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Research Article

Growth and ability of *Senna alata* in phytoremediation of soil contaminated with heavy metals

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Abstract

The performance and impact of *Senna alata* on experimental heavy metal contaminated soil were investigated in this study. Soils in different pots were contaminated with different levels of lead, nickel, chromium and cadmium based on WHO limits for heavy metals. Seeds of *S. alata* were planted in the contaminated soils. The plant growth was studied for 60 days. Some soil parameters and heavy metal contents of the soil were evaluated at the beginning and at the end of the study. The leaf area, the plant height and the number of actively growing stems decreased with increase in the amount of each metal added to the soil. At 60 days, there was significant reduction ($p<0.05$) of the heavy metals due to the growth of *S. alata* compared to the soil without the plant. There was reduction in the total organic matter content and the pH of the soil, but the moisture content of the contaminated soils generally increased due to the growth of *S. alata*. There was a positive correlation ($p = 0.918$) between the percentage remediation and the bioaccumulation factor, suggesting that the remediation of the heavy metals by the plant mostly occurred through bioaccumulation. A positive correlation between the percentage reduction of the heavy metals and the reduction of pH of the soil noticed suggests that growth of *S. alata* leads to decrease in soil pH and will enhance the remediation of soil contaminated with the heavy metals. The findings of this study show that apart from the medicinal values of *S. alata*, it can be useful in remediation of heavy metal polluted soils which occurs mostly through phytoextraction.

Keywords: bioaccumulation; contaminated soil; heavy metals; phytoremediation; *Senna alata*

Introduction

Senna alata is native to tropical South America (i.e. French Guiana, Guyana, Surinam, Venezuela, Brazil and Colombia). It is widespread species with a scattered distribution throughout northern and eastern Australia. It is most common in the coastal and sub-coastal parts of the Northern territory and northern Queensland but less common along the central and southern coasts of Queensland. It has also been recorded in north-western Western Australia. It has naturalised in tropical Africa, tropical Asia, Papua New Guinea, Mexico, south-eastern USA (i.e. Florida), the Caribbean and on several Pacific islands (i.e. the Cook Islands,

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Fiji, Guam, Palau, Tonga, Western Samoa and Hawaii). It grows rapidly in full sun on a wide range of soils (Gilman and Watson, 1993)

There are many medicinal and industrial uses of *Senna alata*. *S. alata* is used as a laxative or purgative and in the treatment of skin problems (Villasenor *et al*., 2000; Idu *et al*., 2007; Lewis and Levy, 2011). In addition, many species of *Senna* have been shown to have the ability to enhance the remediation of different heavy metals. Some of such include: *Cassia tora* (Ghose and Singh, 2005; Gupta and Sinha, 2008), *C. multijuga* (Siringoringo, 2000), *C. siamen* (Kumar *et al*., 2002; Raju *et al*., 2008; Jamhulkar and Juwarkar, 2009), *C. fistula* (Hanif *et al*., 2007) and *C. italic* (Al-Qahtani, 2012). However, little or no information in literature on the ability of *S. alata* to enhance the clean-up of heavy metals contaminated was available as at the time of this study. Establishing such will add to the economic value of the plant and increase the number of plants that can be used to remove heavy metals from contaminated soil

Heavy metal pollution poses serious problem to the ecosystem and the dependent organisms. According to Aluko *et al.* (2018), several studies have linked heavy metal accumulation to numerous several health diseases and abnormalities which include short- and long-time safety alongside environmental and health risk. Heavy metals toxicity induces different physiological interferences in different organisms in the ecosystem affecting their performance and survival. According to Sarma (2011), exposure to high levels of heavy metals has been linked to adverse effects on human health and wildlife. In plants, heavy metal toxicity can be manifested in form of reduced root length and shoot height and reduced yield. These can occur due to the interference of heavy metals with net photosynthetic rate and limitations in stomatal conductance which occur as a result of the disorganization of chloroplast structure by heavy metals like Cr (Santana *et al*., 2012)

The major sources of heavy metals contamination are geological and anthropogenic activities (Dembitsky, 2003). Industrial effluents, fuel production, mining, smelting processes, military operations, utilization of agricultural chemicals, small-scale industries, brick kilns and coal combustion are the major anthropogenic activities that serve as sources of heavy metals to the environment (Zhen-Guo *et al*., 2002).The major heavy metals found in contaminated sites are lead, chromium, arsenic, zinc, cadmium, copper, mercury, and nickel (GWARTAC, 1997). The total or the amount of heavy metals present in the soil is a function of the metal present in the parent material, atmospheric deposition, agrochemical sources, organic waste, inorganic pollutants, crop removal ability and losses due to leaching, volatilization etc. (Alloway, 1995; Lombi and Gerzabek, 1998). As heavy metals generally do not undergo degradation, their impacts persist for long in the environment (Adriano, 2003). Therefore, it is important to remove the heavy metals from the environment.

