijebu Igbese soils (Tables 6 and 7).

Discussion

The pre-planting soil analysis (Table 1) revealed marked differences between soils from FRIN and Ijebu-Igbese, which are critical for understanding heavy metal behaviours and plant uptake. Both soils were predominantly sandy, with FRIN classified as loamy sand and Ijebu-Igbese as sandy. High sand content is known to enhance metal mobility due to low adsorption capacity, thereby increasing metal bioavailability for plant uptake (Alloway, 2013; Kabata-Pendias, 2011). This condition is advantageous for evaluating phytoremediation potential, as plants are more likely to absorb metals under such soil textures. The slightly acidic pH observed, particularly in Ijebu-Igbese soil (pH 5.69), further favours metal solubility and uptake. Acidic soils reduce metal precipitation and increase the concentration of free metal ions in soil solution (Adriano, 2001). However, the lower organic carbon and nitrogen contents in Ijebu-Igbese soil suggest reduced metal complexation and buffering capacity compared to FRIN soil, which may partly explain differences in plant growth responses and metal accumulation between locations. Heavy metal concentrations differed substantially between sites. Ijebu-Igbese soil exhibited notably higher Zn levels (184 mg/kg), while FRIN soil showed elevated Mn, Fe, and Pb concentrations. These values exceed typical background levels for

Table 4: Analysis of variance (ANOVA) of heavy metals contamination on Collar Diameter of different species from FRIN

Sources	Df	Months after transplanting							
		2	4	6	8	10	12	14	16
Conta (C)	2	68.6	657.78*	128.26	215.82	376.80	626.86	476.82	1542.95*
Species (S)	4	563.2**	1205.67**	2387.08**	4351.7**	7116.24**	11312.2**	12541.74**	12062.18**
C x S interaction	8	328.79**	472.19**	192.33*	659.85**	571.32*	692.73**	347.96	581.45
Error	30	105.22	139.97	210.23	198.35	206.60	195.35	257.51	358.17
Total	44								
CV (%)		32.70	25.72	25.25	19.42	16.87041	14.39	14.62	15.15

*Significantly lower at *P<0.05,* **Significantly lower at *P<0.01*

Table 5: Analysis of variance (ANOVA) of heavy metals contamination on Collar Diameter of different species from Ijebu-Igbese

Sources	Df	Months after transplanting							
		2	4	6	8	10	12	14	16
Conta (C)	2	10.45**	0.39	0.36	1.69	23.95	1.87	10.00*	21.27
Species (S)	4	8.07**	23.21**	74.67**	222.15**	347.38**	266.81**	332.57**	357.18**
C x S interaction	8	7.62**	2.26	2.83	3.84	7.89*	13.62*	7.58*	28.56*
Error	30	2.13	1.73	3.72	2.89	8.51	4.96	2.60	318.77
Total	44								
CV (%)		21.88	15.64	17.73	11.48	19.23	14.36	9.31	16.69

*Significantly lower at *P<0.05,* **Significantly lower at *P<0.01*

Table 6: Analysis of variance (ANOVA) of heavy metals contamination in Leaves of different tree species from FRIN

Sources	Df	Months after transplanting							
		2	**4**	**6**	**8**	**10**	**12**	**14**	**16**
Conta (C)	2	135.49	3443.62*	212.87	2784.87	2872.02	954.60	109.62	172.36
Species (S)	4	406.02**	994.70**	2251.94**	3336.24	9145.24**	9490.22**	1779.92**	950.53**
C x S interaction	8	374.74**	663.73**	279.23	1519.06	1313.74	435.82	125.21	57.22
Error	30	97.98	56.93	594.22	1963.00	1480.49	627.18	269.64	123.47
Total	44								
CV (%)									

*Significantly lower at *P<0.05,* **Significantly lower at *P<0.01*

Table 7: Analysis of variance (ANOVA) of heavy metals contamination in Leaves of different tree species from Ijebu-Igbese

