Evaluation of the Phytoremediation Ability of *Amaranthus cruentus*, *Brassica oleracea* var. *capitata* and *Helianthus annuus* in Metal Contaminated Soil

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Abstract

Artisanal mining for Gold in Zamfara state of Nigeria led to massive contamination of the environment with lead (Pb) leading to poisoning and death. The approach for the clean-up involves excavation of the soil and dumping it somewhere which is a temporary solution that is equal to postponement of the reckoning day. The aim of this study was to evaluate the phytoremediation potential of some plants as a cheaper solution to this problem. The treatments consisted of three plant species (*Amaranthus cruentus*, *Brassica oleracea* var. *capitata* and *Helianthus annuus*) factorially combined with four soils (the top soils of Regular Agricultural soil from BUK, Lead (Pb) contaminated soil from Zamfara, Soil from Sheka area peri-urban garden along the banks of Salanta stream contaminated with tannery effluents from Sharada Industrial Estate and BUK soil artificially polluted with a standard addition of Nitrate salts of Pb, Cd, Cr and Ni at the rate of 200 mg/kg for Pb and Cr, and 40 mg/kg for Ni and Cd), all laid out in a Completely Randomized Design (CRD) and replicated three times. Results have shown that Amaranth emerged as the plant with the highest accumulation of metal in its tissue. Across the three plant species, Pb is the most highly accumulated metal and Ni is the least concentrated. The Bioconcentration Factor (BCF) index >2 was recorded for Cr, Mn, and Cd in the tissue of Amaranth. The Translocation Factor index >1 was recorded for Mn, Cd, Pb, Cr, Ni, and Zn. Cabbage had relatively high BCF index for some metals, meaning it can sequester Cd, Cr, Mn and Pb. The TF index >1 was recorded for all of the metals. The implication of this is that Cabbage had the ability to translocate all the tested metals. Sunflower has also accumulated a good amount of the various heavy metals. BCF index >2 was recorded with Cd, Cr, Cu, Mn and Pb. But the TF index >1 was seen across all the metals. Soil from Zamfara was observed to produce plants with significantly higher Pb in the shoot, while differences in metal content in the shoot tissue among plant species was not significant.

Keywords: Phytoremediation; Heavy Metals; Amaranth; Cabbage; Sunflower

Introduction

The well-being of living organisms is a function of the quality of their environment. Soil environment, being a major sink for all contaminants that are found in water or air occupy a place of primary concern. The pollutants that contaminate soil ecosystem could be of organic or inorganic origin. Organic pollutants of soil

include Polycyclic Aromatic Hydrocarbons (PAH), Polychlorinated biphenyls (PCB), pesticides, herbicides, 2,4,6 Trinitrotoluene (TNT), crude oil and its derivatives. Radionuclide, metalloid and heavy metals are examples of pollutants of inorganic origin.

Heavy metals contamination of soil is a serious threat that affect soil quality and soil function due to the metals' toxicity, persistence

as well as tendency for diffusion [10], thereby engendering a major environmental crisis [30]. The danger associated with heavy metal pollution is due to their toxicity and persistence. Heavy metals are persistent because as elements they cannot be broken down, that is they cannot be degraded or destroyed (non-biodegradable).

The main sources of heavy metals that pollute soil ecosystem are two, namely naturally occurring in the geologic formation of rocks in a given area and from anthropogenic sources, that is human activities such as civil, agricultural and industrial activities [10]. Serious environmental problems with global dimensions have been created unwittingly in the quest towards industrialisation of countries [30]. This stockpile of heavy metals in the soil above the natural background concentration has consequential environmental and public health implications.

Heavy metals present in soil enter the food chain via crop plants that grow on contaminated soils. These metals get into our body through our drinking water, for instance water sourced near a source of a pollutant such as mining companies. Heavy metals also get in to our system from high ambient air concentration. Modern life has made heavy metals common contaminant because they are found in electronics, machineries and industrial products for household usage. The disturbing trend is that these persistent pollutants tend to bio accumulate in living organism due to its low solubility and the fact that some of these heavy metals are documented as carcinogenic and mutagenic substances [7]. Kano state in Nigeria is the most populous state based in 2006 census and commercial nerve centre of northern Nigeria. As a result of this food demand is high particularly fruits and vegetables. This made farmers to grow crops using water from Watari River that is contaminated with tannery effluents containing a lot of heavy metals. Artisanal mining for Gold in Zamfara state led to massive contamination of the environment with lead (Pb) leading to poisoning and death. The approach for the clean-up involves excavation of the soil and dumping it somewhere which is a temporary solution that is equal to postponement of the reckoning day. The aim of this study was to evaluate the phytoremediation potential of *Amaranthus cruentus*, *Brassica oleracea* var. *capitata* and *Helianthus annuus* in soils contaminated with heavy metals. To achieve this aim, our objectives were to collect and analyse soils for Cr, Mn, Fe, Ni, Cu, Zn, Cd

and Pb from 3 sites, determine the uptake of metals from the soil to the plant, determine the bioconcentration factor and translocation factor of each plant and compare the metal translocation ability of the test plants *vis-à-vis* one another.

