Phytoremediation of Lead Contaminated Soil from an Abandoned Urban Lot

by

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Phytoremediation of Lead Contaminated Soil from an Abandoned Urban Lot

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Abstract

Soil is subjected to contamination from industrial activities as well as from old house paint. There are many soil remediation technologies including solidification, leaching, soil washing. However, these techniques are not cost effective and cause secondary pollution for the environment. (Jeanna R. Henry, 2000). Phytoremediation, the technology of using plants and their associated soil microorganism to remove environmental contaminants has recently been shown to be effective for removing lead from soil.

The aim of this project is to evaluate two different plants, *Helianthus annuus* (Sunflower) and Brassica Juncea (Indian Mustard) , as well as the chealator N-(2-Hydroxyethyl) ethylenediamine- N,N′,N′-triacetic acid trisodium salt (EDDS) for remediating lead contaminated residential soil.

There was significant interactions in roots between metal concentration and growth times ($\alpha = 0.005$), and metal concentration and the different treatments ($\alpha = 0.004$). However, there was no significant interactions between metal concentration values, treatment and growth time in the soil and shoots. With longer growth times, different metal extraction methods, multiple plants in a single pot would increase metals uptake, particularly lead.

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TABLE OF CONTENTS

LIST OF FIGURES

CHAPTER 1: INTRODUCTION

1.1 Lead pollution in urban soils

Urban soils are subject to metal contamination from point sources of air pollution such as from industrial sites or nonpoint sources, such as highways and roads or from past local land use (Alloway, 2004). Indeed in the U.S. alone there are more than 600,000 ha of documented metal contaminated brown fields, not including smaller urban/suburban sites (Mahar et al, 2016). The most common heavy metal contaminants are Lead (Pb), Mercury (Hg), Cadmium (Cd), Chromium (Cr), Copper (Cu), and Zinc (Zn) which, unlike organic contaminants, are not degraded and require removal or immobilization (Lasat, 2002). Of these, lead is one of the most significant contaminants causing detrimental health hazards. Children under the age of 6 are especially vulnerable to lead poisoning, which can severely affect their mental and physical development including lower IQ, impaired development, and mental deterioration (Alexander et al. 1974; Chamberlain et al. 1978; James et al. 1985; Ziegler et al. 1978 as cited in ATSDR 1999). They are exposed to lead by inhaling lead dust from lead-based paint or lead-contaminated soil, playing with toys that has lead paint, or from food or water that contains lead. Adults who conduct home renovations or are otherwise exposed to lead may also have health risks, and of particular concern is a lead associated problem in fetal bone and organ development when pregnant women are exposed to lead (Baghurst PA *et al*,. 1987).

Many communities across the US have suffered from both deindustrialization and economic divestment leaving huge swaths of suburban impoverishment. Due to the ages of the homes, it is likely that many homes contain lead (Pb)-based paints, which causes significant contamination of soil around the homes. A recent report found soil Pb levels in Appleton, WI as high as 32,483 μg/g for homes built before 1960 compared to 755 μg/g for homes built after 1960 which are high compared to US EPA soil limits of 400 μg/g for play areas and 1200 μg/g for other areas of the yard (Clark and Knudsen, 2013). The effects of soil contamination by Pb in urban areas often have a disproportionate effect on older and low-income neighborhoods and therefore can be seen as an environmental justice issue (McClintock, 2012). A recent demolition program (Moving Ohio Forward) aimed at restoring poverty blighted neighborhoods in Warren, Ohio has left 6 to 12% of the residential lots vacant. Normal productive use of these vacant lots include side yard expansion, community gardens, small parks or rain gardens, however, these options are all impacted by potential soil contamination with lead (Alloway, 2004). Unfortunately, the scope of the neighborhood restoration program did not include resources for Pb analyses nor for implementing lead containment during demolition even though 89% of these homes were constructed before 1978 when lead based paints were commonly used (TNP data). Likely many of these vacant lots had high levels of lead remaining in the soil after demolition, as an unintended consequence.

