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Heavy Metal Level of Soil and Gmelina Plantation in Umuahia, Nigeria

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ABSTRACT

This study sought to provide information on levels of heavy metal in soil and gmelina vegetation located around a municipal solid waste dump. Soil and plant samples were collected from different sampling positions in a randomized complete block design. Levels of Zn, Pb and Cd in soil were 53.97-128.95, 6.12-55.92 and 1.4-11.23 mg/kg and 58.03-110.00, 10.00-26.00 and 0.08-2.02 mg/kg in gmelina leaves on a dry weight basis. The concentrations of Zn (128.9 ± 6.0 mg/kg) and Pb (55.9 ± 5.3 mg/kg) in soils were significantly ($P < 0.05$) higher at the crest than at the middle of the slope (101.2 ± 7.6 and 27.4 ± 2.9 mg/kg) or valley (53.9 ± 4.5 and 6.1 ± 1.3 mg/kg). In plants, the Zn concentration was statistically ($P > 0.05$) equal in leaves of gmelina stands located at the crest (110.0 ± 5.7 mg/kg) and middle slope (92.3 ± 8.2 mg/kg) but these values were significantly ($P < 0.05$) higher than the value obtained in the valley (58.0 ± 4.6 mg/kg). Pb was significantly ($P < 0.05$) higher in leaves of gmelina stands at the crest (26.0 ± 2.8 mg/kg) than on the middle slope (13.1 ± 1.7 mg/kg) and valley (10.0 ± 2.3 mg/kg) while Cd was significantly ($P < 0.05$) higher in leaves of gmelina stands located on the middle slope (2.0 ± 0.0 mg/kg) than in the valley (0.2 ± 0.0 mg/kg) and crest (0.08 ± 0.0 mg/kg). There were positive and negative correlations between heavy metals in soil and gmelina leaves at significant and non-significant levels. The findings show that the concentration of Cd was high, and if not checked, can possibly impair the productive potential of the gmelina plantation.

Keywords: crest, gmelina leaves, heavy metals, middle slope, municipal solid waste, soil, valley

INTRODUCTION

Human activities in urban centers have resulted in the generation of a large quantity of waste known as municipal solid waste (MSW). MSW includes refuse from households, non-hazardous solid waste from commercial, institutional, industrial, yard waste, and street sweepings (Ogwueleka 2009). The disposal of these wastes is a serious problem in developing countries because of the high level of corruption in governance, inadequate waste disposal equipment, improper planning and inefficient implementation of environmental laws. Indeed, a large quantity of refuse is generated in urban centers and about a third and half of this waste goes uncollected (Sweet 1999). Solid waste varies in composition, which may be influenced by factors, such as location, culture affluence (Adefemi and Awokunmi 2009). The composition of MSW include garbage, scrap tyres, lubricant oil containers, electrical appliances, metal scrap, plastic, ashes as well as empty containers of canned food, which can constitute health hazard and serious environmental decay. Consequently, the management of our environment and the handling of waste from anthropogenic activities are of high interest to researchers, regulatory bodies, environmental advisory agencies and policy-makers all over the world (Afolabi and Ogundiran 2008).

Improper waste disposal is one of the major routes by which heavy metals may find their way into soils, water, and subsequently living tissues of plants, animal and man. A higher metal content in soils occurs most frequently within urbanized areas (Singh and Kumar 2006). The chemical forms of metals in soil can strongly influence their uptake by plants (Pichtel and Anderson 1997) either as mobile ions present in the soil solution through the roots (Davies 1983) or through foliar adsorption (Chapel 1986) resulting in bioaccumulation of the elements in plant tissues (Amusan *et al.* 2005). This however, is dependent on type of metal, plant species and plant part (Juste and Mench 1992). Metal contamination of the environment is a significant worldwide phenomenon.