Materials and Methods

Site for soil collection

A location in the Bayero University Kano (BUK) new site campus that is annually cultivated for Crop production was chosen as a site in which heavy metals contamination were not expected. This farmland is close to road intersections that run through the campus. The Salanta stream (SS) is a stream that traverses through Sharada Industrial Estate in Kano state Nigeria, that conveys raw industrial wastewater especially tannery effluents that abound in the area. This same stream is used for irrigation in downstream Sheka area by farmers operating peri-urban gardens along its banks. Zamfara soil (ZS) was collected from a site in *Abare* village in Anka L.G.A. of Zamfara state Nigeria where artisanal gold mining is practiced with concomitant lead contamination.

Experimental site

The trial was conducted at the University farm of the Faculty of Agriculture, situated at the new site of Bayero University, Kano about 5 km west of Kano city in Ungogo Local Government Area of Kano state. The site is within latitude 12° 58' N and Longitude 8° 25' E [23] in the Sudan Savannah ecological zone of Nigeria with a mean annual rainfall and temperature of about 800mm and 31 °C respectively [15,23].

Treatments and experimental design

The treatments consisted of three plant species (*Amaranthus cruentus*, *Brassica oleracea* var. *capitata* and *Helianthus annuus*) factorially combined with four soils (the top soils of Regular Agricultural soil from BUK, Lead (Pb) contaminated soil from Zamfara, Soil from Sheka area peri-urban garden along the banks of Salanta stream contaminated with tannery effluents from Sharada Industrial Estate and BUK soil artificially polluted with a standard addition of Nitrate salts of Pb, Cd, Cr and Ni at the rate of 200 mg/kg for Pb and Cr, and 40 mg/kg for Ni and Cd), all laid out in a Completely Randomized Design (CRD) and replicated three times.

Test plants

The plants that were used in this experiment were three. These include; *Amaranthus cruentus* (Vegetable Amaranth), *Brassica oleracea* var. *capitata* (Cabbage) and *Helianthus annuus* (Sunflower).

Cultural practices

- **Land preparations:** In the field, the experiment was conducted in plastic pots measuring 5 litre by volume. The pots were labelled and filled with 5 kg of the soil samples. The pots were irrigated with sufficient water and left to drain for 2 days (holes had been drilled into the pots manually to allow for drainage).
- **Source of the seeds:** The seeds for *H. annuus* were obtained from Institute for Agricultural Research (IAR) at Samaru Zaria. The *Amaranth* seeds were obtained from National Horticultural Research Institute (NIHORT) Bagauda, Kano. The seeds of *B. oleracea* were bought from a licensed dealer at Sabon-Gari market, Kano.

Variety

The varieties of the seeds used for the trial were as follows:

- *A. Cruentus* - NH84/457 -E
- *B. Oleracea* - Gloria F1
- *H. annuus* -Funtua.

Sowing

The seeds were sown on the 31st of October 2011 at the rate of 3-4 seeds per hole within each pot at depth of 2cm for *B. oleracea* and *H. annuus*. The *A. cruentus* seeds were broadcast and lightly covered with soil and mulched to avoid losing seeds by wind or during watering. Germination began on 6th November, 2011 for *H. annuus* plants. The *B. oleracea* and *A. cruentus* were replanted on the 12th November 2011, and germination began 4 days after for all. The seedlings were thinned to 3 plants per pot at three weeks after sowing.

Fertilizer application

NPK 15:15:15 was applied at the rate of 200 kg/ha in single application by side placement 3 weeks after sowing.

Irrigation

Though the plants are tropical, and most are drought tolerant, water is a limiting factor for high productive yield. Therefore watering can was used in the field to irrigate the plants at one day interval throughout the duration of the study.

Weeding, pest and disease control

H. annuus: As a crop, the yield is reduced due to weed competition, but rarely eliminated. The weed was mechanically pulled out from the pots. *B. oleracea* and *A. cruentus* were also well tended and any weed found in the pots was removed manually.

Harvesting

All the three plants were manually harvested by uprooting at 11 weeks after sowing. The harvested plant parts (root and shoot) were used for plant analysis.

Soil analysis

The soil samples from the various sites were subjected to routine soil analysis like determination of particle size by hydrometer method, soil pH using pH meter, measurement of electrical conductivity, determination of Organic carbon using dichromate wet oxidation method, available phosphorus was measured using Bray-P1 method, total nitrogen was determined by the regular micro Kjeldahl procedure, and determination of exchangeable bases using Atomic Absorption Spectrophotometer, all these were determined using standard procedures [4,13].

