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Phytoremediation and Bioconcentration of Mineral and Heavy metals in *Zea mays* Inter-planted with *Striga hermonthica* in Soils from Mechanic Village Wukari

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Abstract

Phytoremediation involves the use of plants to remediate contaminated sites. This study evaluates the effect of phytoremediation on mineral and heavy metal concentration in agricultural soil within the vicinity of mechanic village Wukari using *Zea mays* inter-planted with *Striga hermonthica* (SMV-MS), *Zea mays* alone (SMV-M), *Zea mays* inter-planted with Striga hermonthica alongside the application of fertilizer (SMV-MSF) and *Zea mays* alone alongside fertilizer application (SMV-MF). The bioconcentration of mineral and heavy metal and their translocation factors from the root to shoot of maize plants were estimated using empirical models. The result reveals that the efficiency of phytoextraction of the mineral and heavy metals were within the range: P (3.12 – 44.71 %), K (16.89 – 96.32 %), Mg (0.013 – 94.12 %), Mn (2.31 – 99.98 %), Si (20.92 – 52.07 %), Zn (2.74 – 21.65 %), Pb (10.44 – 100 %), Cd (0.75 – 42.85 %), Fe (7.42 – 98.57 %) and Al (19.14 – 98.69 %) respectively. The mean root and shoot bioconcentration factors (BCFs) of K, Mg, Mn and Al were greater than one indicating higher accumulation of the elements in the root and shoot of the maize plants. The root BCF of the elements was generally in the order: $Mn > K > Mg > Cd > Si > Al > P > Fe > Zn > Pb$ while the shoot BCF was in the order: $Mn > K > Mg > Al > Fe > Cd > Si > P > Zn > Pb$. The mean root to shoot translocation factors (TF) of P, Mn, Zn, Pb, Cd, Fe and Al were greater than one indicating effective translocation of the elements from the root to shoots. The translocation factors were generally in the order: $Fe > Al > Pb > Mn > Zn > P > Cd > Mg > Si > K$.

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1. Introduction

Ecological contamination by heavy metals is of great concern since they are not biodegradable and do accumulate in tissues of living organism causing severe health consequences [1]. Phytoremediation comprises a number of techniques that employs the use of plants to remediate and clean up contaminated sites. The efficiency of the process rest on several plant and soil factors such as: the physico-chemical properties of the soil, bioavailability of metals in soil, microbial and plant exudates. Other factors include the ability of living organisms to uptake, store, isolate, translocate and detoxify contaminants. Methods of phytoremediation may include: phytoextraction, phytostabilization, rhizofiltration, phytodegradation, phytovolatilization, and Phytostimulation. Nevertheless, for the remediation of soil using plants, phytostabilization and phytoextraction are preferred because they are easier to implement with great efficiency [2, 3]. Where phytoextraction entails the use of higher plants to concentrate and translocate soil contaminants to their harvestable above the ground tissues at the end of growth period. The method is effective if the plant use for the remediation is a hyper-accumulator of heavy metals and minerals. Furthermore the shoot should be capable of depositing metal(loid)s species at concentrations 50 to 500 times higher than those in the contaminated soil substrate. For instance, the Asian stone crop *Sedum alfredii* (Crassulaceae) has been employed intensively in that regards due to its higher accumulation rate of Cd, Pb and Zn [4, 5].

Plant's ability to accumulate metals from soils can be estimated using the bio-concentration factor (BCF), which is defined as the ratio of metal content in the plant's root or shoot to that in soil [6, 7]. Plant's ability to translocate metals from the roots to the shoots is measured using the translocation factor (TF), which is defined as the ratio of metal concentration in the shoot to the root [8]. Enrichment is said to be successful when the contaminant taken up by a plant is not degraded rapidly, resulting in an accumulation in the plant. The process of phytoextraction generally requires the translocation of heavy metals to the easily harvestable plant parts like the shoot. Tolerant plants often restrict soil–root and root–shoot transfers, leading to less accumulation in their biomass, while hyperaccumulators dynamically takes up and translocate metals and metalloids into their above the ground biomass. Plants demonstrating translocation factor and most especially bioconcentration factor values greater than one are considered more suitable for phytoextraction [9].

Previous studies reported that concentrations of contaminants are usually higher where significant human activities are recorded [10]. For instance, elevated heavy metals content has been reported in the study area around auto mechanic village Wukari, Nigeria [11]. Since waste generation often goes along side urbanization. And most available techniques that may be employed for the removal of contaminants from the environment such as chemical precipitation, ion exchange, adsorption, membrane filtration, photocatalytic degradation among others does suffers a setback of difficulty to implement in large scale and relatively high cost. Phytoremediation an emerging technology offers a cost effective and eco-friendly alternative for environmental cleanup [12]. The aim of this study is to determine the extent of reduction of mineral and potentially toxic heavy metals levels in agricultural soil within mechanic village using maize plant inter-planted with striga plant as well as to determine the bioconcentration factor and translocation factor of mineral elements and heavy metals in the plants.

2. Materials and Methods

2.1. Study Area and Sample Collection

Mechanic village Wukari with the geographical coordinate $7^{o}51'17.208''N$ and $9^{o}47'40.374''E$ is located in the ancient town of Wukari, Nigeria. The facility has been operating for more than twenty years. Activities in the facility includes: car repairs, painting, and battery replacement among others. A lot of waste are being generated from the facility where in most cases such waste are been discarded in farm lands within the area.

Soil samples was collected by means of stratified technique where a total of seventy five (75) samples unit from agronomical lands situated within the facility and a composite sample drawn to enable a good representation of the study area [14, 15]. *Striga hermonthica* and maize seeds were obtained from the Institute of Agricultural Research, Zaria and identified at the Crop Production and Protection Department of Federal University Wukari, Nigeria. Figure 1 shows the GPS Map of Wukari, Nigeria.

