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Archives of Applied Science Research, 2012, 4 (1):360-371
(http://scholarsresearchlibrary.com/archive.html)

ISSN 0975-508X
CODEN (USA) AASRC9

Lead accumulation in Siam weed (*Chromolaena odorata*), Node weed *(Synedrella nodiflora)* and Water leaf (*Talinum triangulare*): Potential phytoremediators

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ABSTRACT

The plant species used in this experiment Chromolaena odorata, Synedrella nodiflora and Talinum triangulare were selected on the basis of their widespread distribution in Nigeria. The ability of these plants to tolerate and accumulate Pb was investigated. Also, the effect of Ethylene diaminetetraacetic acid (EDTA) on the phytoremediating potential of the plants was monitored. The uptake of Pb in these plants was in the order: S. nodiflora □ C. odorata □ T. triangulare with a corresponding bioaccumulation factor (BF) of 0.28±0.08 - 0.50±0.14, 0.20±0.05 - 0.39±0.16 and 0.17±0.03 - 0.27±0.09 res pectively. Addition of EDTA significantly increased the uptake of Pb in these plants with a consequent increase in the BF of 0.33±0.02 – 0.61±0.09, 0.28±0.09 – 0.43±0.19 and 0.22±0.04 – 0. 28±0.13 in the order above. This order of Pb uptake was the same for untreated and EDTA-treated contaminated soil. However, the transfer factor (TF) was in the order T. triangulare □ C. odorata □ S. nodiflora. Also, S. nodiflora gave the highest root and shoot biomass production which confers on it an additional advantage for the purpose of phytoremediation. S. nodiflora possess the ability to be useful for the purpose of Phytoremediation of Pb contaminated soil.

Keywords: Phytoremediation, Ethylene diaminetetraacetate (EDTA), Soil, heavy metal, contamination.

INTRODUCTION

Phytoremediation is an emerging technology that employs the use of plants for the removal of heavy metals from contaminated soil [1]. However, contamination has resulted from industrial activities such as mining and smelting of metalliferous ores, electroplating, gas exhaust, energy and fuel production, fertilizer and pesticide application and generation of municipal waste [2].

The threat posed by heavy metals to human and animal health is aggravated by their long-term persistence in the environment. For instance, Pb one of the more persistent metals, was estimated to have a soil retention time of 150–5000 years [3]. Phytoremediation has been put forward since the late 1980's to remove heavy metals from contaminated soil by harvesting the plants without damaging the soil. It has attracted much attention because it is environmentally friendly and relatively cheap [4, 5]. Some plants termed as phytoremediators are capable of absorbing large amounts of heavy metals from the soil and accumulating these metals in their tissues [6, 7]. Up to date, over 400 different hyperaccumulating plant species have been identified [8].

One of the greatest concerns for human health is caused by Pb contamination [1]. Lead (Pb) is a major anthropogenic pollutant and has accumulated in different terrestrial and aquatic ecosystems [9]. Pb has limited solubility in soil and is generally not available for plant uptake due to complexation with organic matter, sorption on oxides and clays or precipitation as carbonates, hydroxides and phosphates [10]. Hence the two major limitations to Pb phytoremediation are: low bioavailability in soil and poor translocation from root to shoot [11]. One way to induce Pb solubility is to decrease soil pH [12]. To enhance metal solubility, plants are believed to excrete organic ligands [13] or lower the soil pH in the rhizosphere [14].

The use of synthetic chelates has been shown to dramatically stimulate the potential for Pb accumulation in plants. These compounds such as EDTA, DTPA(Diethylene triamine pentaacetate) and low molecular weight organic acid such as oxalic acid and citric acid, prevent Pb precipitation and keep the metals as soluble chelate-Pb complexes available for uptake into roots and transport within plants[1]. Ethylene diaminetetraacetate (EDTA) is probably the chelating agent that is most efficient at increasing the solubility of heavy metals in soil solutions from the solid phase [15-18). EDTA application solubilizes about 80% of the total soil metal thereby making them available for phytoextraction [19].

In furtherance to the ongoing investigation in the field of phytoremediation, *Talinum triangulare, Chromolaena odorata* and *Synedrella nodiflora* had been used in this study to evaluate their tolerance and accumulation ability to lead. Also, the effect of EDTA on the phytoremediating potential of these plants had been investigated. The choice of these plants is based on their widespread availability and demonstration of tolerance to conditions not favourable for the growth of other plants in Nigeria. Also, these plant species have the ability to co-exist on the same field. This feature prompted their simultaneous study under similar experimental conditions. This research work was carried out at the Chemistry Department of The Federal University of Technology, Akure, Nigeria.