Heavy metal analysis

Concentration of total metal and bioavailable metal in soil

Total metal in soil was determined by digesting 250mg of soil (on sand bath) in a mixture of 3 ml of Nitric acid, 2ml of Hydro-

fluoric acid, and 1ml Hydrogen peroxide solution in a platinum vessel and lightly covered. After the acids had been digested and evaporated, 0.5ml of HNO₃ and 10ml of water were added, and then transferred into 50ml measuring flasks, and filled to volume and kept in polyethylene bottle for the determination of the metal content. Bioavailable metals were determined by "BCR" sequential extraction scheme [28].

Plant analysis

After harvesting the test plants, the roots and shoots of the plants were washed with tap water and rinsed with deionised water and the mass weighed on a weighing balance. After taking measurement of the fresh plant material, the plant was dried in an oven to a constant weight at 70 °C for 48 hours. The dried plant material was weighed again for both the shoot and root regions. Then the material was milled and a few grams (0.12-0.2g for root and for shoot) of the grounded sample was digested with a mixture of HCl/HNO₃ (4:1, v/v), and heavy metals like Pb, Zn, Ni, Cd, Cr, Mn, Fe and Cu in the digest determined by flame AAS (Buck Scientific 210 VGR) at appropriate metal wavelength.

Meteorological data

The data on rainfall, temperature, relative humidity and sunshine hours covering the period of the experiment were collected from the meteorological unit of Irrigation Research Station of IAR Ahmadu Bello University Zaria.

Bioconcentration factor and translocation factor

Bioconcentration factor is used as an index to determine the quantity of metal extracted by the plant from soil (Mellem., *et al.* 2009). The Bioconcentration factor (BCF) is a measure of the plant's ability to absorb and accumulate metal from its growth medium which in this case is soil. The BCF index according to [9] is calculated using the formula,

$$BCF = \frac{\text{MetalConcentration tissueofwholeplant}}{\text{Initialconcentrationofmetalsoil}}$$

It was asserted by [5] that higher BCF value is an indicator of plant species' suitability for phytoextraction. BCF values 2 were regarded as high values [22].

Translocation factor (TF) is a value that indicate the ability (or inability) of plant to translocate metal from the root to the shoot region of the plant [20]. This ratio is given by the following relation;

$$TF = \frac{\text{Metalconcentrationaerialparts}}{\text{Metalconcentrationroots}}$$

A TF value < 1 is an indicator of metal accumulation and storage in root. While TF value > 1 indicate translocation to aerial part of plant [22]. Hence the plant is suitable for phytoremediation.

Statistical analysis

The data obtained from the research was subjected to analysis of variance (ANOVA) in completely randomised design, utilizing SAS software for statistical analysis. [24]. The treatment means were separated using Duncan's Multiple Range Test [8].

Results

Heavy metal concentration in soils from BUK, Salanta and Zamfara

Figures 1- 3 shows the individual concentration of Cr, Mn, Fe, Ni, Cu, Zn, Cd and Pb in the soil samples from BUK, Salanta and Zamfara. There is a wide degree of differences in the concentrations of the same metals across the soils mentioned. Cr concentration ranges from 4.6mg/kg for Zamfara to 9.4 mg/kg for both BUK and Salanta soils. Manganese concentrations start from 10mg/kg for BUK and Zamfara soil, peaking at 20 mg/kg for Salanta soil. Fe concentration ranges from 22.8 mg/kg for Salanta soil, 34.2 mg/kg for Zamfara and reaches 97.2 mg/kg for BUK soil.

The concentration for Ni was found to have a close margin, starting with 25.0 mg/kg for BUK to 30.2 mg/kg for Zamfara and finishing at 32.4 mg/kg for Salanta. Cu concentration on soil ranges from 12 mg/kg for Zamfara, to 18 mg/kg for BUK and 24.2 mg/kg in Salanta soil.

Zn concentration ranges from 92.8 mg/kg in Zamfara to 316.0mg/kg for BUK and reaching 358 mg/kg for Salanta. Cd level ranges from 4.8 mg/kg for BUK and Zamfara, reaching 9.8 mg/kg for Salanta. Pb concentration in the soil was found to be 100 mg/kg for Salanta, reaching up to 111.2 mg/kg in BUK and finishing at 144.4 mg/kg for Zamfara soil. Figure 9 - 12 shows the heavy metals concentration in each particular soil visually and the trend remains the same.

Figure 1: Relative comparison of heavy metals concentration in soils from the three sites i.e. BUK, Salanta and Zamfara.

B: BUK, S: Salanta and Z: Zamfara.

Comparison was made of the concentration level of all the metals mentioned earlier (figure 4), BUK soil was characterised by the highest concentration of Zn and Pb. Salanta soil was characterised with the highest concentration of Zn, 358 mg/kg; Ni, 32.4mg/kg; Cu, 24.2mg/kg, Manganese, 20mg/kg and Cr, 9.4 mg/kg (Figure 2).

