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EVALUATION OF HEAVY METAL CONCENTRATION IN AGRICULTURAL SOIL, A CASE STUDY OF DAMATURU AND ITS ENVIRONS.

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ABSTRACT

The accumulation of heavy metals in agricultural soil due to increase in both natural and anthropogenic pollution sources is an issue of serious concern to crop production, human and animal health. Some heavy metals are essential in trace quantities for healthy growth and efficient plant yields, e.g. iron, zinc, copper, manganese, cobalt, and chromium. But in excess concentration, they constitute health hazards to plants, humans and animals. Heavy metals such as cadmium, mercury and arsenic are purely nonessential micronutrients to plants and they inhibit plants growth and eventually destroy them. Five soil samples were carefully collected from areas where large farms were cultivated in Damaturu and its environs, the soil samples were analyzed to determine the concentration of the following heavy metals: lead, chromium, cadmium, iron, zinc, manganese, copper and nickel present in the soil. The soil PH values were measured and recorded. The concentration of the heavy metals present in the soil samples were analyzed using Atomic Absorption Spectrometer (AAS) and the values obtained were compared with the international set standards. Generally, the heavy metal concentrations of the soil samples were within the acceptable limits and the agricultural soil in the area is considered not polluted. The correlation of the

concentration values of the heavy metals indicates that some of the heavy metals have a common source or origin.

Keywords: heavy metals, contamination, concentration, plant, soil and pollution.

1.0 INTRODUCTION

Recent increase in food shortages within the semi-arid region of Africa has called for intensive research in identifying the factors responsible for it, and possible solution to the prevailing food insecurity. It is obvious that climate change has contributed immensely to food insecurity within the semi arid region due to its effect on the amount of annual rainfall and drought prevalence within the region. Political instability and terrorism have directly or indirectly affected food production in the area. Besides the well known factors that have contributed to low food production in the region, there is another salient factor which affect food production globally, and its effects cannot be overlooked in the Semi arid region of Africa. Soil pollution by heavy metals is a factor that has indirectly contributed to food insecurity globally due to its harmful effects on plant physiology and metabolic processes. It inhibits photosynthesis process and mineral uptake in plants. Soil is considered to be polluted when it contains high concentrations of heavy metals such as nickel, cadmium, cobalt, copper, iron, manganese, molybdenum, vanadium, strontium, zinc, lead, arsenic, and mercury. The term "heavy metals" refers to any metallic element that has a relatively high density and is toxic or poisonous even at low concentration (Lenntech et al., 2004). Plants are sensitive to both deficiency and excessive availability of some heavy metals in the soil. Contamination of agricultural soil by heavy metals is a serious environmental issue due to its ecological adverse effects. Toxic elements such as heavy metals are considered as soil pollutants due to their widespread occurrence and their acute and chronic toxic effect on plants grown from such soils (Reeves and Baker, 2000). Generally agricultural soils have not been fertile as it used to be in the time past despite the use of quality fertilizers to improve soil fertility in the semi arid regions. In recent times, increase in industrialization, urbanization and certain anthropogenic activities have directly enhanced the enrichment of heavy metals in agricultural soil. Activities such as mining, smelting of metals, burning of fossil fuels, oil spillage, and use of fertilizers, herbicides and pesticides in agriculture, indiscriminate disposal of domestic and industrial wastes have contributed much to the heavy metal content of the soil. Friedlova (2010) investigated the influence of heavy metals on soil biological and chemical properties. Aderinola et al., (2009) reported that the concentration of heavy metals in the sediment of Lagos lagoon was generally low and it is within the permissible limits described by WHO and FEPA. Excess accumulation of heavy metals in arable land affects food quality and human health. Evidence of heavy metal contamination of farm land and uptake by heavy metals in vegetables and fruits in Romania and Brazil were reported by Lacatusu et al., (2008). They observed that the toxic effects of some heavy metals in vegetable such as copper and lead affect several human body organs such as liver, kidneys, spleen and lungs, causing various biochemical defects. Therefore, it is important to monitor heavy metal concentrations in farm lands. Semi arid area such as Damaturu in Yobe State in Nigeria has little or no record on the effects of heavy metals on crops growth and yields. The climatic condition of the area favors the cultivation of the following crops; groundnut, millet, guinea corn, beans and vegetables. This study is focused on evaluating the heavy metal concentration of the agricultural soils in Damaturu and its environs.

2.0 MATERIALS AND METHODS

The study area is located in longitude 11^{o} $56^{'}$E and latitude $11^{o}45^{'}$N. It is known to be underlain by the sediments of Chad basin. It has a semi- arid climate characterized by long dry season (October – May) and a short rainy season (June to September). The annual rainfall ranges from 500mm – 1000mm (Agada et al., 2011). The selection of the sampling sites was based on ease of access and safety. Soil samples were collected from farm lands along, Gujba, Potiskum, Maiduguri, Gashua roads and from the Yobe state university area where there were large farm lands. The samples were collected from top soil layer (0-30 cm) and their pH values were recorded. The samples were stored in loosely fastened plastic bags in a dark room.