MATERIALS AND METHODS

2.1 Soil sampling and characterization

Soil used in this experiment was obtained from a Pb-uncontaminated area within the territory of The Federal University of Technology, Akure, Nigeria. All reagents used were of analytical grade (BDH Laboratory supplies, Poole, England) The soil pH was determined in a mixture of soil and deionized water (1:2, w/v) with a glass electrode [20]. Total organic carbon content was determined using the Walkey-Black wet oxidation approach [21]. Total Nitrogen was determined using the Kjeldhal method [22]. Cation exchange capacity (CEC) and amounts of exchangeable Ca and Mg were determined using the ammonium acetate method [23]. Total phosphorus was

determined colourimetrically. Total background lead concentration was determined using Atomic Absorbtion Spectrophotometer (Buck scientific,210 VGP) after the soil sample (1g) was weighed and digested with a mixture of concentrated HF and aqua-regia. Soil particle size was determined using the hydrometer method.

2.2 Pot experiments

2kg of air dried soil was weighed and transferred into plastic pots and watered with deionized water. Seedlings of these plants were transplanted from the Pb-uncontaminated site into the pots and allowed to stabilize for about one week. The soil had been treated with NPK fertilizers to enhance the growth of the plants. After 1 week when the plant samples had stabilized, the pots were weeded and thinned to one plant per pot for contamination. The pots with the plant samples were placed in a screenhouse where they are exposed to approximately 12 hours of daylight. 125pots per plant species were monitored over a period of 4 weeks.

2.3 Lead contamination and amendment treatment

Each plant specie had five controls. Different concentrations of 50, 100, 200, 500 and 1000ppm of Pb [from $Pb(NO_3)_2$] were prepared. 150ml of 50ppm lead concentrations was added to 24pots. This was then repeated for the other lead concentrations to make a total of 120 contaminated pots. EDTA concentrations of 50,100, 200, 500 and 1000ppm were also prepared. 60 out of the already contaminated pots were treated with 75ml of corresponding EDTA solutions (Pb: EDTA; 1:1). This procedure was repeated for the other plant samples.

2.4 Plant harvest and analysis

Plants on contaminated soil treated with EDTA and those not treated with EDTA were harvested in triplicates on a weekly basis. The plant shoot cut at the soil surface were harvested, the roots were washed in tap water until free of soil particles. The shoots and roots are then washed with deionized water, oven dried at 80^0C for 24hours, weighed and then ground into powder using pestle and mortar.

0.5g of dried plant sample was weighed and digested overnight in 69% HNO_3 and 30% H_2O_2 (vlv : 10ml) and later heated at 120^oC for 2hours[24]. The digested solutions were filtered using whatman no 1 filter paper and diluted to 50ml with deionized water. The concentrations of Lead in the digested solutions were determined using Atomis Absorbtion Spectrophotometer (Buck scientific, 210 VGP).

2.5 Statistical analysis

Each set-up was done in triplicates to ensure reproducibility and minimize error. Data were expressed as means with standard deviation and were subjected to two-way ANOVA with soil treatments and plant species as independent factors. The Least Significant Difference (LSD) multiple range test ($P \leq 0.05$) was used to evaluate differences between means of treatments and plant species.

RESULTS AND DISCUSSION

3.1 Soil physicochemical properties

The results obtained from the soil analysis are as shown in table 1. The study soil had a pH of 5.96 which is weakly acidic and will not favour bioavailability of Pb in soil solution. According

to McBride [12], one way of increasing the Pb solubility in the soil is to reduce soil pH .Hence, the addition of EDTA as an enhancing agent to improve the bioavailabilty of the metal in the soil. Furthermore, the soil particle size recorded was 53.52% sand, 32.48% clay and 14% silt. The classification on the textural triangle is sandy-clay-loam. This relatively high percent of clay could encourage sorption of Pb thereby reducing its solubility and bioavailability in the soil [1]. The organic matter content, level of N and P were relatively low which shows that the soil is deficient of nutrient. For the purpose of phytoremediation, a plant with a healthy growth and good biomass yield is desired, hence, the need for addition of NPK fertilizer. The soil background Pb concentration was 53.57mg/kg.

Table 1: Soil characterization

pH	Texture (%)			OM(%)	CEC (cmol/kg)	N(%)	P (%)	Pb (mg/kg)	Ca/Mg
	Sand	Clay	Loam						
5.96	53.52	32.48	14.00	2.05	13.14	0.378	0.07	53.57	1.73