The different methods of heavy metal remediation are classified into four categories namely; isolation, immobilization, toxicity/mobility reduction and extraction (GWRTAC, 1997). As was noted by GWRTAC (1997), immobilization, soil washing and phytoremediation are techniques that are frequently listed among the Best Demonstrated Available Technologies (BDATs) for remediation of heavy metal contaminated sites. Phytoextraction, rhizoextraction and phytostabilization (immobilization) are the major processes for phytoremediation of heavy metals. Phytoremediation takes the advantage of the unique and selective uptake capabilities of plant root system together with the translocation, bioaccumulation and contaminant degradation abilities of the entire plant body (Hinchman *et al*., 1995)

In this study, the potential of *Senna alata* to remediate soils contaminated with heavy metals was investigated using artificially contaminated soil. It was based on the discovery of the environmental role of *S. alata* putting to consideration the well documented medicinal functions of the plant. Reports of Silva *et al.* (2014) showed that *Cassia alata* can be found in area used to disposal of waste and contaminated with heavy metals, mainly cadmium, copper, zinc, and lead. Review by Sarma (2011) showed list of some hyperaccumulating plants; however, *S. alata* was not included in such list. This suggests that little is known about the potential of *S. alata* as a hyperaccumulator of heavy metals.

Materials and Methods

Sources of materials

Experimental design

The soil used for this study was obtained from the University of Lagos Botanical garden, Akoka Lagos, Nigeria. The soil was properly sieved to remove debris and stones. One kilogram of the sieved soil was used to fill each of the experimental pots (20 cm wide and 10 cm high). A total of seventy-eight pots were used grouped into twelve groups of six pots each and each group was contaminated with a given amount of each heavy metal based on WHO limits (WHO, 1996) for heavy metals in plants. A group of three pots were not contaminated with any heavy metal and served as control for the growth study. Each group was divided into two subgroups (three pots each). One subgroup had no *Senna alata* which served as the control for the remediation study (Njoku *et al.*, 2014) while each pot of the other subgroup was planted with ten seeds of *S. alata*.

Contamination of soil and planting of seeds

Each of the two groups of pots was experimentally contaminated with a given a quantity of a particular heavy metal. The levels of the heavy metals used were: lead (150 mg/kg, 300 mg/kg and 450 mg/kg), cadmium (1.5 mg/kg, 3.0 mg/kg, 4.5 mg/kg), nickel (25 mg/kg, 50 mg/kg and 75 mg/kg) and chromium (50 mg/kg, 100 mg/kg and 150 mg/kg). After contamination, the soils and the salts were thoroughly mixed with hand trowel to ensure uniform distribution of the metals. The pots were regularly watered with 100 mls of water.

Determination of the performance of S. alata in heavy metal contaminated soil

The performance of the *S. alata* seedlings in heavy metal contaminated soils was determined by measuring the plant height, the leaf area (Francis *et al.*, 1969) and number of actively growing branches.

Collection and preparation of soil and plant samples

The soil samples were collected from each of the experimental pot on the day of contamination (initial sample) and on 60 days after planting the seeds of *S. alata* (final sample). Plant samples were collected by carefully uprooting the plants from the experimental pots on day 60. The soil and the plant samples were air dried. The soil samples were sieved while the plant samples were ground to fine powder.

Determination of heavy metals levels in the soil and plant samples

The heavy metals in the soil were extracted using the Potentials Bioavailable Sequential Extraction (PHASE) method as described by Basta and Gradwohl (2000) while the heavy metals in the plant samples were extracted using the wet ashing method as described by Tüzen (2003). The levels of heavy metals in the extracts were determined using the atomic absorption spectrophotometry method as was described in Aluko *et al.* (2018).

Bioaccumulation factor and remediation potentials

The bioaccumulation factor (BAF) of the plant tissues was calculated as a ratio of heavy metal level in the plant tissue to that in the soil using the formula of Ghosh and Singh (2005).

$$\text{Bioaccumulation Factor} = \frac{\textit{Heavy metal level in the plant tissue}}{\textit{heavy metal level in the soil}}$$

The ability of *S. alata* to remediate heavy metal contaminated soil (remediation potential) was calculated using the formula stated in Njoku *et al.* (2014) as follows

Remediation potential (% reduction due to plant growth)

$$= \frac{\textit{Amount of heavy metal lost due to growth of S.alata}}{\textit{final heavy metal level in the soil in soil without plant}} \text{ X } 100$$

Amount of heavy metal lost due to growth of *S. alata* = final amount of heavy metal is soil without *S. alata* - final amount of heavy metal in soil with *S. alata*.

Effect of the growth of S. alata on the physico-chemical characteristics of the contaminated soil

The effect of growth of *S. alata* on the pH and the cation exchange capacity of the heavy metal contaminated soil were determined as described by Ugwu (2015). The moisture content and the total organic matter contents of the soils were determined as described by O'Kelly (2004) and Azlan *et al.* (2012) respectively. The impact of the growth of the plant on each parameter was determined by subtracting the final value in the soil with the plant from the final value in soil without plant and using that as a percentage of the final level of the parameter in soil without the plant.

Statistical analyses

Data obtained were statistically analysed using the GraphPad Prism software 7.0 version. Means were compared at 95%, 99% and 99.9% levels of significance. Data were correlated to determine their levels of association and relatedness.