2.1 Analytical Instrumentation

A Perkin- Elmer 800 model Atomic Absorption Spectrometer with inverse longitudinal Zeeman Effect background correction system was used for the quantification of the heavy metals present in the soil samples. This instrument was equipped with a Perkin-Elmer THGA type graphite oven and an AS-70 auto- sampler. The AAS apparatus was warmed for 15 to 20 minutes before carrying out the analysis. Concentration measurements of the heavy metals (Cu, Co, Cr, Ni, Fe, Mn, Zn and Pb) were determined from a working curve after the calibration of the instrument with standard solutions of known concentration.

2.2 Sample Digestion and Analysis

The soil samples were dried in an oven at about 100^{o}C. The dry samples were gently crushed and sieved to collect grain sizes below 60µm. 2g of each soil sample was weighed and heated to a temperature of 500^{o}C. The soil samples were digested by wet ash method following the process recommended by International Organization for Standardization, ISO 11466 (Melaku et al., 2005). This consisted of using 6ml each of concentrated H_2SO_4 and Hydrochloric acid to digest the sample for 2 hours over a low heat at 60°C. The digested samples were diluted to a volume of $20cm^3$ with deionised water and then filtered to remove silicate and other insoluble materials that could clog the atomizer. The stock solution of the samples was aspirated into the Atomic Absorption Spectrometer (AAS) equipped with mono-elemental hollow cathode lamps and digital read out to ascertain the elements of interest at specific wavelength and lamp current. A plot of concentration against the absorbance constitutes the concentration of the element under study. The characteristic wavelengths are element specific and accurate to 0.01 – 0.1nm. To obtain the element specific wavelengths, a light beam from a lamp whose cathode is made of the element being determined is passed through the graphite tube. A photon multiplier in the system was used to detect the amount of reduction of light intensity due to absorption by the analyte, and this was related to the amount of the element in the sample.

2.3 **Data Analysis**

The data obtained was analyzed using STATISTICA software. Basic statistics such as minimum, maximum, mean, standard deviation and correlation coefficient were used to evaluate the data obtained. Correlation coefficients among various heavy metals were calculated and possible sources of heavy metal were identified.

3.0 **RESULTS AND DISCUSSION**

Table 1. The table below shows the summary of results of the analyzed soil samples.

Sample	Heavy Metals Concentration (mg/kg)							
	Lead	Chromium	Cadmium	Nickel	Copper	Iron	Manganese	Zinc

	(Pb)	(Cr)	(Cd)	(Ni)	(Cu)	(Fe)	(Mn)	(Zn)
A	0.46	2.26	0.24	0.43	0.80	190.00	25.70	5.30
B	0.50	2.15	0.32	0.41	0.70	200.00	22.48	3.50
C	0.42	1.80	0.28	0.47	0.62	212.00	26.33	6.40
D	0.58	2.96	0.23	0.39	0.46	196.00	26.06	5.20
E	0.32	2.35	0.21	0.31	0.56	180.00	24.30	4.15
Average	0.46	2.30	0.26	0.40	0.628	195.60	24.97	4.19
S.D	0.10	0.42	0.04	0.06	0.130	11.87	1.60	1.12
Max.	0.58	2.96	0.32	0.47	0.80	212	26.33	6.4
Min.	0.32	1.80	0.21	0.31	0.46	180	22.48	3.5

S.D = Standard deviation, Max = Maximum, Min = Minimum.

Table 2. Comparison of the heavy metal concentration values obtained with the International set standards.

Sample	Heavy Metals concentrations in mg/kg							
	Lead	Chromium	Cadmium	Nickel	Copper	Iron	Manganese	Zinc
Damaturu	0.46± 0.10	2.30±0.42	0.26±0.04	0.40±0.06	0.63±0.13	195.60±11.87	24.97±1.60	4.19±1.12
G.B	300	150	3	75	140	-	-	300
Austrilia	100	100	5	100	100	-	-	300
Canada	200	75	8	100	100	-	-	400
Poland	100	100	3	100	100	-	-	300
Germany	500	200	2	100	50	-	-	300

Japan	100	-	-	100	125	-	-	250

Source: (Lacatusu, 2000). G.B = Great Britain.

Table 3. Pearson's Correlation of the Heavy Metals.