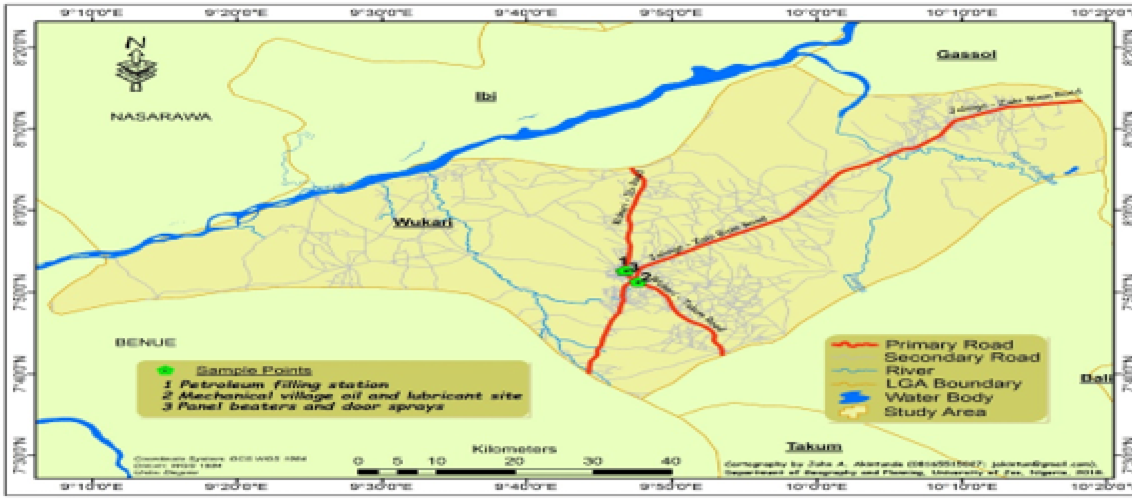

Figure 1. GPS Map of Wukari, Nigeria.

2.2. Phytoremediation Studies

The composite soil sample collected from Mechanic village Wukari was divided into four parts each measuring 4.0 L and placed in polythene pot before transferring into the greenhouse.

Three maize seeds were planted on the first portion of soil and 2 g of Nitrogen Phosphorus Potassium (NPK) fertilize applied at the third week of up shoot to aid the development of maize plant. After harvesting the maize, the soil was labeled SMV-MF. The same procedure was carried out on the second portion soil portion but devoid of fertilizer application. At harvest, the soil was labeled SMV-M.

The third part of the soil was seeded with 50 g of the striga mixed with 50 g of the soil before implanting 3 seeds of maize and 2 g of NPK fertilize applied at the third week of shoot immergence to aid the development of maize and striga plant [16]. At harvest, the remediated soil was tagged SMV-MSF. The same procedure was carried out on the fourth soil portion but devoid of fertilizer application to serve as control. At harvest of the plant tissues, the soil was tagged: SMV-MS.

The striga plant could not germinate nevertheless; maize plants harvested at maturity were washed with water and rinsed with deionized water, to get rid of surface contaminants. Each plant was separated into root and shoot. The plant samples were dried at room temperature for about a month before grinding and sieving through 2 mm pore size mesh. The plant materials were preserved for digestion and onward determination of bio-accumulation of mineral and heavy metals within them.

2.3. Determination of Total Heavy Metal and Mineral Concentration

Digestion of soil and the plant tissue samples was carried out with the aid of a microwave digestion system as adopted by Yerima *et al.* [11]. Where 10 mL of 1 : 1 HNO_3 was added to 1.0 g of the sample in glass digestion tube and the sample were then heated to 100 ^oC for about 15 minutes then allowed to cool before additional 5 mL of 1 : 1 HNO_3 and heating for another 15 minutes. The digests were allowed to cool, before additional 2 mL of deionized water; 4 mL of 30 % H_2O_2 was added and heated to 100 ^oC until the sample volumes reduced to approximately 5 mL.

The digests were cooled, filtered and diluted to 50 mL with deionized water. Total P, K, Mg, Mn, Al, Si, Zn, Fe, Pb and Cd levels in the samples were estimated using Micro Plasma Atomic Emission Spectrophometer (4210 MP-AES Agilent technologies).

2.4. Data Processing and Statistical Analysis

The bioconcentration factor or soil-plant transfer coefficient (f) was determined using the equations [$BCF = C_{root}/C_{soil}$] and [$BCF = C_{shoot}/C_{soil}$] while the root-shoot transfer coefficient using equation [$TF = C_{shoot}/C_{root}$] [17, 18]. The determinants data were fitted into a one-way analysis of variance (ANOVA) using the Statistical Package (IBM SPSS Statistics 20) ($P < 0.05$).

3. Results and Discussion

3.1. Mineral and heavy metal content of soil before and after remediation

Table 1. Soil Mineral Concentration (mg/kg) and Bioconcentration Factor.