1.2 Phytoremediation

Phytoremediation is a cost effective sustainable use of plants and their associated microbes, amendments, and agronomic techniques to remediate environmental contaminants (Baker *et al.*, 1994; Cunningham *et al.*, 1996) (Schnoor et al. 1997;

Watanabe, 1997). Mechanisms of soil phytoremediation can include contaminant extraction (phytoextraction), degradation (phytodegradation), volatilization (phytovolatilization) or immobilization (phytostabilization) (Mahar et al., 2016). Phytoextraction leads to the most desirable long-term outcomes for remediating metal contaminated soil, since the contaminant is accumulated by plants and is removed from the site when the plant is harvested. This allows the soil to remain in place with reduced health and environmental risks. The most efficient plants for phytoextraction are hyperaccumulators, which can accumulate high concentrations of metals in their above ground biomass (their shoots), making metal removal feasible upon plant harvest. There are over 450 known hyperaccumulator species (Rascioa and Navari-Izzo, 2011). There are other remediation technologies including solidification, leaching, soil washing and permeable barriers, however, they are expensive and may cause secondary pollution (Jeanna R. Henry, 2000). Two of the most effective hyper accumulators are *Helianthus annuus* (Sunflower) and *Brassica juncea* (Indian mustard).

1.3 Indian mustard & Sunflower as hyperaccumulators

Reports of phytoremediation investigations indicate there are several plants that are good candidates for phytoremediation of Pb, including geraniums (Mahdieh et al 2013), corn and peas (Huang et al. 1997), alfalfa (Lopez et al. 2005), indian mustard and sunflowers (Lin et al. 2009, Rahman et al. 2013). The latter two have been used successfully in phytoextraction strategies. In one report, indian mustard was shown to efficiently remove Pb when chelating agents, as soil-additives, were added (Blaylock et al. 1997). A recent review of plants used for phytoremediation of toxic metals reported that Indian mustard and sunflowers can accumulate up to 100 µg/g and 60 µg/g of Pb, respectively (Tangahu et al. 2011). Although indian mustard is able to accumulate higher plant concentrations of Pb, the use of sunflowers was also effective because the plants produce large amounts of biomass which acts as a reservoir and facilitates removal of the extracted Pb (Adesodun et al 2010). An additional advantage of using sunflowers for phytoremediation is that they most rapidly accumulate lead within the first few weeks of planting, as demonstrated by Adesodun et al., 2009 in soils spiked with 400 ppm lead nitrate.

1.4 Chelator effects on phytoremediation

Many phytoremediation studies have shown the effectiveness of using a chelator to enhance the bioavailability of the metal contaminant leading to enhanced metal uptake by the plant. EDTA is most commonly used chelator in phytoremediation. The use of chelating agents has been reported as a means for increasing the removal efficiency of Pb by phytoremediation approaches (Huang et al. 1997, Blaylock et al. 1997, Liu et al. 2007, Hadi et al. 2010). Chelating agents increase the solubility and mobility of metals in soils making them more available to plants and increases metal transport from the roots into the above ground plant tissues. When the chelating agent EDTA was added to soils containing 600 mg/kg Pb, indian mustard accumulated up to 1.5% of Pb in plant shoots (Blaylock et al. 1997). EDTA also increased Pb mobilization and accumulation of Pb in plant tissues of sunflowers (Lin et al. 2009; Seth et al. 2011). Although EDTA increases phytoextraction efficiency, it is a synthetic compound that is not biodegradable and can contribute to increased mobilization of other toxic elements that could cause contamination of groundwater or other environmental problems. For this reason, there is interest in identifying other chelating compounds that provide enhancements in phytoextraction efficiency but that are also biodegradable. An alternative compound shown to be an efficient chelating agent is N-(2-Hydroxyethyl)ethylenediamine- N,N′,N′-triacetic acid trisodium salt (EDDS), which is similar in structure to EDTA but is also biodegradable (Niiane et al. 2008). A recent study with sunflowers in soil showed EDTA increased phytoremediation (30% less Pb remaining) in Pb spiked soils than was found in controls (Chirakkara 2015). These results were supported in another phytoremediation study of soil highly contaminated with Pb (1221 mg Pb/kg); moreover with an additional electrical charge treatment Pb phytoremediation was even greater (Tahmasbian and Sinegani, 2016). One study comparing EDTA and EDDS in phytoremediation of Pb in soils showed that EDTA enhances Pb removal, however EDDS has the advantage of rapid biological degradation with less detrimental environmental impact (Epelde et al, 2008).