The environmental status of the 2.2 ha of pure *Gmelina arborea* Roxb. (Verbenaceae) plantation in Umuahia is fast becoming unwholesome due to uncontrolled dumping of MSW around the plantation. The composition of the wastes can influence heavy metal level of the soil and subsequent uptake by gmelina stands. Several recent studies have been carried out on MSW dump soil (Pichtel and Anderson 1997; Okoronkwo *et al*. 2006) and metal uptake by water leaf, cocoyam, okro and paw paw (Amusan *et al.* 2005), *Talinum triangulare* and *Carica papaya* (Ebong *et al*. 2008), *Manihot esculenta*, *Xantosoma mafaffa* and *Talinum triangulare* (Oluyemi *et al.* 2008) as well as *Amaranthus cruentus* (Adefemi and Awokunmi 2009) around MSW dump, but in recent times, there has been a global concern for better understanding of urban soil pollution (Manta *et al*. 2002) and vegetation present in cities. In areas with high influx of human and industrial activities, urban forests plantation are the only habitats that serves as sink for pollutants, and the leaves of such tree plantations are to be used as a reflection of the quantitative uptake of metals in plants. A thorough literature search has shown that no work has been carried out on heavy metal level of soil and unique ecosystem such as pure *Gmelina arborea* Roxb plantation. This paper, therefore, was designed to have an understanding of the influence of MSW on metal level of soil and leaves of gmelina plantation.

MATERIALS AND METHODS

Influence of municipal solid waste on heavy metal level of soil and leaves of gmelina plantation was carried out in pure *Gmelina arborea* at Okpara Square Umuahia, Nigeria. Umuahia is located on the lowland rainforest zone of Nigeria (Keay 1959), which lies

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on latitude 05° 29′ to 05° 42′ N and longitude 07° 24′ to 07° 33′E. The area has an average rainfall of 2238 mm per year that is distributed over seven months rainy season period (Nzegbule and Ogbonna 2008). Its minimum and maximum temperature is 23 and 32°C, respectively and a relative humidity of 60-80% (Ogbonna and Nzegbule 2010).

Collection of soil and plant samples

Soil samples were randomly collected from three different sampling positions (crest, middle slope and valley) along a toposequence. The control sample was collected from the municipal solid waste dump. Soil samples from each sampling positions were bulked, properly mixed and air-dried to a constant weight before screening with a 2 mm sieve. The fraction that passed through the sieve was placed in a well labeled cellophane bag for analysis of heavy metals.

Leaf samples of gmelina were collected with litter trays whose size is 1 m × 1 m × 0.2 m with base covered with polythene material. Three (3) litter trays were placed at the crest, middle slope and valley. The control sample was collected from the gmelina plantation at the Forestry Research Institute of Nigeria (FRIN) Umuahia. The leaf samples were placed in well labeled envelopes before oven drying at 70°C to a constant weight. The dried samples were milled with Wiley milling machine and the replicate samples were analysed for Zn, Pb and Cd.

Analytical procedure

The analysis was carried out according to the method of Steinborn and Breen (1999). Digestions of both soil and plant samples (1 g) were carried out in 10 ml concentrated HNO_3-HCl solution (3: 1, analar graded) at approximately 125°C. Digested samples were then filtered and subsequently diluted with de-ionized water and the clear supernatant was analysed. All glassware was acid-washed using 10% nitric acid before use. Blanks and standards were made up using the same method. All determinations were carried out by means of a Varian Plus atomic absorption spectrophotometer (AAS) using an air-acetylene flame. The data were subjected to one-way analysis of variance (ANOVA) using Statistical Package for Social Science (SPSS) v. 15 and mean separation done according to Steel and Torrie (1980) at $P < 0.05$.