OM: Organic matter, CEC: Cation exchange capacity

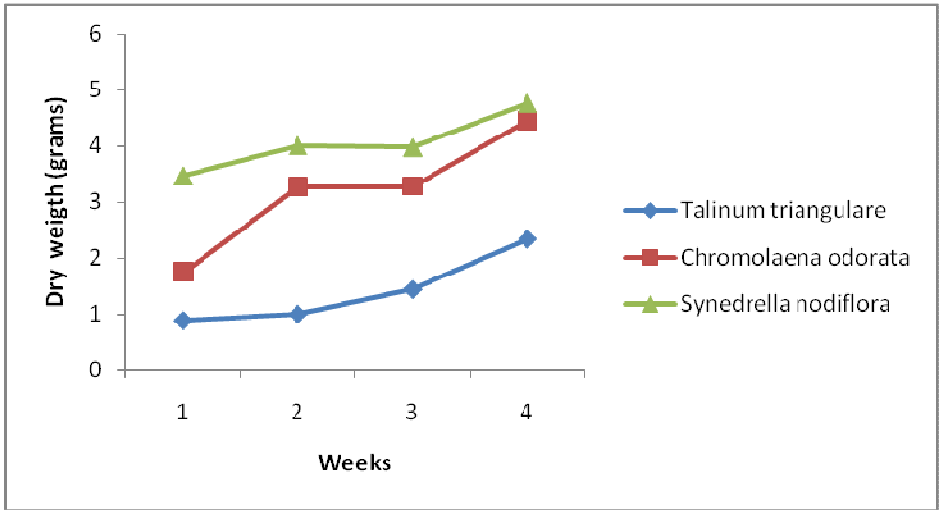
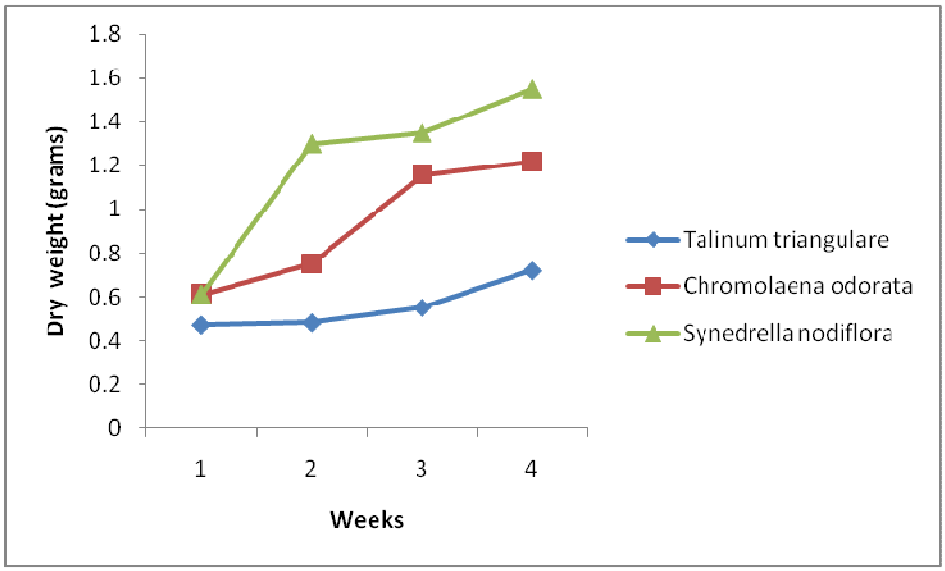


Fig 1a: Plot of dry weight of shoots against Weeks after Planting (WAP)

3.2 Effect of contamination on plant growth

At harvest, *T. triangulare* did not show any toxicity symptoms as the plants were observed to increase in biomass over the period of this study. Figures 1a and b shows the plot of dry weight of plants on 1000 ppm contaminated soil against weeks. It could be seen that these graphs gave a positive slope indicating a direct relationship between dry weight and duration of study (in weeks). Similarly, *C. odorata* did not show any symptons of toxicity during the period of this study indicating the low concentration of Pb in this plant. This is in agreement with the report of Nie et al [25] that Lead with low concentration could accelerate the growth of *C.odorata*. For *S. nodiflora*, contaminants do not have any effect on the plants in the first three weeks after contamination. However, in the fourth week, yellowing of the plant leaves were observed in those contaminated with 1000ppm of Pb treated with EDTA which coincidentally gave the highest absorbtion of Pb. This yellowing indicates the phytotoxicity of the EDTA-metal complex.



1b: Plot of dry weight of roots against Weeks after Planting (WAP)

Of the three plant species, *T. triangulare* gave the smallest biomass (both root and shoot), followed by *C. odorata*. The highest root and shoot biomass was observed in *S. nodiflora*. In view of this biomass production, *S. nodiflora* may be the preferred choice since the target of phytoremediation is to harvest the overground parts of the plants which is expected to be rich in the concentration of the heavy metal of interest.