Heavy metal concentrations in plant samples based on the portal of storage

Amaranth from BUK soil shows that Pb is the most extracted metal by the plant with 63.8 mg/kg shoot and 35.7 mg/kg for root (Figure 5). The cabbage from BUK soil also presented Pb as the most extracted metal by the plant with 62.0 mg/kg in the shoot and 37.9 mg/kg root concentration (Figure 6). At BUK Sunflower follows suit, showing Pb as the most extracted metal with 61.1

mg/kg in the shoot and 40.8 mg/kg root concentrations (Figure 7). Apart from Pb, Amaranth, Cabbage and Sunflower on BUK soil shows a good extraction of Cd, at the rate of 31.5 mg/kg in the shoot and 16.8 mg/kg in the root for Amaranth, 39.5 mg/kg in the shoot and 19.9 mg/kg in the root for Cabbage; and 33.4 mg/kg in the shoot and 16.6 mg/kg found in the root of Sunflower. The least extracted metal was Ni at 7.4 and 6.5 mg/kg in the shoot and root respectively.

Amaranth from Salanta soil shows that Pb was the most dominant metal extracted followed by Cd, Cr, and Ni. Pb was extracted at the rate of 49.8 mg/kg - shoot and 47.2 mg/kg - root concentration. Cd was concentrated at 31.3 mg/kg - shoot and 29.0 mg/kg - root. Cr was extracted at rate of 19.4 mg/kg - shoot and 17.5 mg/kg - root. Ni was found at 8.5 mg/kg -shoot and 7.4 mg/kg - root (Figure 8). Cabbage from Salanta shows a predominance of Pb, followed by Cd, and Zn, Fe, Cr, Cu and Ni. Pb was extracted at 49.5 mg/kg for both shoot and root; while Cd was concentrated at the rate of 32.2 mg/kg - shoot and 25.0 mg/kg - root (Figure 9).

Sunflower on Salanta soil shows a similar predominance of Pb, followed by Zn and Cd. Pb was concentrated at the rate of 49.0 mg/kg - shoot and 39.3 mg/kg - root. Zn at the rate of 33.3 mg/kg - shoot and root and Cd at 18.7 mg/kg- shoot and 29.1 mg/kg - root (Figure 10). The least extracted at this site was Ni in Cabbage at the rate of 6.5 mg/kg - shoot and 4.7 mg/kg - root concentration (figure 9).

Amaranth on Laboratory contaminated soil depicts Pb as the most extracted metal. The concentration of Pb in the plant was 140.2 mg/kg - root and 58.3 mg/kg - shoot, while Ni was the least extracted at 6.5 mg/kg - Shoot and Root. (Figure 11). Cabbage extracts highest Pb concentration at the rate of 54.6 mg/kg. The least extracted was Ni at 6.5 mg/kg - Shoot and 3.7 mg/kg - Root (Figure 12). Sunflower on Laboratory soil extracted Pb as the most accumulated metal at the rate of 72.6 mg/kg - shoot and 229.6 - root. The least extracted metal here was Ni at 6.5 mg/kg -shoot and 3.7 mg/kg - root (Figure 13).

Amaranth on Zamfara soil shows Pb as the most readily extracted metal with 494.0 mg/kg - root and 283.8 mg/kg - shoot, it was the highest metal concentration in plant species in this work (Figure). This was followed by Cabbage with Pb concentration of

450.9 mg/kg -root and 74.0 mg/kg - shoot. Sunflower in Zamfara soil extracted Pb at the rate of 172.6 mg/kg - root and 162.9 mg/kg - shoot (Figure).

Figure 2: Heavy metal accumulation in root and shoot of Amaranth determined from Bayero University New campus soil (2011/2012 dry season).

Figure 3: Heavy metal accumulation in root and shoot of Cabbage determined from Bayero University New campus soil (2011/2012 dry season).

Figure 4: Heavy metal accumulation in root and shoot of Sunflower determined from Bayero University New campus soil (2011/2012 dry season).

Figure 5: Heavy metal accumulation in root and shoot of Amaranth determined from Salanta peri urban garden soil (2011/2012 dry season).

Figure 6: Heavy metal accumulation in root and shoot of Cabbage determined from Salanta peri-urban garden soil (2011/2012 dry season).

Figure 7: Heavy metal accumulation in root and shoot of Sunflower determined from Salanta peri-urban garden soil (2011/2012 dry season).

Figure 8: Heavy metal accumulation in root and shoot of *Amaranth* determined from Laboratory artificially contaminated soil (2011/2012 dry season).

Figure 11: Heavy metal accumulation in root and shoot of *Amaranth* determined from Zamfara lead contaminated soil (2011/2012 dry season).

Figure 9: Heavy metal accumulation in root and shoot of *Cabbage* determined from Laboratory artificially contaminated soil (2011/2012 dry season).

Figure 12: Heavy metal accumulation in root and shoot of *Cabbage* determined from Zamfara lead contaminated soil (2011/2012 dry season).