Results

The performance of Senna alata in heavy metal contaminated soil

The leaf area, plant height and number of actively growing branches of *S. alata* grown in heavy metal contaminated soils are shown in Table 1. The leaf area, the plant height and the number of actively growing stems generally decreased with increase in the amount of each metal added to the soil. Plants in lead contaminated soil had best growth performance while the performance of the plant was generally worst in cadmium contaminated soil. The values of the growth parameters varied according to the metals. The leaf area of the plant in soil treated with 450 mg lead and 75 mg nickel were significantly lower ($p<0.05$) than the leaf area of the plant in the soil without the heavy metal. The leaf area has positive correlation of $r = 0.909$ and $r = 0.845$ with the shoot height and the number of branches respectively. Cadmium had greatest effect on leaf area and number of actively growing branches (41.67% reduction and 80.34% reduction respectively) which the greatest effect on the plant height was produced by nickel (71.70% reduction). For all the growth parameters measured, the effects of nickel and cadmium treatment were least on the leaf area and greatest on the number of actively growing branches. For lead treatment, the least effect was on the actively growing branches (31.62%) and the greatest effect was on the plant height (45.28%) and in the case of chromium treatment, the effect was least on the leaf area (36.67%) and greatest on the number of the actively growing branches (68.38%).

Heavy metal content of the soil and the percentage loss for each heavy metal

The amount of each of the heavy metals in the soil at the end of the study and the percentage loss for each heavy metal is shown in Table 2. The amount of each heavy metal in the soil reduced at the end of the study (60 days). Further reduction of the amount of each heavy metal was observed in soils with *S. alata* compared to soils without the plant at the end of 60 days. The highest reduction of the metals due to the growth of *S. alata* occurred in soil with 3.0 mg/kg of Cd (82.83%). The least reduction was observed in soil treated with 50 mg/kg of Ni (18.60 % reduction). There was significant reduction ($P<0.05$) of the heavy metals due to the growth of *S. alata* compared to that in soil without plant.

Table 1. The leaf area, plant height and number of actively growing branches of *S. alata* grown in heavy metal contaminated soils

Heavy metal	Amount added to the soil (mg/kg)	Leaf area (cm^2)	Plant height (cm)	Number of actively growing branches
Lead	0	3.00±0.622	15.90±0.361	11.70±1.528
	150	2.40±0.403	9.80±2.646	9.70±1.528
	300	No Growth	No Growth	No Growth
	450	2.03±0.212	8.70±0.345	8.00±2.00
	% Effect (reduction)	32.33%	45.28%	31.62%
Chromium	0	3.00±0.622	15.90±0.361	11.70±1.528
	50	2.20±0.191	10.00±0.808	5.30±1.115
	100	2.00±0.064	6.40±0.351	3.70±1.528
	150	1.90±0.071	6.00±0.200	3.70±2.002
	% Effect (reduction)	36.67%	62.26%	68.38%
Nickel	0	3.00±0.622	15.90±0.361	11.70±1.528
	25	2.28±0.064	9.20±0.723	4.30±1.528
	50	2.20±0.509	5.40±0.200	3.70±1.115
	75	1.80±0.177	4.50±0.153	3.00±1.000
	% Effect (reduction)	40.00%	71.70%	74.36%
Cadmium	0	3.00±0.622	15.90±0.361	11.70±1.528
	1.5	2.20±0.504	8.20±0.667	4.30±1.528
	3.0	1.80±0.177	5.10±0.115	4.30±2.517
	4.5	1.75±0.212	5.50±0.208	2.30±0.577
	% Effect (reduction)	41.67%	65.41%	80.34%

Values = mean ± standard error of mean

Table 2. Heavy metal level (mg/kg) in soils before and after remediation with *S. alata.*

Heavy metal	Amount added to the soil (mg/kg)	Initial level	Final level in soil without plant	Final level in soil with plant	Percentage reduction due to plant growth
Lead	150	147.90±0.005	117.67±0.005	84.05±0.005	28.57
	300	295.40±0.003	168.80±0.004	No Growth	Not Applicable
	450	446.92±0.006	207.87±0.004	165.52±0.006	20.37
Chromium	50	46.50±0.002	37.20±0.003	26. 37±0.003	21.05
	100	97.09±0.003	55.47±0.004	45.16±0.004	18.59
	150	148.02±0.004	68.85±0.004	53.02±0.004	22.99
Nickel	25	24.00±0.003	19.20±0.002	13.72±0.003	28.54
	50	48.94±0.004	27.97±0.003	22.77±0.002	18.60
	75	76.88±0.003	35.76±0.002	27.77±0.003	22.36
Cadmium	1.5	1.01±0.001	0.81±0.000	0.58±0.000	28.55
	3.0	2.72±0.000	1.56±0.000	0.27±0.000	82.83
	4.5	3.88±0.001	1.81±0.000	1.41±0.000	21.83

Values are mean ± standard error of mean of three replicates. NG = No growth; NA = Not Applicable

Bioaccumulation of heavy metals in the plant tissues

The amount of lead and chromium metals accumulated in the plant tissues increased with increase in the amount of heavy metal added to the soil (Table 3). In the case of nickel, the level of accumulation decreased with increase in the amount of the metal added to the soil. Accumulation of cadmium in the soil was highest in the soil treated with 3.0 mg of cadmium. The highest bioaccumulation factor (9.47) was observed in the plant that grew in the soil treated 3.0 mg of cadmium. This was followed by the plant that grew in the soil treated with 3.0 mg of cadmium. The least bioaccumulation factor was recorded in plant that grew in soil 75 mg of nickel (0.04) on the average, the plant that grew in lead contaminated soil had the least bioaccumulation factor while the plants that grew in the cadmium contaminated soil had the highest average bioaccumulation factor. The trend of bioaccumulation factor recorded is similar to that of the accumulation of the heavy metals in the plant tissues.