3.3 Uptake of lead into plant parts

3.3.1 Non-EDTA treated contaminated soil

All the plants showed absorbtion as there was a significant difference ($P \leq 0.05$) between the Pb uptake in the plants used for the experiment and their control (plants on non-contaminated, non-treated soil). The uptake of Pb in the control is shown in table 2 while table 3a and b shows the uptake of Pb into the roots and shoots respectively of plants on untreated, contaminated soil. The highest absorbtion of 81.67±2.35 mg/kg in the roots and corresponding value of 77.35±1.58 in the shoot of *T. triangulare* on 1000ppm contaminated soil was recorded by the second week. These values were significantly higher ($P \leq 0.05$) than those recorded for the lower contaminant concentration (Table 3a and b). Obtaining these values by the second week after contamination suggests that *T. triangulare* has gotten to its maximum tolerable limit and the reduction in uptake could arise from the plant adopting a process of detoxification by exudation [1]. *C. odorata* gave the maximum absorbtion of 103.73±10.2mg/kg in the roots and a corresponding value of 55.68±3.39mg/kg in the shoots by the fourth week. This value however is lower than that reported by Tanhan et al [26] for *C. odorata* on different areas in Bo Ngam lead mine and it could be due to the longer period in which this plant had stayed on this Pb-contaminated soil, the high bioavailability of the metal in the soil and the soil properties. Also, *C.odorata* had a higher uptake into the roots, however the shoot uptake of 55.68±3.39mg/kg which is significantly lower than 77.35±1.58 mg/kg recorded for *T.triangulare* may be an indication of low translocation of the metal from the root to shoot. Of the three plant species studied, *S. nodiflora* gave the highest absorbtion of 309.52±0.59mg/kg in the root and 127.06±0.30mg/kg in the shoot of plant on 1000ppm contaminated soil by the fourth week.

Furthermore, all the plants showed a direct relationship between Pb-uptake and contaminant concentration and this sequence is similar to that reported by Wang et al [11] for *Bidens maximowicziana* where the highest absorbtion of 1509.3±98.15 mg/kg in the roots and 2164.7±105.23mg/kg in the shoots of plant on 2000ppm contaminated soil were recorded.

Table 2: concentration (mg/kg) of Pb in control plants

Plant	Root	Shoot	TF*
Talinum triangulare	22.14±1.78	16.53±2.14	0.75±0.89
Chromolaena odorata	19.42±4.29	11.54±2.37	0.49±0.15
Synedrella nodiflora	35.84±2.40	19.88±2.02	0.52±0.55

**TF: Transfer factor*

Table 3a: Values of Pb absorbed (mg/kg) into the roots of plant on non-EDTA treated contaminated soil

Week 1	**50ppm**	**100ppm**	**200ppm**	**500ppm**	**1000ppm**
T. triangulare	19.81±0.28Aa	24.97±7.13Aa	24.75±6.87Aa	34.75±6.70Aa	69.86±0.20Ba
C. odorata	21.87±0.85Aa	25.10±6.38Aa	33.33±0.49Bb	50.10±0.49Cb	52.10±0.49Ca
S. nodilflora	25.10±11.78Aa	64.94±11.02Bb	66.67±0.59Bc	145.46±1.22Cc	245.10±6.36Db
Week 2					
T. triangulare	29.77±9.86Aa	48.04±9.19Aa	29.88±13.97Aa	42.86±4.19Aa	**81.67±2.35Ba**
C. odorata	26.91±10.89Aa	43.27±13.32Ba	48.27±13.32ABa	52.13±10.21Ba	57.70±10.21Bb
S. nodilflora	50.10±0.49Ab	73.52±14.41ABb	141.67±11.79Bb	191.67±11.79Cb	296.97±21.43Dc
Week 3					
T. triangulare	22.48±3.49Aa	29.52±0.69Aa	30.01±7.30Aa	40.33±8.79Ba	55.02±7.06Ba
C. odorata	33.33±0.49Ab	48.90±15.54Aa	50.20±23.57Aa	66.67±0.50Bb	79.27±19.60Bb
S. nodilflora	50.10±0.81Ac	74.90±18.77Ab	141.67±11.79Bb	183.34±23.58Cc	306.11±55.72Dc
Week 4					
T. triangulare	17.48±3.49Aa	33.96±1.49Ba	24.52±6.38Aa	29.51±6.50Aa	45.45±9.21Ba
C. odorata	46.64±15.63Ab	62.89±19.85Ab	60.10±3.39Ab	81.35±6.80Bb	**103.73±10.20Cb**
S. nodilflora	66.67±0.49Ab	93.81±28.96Ab	131.07±20.36Bc	163.61±10.03Bc	**309.52±10.59Cc**

** Values with different upper case letters(A-D) along the rows and different lowercase letters(a-c) down the column per week are significantly different from each other using LSD test(P≤0.05).*

Table 3b: Values of Pb absorbed (mg/kg) into the shoots of plant on non-EDTA treated contaminated soil