Figure 10: Heavy metal accumulation in root and shoot of *Sunflower* determined from Laboratory artificially contaminated soil (2011/2012 dry season).

Figure 13: Heavy metal accumulation in root and shoot of *Sunflower* determined from Zamfara lead contaminated soil (2011/2012 dry season).

Heavy metals concentration in shoot and roots as affected by different test plants and soil

Table 1 shows that the concentrations of Mn, Fe, Ni, Cu and Zn were not affected significantly by the different soils. For Cr Salanta and Laboratory soil had similar content of this element but they were statistically similar to BUK but significantly higher than Zamfara soil. BUK soil had significantly higher Cd content than Laboratory and Zamfara soils but was at par with Salanta soils. For Pb content Zamfara soil was significantly higher than all the other types of soil which statistically the same.

Significant differences in concentrations of heavy metals among plant species was only observed with respect to Cr and Pb. Cabbage had significantly higher concentration of Cr than Amaranth and Sunflower which were similar in Cr content. In terms of lead content Sunflower had significantly higher Pb content than Cabbage but was at par with Amaranth.

Table 2 shows the heavy metals concentration as affected by the soil types and plant species. The results revealed that there were no significant differences among soil with respect to concentrations of Cr, Fe, Cu and Zn, however, Zamfara soil had higher concentrations of Mn than BUK and Laboratory soil but at par with Salanta soil. It was also significantly higher in Ni content than Laboratory soil but statistically similar to BUK and Salanta soils. Lead (Pb) content of Zamfara soil was also significantly higher than Laboratory soil which was in turn higher than BUK and Salanta soils that were at par. In terms of Cd Laboratory soil had significantly higher Cd content than BUK and Zamfara soil but was at par with Salanta soil.

The three test plants did not differ in terms of the concentration of these heavy metals present in their tissue.

Treatment	Heavy Concentration (mg/kg)							
Soil	Cr	Mn	Fe	Ni	Cu	Zn	Cd	Pb
BUK	17.5ab	12.5	22.2	6.2	14.2	29.1	34.7a	62.3b
Salanta	21.3a	11.8	21.5	7.1	11.5	31.9	27.4ab	49.5b
Laboratory	21.3a	11.8	22.2	6.1	11.5	30.5	25.2b	61.8b
Zamfara	14.4b	13.1	20.7	7.5	10.6	26.6	24.3b	173.6a
Significance	*	NS	NS	NS	NS	NS	NS	**
SE (±)	2.71	2.66	2.29	1.37	2.35	4.67	4.03	24.13
Plant Species								
Amaranth	15.2b	12.5	21.5	6.9	12.6	30.2	27.8	86.4ab
Cabbage	23.7a	13	22	5.8	12.6	29.1	29.4	60.0b
Sunflower	17.0b	14	21.5	7.5	10.6	29.3	26.6	113.9a
Significance	*	NS	NS	NS	NS	NS	NS	*
SE (±)	2.35	2.3	1.98	1.19	2.04	4.04	3.49	20.9
Soil x Spp.	NS	NS	NS	NS	NS	NS	NS	NS

Table 1: Heavy metals concentration (mg/kg) in shoot of test plants as affected by soil from different sources and types of plants at Bayero University Kano (BUK) in 2011/2012 dry season.

Means followed with the same letter(s) within a treatment group are not significantly different at 5% level of probability using DMRT.

Treatment	Heavy Concentration (mg/kg)							
Soil sample	Cr	Mn	Fe	Ni	Cu	Zn	Cd	Pb
BUK	21.3	10.4b	23.8	7.8ab	16.9	31.9	17.7c	38.1c
Salanta	18.7	15.9ab	23.0	6.8ab	12.2	33.3	27.7ab	45.3c
Laboratory	14.2	13.8b	23.0	5.2b	13.3	43.7	36.2a	168.9b
Zamfara	19.2	20.7a	24.6	9.1a	17.8	30.5	22.2bc	372.5a
Significance	NS	*	NS	*	NS	NS	**	**
SE (±)	4.1	2.98	3.14	1.3	5.12	4.43	4.29	72.16
Plant Species								
Amaranth	14.1	17.7	22.6	7.9	16.0	30.2	26.3	120.5
Cabbage	20.3	15.6	23.2	6.0	11.1	34.3	27.4	168.8
Sunflower	20.7	12.3	25.0	7.7	18.0	33.3	24.2	179.2
Significance	NS	NS	NS	NS	NS	NS	NS	NS
SE (±)	3.55	2.58	2.72	1.13	3.83	3.83	3.71	6.49
Soil x Spp.	NS	NS	NS	NS	NS	NS	NS	NS

Table 2: Heavy metals concentration (mg/kg) in roots of test plants as affected by soil from different sources and types of plants at Bayero University Kano (BUK) in 2011/2012 dry season.

Means followed with the same letter(s) within a treatment group are not significantly different at 5% level of probability using DMRT.