Table 3. Heavy metal level in plants tissues and their bioaccumulation factor

Heavy metal	Amount added to the soil	Final level in soil with plant	Amount in the plant tissue	Bioaccumulation factor (BAF)
Lead	150	84.05±0.005	12.15±0.000	0.14
	300	No Growth	Not Applicable	Not Applicable
	450	165.52±0.006	25.75±0.000	0.16
Chromium	50	26.37±0.003	6.56±0.003	0.25
	100	45.16±0.004	8.20±0.004	0.18
	150	53.02±0.004	11.00±0.003	0.21
Nickel	25	13.72±0.003	4.79±0.002	0.35
	50	22.77±0.002	3.32±0.003	0.15
	75	27.77±0.003	1.03±0.000	0.04
Cadmium	1.5	0.58±0.000	1.87±0.004	3.24
	3.0	0.27±0.000	2.53±0.004	9.47
	4.5	1.41±0.000	1.45±0.004	1.02

The effect of Senna alata growth on the pH of heavy metal contaminated soils

The pH of the heavy metal contaminated soil at the beginning and the end of the study is shown in Table 4. The pH of the soil generally dropped with the addition of the heavy metals. Addition of Pb led to the highest drop of the pH of soil while the addition of Cd led to the least drop of the soil pH. The pH of the soil dropped generally at the end of 60 days compared to the initial pH. The growth of *S. alata* contributed to further drop of the pH of the soil in all the treatments. The highest drop of the soil pH due to the growth of *S. alata* occurred in soil with 25 mg Ni (8.02%). The drop of soil pH due to the growth of *S. alata* was least in the soil with 1.5 mg of Cd (5.14%). The pH of soil with *S. alata* significantly dropped ($P<0.05$) compared to the initial pH.

Table 4. pH of soils before and after remediation of heavy metals with *S. alata*

Heavy metal	Amount added to the soil (mg)	Initial pH	Final pH in soil without plant	Final pH in soil with plant	Percentage reduction due to plant growth
Lead	150	7.21	6.89	6.53	5.22
	300	7.08	6.62	No growth	Not Applicable
	450	6.89	6.57	6.21	5.48
Chromium	50	7.29	6.97	6.61	5.16
	100	7.15	6.88	6.47	5.96
	150	7.105	6.73	6.32	6.09
Nickel	25	7.30	6.98	6.42	8.02
	50	7.17	6.85	6.49	5.26
	75	7.09	6.77	6.41	5.32
Cadmium	1.5	7.32	7.00	6.64	5.14
	3.0	7.21	6.89	6.53	5.22
	4.5	7.10	6.78	6.42	5.31

The effect of Senna alata growth on the total organic matter content of heavy metal contaminated soils

The organic matter content of heavy metal contaminated soil before and after remediation of heavy metals with *S. alata* is shown in Table 5. The organic matter content of the soils reduced with the addition of heavy metals. There was also reduction of the organic matter content of the soil at the end of 60 days. Growth of *S. alata* led to further reduction of the organic matter content of the soil. The highest reduction of the total organic matter content of the soil due to the growth of *S. alata* (51.65%) was observed in the soil with 50 mg of Cr of treatment. The least reduction of the total organic matter content of the soil due to the growth of *S. alata* was observed in soil with 4.5 mg of Cd (10.29%). The organic matter content of the soil on day 60 in soil with 100 mg/kg chromium was significantly lower than the initial organic matter content ($p<0.05$).

Table 5. Organic matter content of soil before and after remediation of heavy metals with *S. alata*

Heavy metal	Amount added to the soil	Initial level	Final level in soil without plant	Final level in soil with plant	Percentage reduction due to plant growth
Lead	150	77.90	58.05	49.40	14.90
	300	77.32	56.45	No Growth	Not Applicable
	450	77.00	56.45	44.57	21.05
Chromium	50	78.12	58.39	50.81	12.98
	100	75.12	57.27	27.69	51.65
	150	73.03	56.18	45.60	18.83
Nickel	25	78.46	59.07	49.49	16.22
	50	78.25	57.61	48.03	16.63
	75	78.21	56.31	47.78	15.15
Cadmium	0	79.02	72.38	71.99	0.54
	1.5	78.84	57.99	50.41	13.07
	3.0	78.45	55.66	49.02	11.93
	4.5	78.07	54.22	48.64	10.29

The effect of Senna alata growth on the moisture content of heavy metal contaminated soils

Table 6 shows the moisture content of heavy metal contaminated soil before and after remediation of heavy metals with *S. alata*. The moisture content increased generally with the addition of the heavy metals. Addition of lead to the soil led to the highest increase in the moisture content. The initial moisture content increased generally with the increase in the amount of the metals added to the soil. For soil without heavy metals, there was 0.78% reduction of the moisture content due to the growth of *S. alata*. For the contaminated soils, the moisture content of the soil at the end of 60 days dropped in soils without plant. However, the moisture content of soil due to growth of *S. alata* generally increased. The percentage increase of the moisture content of the soil due to the growth of *S. alata* generally decreased as the amount of heavy metal added to the soil increased.