Element	Sample	Soil	Root	Shoot	Root/Soil	Shoot/Soil	Shoot/Root
	SMV	221.22 ± 5.47					
	SMV-MF	212.88	7.78	ND	0.04	0.00	0.00
P	SMV-M	177.92	38.42	57.81	0.22	0.33	1.50
	SMV-MSF	194.31	70.15	108.47	0.36	0.56	1.55
	SMV-MS	122.30	35.83	40.5	0.29	0.33	1.13
Mean			38.045	68.92667	0.227	0.305	1.045
	SMV	298 ± 3.88					
	SMV-MF	305.92	1617.91	181.91	5.288	0.594	0.112
K	SMV-M	299.57	974.18	322.19	3.251	1.075	0.331
	SMV-MSF	253.11	1024.75	611.87	4.048	2.417	0.597
	SMV-MS	13.53	2473.42	637.22	182.81	47.09	0.258
Mean			1522.56	438.29	48.85	12.79	0.32
	SMV	298.05 ± 3.88					
	SMV-MF	298.01	415.11	100.21	1.39	0.34	0.24
Mg	SMV-M	22.33	256.87	159.06	11.50	7.12	0.62
	SMV-MSF	314.17	429.93	196.99	1.37	0.63	0.46
	SMV-MS	17.5	510.24	195.94	29.15	11.19	0.38
Mean			403.03	163.05	10.85	4.82	0.42
	SMV	231.97 ± 0.74					
	SMV-MF	226.60	22.55	42.52	0.09	0.19	1.89
Mn	SMV-M	0.03	12.59	30.3	419.60	1010.00	2.41
	SMV-MSF	219.36	6.58	33.77	0.03	0.15	5.13
	SMV-MS	10.10	13.76	22.69	1.36	2.25	1.65
Mean			13.87	32.32	105.27	253.1475	2.77
	SMV	64.27 ± 0.43					
	SMV-MF	30.80	35.61	15.81	1.16	0.51	0.44
Si	SMV-M	50.82	37.69	18.44	0.74	0.36	0.49
	SMV-MSF	33.47	19.56	12.76	0.58	0.38	0.65
	SMV-MS	40.47	31.79	2.07	0.79	0.05	0.07
Mean			31.1625	12.27	0.8175	0.325	0.4125

SMV=Test soil before remediation; SMV-MF=Test soil remediated with maize and fertilizer application; SMV-M= Test soil remediated with maize only; SMV-MSF= Test soil remediated with maize inter-planted with striga with fertilizer application; SMV-MS= Test soil remediated with maize inter-planted with striga

Phosphorus content

The mean concentration of phosphorus in soil around the mechanic village SMV before phytoremediation was 221.22 ± 5.47 mg/kg while after remediation it was 212.88 ± 9.53 mg/kg, 177.92 ± 4.49 mg/kg, 194.31 ± 2.20 mg/kg and 122.30 ± 5.13 mg/kg for SMV-MF, SMV-M, SMV-MSF and SMV-MS respectively. There was generally a significant decrease in mean phosphorus content from 3.12 % to 44.71 % due to phytoremediation ($P < 0.05$). The reduction in phosphorus content after remediation may be due to effective phytoextraction into the plant tissues [2, 3]. As demonstrated by maize plant inter-planted with striga devoid of fertilizer application in Figure 2.

Table 2. Soil Heavy Metal Concentration (mg/kg) and Bioconcentration Factor.

Element	Sample	Soil	Root	Shoot	Root/Soil	Shoot/Soil	Shoot/Root
	SMV	184.83 ± 0.47					
	SMV-MF	144.8	14.71	27.94	0.10	0.19	1.99
Zn	SMV-M	145.95	20.47	27.5	0.14	0.19	1.34
	SMV-MSF	171.61	19.08	53.14	0.11	0.31	2.79
	SMV-MS	179.75	33.99	23.45	0.19	0.13	0.69
Mean			22.06	33.00	0.14	0.21	1.70
	SMV	86.29 ± 0.31					
	SMV-MF	77.28	2.36	7.00	0.03	0.09	2.97
Pb	SMV-M	58.41	5.38	6.83	0.09	0.12	1.27
	SMV-MSF	65.37	1.21	10.15	0.02	0.16	8.39
	SMV-MS	ND	2.46	5.72	NA	NA	2.33
Mean			2.85	7.42	0.046	0.12	3.74
	SMV	1.33 ± 0.06					
	SMV-MF	0.76	0.84	0.93	1.11	1.22	1.11
Cd	SMV-M	1.01	0.83	0.89	0.82	0.88	1.07
	SMV-MSF	0.88	0.83	0.91	0.94	1.03	1.09
	SMV-MS	1.32	0.80	0.84	0.61	0.64	1.05
Mean			0.82	0.89	0.87	0.94	1.08
	SMV	20723.64 ± 153.71					
	SMV-MF	19184	450.37	2447.71	0.023	0.128	5.435
Fe	SMV-M	17113.78	685.78	2475.44	0.040	0.145	3.609
	SMV-MSF	18928.72	134.08	2633.85	0.007	0.139	19.64
	SMV-MS	294.56	540.08	1411.55	1.834	4.792	2.614
Mean			452.57	2242.13	0.47	1.30	7.82
	SMV	3753.80 ± 30.54					
	SMV-MF	3035.25	169.42	447.26	0.055	0.147	2.639
Al	SMV-M	52.00	238.16	419.73	4.58	8.072	1.762
	SMV-MSF	2996.11	57.31	588.3	0.019	0.196	10.27
	SMV-MS	90.91	207.68	405.68	2.284	4.462	1.953
Mean			168.14	465.24	1.73	3.22	4.16

SMV=Test soil before remediation; SMV-MF=Test soil remediated with maize and fertilizer application; SMV-M= Test soil remediated with maize only; SMV-MSF= Test soil remediated with maize inter-planted with striga with fertilizer application; SMV-MS= Test soil remediated with maize inter-planted with striga

3.2. Bio-concentration factor and translocation factor of phosphorus

As shown in Table 1; accumulation of phosphorus from soil obtained in farm lands around the mechanic village reveals that the BCF of phosphorus in the roots of maize plant labeled: SMV-MF, SMV-M, SMV-MSF and SMV-MS were 0.04, 0.22, 0.36 and 0.29 while the shoot BCF was 0.00, 0.33, 0.56, and 0.33. The root to shoot TFs was 0.00, 1.50, 1.55 and 1.13 respectively. The BCFs of phosphorus in the roots and shoot were generally less than 1 therefore indicating less accumulation of phosphorus in the plant tissues. Apart from SMV-MF (0.00), the root to shoot TFs were generally greater than 1, suggesting high mobility of P within the plant and hence higher accumulation in shoots compared to the roots [19].