Week 1	**50ppm**	**100ppm**	**200ppm**	**500ppm**	**1000ppm**
T. triangulare	14.42±7.54Aa	14.91±7.10Aa	19.67±0.48ABa	24.40±6.89Ba	34.52±6.37Ba
C. odorata	16.67±0.50Aa	25.10±11.78Ba	25.10±11.78Ba	26.67±0.50Ba	30.30±0.55Ba
S. nodilflora	18.62±0.62Aa	29.14±12.67Aa	37.23±1.23ABb	55.85±0.49Bb	64.94±11.03Bb
Week 2					
T. triangulare	30.40±13.45Aa	22.99±2.86Aa	21.98±2.79Aa	43.41±6.35Ba	**77.35±1.58Cb**
C. odorata	24.05±6.79Aa	36.06±10.20Aa	36.06±10.20Aa	24.04±6.80Aa	28.85±0.49Aa
S. nodilflora	37.23±1.23Aa	37.67±0.62Aa	55.85±1.84Bb	74.47±2.45Cb	83.56±10.39Cb
Week 3					
T. triangulare	26.02±7.09Aa	17.95±8.85Aa	33.89±1.41Ba	37.78±17.20Ba	34.96±7.15Ba
C. odorata	25.10±11.78Aa	36.67±0.50Ab	33.32±0.47Aa	25.10±11.78Aa	33.34±13.57Aa
S. nodilflora	37.23±1.23Aa	55.85±1.84Bb	46.33±11.63ABa	55.85±1.84Bb	83.56±10.39Cb
Week 4					
T. triangulare	30.22±1.12Aa	27.80±9.98Aa	27.79±10.29Aa	36.01±4.36Aa	40.55±7.83Aa
C. odorata	44.90±18.09Ab	50.45±10.20Ab	45.67±16.98Aa	40.87±10.20Aa	**55.68±3.39Ba**
S. nodilflora	27.71±12.23Aa	36.16±1.13Aa	55.85±1.82Bb	55.85±7.82Bb	**127.06±10.30Cb**

** Values with different upper case letters (A-D) along the rows and different lowercase letters(a-c) down the column per week are significantly different from each other using LSD test(P≤0.05).*

3.3.2 EDTA treated contaminated soil

As anticipated from previous studies involving other plants [10, 15, 27] higher absorbtion of Pb was recorded for plant species on soil treated with EDTA. *T.triangular*e had its highest absorbtion of 88.65±4.28mg/kg in the root and 64.31±7.50mg/kg in the shoot of the plant on 500ppm contaminated soil by the second week. (Table 4a and b).The fact that this absorbtion was observed at 500ppm contamination indicates that EDTA had enhanced the bioavailabilty of the metal when compared to the value of 81.67±2.35mg/kg which was recorded in the root of the plant on 1000ppm contamination without EDTA. Furthermore, obtaining this value by the second week corroborates our earlier claim (from the non-EDTA treated soil) that *T.triangulare* attained its maximum absorbtion within two weeks of this study. Similarly, *C.odorata* gave its highest absorbtion of 165.86±10.2mg/kg in the root and 74.52±33.99mg/kg in the shoot of the plant on 1000ppm contaminated soil treated with EDTA and these values are significantly higher (P≤0.05) than 103.73±10.2mg/kg in the roots and 55.68±3.39 in the shoot of the plant on 1000ppm contaminated soil not treated with EDTA. Also, *S. nodiflora* gave a higher absorbtion of 412.88±36.06 in the root and 129.44±48.37mg/kg in the shoot of plant on 1000ppm contaminated soil by the second week. This value, which is the highest of all, indicates that the EDTA had enhanced the bioavailability of the Pb in the soil. Hence *S. nodiflor*a was able to attain its highest uptake by the second week and this high absorbtion was evident in the yellowing of the leaves of this plant indicating its phytotoxicity at this level. The higher uptake or absorbtion of Pb by the plants on the EDTA-treated soil confirms the report of McBride [12] that one way to induce Pb solubility is by reducing soil pH.

Table 4a: Values of Pb absorbed (mg/kg) into the roots of plant on EDTA treated contaminated soil

Week 1	**50ppm**	**100ppm**	**200ppm**	**500ppm**	**1000ppm**
T. triangulare	10.57±0.78Aa	14.87±7.16Aa	19.72±7.70Aa	39.96±14.22Ba	29.88±0.17Ca
C. odorata	33.41±13.66Aa	52.92±19.45Ba	50.20±13.57Bb	63.35±19.27Bb	114.52±31.53Cb
S. nodilflora	58.34±11.78Ab	93.08±3.05Ab	108.35±11.79ABc	165.96±22.43Bc	296.97±42.85Cb
Week 2					
T. triangulare	37.35±3.52Aa	44.93±7.20Aa	48.57±7.11Aa	**88.65±4.29Ba**	79.68±8.39Ba
C. odorata	56.30±22.37Ab	57.72±27.15Aa	64.90±10.20Aa	70.33±16.98Ba	134.61±40.80Bb
S. nodilflora	91.67±11.79Ac	139.40±8.58Ab	200.03±47.09Bb	227.39±15.08Bb	**412.88±68.03Cc**
Week 3					
T. triangulare	29.95±1.09Aa	32.87±9.91Aa	39.93±2.71Aa	55.07±7.02Ba	59.87±14.11Ba
C. odorata	51.51±2.11Ab	58.35±11.79Aa	58.39±11.72Aa	82.68±24.71Ba	133.33±23.57Cb
S. nodilflora	91.67±11.79Ac	148.49±21.43Ab	192.17±36.06Bb	218.94±50.36Bb	402.43±21.22Cc
Week 4					
T. triangulare	28.93±6.96Aa	33.88±12.67Aa	35.79±2.91Aa	52.29±4.70Ba	42.89±18.20Aa
C. odorata	49.51±9.11Aa	56.13±3.39Aa	52.12±10.20Aa	62.02±0.46Aa	**165.77±10.32Bb**
S. nodilflora	98.81±21.89Ab	123.81±13.46Ab	180.56±36.94Bb	205.61±26.78Bb	331.07±20.36Cc