The effect of Senna alata growth on the cation exchange capacity of heavy metal contaminated soils

The effect of *Senna alata* growth on the cation exchange capacity of heavy metal contaminated soils is shown in Table 7. The cation exchange capacity of the soil generally increased with the addition of the heavy metals into the soil. There was reduction of the cation exchange capacity at the end of 60 days. This was further reduced due to the growth of *S. alata*. The reduction of the cation exchange capacity was highest in soil without any metal (46.51%). In the soils treated with the different heavy metals, the reduction of the cation exchange capacity due to the growth *S. alata* generally increased with the amount of heavy metal added into the soil. However, for the soil treated with cadmium, the percentage reduction of cation exchange capacity due to the growth of *S. alata* decreased with increase in amount of the metal added into the soil.

Table 6. Moisture content of soil before and after remediation of heavy metals with *S. alata*

Heavy metal	Amount added to the soil	Initial level	Final level in soil without plant	Final level in soil with plant	Percentage change due to plant growth
Lead	150	8.31	6.15	14.00	127.64
	300	9.20	6.63	No growth	Not Applicable
	450	10.63	7.63	13.08	71.43
Chromium	50	8.58	5.45	18.45	238.53
	100	8.58	6.00	15.88	164.67
	150	9.73	6.55	16.09	145.65
Nickel	25	7.76	5.18	18.05	248.46
	50	8.03	5.45	14.81	141.10
	75	8.31	5.73	13.14	129.32
Cadmium	1.5	7.78	5.20	17.15	229.00
	3.0	8.08	5.50	14.25	159.09
	4.5	8.38	5.80	16.81	189.66

Table 7. Cation exchange capacity of soil before and after remediation of heavy metals with *S. alata*

Heavy metal	Amount added to the soil	Initial level	Final level in soil without plant	Final level in soil with plant	Percentage reduction due to plant growth
Lead	150	30.58	18.62	15.15	18.64
	300	32.56	17.22	No Growth	No Growth
	450	35.48	15.99	12.50	21.84
Chromium	50	28.84	15.84	12.55	20.77
	100	28.84	14.23	11.08	22.14
	150	31.49	13.71	10.48	23.56
Nickel	25	22.43	11.49	8.98	21.64
	50	24.39	10.53	7.55	28.30
	75	26.93	9.34	6.89	26.23
Cadmium	1.5	23.30	13.31	10.83	18.63
	3.0	25.88	12.05	10.08	16.34
	4.5	27.54	11.81	9.11	22.86

The correlation analysis of the different soil parameters is shown in Table 8. The percentage remediation of the heavy metals had a high positive correlation with the bioaccumulation factor ($r = 0.918$) and No correlation ≈ 0 with the soil moisture change ($r = -0.035$). The total organic matter reduction of the soil also has a negative correlation ($r = -0.165$) with the bioaccumulation factor. The bioaccumulation factor also had a negative correlation ($r = -0.158$) with the cation exchange capacity of the soil. The highest correlation of the pH was with the soil cation exchange capacity ($r = 0.810$) while no correlation of the pH was with the bioaccumulation factor ($r = 0.032$). The correlation of the organic matter content of the soil was with pH ($r = 0.731$) while the least correlation was with bioaccumulation ($r = 0.172$)

Table 8. Pearson correlation coefficient of percentage remediation, pH, TOM, Moisture content, bioaccumulation factor and cation exchange capacity

	% Remediation	BAF	pH reduction	Moisture change	Organic matter reduction	Reduction in CEC
% Remediation	1					
BAF	0.918	1				
pH reduction	0.341	0.032	1			
Moisture change	-0.035	-0.165	0.471	1		
Organic matter reduction	0.310	0.172	0.731	0.187	1	
Reduction in CEC	0.114	-0.158	0.810	0.439	0.523	1

Discussion

The choice of a plant for phytoremediation of heavy metal contaminated medium depends on some factors like the level of tolerance of the proposed plant to the pollutant in question and the ability of the plant to uptake, accumulate and translocate the heavy metal (Sarma, 2011**).** The ability of an organism to survive the conditions in a contaminated medium is a major factor to be considered when choosing an organism for bioremediation studies, thus the ability of *S. alata* to survive in the heavy metal contaminated soils used in this study suggests that its ability to remediate heavy metal contaminated soils in the field can be validated. The results we obtained in this study generally indicate that the growth of *S. alata* is negatively affected by the increase in the level of each of the metals in the soil but there was reduction in heavy metals levels in soils due to the growth of *S. alata*. Significant reduction of the heavy metals due to the growth of *S. alata* being reported in this study points to the fact that the plant can be used to reclaim soils contaminated with heavy metals especially cadmium. This thus shows that apart from the well reported medicinal values of the plant (Villasenor *et al*., 2000; Idu *et al*., 2007; Lewis and Levy, 2011), it has good environmental values as it is the case of the other species of Senna.

The bioavailability of heavy metals and their uptake by plants depend on several factors. In phytoremediation of heavy metals, the factors that affect heavy metals bioavailability and uptake play crucial roles. The results of the correlation analysis which were obtained in this study suggest that remediation of the heavy metals by *S. alata* may be much slightly inhibited by high moisture content of the soil and may be highly favoured by high bioaccumulation ability of the plant. This is in agreement with the work of Angle *et al.* (2003) which shows that in general, extractable soil concentrations of Ni and Zn decrease with increasing soil moisture content. According to Rieuwerts *et al.* (1998) most metals including Zn, Cd, and Ni in waterlogged soils exhibit complicated solubility with generally reduced solubility due to low redox potential and formation of sparingly soluble sulfides (Marschner, 1995).