Potassium content

Concentration of potassium in the soil SMV before remediation was 368.13 ± 2.17 mg/kg while after remediation it was 305.92 ± 2.24 mg/kg, 299.57 ± 7.38 mg/kg, 253.11 ± 1.28 mg/kg and 13.53 ± 0.00 mg/kg for SMV-MF, SMV-M, SMV-MSF and SMV-MS respectively. There was generally a significant decrease in mean potassium content by 16.89 % in SMV-MF to 96.32 % in SMV-MS due to phytoremediation ($P < 0.05$). This implies greater extraction of

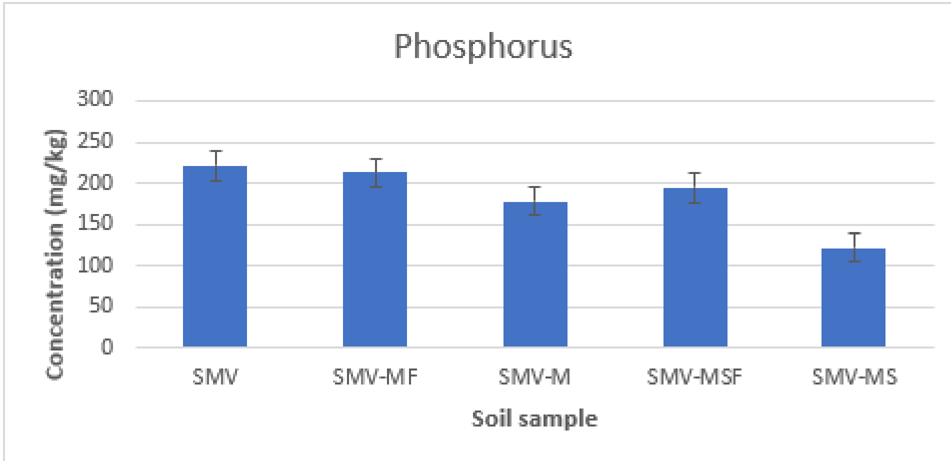

Figure 2. Effect of phytoremediation on Phosphorus content.

potassium from the soil SMV by maize inter-planted with striga devoid of fertilizer application. Figure 3 represents the effect of phytoremediation on Potassium content.

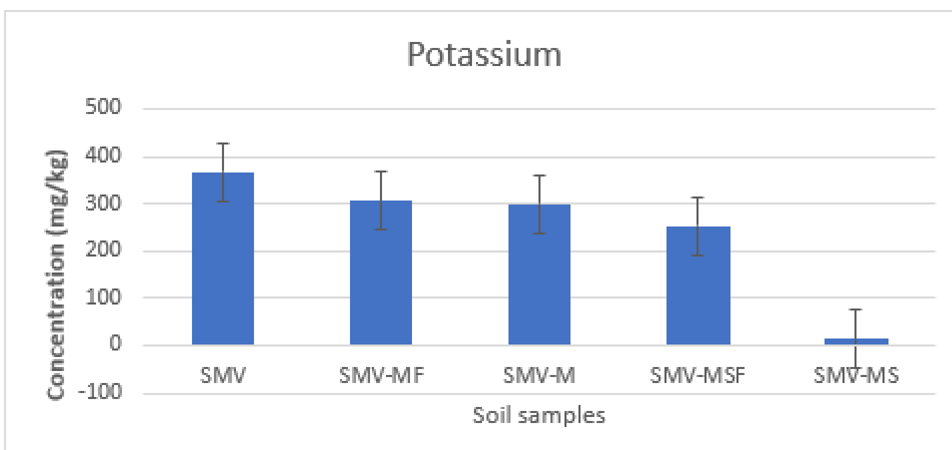

Figure 3. Effect of phytoremediation on Potassium content.

3.3. *Bio-concentration factor and translocation factor of potassium*

Accumulation of potassium from soil obtained in farmlands around the mechanic village revealed that the BCFs of potassium in the roots of maize plant labeled: SMV-MF, SMV-M, SMV-MSF and SMV-MS were 5.288, 3.251, 4.048 and 182.81 while the shoots BCFs were 0.594, 1.075, 2.417 and 47.09 respectively. Likewise, the roots to shoot translocation factors (TFs) were 0.112, 0.331, 0.597 and 0.258 respectively. Beside the 0.594 BCF of potassium in the shoot of SMV-MF, the BCF of potassium in the roots and shoot was generally greater than 1 which suggested significant accumulation of the element in the plant tissues. The root to shoot TF were generally less than 1, hence the total accumulation of potassium in the shoots was less than that of the roots.

Magnesium content

Before phytoremediation, the mean magnesium content of soil SMV was 298.05 ± 3.88 mg/kg while after remediation it was 298.01 ± 5.27 mg/kg, 22.33 ± 0.15 mg/kg, 314.17 ± 1.49 mg/kg and 17.50 ± 7.07 mg/kg for SMV-MF, SMV-M, SMV-MSF and SMV-MS respectively. The percentage decrease in mean magnesium content was relatively insignificant by 0.013 % in SMV-MF to a significant reduction of 94.12 % in SMV-MS due to phytoremediation ($P < 0.05$). Figure 4 represents the effect of phytoremediation on Magnesium content.

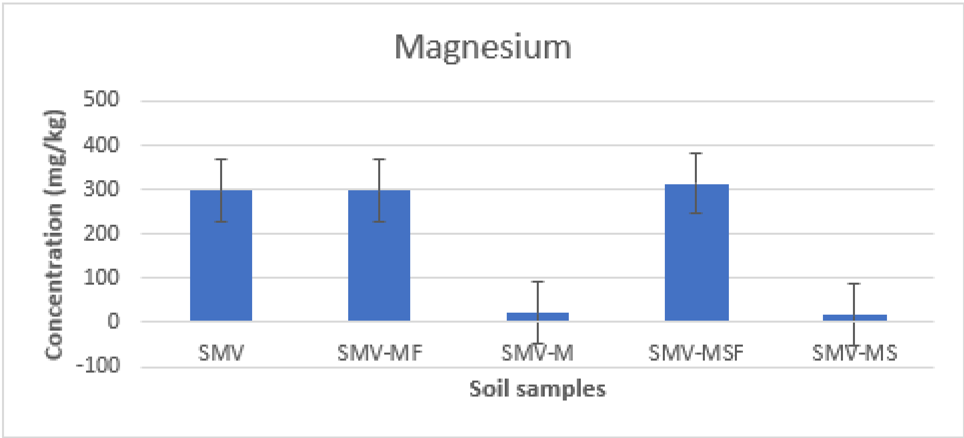

Figure 4. Effect of phytoremediation on Magnesium content.