RESULTS AND DISCUSSION

Heavy metal level in soil

The concentrations of heavy metals in soil at the gmelina plantation are summarized in **Table 1**. The concentration of Zn in soil ranged from 53.9 ± 4.5 (valley) – 128.9 ± 6.0 mg/kg (crest). The sampling position (crest) closest to the municipal solid waste dump had the highest ($P < 0.05$) concentration of Zn (128.9 ± 6.0 mg/kg) in soil and this value was significantly ($P < 0.05$) higher than values obtained in soils at middle slope (101.2 ± 7.6 mg/kg) and valley (53.9 ± 4.5 mg/kg). The range of Zn in this study is well below 655-770 mg/kg (Pichtel and Anderson 1997) and 188-1350 µg/g (Kakulu 2001). However, the concentration of Zn in this study was higher than 0.0118-0.0988 mg/kg in a similar study (Pawan *et al.* 2006). The sources of Zn in the soil, since there were no industries in Umuahia may be associated with the various component of wastes at the dump such as magazine papers (Alexander and Pasquini 2004), lubricating oil containers in which Zn is one of the additives (Okunola *et al.* 2007) and metal scraps. Cd in soil ranged from 1.1 ± 0.3 (valley) – 11.2 ± 0.9 mg/kg (crest). The value of Cd at the crest (11.2 ± 0.9 mg/kg) and middle slope (8.1 ± 1.5 mg/kg) were statistically ($P < 0.05$) equal but these values were significantly ($P < 0.05$) higher than the value obtained in soil at valley (1.1 ± 0.3 mg/kg). Thus, this suggests that Cd has high mobility rate. The level of Cd at the crest substantially exceeds the average concentration of Cd in worldwide soils which is 0.06 mg/kg (He *et al* 2005). The high level of Cd (in soil) observed in this study may be attributed to large quantities of used fluorescent light tubes

Table 1 Heavy metal concentrations (mg/kg) in soils under gmelina plantation.

Heavy metals	Crest*	Middle slope*	Valley*	MSW dump (control)*
Zn	128.95 ± 6.0 b	101.25 ± 7.6 c	53.97 ± 4.57 d	207.66 ± 24.2 a
Cd	11.23 ± 0.9 b	8.10 ± 1.5 b	1.14 ± 0.3 c	19.82 ± -1.7 a
Pb	55.99 ± 5.3 b	27.46 ± 2.9 c	6.12 ± 1.3 d	88.43 ± 9.5 a

* = Different letters within a column indicate significant differences (P<0.05).
MSW = municipal solid waste

Table 2 Heavy metal concentrations (mg/kg) in gmelina leaves.

Heavy metals	Crest*	Middle slope*	Valley*	Control *
Zn	110.00 ± 5.7 a	92.33 ± 8.2 a	58.03 ± 4.6 b	20.03 ± 2.8 c
Pb	26.00 ± 2.8 a	13.10 ± 1.7 b	10.00 ± 2.3 b	1.10 ± 0.1 d
Cd	0.08 ± 0.0 c	2.02 ± 0.0 a	0.20 ± 0.0 b	ND

* = Different letters within a column indicate significant differences (P<0.05)
ND = not detected

and metal paint containers at the dump. Wearing of paints from the body of vehicles is a major contributor of Cd in the environment (Asthana and Asthana 2006), hence, paint contains this element. Cd is not an essential nutrient and is highly toxic for plants where it produces oxidative stresses (Dixit *et al.* 2001), in the soil-plant system it is easily absorbed and transported by transpiration stream (Salt *et al.* 1995) to stem, leaves and fruits (Moral *et al.* 1994). The high concentration of Cd in soil may have produced toxic impact on the gmelina stands by reducing its productive potential. The ions of Zn and Cd bind strongly to soil particles, cause metal pollution when dissolved in water and inadvertently negate the activity of micro and macro organisms in soil (Pawan *et al.* 2006). The concentration of Pb in soil ranged from 6.12 (valley) – 55.92 mg/kg (crest), which was lower than 210 mg/kg (Pichtel and Anderson 1997), within the average concentration in worldwide soil which is 10-150 mg/kg (He *et al.* 2005) but exceed 25 mg/kg Pb in soil (Canadian Environmental Quality 1992). The accumulation of heavy metals in soils is a big environmental problem since this could have long-term implications for the biological, chemical and physical properties of agricultural and forest soil and its fertility as well as productivity (Nicholson *et al.* 2003). Heavy metal accumulation in soil may be dependent on factors such as composition of waste, type of soil, chemical form of pollutants and intensity of rainfall. The source of Pb can be attributed to large quantities of battery at the dump, since batteries are good sources of several elements including Pb, Cd and Ni (Lisk 1988). Elevated Pb in soils may decrease soil productivity, and a very low Pb concentration may inhibit some vital plant processes, such as photosynthesis, mitosis and water absorption with toxic symptoms of dark green leaves, wilting of older leaves, stunted foliage and brown short leaves and brown short roots (Kabata-Pendias 2001; Yang *et al.* 2004). Generally, the concentration of Zn, Cd and Pb were highest in the municipal solid waste dump (control) than in crest, middle slope and valley.