The positive correlation between heavy metal remediation and the reduction of the organic matter content we reported so far in this study could be ascribed to the views of Suave *et al.* (2000) who had pointed out that solid phase soil organic matter inhibits bioavailability and mobility of metals in the soils. Thus, as the organic matter content reduces, the heavy metals become more bioavailable and more mobile thereby increasing ability of plants to absorb them. Also, Angelova *et al.* (2010) showed that amending soil with different organic soil additives increased the immobility of heavy metals (Zn, Pb, Cd and Cu) and reduced their phyto accessibility and accumulation by potato. This could be due to the adsorption of the heavy metals by organic matter as was suggested by Kabata Pendias (2001). Similarly, the works of Silva *et al.* (2014) showed that organic matter content of soil have negative correlation with the available iron, lead, cadmium, copper and zinc in the soil. The availability of the metals is a major factor that affects the uptake and remediation by plants. The organic matter is one of the factors that may reduce the ability of metals to be phytotoxic in the soil due to metal-organic complexation. Notwithstanding the reduced absorption of heavy metals by plants which the presence of organic matter in the soil causes, augmenting the soil contaminated with heavy metals with organic matter can positively influence the remediation of the soil plant as the plants will have less toxic effect and can grow and secrete enzymes and proteins that will enhance the chelation of the heavy metals and their subsequent removal from soil. In fact, soils with low organic matter content have low biological activities and such activities are the basis of biological remediation. It should be of note that the phytoextraction of each heavy metal is optimum at different organic matter levels in the soils (Anh *et al.*, 2010; Ha *et al.*, 2018). Thus, in augmenting a heavy metal contaminated soil with organic matter to enhance phytoremediation, one needs to understand the optimum organic matter content for the heavy metal of interest. In addition, although high level of organic matter interferes with the bioavailability and phytoextraction of heavy metals, it helps in phyto stabilization of heavy metals which is another mechanism of phytoremediation of heavy metal contaminated soil. This shows that organic matter plays both active and passive roles in the cleaning or reducing the health risk associated with heavy metal contaminated soils

The reduction of the pH of the soil can slightly favour remediation of the heavy metals as they showed positive correlation with the percentage remediation. This is in consistent with reports of previous studies that heavy metals become more bioavailable at low pH. The reports of McBride (1994), Blaylock and Huang (2000) and Prasad and Freitas (2003) have shown that reduction in soil pH reduces the adhesion of metals to soil particles thereby increasing their bioavailability and possible uptake by plants. This will increase the ability of plants to remove heavy metals from soil. Our results from this study also conform to such as the correlation between the percentage remediation and bioaccumulation of the heavy metals showed positive relationship with the reduction in the pH of the soil. These may suggest that reduced adhesion and increased bioavailability are positive factors that affect heavy metal bioaccumulation. Similar inference was made by Adamcyzk-Szabela *et al.* (2015) who stated that low pH prompts high metal mobility. The solubility of metals and the pH of soil are known to have inverse relation (Rieuwerts *et al.*, 1998) implying that to achieve higher solubility of the heavy metals the pH should be low thus reduction of the pH of the soil due to the growth *S. alata* may be a mechanism that the plant uses to enhance the remediation of heavy metal polluted soil

The reduction in the cation exchange capacity as the plant grew showed a positive correlation with the pH, the moisture, the organic matter content and the remediation of the heavy metals which suggests that the CEC influences these factors. It further suggests that to achieve good remediation results, it will be good to reduce the cation exchange capacity of the soil. This is consistent with the reports of Hinesly *et al.* (1982) which stated that cadmium uptake is inversely related with cation exchange capacity of a soil. The reduction of the cation exchange capacity observed in this study possibly occurred due to the interaction of the plant exudates released into the soil by *S. alata* with the soil properties. It is a known fact that the lower the CEC of a soil, the faster the pH will decrease and decrease in pH enhances the mobility and bioavailability of metals hence their uptake. Therefore, the reduction in CEC of the soil due the growth of *S. alata* as we have reported in this study could be one the reasons the pH of the soil dropped and hence making it possible for the plant to uptake the heavy metals.

Sarma (2011) noted that the uptake of metals largely depends on the type and chemical speciation of metal and habitat characteristics of plants. The difference in the ability of *S. alata* to bioaccumulate different heavy metals which we noticed in this study is similar to the observations of Jin *et al.* (2009) who reported that *Sedum alfredii* has higher bioaccumulation for Zn than Cd and Banasova and Horak (2008) who also showed that *Thlaspi caerulescens* had higher bioaccumulation for Zn than Cd. These imply that no matter the level of efficiency of plant in enhancing the removal of heavy metals from the soil/environment, each plant can effectively lead to better removal of a particular heavy metal. This could be attributed to the can kind of exudate released by such plant the type of rhizospheric environment associated with the plant. The marginal high positive correlation ($p = 0.918$) between the percentage remediation and the bioaccumulation suggests that remediation of the heavy metals has a close association with their accumulation in the plant tissues.