** Values with different upper case letters (A-D) along the rows and different lowercase letters(a-c) down the column per week are significantly different from each other using LSD test(P≤0.05).*

3.4 Efficiency for phytoremediation

For the purpose of successful phytoremediation, plants must be able to extract, accumulate and tolerate high levels of heavy metals [28]. The efficiency of these plants for the phytoremediation of Pb will be determined by: Bioaccumulation factor (BF) which is given as ratio of metal concentration in plant shoot to that in soil; and Transfer factor (TF) defined as ratio between concentrations of metals in the shoot to that in the root.

Table 4b: Values of Pb absorbed (mg/kg) into the shoots of plant on EDTA treated contaminated soil

Week 1	**50ppm**	**100ppm**	**200ppm**	**500ppm**	**1000ppm**
T. triangulare	34.32±6.94a	29.96±0.51Aa	29.81±0.28Aa	29.82±13.61Aa	34.68±7.54Aa
C. odorata	25.01±11.79Aa	25.01±11.79Aa	38.34±16.50Ab	25.21±11.78Aa	29.18±5.89Aa
S. nodilflora	37.23±1.23Aa	37.23±1.23Aa	46.75±14.69Ab	65.37±15.30Bb	100.09±12.74Cb
Week 2					
T. triangulare	29.38±0.91Aa	28.28±1.17Aa	29.17±5.89Aa	**64.91±6.65Bb**	51.48±10.90Bb
C. odorata	39.85±18.43Ab	41.77±20.51Ab	46.71±15.36Ab	40.87±3.39Aa	38.47±6.80Aa
S. nodilflora	39.23±2.25Ab	46.33±11.63Ab	64.94±11.03Bc	64.94±15.92Bb	**129.44±48.36Cc**
Week 3					
T. triangulare	22.26±3.20Aa	28.43±1.39Aa	29.16±7.29Aa	31.21±2.55Aa	55.94±18.10Ba
C. odorata	36.68±18.86Aa	53.01±4.24Ab	49.98±23.58Ab	41.67±11.79Aa	63.48±26.95Aa
S. nodilflora	39.23±2.25Aa	49.37±11.63Ab	68.94±11.03Bb	67.34±15.92Bb	116.92±47.69Cb
Week 4					
T. triangulare	40.64±5.90Ba	23.21±4.54Aa	42.08±4.14Ba	41.61±12.11Ba	43.89±7.30Ba
C. odorata	40.13±3.55Aa	50.11±4.14Ab	56.54±29.16Ab	54.37±12.39Aa	**74.52±23.98Bb**
S. nodilflora	37.23±1.23Aa	54.55±0.49Ab	72.14±0.83Bb	72.82±0.52Bb	92.65±23.26Bb

** Values with different upper case letters (A-D) along the rows and different lowercase letters(a-c) down the column per week are significantly different from each other using LSD test(P≤0.05).*