Heavy metal level in gmelina leaves

Heavy metal level in gmelina leaves is summarized in **Table 2**. Normally, plant metal levels for Zn, Pb and Cd vary in the ranges of 25-200, 1-12 and 0.1-2.4 mg/kg dry weight, respectively (Fleming and Parle 1977; Alloway and Ayres 1997). The highest concentration of Zn was obtained in leaves of gmelina stands located at crest (110.0 ± 5.7 mg/kg) and middle slope (92.3 ± 8.2 mg/kg) and these values were significantly ($P < 0.05$) higher than the value obtained in gmelina stands at valley (58.0 ± 4.6 mg/kg). The concentration of Zn in gmelina leaves ranged from 58.0 ± mg/kg (valley) – 110 ± 5.7 mg/kg (crest). The concentration of Zn (58.0 ± 4.6 – 110 ± 5.7 mg/kg) in gmelina leaves was similar to its concentration (53.9 ± 4.5 - 128.9 ± 6.0 mg/kg) in the soil. Usually, Zn and Zn^{2+} are the forms of Zn that are readily available to plants and its uptake has been reported to be linear with concentration in soil (Kabata-Pendias and Pendias 1992). The range of Zn in gmelina leaves is within the range proposed by Fleming and Parle (1977) and Alloway and Ayres (1997), which could have aided in normal physiological development of the stands. Zn is an essential micronutrient to higher plants and is involved in several metabolic processes (Balsberg Pahlsson 1989; Marschner 1995). Above certain threshold, this element (Zn) is toxic but, due to its role of micronutrient, plants can not exclude its uptake. In order to resist the damaging effect of excesses of heavy metals in soil, plants adopted different strategies which are active not only in hyper-accumulators, where they are definitely accentuated but also in normal plants, and they vary according to the plant genotype (Foy *et al.* 1978; Carafa *et al.* 2009). Some of the most effective regulation mechanisms are exclusion, reduced transfer to the shoot of metals adsorbed at the cell walls of the root, chelation and compartmentation of the metals in the vacuole through the production of organic acids and formation of metal-binding polypeptides known as phytochelatins (Hall 2002). The highest concentration of Pb in gmelina leaves was obtained in gmelina stands located at crest (26.0 ± 2.8 mg/kg) and this value was significantly ($P < 0.05$) higher than values obtained in gmelina stands at middle slope (13.1 ± 1.7 mg/kg) and valley (10.0 ± 2.3 mg/kg). The concentration of Pb in gmelina leaves ranged from 10 ± 2.3 mg/kg (valley) – 26.0 ± 2.8 mg/kg (crest). The uptake of this metal resulted to its bioaccumulation in gmelina leaves, thus, exceeded the range of 1-12 mg/kg Pb in plants (Fleming and Parle 1977). Plants growing on metal contaminated soils may mine and deploy metals in their organs. The high concentration of Pb in gmelina stands might have resulted to die-back of some of gmelina branches. Pb does not play any significant role in plants physiology. High concentration of Pb in soil has been implicated for the death of plants and Pb contaminated soils are often devoid of vegetation (Thornton 1982). Similarly, when plants are subjected to stress, they become weaker (Odjegba 2005) and as stress lasts for considerable time, latent damage develop develop into chronic disease in plants (Larcher 1981). Leaf chlorosis, poor nutritional quality, stunted growth as well as reduction in biomass production are symptoms and signs of metal toxicity to plants (Clijsters *et al.* 1999). The highest concentration of Cd in gmelina leaves was obtained in gmelina stands located at middle slope (2.0 ± 0.0 mg/kg) and this value was significantly ($P < 0.05$) higher than values obtained in gmelina stands at valley (0.2 ± 0.0 mg/kg) and crest (0.08 ± 0.0 mg/kg). The concentration of Cd in gmelina leaves ranged from 0.08 ± 0.0 mg/kg (crest) – 2.0 ± 0.0 mg/kg (slope). The contents of Cd in the leaves of gmelina stands fall within the range of 0.1 - 2.40 mg/kg (Alloway and Ayres 1997). The high level of Cd in leaves of gmelina stands at middle slope may be associated with the leaching effect of rainfall, considering the sloppy nature of the site. Environmental impact of Cd as well as its effect has been a source of major concern (Kakkar *et al.* 2004; Bakirdere and Yaman 2008). The outbreak of Itai-itai disease in Japan was due to consumption of rice containing high levels of Cd (Asthana and Asthana 2006) is one of the adverse effects of environmental pollution due to its toxicity. People exposed to low levels of Cd over time may incur kidney damage, osteomalacia, bone deformities, cardiovascular system and reproductive system damage (WHO 1993; Curtis and Smith 2002; Fritioff and Gregerl 2007).