	Lead	Chromium	Cadmium	Nickel	Copper	Iron	Manganese	Zinc
Lead	1							
Chromium	0.531	1						
Cadmium	0.291	-0.545	1					
Nickel	0.395	-4.880	0.600	1				
Copper	-0.148	-0.583	0.401	0.425	1			
Iron	0.383	-0.457	0.706	0.861	0.035	1		
Manganese	0.115	0.130	-0.484	0.373	-0.243	0.239	1	
Zinc	0.058	-0.209	-0.169	0.629	-0.074	0.527	0.928	1

Table 4. Soil Sample PH values

S/N	Sample	PH Values
1	A	6.60
2	B	7.10

3	C	6.72
4	D	7.20
5	E	7.40

Soil polluted with heavy metals is known to be dangerous to human, animals and plants. Consumption of agricultural products contaminated with heavy metals could cause serious health complications. Lead is a potential environmental pollutant. It is released into the environment through the combustion of petroleum products and the disposal of both industrial and certain domestic waste that contain lead particles. Lead particles accumulate in the soil and they get easily absorbed by plants. Lead is a nonessential element for plant growth. The result of this study showed that the mean concentration of lead in agricultural soil in the area of study is 0.46 $\pm$ 0.10 mg/kg. The mean concentration of lead in the agricultural soil samples analyzed is within the acceptable limit of the international sets standards as shown in table 2 above. Hence the soil is not polluted with lead. Excess Lead concentration in agricultural soil causes a number of defects in plants, e.g. stunted growth, chlorosis and inhibition of seed germination (Morzck and Funicclli, 1982). It affects the process of photosynthesis by the inhibition of carboxylating enzymes (Stiborova et al., 1987).

Chromium is found in rocks, animals, plants and soil. It can be liquid, solid or gas and it is used in electroplating of metals; magnetic tape; and pigments for paints, cement, paper, rubber and other materials. Chromium compounds are toxic to plants and it affects plant physiological and development system. The mean concentration of chromium in the agricultural soil in the study area is 2.30 $\pm$ 0.42 kg/mg. The main sources of Chromium contamination are steel industries and sewage sludges. The soil is not polluted with Chromium since the mean concentration of

Chromium in the area is within the acceptable limit as shown in table 2. Excess Chromium in agricultural soil causes inhibition in seed germination (Peralta et al., 2001). It retards the production of chlorophyll and anthocyanin which are essential for plant photosynthesis (Boonyapookana et al., 2002). Plants cultivated in soil polluted with Chromium could cause serious health hazards when consumed. Chromium (VI) compounds are known human carcinogens and can cause damage to the liver and kidney (ATSDR, 2000). Cadmium is a nonessential element for plant growth and development. The mean concentration of Cadmium in the soil in the study area is 0.26 $\pm$ 0.04 kg/mg as shown in table 2. The soil is not polluted with Cadmium when compared with the international set standards as shown in table 2. Plants grown in soil polluted with Cadmium are mostly affected by chlorosis, stunted growth, rolling of leaves and possibly death. Cadmium reduces the absorption of nitrate and its transport from root to shoots by inhibiting the nitrate reductase activity in the shoots (Hernandez et al., 1996). Some sources of Cadmium to agricultural soil are batteries and inorganic fertilizers produced from phosphate ores which constitute a major source of diffuse cadmium pollution (Eaton, 2005).

Nickel occurs naturally in soil in trace amount. It is an essential element for plant growth and development. The mean concentration of Nickel in the agriculture soil investigated is o.40 $\pm$ 0.06 kg/mg. The accumulation of Nickel in agriculture soil is enhanced by the deposition of Nickel particles from the combustion of petroleum products such as gasoline and the deposition of Nickel containing particles from both industrial and domestic waste on arable land. Nickel is good for plant metabolism, but in excess amount it is toxic to plant. Excess concentration of Nickel in soil inhibits seed germination, shoot and root growth, affect branching development, fruit production and enhance iron deficiency such that causes chlorosis. It affects nutrient absorption by roots and general plant metabolism. High uptake of Ni^{2+} causes a decline in water content of dicot and monocot plant species (Pandey and Sharma, 2002). Copper is an essential element for plant growth and general development (Thomas et al., 1998). It is important for Carbon dioxide assimilation and ATP synthesis during photosynthesis and healthy growth of plants. Excess concentration of copper in soil causes growth retardation and leaf chlorosis (Lewis et al., 2001). The concentration of copper in the soil in the area investigated is 0.63 $\pm$ 0.13 kg/mg. The concentration is within the acceptable limit as shown in table 2 above, therefore, the soil is not contaminated by copper. Iron is an essential micronutrient for plants. It performs a vital function in the development of chlorophyll, chloroplast and photosynthesis process. The concentration of iron in the soil investigated is 195.60 $\pm$ 11.87 kg/mg as shown in the table 2 above. This value is within the acceptable limit and the soil is considered non-polluted (Table 2). The toxicity of iron occurs when it accumulates in high concentration. Excess iron in the soil causes reduction in photosynthesis and eventually leads to crop low yield (Sinha et al., 1997).