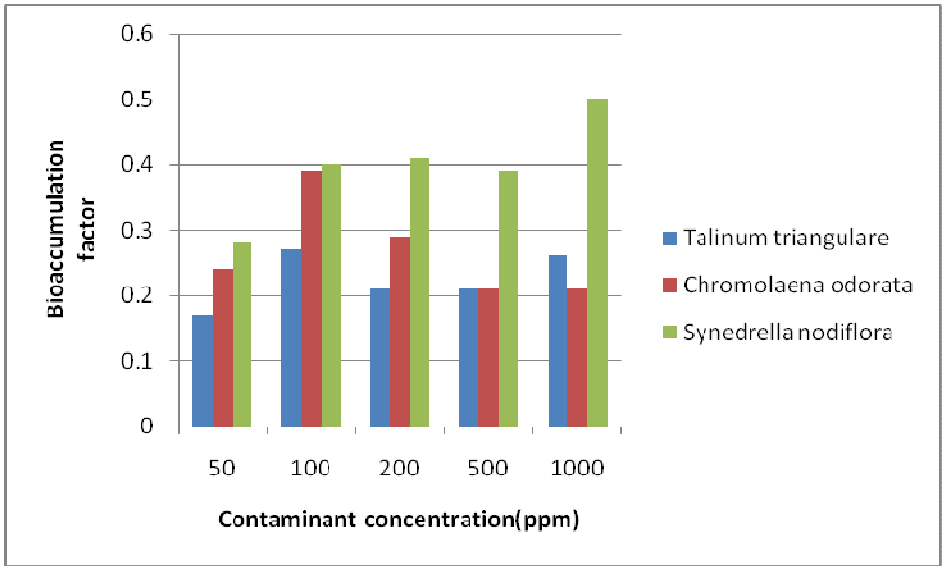


Fig 2a: Bioaccumulation factor for plants on untreated soil

Figure 2a shows a plot of the bioaccumulation factor of the plants on untreated soil against the concentration of contaminants. The BF for the plant species was in the order *S. nodiflora* > *C. odorata* > *T. triangulare*. It was observed that *S. nodiflora* gave the highest bioaccumulation factor ranging from 0.28 - 0.50 and these values were increasing with a corresponding increase in contaminant concentration.
C. odorata gave a bioaccumulation factor ranging from 0.20 - 0.39 while *T. triangulare* gave the least value ranging from 0.17 - 0.27.

Plants on EDTA treated soil gave a higher BF (fig 2b) compared to those on untreated, contaminated soil. This may be as a result of the increased bioavailability of Pb in the soil solution which will be available for plant uptake. The values of 0.22 - 0.28, 0.28 - 0.43 and 0.33

– 0.61 were recorded for *T. triangulare*, *C.odorata* and *S.nodiflora* respectively in the same order as those on untreated soil above.

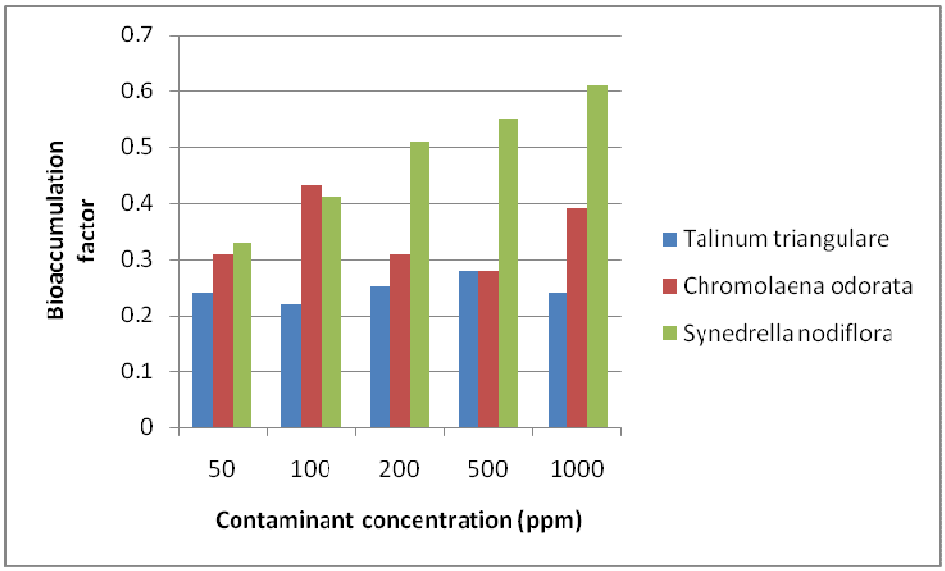


Fig 2b: Bioaccumulation factor for plants on EDTA-treated soil

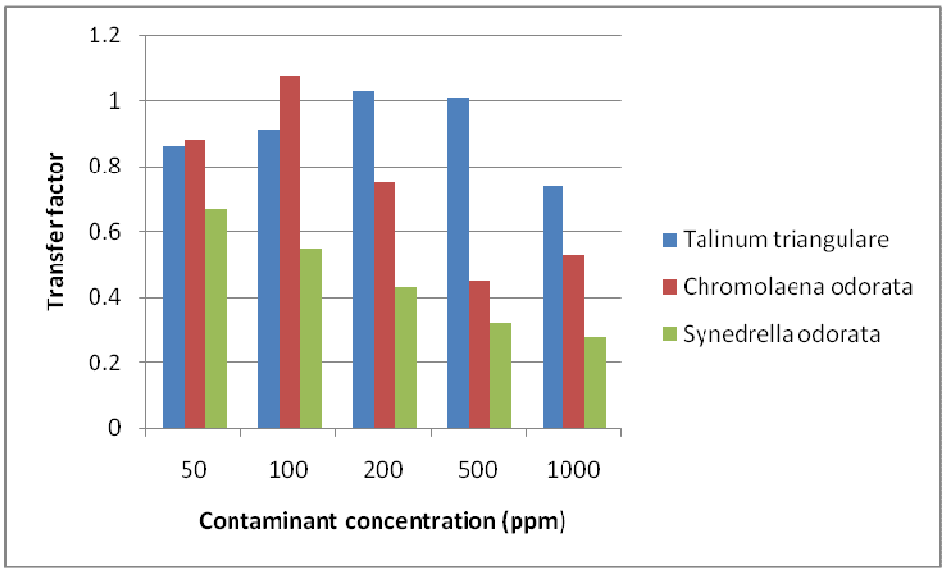


Fig 3a: Transfer factor of plants on untreated soil.