3.4. *Bio-concentration factor and translocation factor of magnesium*

Accumulation of magnesium from soil obtained in farmlands around the mechanic village SMV in terms of root bio-concentration factors (BCFs) of maize plant labeled: SMV-MF, SMV-M, SMV-MSF and SMV-MS were 1.39, 11.50, 1.37 and 29.15 while the shoot BCFs, were 0.34, 7.12, 0.63 and 11.19 respectively. The roots to shoots TFs were 0.24, 0.62, 0.46 and 0.38 respectively. The BCFs of magnesium in the roots were generally less than 1 which implies less accumulation of magnesium in the root. The root to shoot TF was generally less than 1, suggesting higher magnesium accumulation in roots tissues in comparison with the shoot. The higher levels of magnesium in the root suggest an efficient phyto-stabilization of the element within the root tissues [2, 3].

Manganese content

Effect of phytoremediation on the manganese content

The mean manganese levels in soil SMV prior to phytoremediation was 231.97 ± 0.74 mg/kg while after remediation it was reduced to 226.60 ± 1.41 mg/kg, 0.03 ± 0.01 mg/kg, 219.36 ± 0.86 mg/kg and 10.10 ± 0.00 mg/kg for SMV-MF, SMV-M, SMV-MSF and SMV-MS respectively. The percentage decrease in mean manganese content was relatively insignificant by 2.31 % in SMV-MF to a significant reduction of 99.98 % in SMV-M ($P < 0.05$).

The significant reduction in manganese level after remediation notable in soil planted with maize only devoid of fertilizer application SMV-M shown in Figure 5, was likely due to effective phytoextraction into the plant tissues [2, 3].

3.5. *Bio-concentration factor and translocation factor of Manganese*

Bio-concentration of manganese from soil sourced from the study area in terms of BCFs in the roots of maize plant labeled: SMV-MF, SMV-M, SMV-MSF and SMV-MS were 0.09, 419.60, 0.03 and 1.36 while the shoot BCFs were: 0.19, 1010.00, 0.15 and 2.25. The roots to shoots TFs were 1.89, 2.41, 5.13 and 1.65 respectively. The BCFs of manganese in the roots and shoots of plants amended with fertilizer (SMV-MF and SMV-MSF) were less than 1 which suggest less accumulation of the element in the plant tissues while the BCF of maize planted devoid of amendment with fertilizer (SMV-M and SMV-MS) were greater than one indicating significant accumulation of Mn in the plant tissues, the higher accumulation of Mn may be due to the absence of adequate macro element such as N, P, K, the plant now utilizes the available Mn. Nevertheless, the root to shoot TFs were generally greater than 1, suggesting an efficient phyto-extraction of Mn to the above the ground tissues [9].

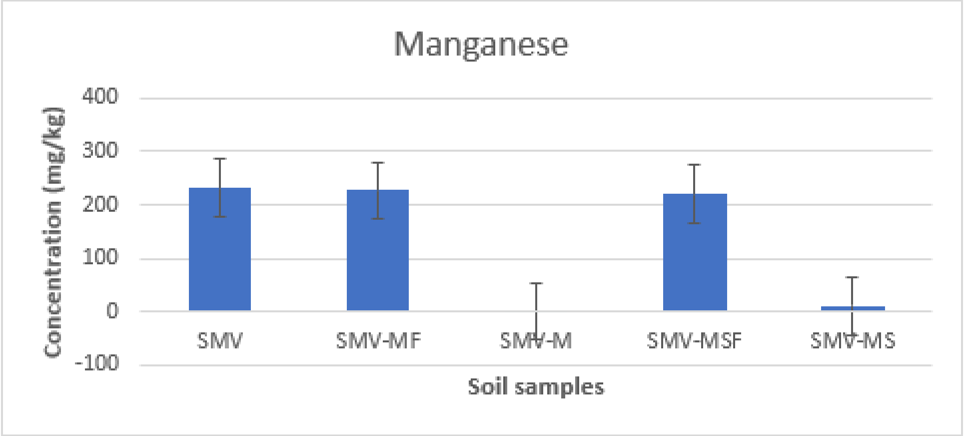

Figure 5. Effect of phytoremediation on Manganese content.

Silicon content

Effect of phytoremediation on the silicon content

Before phytoremediation, the silicon content in soil SMV was 64.27 ± 0.43 mg/kg while after remediation it was reduced to 30.80 ± 0.41 mg/kg, 50.82 ± 0.52 mg/kg, 33.47 ± 0.40 mg/kg and 40.47 ± 4.94 mg/kg in SMV-MF, SMV-M, SMV-MSF and SMV-MS respectively. The percentage decrease in mean silicon content was generally significant ranging from 20.92 % in SMV-M to 52.07 % in SMV-MF due to phytoremediation. Figure 6 shows the effect of phytoremediation on Silicon content.