Manganese is an essential element for healthy plant growth and is involved in the reduction of nitrates in green plants and algae. It is an essential trace element in higher animals, and participates in the action of many enzymes. The concentration of manganese in the agricultural soil in the area investigated is 24.97 $\pm$ 1.60 as shown in table 2. The soil is not contaminated with manganese. Excess manganese in agriculture soil could interfere with the absorption, translocation and utilization of other essential mineral elements such as calcium, magnesium, iron and phosphorous (El-Jaoual and Cox, 1998). Zinc is an essential micronutrient in plants. It is involved in both physiological and metabolic processes in both plants and animals. Zinc is required in various enzymatic reactions, energy transfer and protein synthesis. It influences the activities of hydrogenase and carbonic anhydrase, stabilization of ribosomal fractions and synthesis of cytochrome (Tisdale et al., 1984). The concentration of Zinc in the area investigated is 4.19 $\pm$ 1.12

kg/mg as shown in table 2 above. The area is not contaminated with zinc when compared with the international set standards as shown in table 2 above. Zinc toxicity in plants limit growth in both root and shoot (Ebbs and Kochain, 1997: Fontes and Cox, 1998). Excess zinc can also give rise to manganese and copper deficiencies in plant shoot. A correlation value of 1.0 is a perfect positive correlation. The variables having the values R> 0.5 and R< -0.5 are considered significant. Zinc and manganese correlated positively well in the study area as shown in table 3. This implies that zinc and manganese have a common source. Iron and nickel correlated positively well as well as iron and cadmium, their high positive correlation shows that these metals have common origin.

The PH of the soil in the study area is an important factor which influences mineral migration in the soil. The PH values of the soil varied from 6.60 to 7.40 in water indicating slight acidic to slight basic as shown in table 4. The acidic nature of the soil could be caused by agricultural activities such as application of fertilizers, insecticides, bush burning and Harmattan dust. According to Brady and Weil (1999), the neutral to alkaline soil PH values in semi-arid areas is due to low rainfall and alkaline compounds that were not leached away.

4.0 Soil Remediation

Soil contaminated by heavy metals can be best remediated through the following processes: phytoextraction, rhizofiltration and phytostabilization. Plants are very effective in remediating soil contaminated by heavy metals (Wenzel et al., 1999). Phytoextraction is the process whereby plants known as hyper-accumulators are grown in a soil contaminated with heavy metals, in order to reduce the concentration of the heavy metals. Hyper-accumulators are plants species which have the ability to absorb more than 1000milligram per kilogram of cobalt, copper, chromium, lead and nickel (Baker and Brooks, 1989). The hyper-accumulators absorb the heavy metals through their roots and translocate the metals to their shoots and stems. The plants are harvested when fully grown and burnt. Their ashes are taken to a waste landfill for disposal. The hyper-accumulator plants are planted several times on the contaminated soil to achieve an acceptable limit for the heavy metals concentration in the soil.

Rhizofiltration refers the use of plant roots to absorb, concentrate and precipitate toxic metals from a contaminated soil or groundwater. This process involves the use of suitable plants with stable root systems; the plant roots are supplied with contaminated water to acclimate the plants. The plants are transferred to the contaminated site to collect the contaminants, and once the roots are saturated, they are harvested. Various plant species can effectively remove heavy metals such as copper, cadmium, nickel, chromium, lead and zinc. In Chernobyl, Ukraine, Sunflowers were used in this way to remove radioactive contaminants from groundwater (EPA, 1998).

Phytostabilization involves the reduction of the mobility of heavy metals in soil. Immobilization of metals can be achieved through reduction of soil erosion, wind erosion and contaminant solubility. Addition of soil amendments such as organic matter, phosphates, and alkaline agents can reduce solubility of metals in soil. Phytostabilization is a cost efficient method when compared with other methods (Schnoor, 1997).

5.0 Conclusion

Generally, heavy metals are natural occurring substances which are present in the soil at low levels and in large quantity it is dangerous to plants. Excess quantity of heavy metals in the soil affects plant physiological and photosynthetic processes. It is dangerous to both humans and animals when consumed through food crops. It was observed that the heavy metal concentration of the soil investigated is within the acceptable international standard as shown in table 2 above, and has not constituted soil pollution in the area. Damaturu and its environs are not highly industrialized, therefore, the industrial waste produced from the environment is very little. Crop production in the semi arid region of Nigeria is highly dependent on the use of both organic and inorganic fertilizers. Animal manure, organic fertilizers and sewage sludge, enhances the enrichment of heavy metal content of agriculture soil. Contamination of agricultural soil is a serious environmental issue that deserves proper attention in order to avert its adverse effect on human and animals. Heavy metal contaminated crops are well known health hazards. Therefore, periodic investigation of heavy metal concentrations in agricultural soil is highly important for good economic planning and the ecosystem.

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