The Transfer factor (TF) is equally an important parameter in accessing the ability of a plant for successful phytoremediation. It measures the efficiency of a plant in translocating metals from root to overground parts which is a very important process in phytoremediation. One of the indicators that define a Pb hyperaccumulator is that the TF or shoot:root ratio □1 [8]. A higher TF is important in practical phytoremediation of heavy metal contaminated soil because it enables phytoremediation by harvesting only the above-ground parts of the plants [29]. However, the plants used in this study showed a poor translocation of Pb from root to shoot as majority of

the plants gave TF less than 1(Fig 3a and b).This constitutes another constraint to the phytoremediation of Pb by these plants.

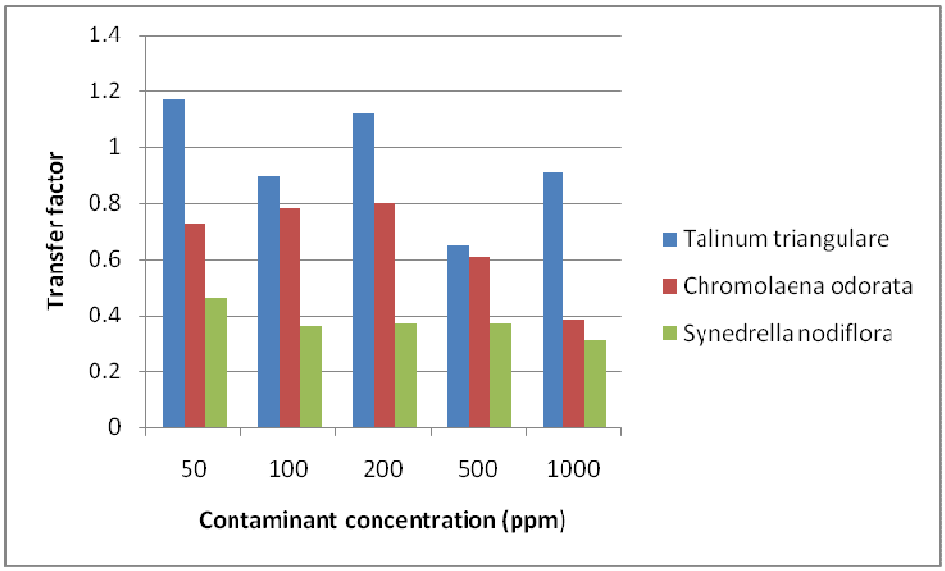


Fig 3b: Transfer factor of plants on EDTA-treated soil.

The transfer factors observed in these plants are in the order: *T. triangulare* *C. odorata* *S. nodiflora*. The highest uptake of Pb into the plant parts was observed in *S. nodiflora*, however, it exhibited the lowest transfer factor, both for treated and untreated soil, which constitute a major set-back to its use as a potential phytoremediator of Pb since the success of phytoremediation depends on harvesting the above-ground parts. *T. triangulare* which showed the lowest uptake of Pb out of the three plant species, however, gave the highest transfer factors both for treated and untreated soil which could have been an added advantage to its phytoremediation ability except for its low uptake of Pb. Furthermore, C. odorata gave transfer factors that falls within the range for the other two plant species.

A plant that will be classified as a Pb hyperaccumulator should meet the following conditions: (1)the concentration of Pb in plant shoots 1000mg/kg [8]; (2) the concentration of Pb in shoots is 10-500 times more than Pb in plants from non-polluted area (control) [30]; (3) the TF or shoot:root ratio 1 [8,31]. The plants investigated in this study, however did not successfully meet these requirements and they may not be classified as a hyperaccumulator of Pb.

CONCLUSION

The plant species used in this experiment showed a significantly higher absorbtion of Lead compared to their individual control. It could also be observed that treatment of the soil with EDTA enhanced the uptake of Pb in the plants by increasing the bioavailability of Pb in soil solution. The uptake of Pb observed in these plants are in the order *S. nodiflora* *C. odorata* *T. triangulare* both in the roots and shoots and this order holds both for treated and untreated soil.

In the light of this study, *S. nodiflora* has shown the potential to be useful for phytoremediation of Pb-contaminated soil as it gave a significantly higher absorbtion of Pb even on soil not amended with EDTA despite the challenges of Pb phytoremediation. According to Baker and Brooks [8], hyperaccumulators are metal specific and are adapted to precise climate and soil conditions. Hence, these plants could also be investigated for the phytoremediation of other heavy metals. Furthermore, more research work should be done to explore the phytoremediation potential of *S. nodiflora*.

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