CHAPTER 2: RESEARCH GOALS AND HYPOTHESIS

2.1 Research Goals:

The goals of this research are to 1) to assess the potential for phytoremediation to be considered as an option for reducing lead concentrations in an lead paint contaminated urban soil such that the soil could be considered safe to remain on site; 2) to determine which of two known Pb hyperaccumulators, *Helianthus annuus* and *Brassica juncea*, demonstrates better Pb uptake; 3) to determine if a single crop or if two crops grown sequentially within the same total time show better Pb removal; and 4) if addition of a biodegradable chealator (EDDS) enhances Pb removal.

2.2 Hypothesis

Use of hyperaccumulators and chelators as well as multiple planting and harvesting in same soil would remove more Pb than a single planting and harvesting for the species of Sunflower and Indian mustard.

CHAPTER 3: MATERIALS AND METHODS

3.1 Selected plant species

Two plants *Helianthus annuus* L (Family: Asteraceae) (Burpee Sunflower, Elf, Girasol elf) and *Brassica juncea* (Family: Brassicaceae) were chosen for this study based on their classification as hyperaccumulators of Pb, availability of seeds, commonness, and familiarity to neighbors, and are already present and not considered as invasive species to Ohio. Because of its ability to grow fast, having high biomass production, easiness to harvest and accumulation of several toxic heavy metals the *H. annuus* (sunflower) fits efficient phytoremediation easily. (Maite et al. 2004; Sharma et al. 2004; Sinegani and Khaillkhah 2010). *B. juncea* (Indian mustard) transports lead from the roots to the shoots very efficiently which is key factor in phytoextraction (USEPA, 2000).

3.2 Planting

Sunflower and mustard seeds were germinated in seed starter (Percival, Intellus Control System) for 7 days before being transferred to pots (9 cm bottom, 12 cm top, and 14 cm tall) that contain 700 g of lead contaminated soil collected and processed (described below). Plants (Group A and B) were lightly watered daily and each pot was fertilized once on June 20 with 15 ml of diluted fertilizer (Water Soluble All Purpose Plant Food, Miracle GRO; 5 g diluted into 3785 ml) as recommended by the manufacturer. Group A was fertilized again on July 20 following initial harvest and second planting (July 10). The fertilizer was reported by the manufacturer to consist of the following:

Total Nitrogen ………………………24% (1.2 g in 5 g) = (4.8 mg/pot)

Available Phosphate (P_2O_5)…………8% (0.4 g in 5 g) = (1.6 mg/pot)

Soluble Potash (K_2O)………………..16% (0.8g in 5 g) = (3 mg/pot)

Boron (B)…………………………….0.02% (trace)

Copper (Cu)…………………………..0.07% (trace)

Iron (Fe)………………………………0.15% (trace)

Manganese (Mn)……………………...0.05% (trace)

3.3 Site History

The study site soil was collected from a suburban property located in Warren, north eastern Ohio. Structures on the property included a two story house built in 1900 with 2 stories and a stand-alone garage constructed in 1956. In 2014 Trumbull County Land Reutilization Corporation (TCLRC), a nonprofit community corporation, bought the property and demolished the structures as part of local revitalization efforts. This site was one of several selected by TCLRC for suitability (likelihood of having soil contamination from lead based paint). Soil samples (how many, when) were tested and found to contain moderate Pb levels (~200 ppm). Soil used in this current study was collected from the site on May 10, 2015.

Figure 1 Site location, Warren, north eastern Ohio. (Google maps, 2016)