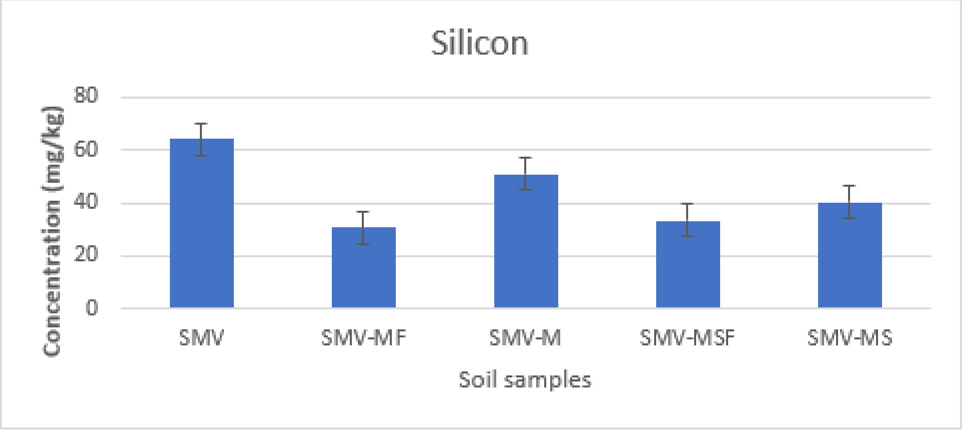

Figure 6. Effect of phytoremediation on Silicon content.

3.6. Bio-concentration factor and translocation factor of silicon

Bio-concentration of silicon from the studied soil SMV showed the BCFs of silicon in the roots of maize plant labeled: SMV-MF, SMV-M, SMV-MSF and SMV-MS as 1.16, 0.74, 0.58 and 0.79 while the shoot BCFs as 0.51, 0.36, 0.38 and 0.05. The roots to shoot TFs were 0.44, 0.49, 0.65 and 0.07 respectively.

The BCFs of silicon in the roots and shoots of plants were generally less than 1 which indicates less accumulation of silicon in the maize plant tissues with the exception of the root of SMV-MF (1.16). Likewise, the root to shoot TFs were equally less than 1 all through, suggesting an efficient phyto-stabilization of silicon within the root of the plants [2, 3].

Zinc content

Effect of phytoremediation on the zinc content

Prior to phytoremediation, the zinc level in soil SMV was 184.83 ± 0.47 mg/kg while after remediation it was reduced to 144.80 ± 2.13 mg/kg, 145.95 ± 1.25 mg/kg, 171.61 ± 0.35 mg/kg and 179.75 ± 0.94 mg/kg in SMV-MF, SMV-M, SMV-MSF and SMV-MS respectively. The percentage decrease in zinc content was relatively significant and was within the range of 2.74 % in SMV-M to 21.65 % in SMV-MF due to phytoremediation. Figure 7 shows the effect of phytoremediation on Zinc content.

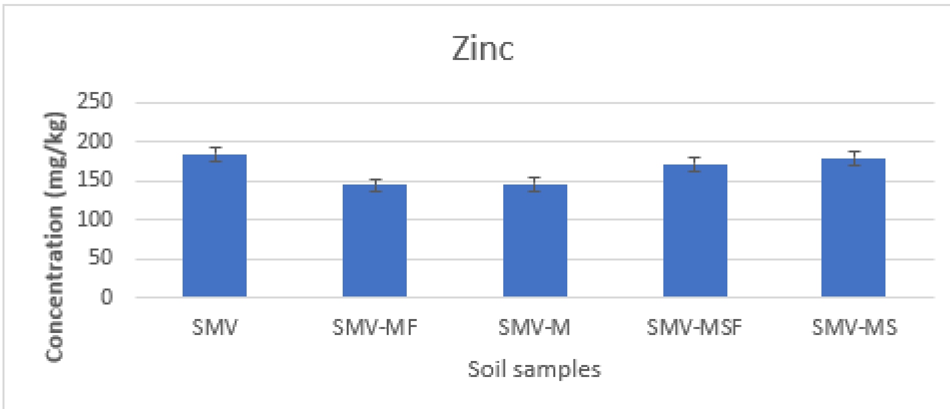

Figure 7. Effect of phytoremediation on Zinc content.

3.7. Bio-concentration factor and translocation factor of zinc

Accumulation of zinc from soil obtained in farmlands around the mechanic village showed that the BCFs of zinc in the roots of maize plant labeled: SMV-MF, SMV-M, SMV-MSF and SMV-MS were 0.10, 0.14, 0.11 and 0.19 while the shoots BCFs were 0.19, 0.19, 0.31 and 0.13. The roots to shoots TFs were 1.99, 1.34, 2.79 and 0.69 respectively.

The BCFs of zinc in the roots and shoots of plants were generally less than 1 which in agreement with the 0.26 value reported for maize planted in the irrigation area of Tongliao, China demonstrating less accumulation of zinc in the maize plant tissues [20]. The root to shoot TF were generally greater than 1, suggesting an efficient translocation of Zn from the root to tissues above the ground with the exception of maize inter-planted with striga devoid of amendment (0.69).

Lead content

The mean content of lead in the test soil SMV before phytoremediation was 86.29 ± 0.31 mg/kg while after remediation it was reduced to 77.28 ± 0.54 mg/kg, 58.41 ± 1.39 mg/kg, 65.37 ± 2.34 mg/kg, ND and 6.87 ± 0.08 mg/kg in SMV-MF, SMV-M, SMV-MSF and SMV-MS respectively as shown in Table 2. There was a significant difference between the remediated and un-remediated soil at 95 % confidence limit. The percentage reduction in lead content range from 10.44 % in SMV-MF to 100 % in SMV-MS because of phytoremediation.

The efficient reduction in lead level after remediation demonstrated in soil planted with maize and striga devoid of fertilizer application SMV-MS shown in Figure 8; was likely due to effective phyto-extraction of lead in the absence of available nutrient [2, 3].