Correlation between metals in soils and gmelina leaves

The correlation coefficient between the concentrations of metals in soils and leaves of gmelina stands at crest, middle slope and valley is summarized in **Table 3**, **4** and **5**. At the crest, Zn in soil correlated negatively at ($P < 0.05$) with metals in gmelina leaves except for Pb that it (Zn) correlated with positively at $P < 0.01$; Cd in soil correlated positively at ($P < 0.05$) with heavy metals in gmelina leaves while Pb in soil correlated negatively with metals in gmelina leaves at $P < 0.05$ (**Table 3**).

Table 3 Estimates of correlation coefficient between heavy metals in soil and heavy metals in gmelina leaves at crest.

	Zn	Pb	Cd
Zn	-0.739 ns	0.878 **	-0.739 ns
Pb	-0.436 ns	-0.436 ns	-0.436 ns
Cd	0.697 ns	0.697 ns	0.697 ns

** = significant at 1%
ns = not significant

Table 4 Estimates of correlation coefficient between heavy metals in soil and heavy metals in gmelina leaves at middle slope.

	Zn	Pb	Cd
Zn	0.551ns	0.317ns	0.371ns
Pb	0.971ns	1.000*	0.999*
Cd	-0.984ns	-0.997ns	-1.000*

* = significant at 5%
ns = not significant

Table 5 Estimates of correlation coefficient between heavy metals in the soil and heavy metals in gmelina leaves at the valley.

	Zn	Pb	Cd
Zn	-1.000**	0.934**	1.000**
Pb	0.999*	-0.998*	0.998ns
Cd	1.000**	-1.000**	1.000**

* = significant at 5%
** = significant at 1%
ns = not significant

At middle slope, Zn in soil correlated positively at ($P < 0.05$) with metals in gmelina leaves; Pb in soil correlated positively with heavy metals but was only significant ($P < 0.05$) with Pb and Cd in gmelina leaves while Cd in soil correlated negatively with heavy metals in gmelina leaves but was only significant ($P < 0.05$) with Cd (**Table 4**).

At the valley, Zn in soil correlated positively at ($P < 0.01$) with Pb and Cd but negatively with Zn in gmelina leaves; Pb in soil correlated negatively with Pb but positively with Zn in gmelina leaves at ($P < 0.05$) while Cd in soil correlated positively with Zn and Cd but negatively with Pb in gmelina leaves at $P < 0.01$ (**Table 5**).

CONCLUSION

The results of this research showed that open dumping of municipal solid waste is not only unwholesome but environmentally unfriendly with its concomitant effect of heavy metals on soil and plants. Zn (128.9 ± 6.0 mg/kg) and Pb (55.9 ± 5.3 mg/kg) in soil were more concentrated at the crest than at middle slope and valley. The concentration of Cd in soil was statistically ($P < 0.05$) equal at crest and middle slope but were higher than valley. In gmelina plantation, the concentration of Zn in leaves of gmelina stands at crest was not different ($P < 0.05$) from middle slope but was higher than valley. Pb and Cd were more concentrated in leaves of gmelina stands located at crest and middle slpoe respectively. For the soil and gmelina leaf sample, the concentrations of the heavy metals in this study were found to follow a decreasing order: Zn > Pb > Cd. The source of the metal is most probably from the municipal solid waste dump that composed of excessive unsorted solid waste such as batteries, metal scraps, vegetable matter, plastics, glasses, fluorescent tubes, lubricating oil containers among others. The study also showed a correlation between heavy metals in soils and gmelina leaves. Some metals correlated positively while others correlated negatively at significant ($P < 0.01$ and $P < 0.05$) and non-significant ($P < 0.05$) levels.

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