Discussion
Heavy metals concentrations of soils

In this study four types of soils were used, namely BUK regular Agricultural soil, Salanta soil obtained from a peri-urban garden along the banks of Salanta stream, that is been used to irrigate the gardens neighbouring the stream. The importance of Salanta stream for this work is that it carries tannery effluent containing heavy metals like Chromium [10]. The third soil was taken at Abare village in Anka Local Government area of Zamfara state, Nigeria. Abare village is one of the places that were severely affected by Pb poisoning as a result of artisanal mining of Gold. The last soil named Laboratory soil was actually the BUK soil artificially contaminated with standard addition of the nitrate salts of Pb, Cr, Cd and Ni.

A careful look at concentration level of Cr, Mn, Fe, Ni, Cu, Zn, Cd, and Pb in various soils will generally indicate a pattern as well as variation in the form of metal concentrations across the soils. These trends all implicate anthropogenic source of heavy metal pollution for our soils. When taken as a whole (the soils), the most featured heavy metals in terms of abundance for the three soils were Zn and Pb. Zinc concentration in the soil was at the rate

of 358 mg/kg, 316 mg/kg and 92.8 mg/kg for Salanta, BUK and Zamfara soil respectively (Figure 2). The concentration level is far higher than the maximum permissible standard for Agricultural soil by both United State Environmental Protection Agency (1997) and Nova Scotia Environment and Labour Department (2004). The Pb concentration in the various soils was at the rate of 144.4 mg/kg, 111.2 mg/kg and 100 mg/kg for Zamfara, BUK and Salanta soils respectively. The highly significant ($P < 0.01$) level of Pb concentration in all the soil s is remarkable. The concentration is above the limit set by Great Britain and Nova Scotia, but is below the maximum permissible limit according to USEPA. However, it is a cause for concern when taken into account the potential for the metal to bioaccumulate, translocate and biomagnify across the food chain.

BUK soil was considered as normal agricultural soil without heavy metal contamination except for background metals that are mostly within the range for maximum permissible limit. The trend of heavy metal concentration in this soil were in the order; $Zn > Pb > Fe > Ni > Cu > Mn > Cr > Cd$. The level of Zn and Cd are well above the maximum permissible limits standards of [27] and Nova Scotia Environment and Labour Department. But the rest of the metals were below the limits. The relatively elevated level of metals in the soil, especially Pb may be attributable to the proximity of the farm site to roadside. The road near the farm is always busy with automobile traffic, and lead contained in petroleum from the exhaust pipes of these vehicles might be responsible for the level of Pb in the soil. This was also reported by studies in Nigeria that the soil and vegetation along some roadsides in Nigeria and concluded from the result that automobiles are a major source of heavy metal contamination to the neighbouring environment.

Salanta soil was taken from the peri-urban gardens along the banks of Salanta stream. The stream that carries industrial wastewater including tannery effluent also serves as source of water for irrigating gardens along its banks. The highest concentrations for Zn, Cu, Cd, Ni, Mn and Cr were found in this soil. This was caused by wastewater being used to irrigate the gardens. This is in agreement with [19,21,25]. Use of wastewater causes the build-up of toxic heavy metals in soils that poses public health threat.

The trends in heavy metal concentration in this soil were in the order: $Zn > Pb > Ni > Cu > Fe > Mn > Cd > Cr$. The metals in salanta were all below the maximum permissible limit except for Zn and Cd. The presence of Cr in this soil concur with [10], who reported that tannery effluent contains heavy metals like

Cr. Zamfara soil was taken from *Abare* village at a site that was known to be contaminated with Pb from processing of ores for Gold. A remarkable feature of this soil is that it has the highest concentration of Pb and poor in nutrients. The pattern of heavy metal contamination of this soil is in the trend; $Pb > Zn > Fe > Ni > Cu > Mn > Cd > Cr$. All of these metals were below the maximum permissible limit for Agricultural soil except for Cd, which was well above permissible limit. The elevated concentration of Pb in Zamfara soil is much reported [12,14].

Laboratory soil was actually BUK soil that was artificially contaminated with the standard addition of nitrate salts of Pb, Cd, Cr and Ni, at the rate of 200 mg/kg of Pb and Cr, and 40 mg/kg of Cd and Ni. These were in addition to any heavy metal contaminant present in the soil *ab initio*.

Plants and heavy metal extraction

Three plant species were used in this work, namely vegetable Amaranth (*A. cruentus*), Cabbage (*Brassica oleracea* var. *capitata*) and Sunflower (*Helianthus annuus* L.).

Amaranth

Amaranth emerged as the plant with the highest accumulation of heavy metals in its tissue (both root and shoot). It extracted the highest concentration of Pb and Zn. The ability of this plant to extract metals from soil varies with the different soil s used for the trial. The trend of heavy metal concentration for Amaranth grown in BUK soil were in order of $Pb > Zn > Fe > Cd > Cr > Mn > Cu > Ni$. For Salanta soil, the mean value of heavy metal concentration in the whole plant tissue was in the order: $Pb > Zn > Cd > Fe > Cr > Mn > Cu > Ni$. The Amaranth grown on Laboratory soil has the following trend of heavy metal accumulation; $Pb > Zn > Cd > Fe > Mn > Cu > Cr > Ni$. Finally, Amaranth in Zamfara soil extracts metal in the order of the following magnitude: $Pb > Zn > Cr > Fe > Cd > Cu > Mn > Ni$.