3.8. Bio-concentration factor and translocation factor of Lead

Accumulation of lead from soil obtained in farmlands around the mechanic village revealed the bio-concentration factors (BCFs) of lead in the roots of maize plant labeled: SMV-MF, SMV-M, SMV-MSF and SMV-MS as 0.03, 0.09, 0.02 and NA while the shoot BCFs as 0.09, 0.12, 0.16 and NA. The roots to shoots TFs were 2.97, 1.27, 8.39 and 2.33 respectively. The BCF of lead in the roots and shoots of plants was generally much less than 1 which is in agreement with the 0.19 value reported for maize planted in the irrigation area of Tongliao, China [20], implying insignificant

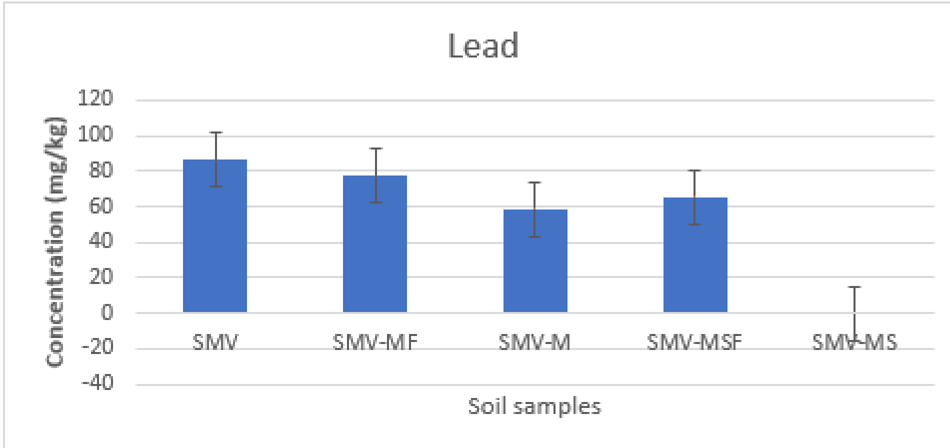

Figure 8. Effect of phytoremediation on Lead content.

accumulation of the lead in the plant tissues while the root to shoot TF was greater than 1 all through, suggesting an efficient translocation of lead from the root to tissues above the ground.

Cadmium content

Effect of phytoremediation on the cadmium content

The concentration of cadmium in the studied soil SMV before phytoremediation was $1.33 \pm 0.06\ mg/kg$ while after remediation it was reduced to $0.76 \pm 0.05\ mg/kg$, $1.01 \pm 0.07\ mg/kg$, $0.88 \pm 0.02\ mg/kg$ and $1.32 \pm 0.06\ mg/kg$ in SMV-MF, SMV-M, SMV-MSF and SMV-MS respectively. The decrease in mean cadmium content was within the range of 0.75 % in SMV-MS to 42.85 % in SMV-MF due to phytoremediation. There was generally insignificant variation statistically between the original and remediated soil except for the soil remediated with maize only alongside the application of fertilizer SMV-MF ($P > 0.05$). Figure 9 represents the effect of phytoremediation on Cadmium content.

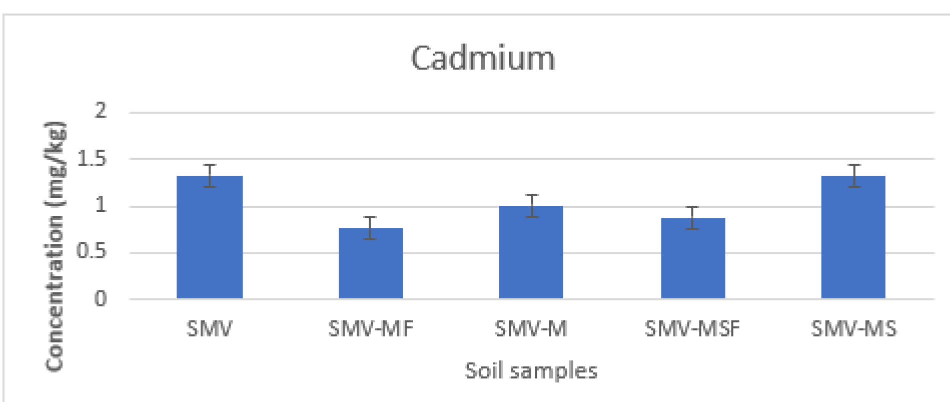

Figure 9. Effect of phytoremediation on Cadmium content.

3.9. *Bio-concentration factor and translocation factor of Cadmium*

The concentration of Cd in plant tissues planted in the studied soil SMV revealed that the bio-concentration factors (BCFs) of cadmium in the roots of maize plant labeled: SMV-MF, SMV-M, SMV-MSF and SMV-MS were 1.11, 0.82, 0.94, and 0.61 while the shoots BCFs were 1.22, 0.88, 1.03 and 0.64. The roots to shoot TFs were 1.11, 1.07, 1.09 and 1.05 respectively.

The BCFs of cadmium in the roots and shoots of plants was generally less than 1 and is in agreement with the 0.03–0.058 and 0.15–0.44 BCFs range reported in dumpsite around Ekiti and Benin cities in Nigeria respectively [21, 22]. This suggest low accumulation of the element in the plant tissues except for SMV-MF whose BCF was greater than one. The roots to shoots TFs were greater than 1 all through, suggesting an efficient translocation of cadmium from the root to shoot

Iron content

Effect of phytoremediation on iron content

Before phytoremediation, the concentration of iron in soil SMV was 20723.64 ± 153.71 mg/kg while after remediation it was reduced to 19184.00 ± 134.92 mg/kg, 17113.78 ± 122.05 mg/kg, 18928.72 ± 88.62 mg/kg and 294.56 ± 0.00 mg/kg for SMV-MF, SMV-M, SMV-MSF and SMV-MS respectively. The percentage decrease in iron content ranged from 7.42 % in SMV-MF to a significant decrease of 98.57 % in SMV-MS demonstrating a statistical difference between the remediated and un-remediated soil due to phytoremediation ($P < 0.05$). Figure 10 represents the effect of phytoremediation on Iron content.