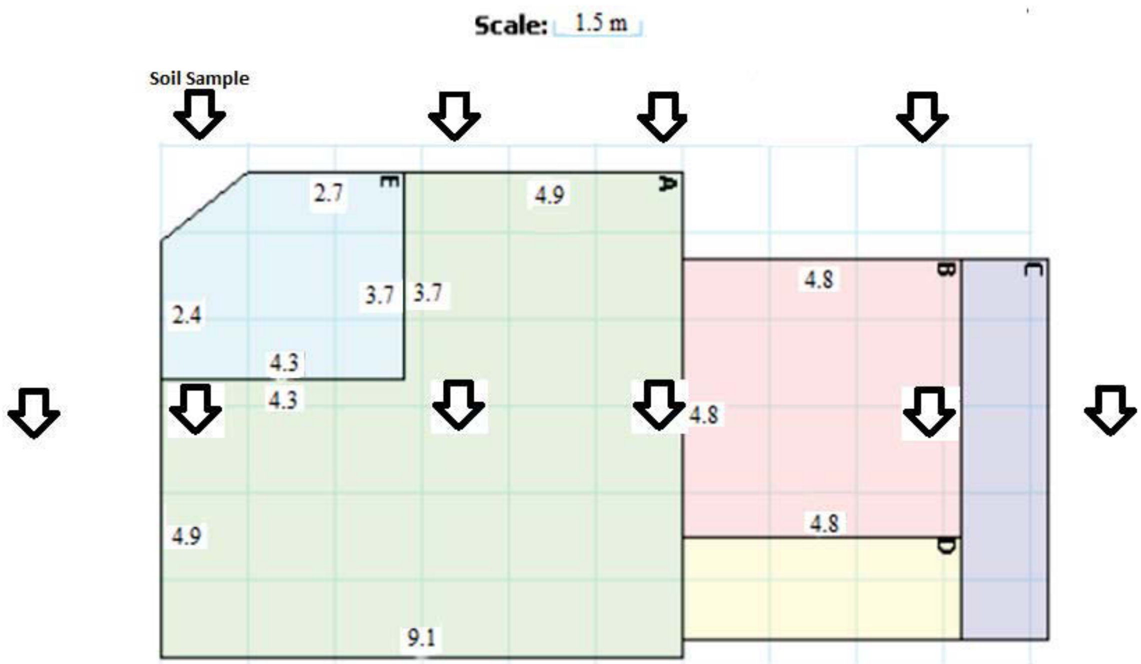

Figure 2 Site map of Warren, Ohio on May 10 indicating where the house structure was located (before demolition) and of locations (Shown as arrows) where soil was collected for this study.

Figure 3 Photograph of the site showing the abandoned house prior to demolition.

3.4 Soil Collection

Surface materials such as twigs, rocks and leaves were removed prior to sampling soil at the Warren site (refer to Figure 3 for soil sample locations). Soil was collected from a depth of 0 - 15 cm using an auger (Basic Soil Sampling Kit, AMS, American Falls, Idaho). Soil was then air dried in a drying oven at 105 ˚C for 24 hours and sieved through a 2 mm mesh and homogenized.

3.5 Removal of organic matter, calibration of hydrometer and soil texture analysis

As determined by Sheldrick and Wang, (1993) soil was pretreated with hydrogen peroxide (H_2O_2) to remove organic matter. 40 g of air dried soil was placed in to 600 ml beaker. 100 ml Di water. 5 ml H_2O_2 was added to soil and then mixed and left in the oven at 90 ˚C for 10 minutes. This procedure was repeated 6 more times.

Sodium – hexametaphosphate (50 g) was added to 1 liter of distilled water and was thoroughly mixed to make the dispersant solution. Dispersant solution (100 ml) was added to 1000 ml a glass graduated cylinder and adjusted up to 1 liter with distill water. After mixing and waiting 30 minutes at room temperature, a hydrometer (brand, model, range of values) was gently lowered in to the solution in order to identify scale reading.

Air dried soil (40 g) was placed in to 600 ml beaker (Duplicate). 100 ml of dispersant solution and 250 ml of distilled water was added in to that beaker and allowed to stay for 24 hours. dispersant treated sample was then transferred in to the mixer and mixed for 5 minutes. Mixed solution then added to 1 L graduated cylinder, Di water was added to a volume of 1 L with distill water (B. H. Sheldrick and C. Wang, 1993).

3.6 Soil pH

Soil pH was determined (triplicate) in a 1:1 (V/V) soil/water mixture which composed of 10 gram 10 ml molecular water on a Dual Channel pH meter (XL50, Dual Channel pH/Conductivity Meter, Accumet Excel, Fisher Scientific) Samples were stirred both before and after a 15 minute equilibration period. The pH meter was calibrated using 4.01 (Oakton, Part Number 00654-00), 7.00 (Oakton part Number 00654-04), and 10.01(Oakton, Part Number 00654-08) buffers (G. W. THOMAS, 1996)

3.7 Organic matter

Loss on ignition method was used for organic matter determination. (Duplicates) The mass of an empty dry porcelain crucible was determined and then placed into the oven (Isotemp 500 Series, Fisher) for two hours at 105^{o} C. Once crucibles were taken from the oven, they were placed into a desiccator to cool down. After the crucibles, Y1 and Y2 were cool to the touch, they were weighed (Y1 23.95, Y2 24.81) ~3 g of air dried sieved soil was added into the crucible and the weights were recorded. Samples were then placed into the furnace (1400 Furnace, Thermolyne) at 400 ˚C for 16 hours. After 16 hours the samples were removed and placed into a desiccator. Samples were allowed to cool to room temperature before weighing again and the weights were recorded. Organic Matter = (105˚Cweight – 400˚Cweight)/105˚C (Ben-Dor and Banin 1989).