The Bioconcentration Factor index (BCF) > 2 for Amaranth in BUK soil was indicated for Cd, Cr and Mn, while Translocation Factor index (TF) > 1 value was for Pb, Cd and Mn. These results enable the conclusion that Amaranth can extract Pb, Cd and Mn from soil and translocate them to the aerial part. However, BCF index shows that Cr can be sequestered from the soil but has limited transportability to the above ground part, although the TF value is approaching unity. The TF index for Pb indicates that it can be translocated to the shoot. This differs from the report of

Cunningham and Berti (2000), that said major proportion of Pb taken by plant from the soil are stored in root.

Salanta soil has BCF index > 2 for Cd and Cr, while the TF index >1 was for Ni and Cr. These results enable the conclusion that Amaranth can sequester Cr from the soil and transfer it to the shoot, indicating a good remediation of Cr through the mechanism of phytoextraction. This is in [22,31], that reported Cr accumulation in *Amaranthus viridis* were primarily stored in shoots and roots in the order: Leaf > Root > Stem. It was reported by [22] that TF index > 1 at the level of 25 ppm Cr concentration in soil, indicating inability for translocation at higher concentrations possibly due to toxicity induced stress. The BCF and TF index for Cd indicate that Amaranth can sequester and translocate Cd to shoot region of plant.

Amaranth in Laboratory soil has the BCF value > 2 for Mn while the TF index > 1 was for Cr, Mn and Zn. These result shows that Amaranth can efficiently extract Mn from soil and translocate it to the above ground part. This is in agreement with an earlier work [31] where it was reported that 82% of Mn was accumulated by *A. viridis* in the aerial parts.

Amaranth in Zamfara soil present a result with BCF index > 2 for Cr, Mn, Cu, Cd and Pb, while the TF index was > 1 for Mn only, and Cd, Ni and Fe has limited translocation to the shoot. These results further corroborate our earlier conclusion that Amaranth can sequester Mn from soil and translocate it to the shoot. The high BCF index value of Cd, Cr, Cu and Pb point to the ability of Amaranth to mobilise and sequester the aforementioned heavy metals in soil similar to Zamfara, hence can serve as a good phytoremediation plant using the mechanism of phytostabilisation.

Assessment of the performance of Amaranth across all soils shows that the concentration of all the heavy metals accumulated in plant tissue fell below the maximum permissible limit as per the standard of WHO, with the exception of Cd, Ni and Pb. Cd and Pb are accumulated in the plant tissue several hundred times higher than the maximum permissible limit.

Cabbage (*Brassica oleracea* var. *capitata*) is another known leafy vegetable with potentials for phytoremediation. The heavy metals were extracted at varying levels by the plant, but the metal with the highest concentration in tissue of Cabbage was Pb. The magnitude of the mean value of metal concentration in Cabbage grown on BUK soil were in the order; Pb > Zn > Cd > Cr > Fe > Ni > Cu > Mn. For cabbage from Salanta soil, the pattern of metal concentration in its tissue were in the order; Pb > Zn > Cd > Fe > Cr > Mn > Cu > Ni. In Laboratory soil, the mean value of metals

extracted into plant tissue were in the trend: Pb > Zn > Cd > Cr > Fe > Mn > Cu > Ni. Zamfara soil had cabbage with the following trend of metal accumulation; Pb > Zn > Fe > Cd > Mn > Cr > Cu > Ni.

The BCF index >2 in cabbage from BUK soil was seen in Cd and Cr, while the TF index >1 was seen in Cd, Mn and Pb. The result enables the conclusion that cabbage can sequester Cd from soil and translocate it to the aerial part of the plant. This was in agreement with [3] who reported the accumulation of elevated amount of Cd and Pb in the above ground part of cabbage. In another previous work on Red Beet and Alfafa, it was reported that the above ground part accumulate high amount of Cd, with TF index of 2.81 and 1.50 for Red Beet and Alfalfa respectively. The >2 BCF for Cr indicated the ability of Cabbage to extract and sequester the metal in the root of the plant, with a limited translocation to the shoot region. Mn has a very good Bioconcentration as well as Translocation coefficient. This calls for more study to look into the possibility of enhancing this potential.

Cabbage grown on Salanta soil present a BCF index >2 for Cd and Cr, while the TF index >1 was seen in Cd, Cu and Ni. These results further add weight to our previous conclusion that cabbage was a good phytoremediation plant for Cd, employing the mechanism of phytoextraction [26].