Conclusions

The results we obtained in this study showed that *S. alata* has the ability to facilitate the removal of different heavy metals from the soil. This study suggests that organic matter negatively influences the extent by which *S. alata* enhances the removal of heavy metals from the soil and bioaccumulation of the heavy metals in the plant tissues. Form the results; we can infer that although *S. alata* can contribute to the removal of the different heavy metals investigated in this study, it has greater influence on the removal of cadmium than the other heavy metals. Our results suggest that *S. alata* can be a good candidate for heavy metal remediation, but care should be taken in its suitability due its ability to bioaccumulate the heavy metals to avoid using it as a channel of transferring heavy metals to consumers in the food chain. This is essential as the plant has been documented to have many beneficial uses. The reduced performance as indicated by the indices we used in this plant shows that heavy metals also affect the growth of the plant.

Conflict of Interests

The authors declare that there are no conflicts of interest related to this article.

References

Adamczyk-Szabela D, Markiewicz J, Wolf WM (2015) Heavy metal uptake by herbs. IV. Influence of soil pH on the content of heavy metals in *Valeriana officinalis* L. Water Air Soil and Pollution 226(4):106.

Alloway BJ (1995). Heavy metals in soils. Blackie Academic and Professional, London, UK, 2nd edition.

Al-Qahtani KM (2012). Assessment of heavy metal accumulation in native plant species from soils contaminated in Riyadh city, Saudi Arabia. Life Science Journal 9:488-496.

Aluko TS, Njoku KL, Adesuyi AA, Akinola MO (2018). Health risk assessment of heavy metals in soil from the iron mines of Itakpe and Agbaja, Kogi State, Nigeria. Pollution 4(3):527-538.

Angelova V, Ivanova R, Pevicharova G, Ivanov K (2010). Effect of organic amendments on heavy metals uptake by potato plants. 19th World Congress of Soil Science, Soil Solutions for a Changing World 1 - 6 August 2010, Brisbane, Australia pp 84-87.

Angle JS, Baker AJM, Whiting SN, Chaney RL (2003). Soil moisture effects on uptake of metals by Thlaspi, Alyssum, and Berkheya. Plant and Soil 256:325-332.

Anh BK, Tua TV, Kim DD, Trang PTH (2010). Effect of N, P on growth and arsenic accumulation in fern *Pteris vittata* L. Journal of Science and Technology 48(2):71-78. (In Vietnamese).

Azlan A, Aweng ER, Ibrahim CO, Noorhaidah A (2012). Correlation between soil organic matter, total organic matter and water content with climate and depths of soil at different land use in Kelantan, Malaysia. Journal of Applied Science and Environmental Management 16(4): 353-359.

Banasova V, Horak O (2008). Heavy metal content in *Thlaspi caerulescens* J. et C. Presl growing on metalliferous and non-metalliferous soils in Central Slovakia. International Journal of Environment and Pollution 33:133-145.

Basta N, Gradwohl R (2000). Estimation of Cd, Pb and Zn bioavailability in smelter contaminated soils by a sequential extraction procedure. Journal of Soil contamination 9(2):149-164.

Blaylock MJ, Huang JW (2000). Phytoextraction of metals. In: Raskin I, Ensley BD (Eds). Phytoremediation of toxic metals: using plants to clean-up the environment. John Wiley & Sons, Inc., New York pp 53-70.

Bolan NS, Adriano DC, Naidu R (2003). Role of phosphorus in (im) mobilization and bioavailability of heavy metals in the soil-plant system. In: Reviews of environmental contamination and toxicology. Springer, New York, NY pp 1-44.

Chu TT, Nguyen PH, Nguyen TH, Ha TV, Nguyen TT, Nguyen DA, Dang VA (2018). Effect of fertilizer on lead (Pb) accumulation ability of *Polygonum hydropiper* L. Journal of Vietnamese Environment 9(2):67-72.

Dembitsky V (2003). Natural occurrence of arseno compounds in plants, lichens, fungi, algal species, and microorganisms. Plant Science 165:1177-1192.

Francis CA, Rutger JN, Palmer AFE (1969). A rapid method for plant leaf area estimation in maize (*Zea mays* L.). Crop Science 9:537-539.

Ghosh M, Singh SP (2005). A comparative study of cadmium phytoextraction by accumulator and weeds species. Environmental Pollution 133:365-371. *http://dx.doi.org/10.1016/j.envpol.2004.05.015*

Gilman EF, Watson DG (1993). Fact sheet ST-125 November 1993 *Cassia alata*. adapted from fact sheet ST-125, a series of the Environmental Horticulture Department, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida.

Gupta AK, Sinha S (2008). Decontamination and/or regeneration of fly ash dyke through naturally growing plant. Journal of Hazardous Materials 153:1078-1087.

GWRTAC (1997). Remediation of metals-contaminated soils and groundwater. Tech. Rep. TE-97-01, GWRTAC, Pittsburgh, Pa, USA, GWRTAC-E Series.

Hanif MA, Nadeem R, Bhatti H, Ahmed NR, Ansari TM (2007). Ni (II) biosorption by *Cassia fistula* (Golden Shower) biomass. Journal of Hazardous Materials 139(2):345-555.