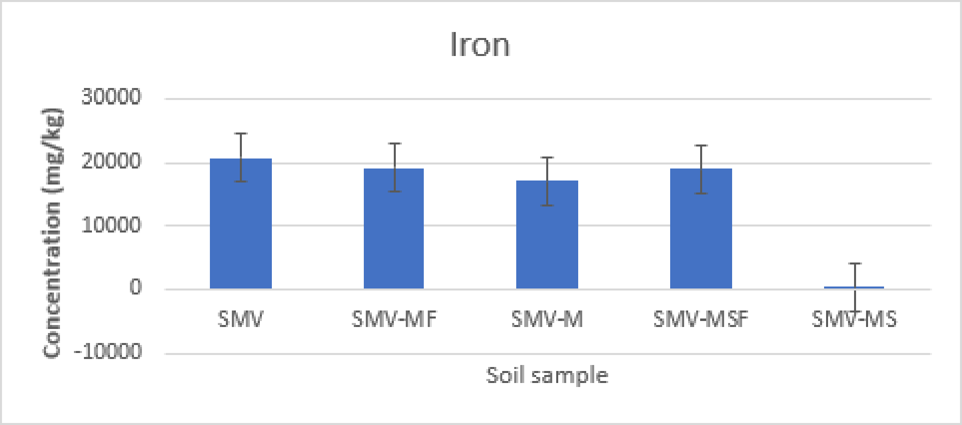

Figure 10. Effect of phytoremediation on Iron content.

3.10. Bio-concentration factor and translocation factor of Iron

Accumulation of iron from soil obtained in farmlands around the mechanic village revealed the BCFs of iron in the roots of maize plant labeled: SMV-MF, SMV-M, SMV-MSF and SMV-MS as 0.023, 0.040, 0.007 and 1.834 while the shoot BCFs as 0.128, 0.145, 0.139 and 4.792. The roots to shoots TFs were 5.435, 3.609, 19.64 and 2.614 respectively.

The BCFs of iron in the roots and shoots of plants were generally less than 1, suggesting less accumulation of the element in the plant tissues except for maize plant planted without striga and amendment SMV-MS (1.834 and 4.792). The root to shoot TFs were greater than one all through, suggesting greater enrichment of iron in the shoot compared to the root [9].

Aluminum content

Effect of phytoremediation on aluminum content

The concentration of aluminum in soil SMV prior to phytoremediation was 3753.80 ± 30.54 mg/kg while after remediation it was reduced to 3035.25 ± 13.14 mg/kg, 52.00 ± 0.04 mg/kg, 2996.11 ± 10.18 mg/kg and 90.91 ± 12.48 mg/kg in SMV-MF, SMV-M, SMV-MSF and SMV-MS respectively. The percentage decrease in aluminum content ranged from 19.14 % in SMV-MF to 98.61 % in SMV-M due to efficient phyto-extraction of Al when no amendment was applied ($P < 0.05$). Figure 11 represents the effect of phytoremediation on Aluminum content.

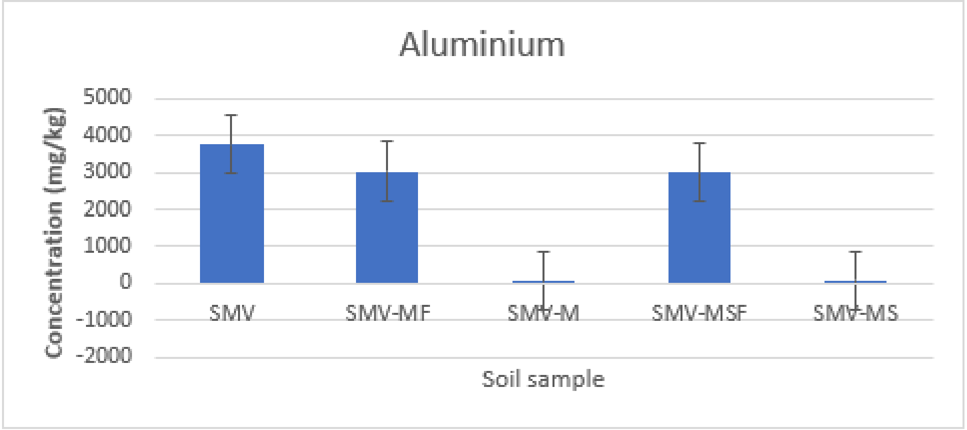

Figure 11. Effect of phytoremediation on Aluminum content.

3.11. Bio-concentration factor and translocation factor of Aluminum

The ratios of aluminum content in the root of maize plant and soil obtained from farmlands within the mechanic village plant labeled: SMV-MF, SMV-M, SMV-MSF and SMV-MS were 0.055, 4.58, 0.019 and 2.284 while the shoots BCFs were 0.147, 8.072, 0.196 and 4.462. The root to shoot translocation factors (TFs) were 2.639, 1.762, 10.27 and 1.953 respectively.

The BCF of aluminum in the roots and shoots of maize planted without fertilizer was generally greater than 1, demonstrating hyper accumulation of the element in the plant tissues while the BCF of maize planted with amendment was less than one. The root to shoot TFs recorded were greater than 1 all through, suggesting an efficient translocation of aluminum from the root to tissues above the ground [9]. Maize planted devoid fertilizer satisfies both the $BCF \geq 0.2$ and $TF > 1$ condition for accumulator plant [23].

4. Conclusion

The minerals and potentially toxic heavy metals content of the studied soil were efficiently reduced due to effective phytoextraction by maize plant inter-planted with *Striga hermonthica*. Where, the mean root to shoot translocation factors of P, Mn, Zn, Pb, Cd, Fe and Al were greater than one indicating effective translocation of the elements from the root to shoots. Iron recorded the highest translocation factor while potassium the least. The root and shoot bio-concentration factors of K, Mg, Mn and Al were also greater than one indicating higher accumulation of the elements in the root and shoot of the maize plants. Manganese and lead recorded the highest and least BCFs.

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