BCF index >2 for cabbage from Laboratory soil was seen only in Mn. TF index >1 was seen in Cr, Fe, Cu and Ni. These result indicate that Mn can be sequestered and stored by cabbage in the root, but cannot be translocated to the aerial part. The TF value >1 for Cr, Fe, Cu and Ni indicate limited accumulation and translocation to the shoot.

Zamfara soil produced cabbage with BCF index >2 for Cr, Cd, Mn and Pb. The TF index >1 was recorded for Zn and was at unity with respect to Cr. These result led to the conclusion that cabbage can sequester Cd, Mn and Pb in the root, whilst it can extract and sequester Cr and Zn from the soil as well as translocate them to the shoot.

Assessment of the heavy metal accumulation in the plant tissue shows that the metals in the plant all fall below the maximum permissible limit except for Cd, Ni and Pb. These were in some cases several times higher than the maximum permissible limit.

Sunflower

This is one of the varieties of plants that are primary sources of vegetable oil and a known phytoremediation plants [30]. The

trend in the concentration of heavy metal in sunflower grown on BUK were in the order of; Pb > Zn > Cr > Cd > Fe > Cu > Mn > Ni. BCF index >2 was reported for Cd, Cr and Cu, while TF index >1 were seen in Cd, Zn and Ni. From these results we can conclusively say that Sunflower can sequester Cd, Ni and Zn from the soil and translocate them to the aerial part of the plant. Moreover, Sunflower can also extract and sequester Cr and Cu from the soil and store them in the root of the plant. The TF index value for Zn was in agreement with [17,18], who reported the suitability of Sunflower for the remediation of Zn contaminated soil. This potential can also be seen in Ni based on its TF index value.

The pattern of metal accumulation in Sunflower grown on Salanta soil were in the order; Pb > Zn > Cd > Fe > Cr > Mn > Cu > Ni. The BCF index >2 were seen in Cd and Cr, while TF index >1 was seen only in Pb. These results were somehow similar to the results of Sunflower from BUK soil, in that it exhibit the ability of the plant to extract and sequester Cd and Cr, as well as a good transportability of Pb (BCF = 1.4) to the above ground part.

The trend of heavy metal accumulation in Sunflower grown on Laboratory soil were in the order; Pb > Cd > Zn > Fe > Cr > Mn > Cu > Ni. The BCF index >2 was seen only in Mn, and TF index >1 were seen in Cr and Mn. These results enable us to reach the conclusion that Sunflower can extract Mn from the soil and translocate it into the shoot region of the plant. It also point at the ability of the plant to translocate Cr to the above ground part.

With respect to other added metals *i.e.* Cd, Ni and Pb, it was observed that they were not bioaccumulated possibly because at their elevated concentration in the soil, the plants were not able to extract and absorb the metals due to toxicity induced stress. This observation was equally true for Cabbage and Amaranth. But, in situation where the metals in high concentration were absorbed by the plant, they mostly remain in the root without being translocated to the shoot. This was in agreement with reports of [2,22,26]. Lead is a metal with limited bioavailability for plant uptake. They noted the limited ability of *A. dubius* to move Pb to the aerial parts [22]. The plant only achieved a TF index >1 at low concentration of 25 ppm.

Sunflower grown on Zamfara soil accumulate heavy metals according to the following descending order; Pb > Cd > Zn > Mn > Fe > Cr > Cu > Ni. The BCF index >2 was seen in Cr, Mn, Cd and Pb, while the TF index > 1 was recorded for Cd and Cu, but Cr has TF = 1. These result can enable us to conclude that Sunflower can extract and sequester Cd, Cr, Mn and Pb, but can only translocate Cd, Cu and possibly Cr (TF = 1). However this conclusion was contrary to

the views of [30] that reported the suitability of Sunflower for only phytostabilisation, due to its inability to translocate Cd to the aerial part.

However it should be noted that with regard to the very high BCF index recorded for Cd (10.0 for BUK, 4.8 for Salanta and 11.2 for Zamfara) this work is in agreement with the previous work of [30] who reported that Sunflower is a good phytoremediation plant in sequestering Cd from soil. The point of disagreement is in the ability of Sunflower to translocate a substantial amount of the metal, which was achieved in this work for both BUK and Zamfara soil. Assessment of the metal accumulation in Sunflower tissue indicated that some of the metals were extracted and bioconcentrated above the maximum permissible limit for plant. These metals were Cd, Cu, Ni and Pb.

Conclusion

Taking cognisance of the BCF and TF indices, they enable the conclusion that Amaranth (*A. cruentus*) can remediate Cr, Mn and Pb from soil. Cabbage can be used in Phytoremediation of Cd, Cr, Mn, and Pb and to some extent Fe from soil. Sunflower proved successful in the remediation of Cd, Cr, Cu, Mn and Pb. However, considering the high cost of Cabbage and its high water requirements, Amaranth and Sunflower are recommended for use in the Phytoremediation of these metals.

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