Hinchman RR, Negri MC, Gatliff EG (1995). Phytoremediation: using green plants to clean up contaminated soil, groundwater, and wastewater. Argonne National Laboratory Hinchman, Applied Natural Sciences, Inc. *http://www.treemediation.com/Technical/Phytoremediation_1998.pdf*.

Hinesly TD, Redborg KE, Ziegler EL, Alexander JD (1982). Effect of soil cation exchange capacity on the uptake of cadmium by corn. Soil Science Society of America Journal 46(3):490-497.

Idu M, Omonigho SE, Igeleke CL (2007). Preliminary investigation on the phytochemistry and anti-microbial activity of *Senna alata* L. flower. Pakistan Journal of Biological Science 10:806-809.

Jambhulkar HP, Juwarkar AA (2009). Assessment of bioaccumulation of heavy metals by different plant species grown on fly ash dump. Ecotoxicity and Environmental Safety 72:1122-1128.

Jin X, Liu D, Islam E, Mahmood Q, Yang X, He Z, Stoffella P (2009). Effects of zinc on root morphology and antioxidant adaptations of cadmium- treated *Sedum alfredii* H. Journal of Plants Nutrition 32:1642-1656.

Kabata-Pendias A (2001). Trace elements in soils and plants. 3rd Ed. CRC Press LLC, Boca Raton, Florida pp 403.

Kumar AP, Vajpayee P, Ali MB, Tripathi RD (2002). Biochemical response of *Cassia siamea* grown on coal combustion residue (fly ash). Bulletin of Environmental Contamination and Toxicology 68:675-683.

Lewis A, Levy A (2011). Anti-inflammatory activities of *Cassia alata* L. leaf extract in complete Freund's adjuvant arthritis in rats. West Indian Medicinal Journal 60(6):20-36.

Lombi E, Gerzabek MH (1998). Determination of mobile heavy metal fraction in soil: results of a pot experiment with sewage sludge. Communications in Soil Science and Plant Analysis 29(17-18):2545-2556.

Marschner H (1995). Mineral nutrition of higher plants. Academic Press Limited, London pp 889.

McBride MB (1994). Environmental chemistry of soils. Oxford University Press, ISBN 0-19-507011-9, New York pp 406.

Njoku KL, Akinola MO, Nkemdilim CM, Ibrahim PM, Olatunbosun AS (2014). Evaluation of the potentials of three grass plants to remediate crude oil polluted soil. Current Advances in Environmental Science 2(4):131-137.

O'Kelly BC (2004). Accurate determination of moisture content organic soils using the oven drying method. Drying Technology 22(7):1767-1776.

Prasad MNV, de Oliveira Freitas HM (2003). Metal hyperaccumulation in plants - biodiversity prospecting for phytoremediation technology. Electronic Journal of Biotechnology 6(3):285-321. *http://dx.doi.org/10.4067/S0717-34582003000300012*

Raju D, Sunil K, Mehta UJ, Hazra H (2008). Differential accumulation of manganese in three mature tree species (Holoptelia, Cassia and Neem) growing on a mine dump. Current Science 94:639-643.

Rieuwerts JS, Thornton I, Farago ME, Ashmore MR (1998). Factors influencing metal bioavailability in soil: preliminary investigations for the development of a critical loads approach for metals. Chemical Speciation and Bioavailability 10:61-75.

Santana KB, De Almeida AAF, Souza VL, Mangabeira PAO, Da Silva DC, Gomes FP, ... Loguercio LL (2012). Physiological analyses of *Genipa americana* L. reveals a tree with ability as phytostabilizer and rhizofilterer of chromium ions for phytoremediation of polluted watersheds. Environmental and Experimental Botany 80:35-42.

Sarma H (2011). Metal hyperaccumulation in plants: a review focusing on phytoremediation technology. Journal of Environmental Science and Technology 4:118-138.
Silva JRR, Fernandes AR, Perez DV (2014). Phytoextraction of heavy metals from a landfill in the metropolitan region of Belém-Pará-Brazil. Amazonian Journal of Agricultural and Environmental Science 57:429-438. *http://dx.doi.org/10.4322/rca.1525*
Siringoringo HH (2000). The role of some urban forest plants in absorbing lead particulate. Bulletin of Penelitian-Hutan 622:1-16.
Tüzen M (2003). Determination of heavy metals in soil, mushroom and plant samples by atomic absorption spectrometry. Microchemical Journal 74(3):289-297.
Ugwu EC (2015). Hydrocarbon degradation and heavy metals uptake by *Senna alata* (L.) Roxb. in soil polluted with spent engine oil. A project report submitted in partial fulfilment of the requirement for the award of Master of Science [M.Sc.] in Environmental Plant Ecology, Department of Plant Science and Biotechnology, University of Nigeria, Nsukka, pp 90.
Villasenor IM, Canlas AP, Pascua MP, Sabando MN, Solien LA (2002). Bioactivity studies on *Cassia alata* L. leaf extract. Phytotherapy Resource 16(1):93-96.
World Health Organization (WHO) (1996). Permissible limits of heavy metals in soil and plants. Geneva, Switzerland.
Zhen-Guo S, Xian-Dong L, Chun-Chun W, Huai-Man H, Hong H (2002). Lead phytoextraction from contaminated soil with high biomass plant species. Journal of Environmental Quality 31:186-190.