Sources	Df	Months after transplanting							
		2	**4**	**6**	**8**	**10**	**12**	**14**	**16**
Conta (C)	2	177.76	1885.96**	807.09	97.40	2546.47**	183.20	115.56	112.29
Species (S)	4	163.59	697.85**	8945.52**	4987.92**	6575 52**	4937.18**	1912.52	714.83*
C x S interaction	8	74.92	980.29**	196.67	1263.78	513.86	494.50	262.39	109.23
Error	30	134.76	96.84	321.62	1053.47	450.84	540.93	128.67	70.17
Total	44								
CV (%)		58.50	37.26	46.76	66.33	46.29	53.83	38.79	37.14

*Significantly lower at *P<0.05,* **Significantly lower at *P<0.01*

uncontaminated soils, confirming significant contamination and justifying the selection of these soils for phytoremediation assessment (Kabata-Pendias & Mukherjee, 2007). The presence of multiple metals provides a realistic scenario for evaluating the tolerance and accumulation capacity of the selected tree species.

The ANOVA results for height growth in both FRIN (Table 2) and Ijebu-Igbese soils (Table 3) revealed highly significant species effects ($P < 0.01$) across all sampling periods. This indicates strong interspecific variation in growth performance under heavy metal stress, reflecting differences in tolerance mechanisms such as metal exclusion, sequestration, and detoxification (Pulford & Watson, 2003). Contamination effects were more pronounced at later growth stages, especially at 16 months after transplanting, suggesting cumulative stress effects of prolonged exposure to heavy metals. Significant contamination × species interactions observed at several growth stages indicate that species responded differently to increasing metal stress, reinforcing the importance of species selection in phytoremediation programs. The consistent significance of species effects across both soils suggests that certain species possess inherent tolerance traits that enable sustained growth despite heavy metal contamination. Species that maintain height growth under such conditions are considered suitable for phytoremediation because adequate biomass production is essential for effective metal removal from soil (Pilon-Smits, 2005). Collar diameter is a reliable indicator of woody plant vigour and structural stability under stress conditions. The highly significant species effects ($P < 0.01$) observed in both FRIN (Table 4) and Ijebu-Igbese soils (Table 5) confirm that heavy metals influenced stem development differently among species. The limited significance of contamination effects alone, particularly at early growth stages, suggests that some species were able to tolerate or buffer initial metal stress. However, the significant contamination × species interactions at later stages highlight differential adaptive responses. Species that maintained or increased collar diameter despite contamination demonstrate physiological resilience and efficient resource allocation under stress, traits commonly associated with phytostabilization and phytoextraction capacity (Mendez & Maier, 2008). Leaf metal accumulation is a key criterion for evaluating phytoremediation potential, especially phytoextraction. The highly significant species effects ($P < 0.01$) observed in both FRIN (Table 6) and Ijebu-Igbese soils (Table 7) indicate substantial variation in the ability of the tree species to absorb and translocate metals to above-ground tissues. Significant contamination effects at certain growth stages, particularly at 4 and 10 months after transplanting, suggest periods of heightened metal uptake. This pattern may be associated with active vegetative growth phases when nutrient and water demand and consequently metal uptake is high (Greger, 2004). The occurrence of significant contamination × species interactions further demonstrates that metal accumulation efficiency is species-specific and influenced by soil characteristics. Species with consistently higher leaf metal concentrations, coupled with sustained growth performance, are strong candidates for phytoextraction, as they can remove metals without severe growth suppression (Ali et al., 2013).

Conclusion

This study demonstrated clear interspecific differences in growth performance and heavy metal accumulation among the evaluated tree species under contaminated soil conditions. Variations in soil properties influenced metal bioavailability; however, species response was the dominant factor determining phytoremediation efficiency. *Gmelina arborea* consistently exhibited superior height growth, collar diameter development, and significant accumulation of heavy metals in leaf tissues across both FRIN and Ijebu-Igbese soils. *Terminalia superba and T. ivorensis* showed moderate tolerance and accumulation potential, while *Tectona grandis and Shorea roxburghii* performed relatively poorly. Overall, *Gmelina arborea* emerged as the most suitable species for phytoremediation of heavy-metal-contaminated soils.

Recommendations

Gmelina arborea is recommended for large-scale phytoremediation of heavy-metal-contaminated soils due to its superior growth and metal accumulation capacity. *Terminalia superba and T. ivorensis* may be integrated as supportive species in mixed plantations. Long-term field trials, biomass disposal strategies, and assessments of below-ground metal accumulation are recommended to enhance remediation efficiency and environmental safety.

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