3.8 Mehlich III Available Metal Extraction

Soil samples (3g) were weighted and passed through 2 mm sieve and then placed into a 125 ml Erlenmeyer flask. Following 30 ml of Mehlich III extraction solution was added into the flask and shaken immediately for 5 minutes. Eventually, the solution filtered through No. 42 Whatman filter paper and filtrate was saved for the ICP analysis (T. Sen Tran and R. R Simard, 1993)

3.9 Metal Extraction by Lithium Metaborate

Dried soil (0.1 g) was added into graphite crucible then 0.5 g of Lithium Metaborate was added to cover the soil. Crucibles were placed into Furnace (Brand, model) for 15 minutes in 1000 ˚C to form a molten state. After 15 minutes the melted soil was poured in EPA ICP 50 ml vials which contains 2% Nitric acid and capped.

3.10 Plant tissue analysis:

Plant parts were washed gently with distilled water then placed on paper towel. Once the water was soaked by paper towel, plant tissues were placed in to oven at 105˚C for overnight. Then plant tissues were separated into roots, flower and stem and leaves and weighted. In order to homogenize the tissues, they were cut into 1 mm pieces and then grind into powder using an acid washed porcelain mortar and pestle. From homogenized plant tissues 0.1 g was taken and added in to the crucibles which was covered with 0.5 g Litium Metaborate and heated at 1000 ˚C for 15 minutes. The fused soil samples were added in to vials that contain 2% Nitric acid solution to be ready for ICP-MS analysis.

3.11 Preparation of standards for standard curve

Standard Solution Preparation for Metal Analysis

The following steps were performed to produce the standard solutions that were used for all metal analysis for this study.

1. To clean the volumetric flask that would be used for metal analysis, the following procedure was performed. First, approximately 20 ml DI water to a 50 ml volumetric flask. 2 ml of Trace Metal Grade Nitric acid (67 – 70% as HNO_3, UN2031, Fisher Scientific) were then added and DI water was then added to create a total volume of 50 ml. This solution was then allowed to sit for 1 hour. The flask was then thoroughly rinsed with DI water at least five times to make sure there were no metal contaminants remaining.

2. Once the volumetric flasks were ready, they were numbered from 1 to 5. 20 ml of DI water was added to each flask followed by 1 ml of nitric acid. Then the following steps were performed for each individual flask:

First volumetric flask (20 ml DI water and 1 ml Nitric acid): Add 0.5 ml of stock solution (Instrument Calibration Standard 2, Cat # CL – CAL – 2, SPEX CertiPrep 100ppm) and produce a total volume of 50 ml with DI water (1000 ppb).

Second vol. flask (20 ml DI water and 1 ml Nitric acid): Add 0.25 ml of stock solution and produce a total volume of 50 ml with DI water (500 ppb).

Third vol. flask (20 ml DI water and 1 ml Nitric acid): Add 0.15 ml of stock solution and produce a total volume of 50 ml with DI water (300 ppb).

Fourth vol. flask (20 ml DI water and 1 ml Nitric acid): Add 0.5 ml of stock solution and produce a total volume of 50 ml with DI water (100 ppb).

Fifth vol. flask (20 ml DI water and 1 ml Nitric acid): Add 0.015 ml of stock solution and produce a total volume of 50 ml with DI water (30 ppb).

Initially, each sample run begins with the probe in a 2% nitric acid bath, then the probe is inserted into a blank, followed by a series of standards for initial calibration then enters a quality check (QC). After this, the probe will enter the first sample vile and begin analysis, followed by another 2% nitric acid rinse between samples. Every 20 samples, another QC will be performed and if the machine deems it necessary, another round of calibrations and QC will be run before sample analysis continues.

3.12 EXPERIMNET DESIGN

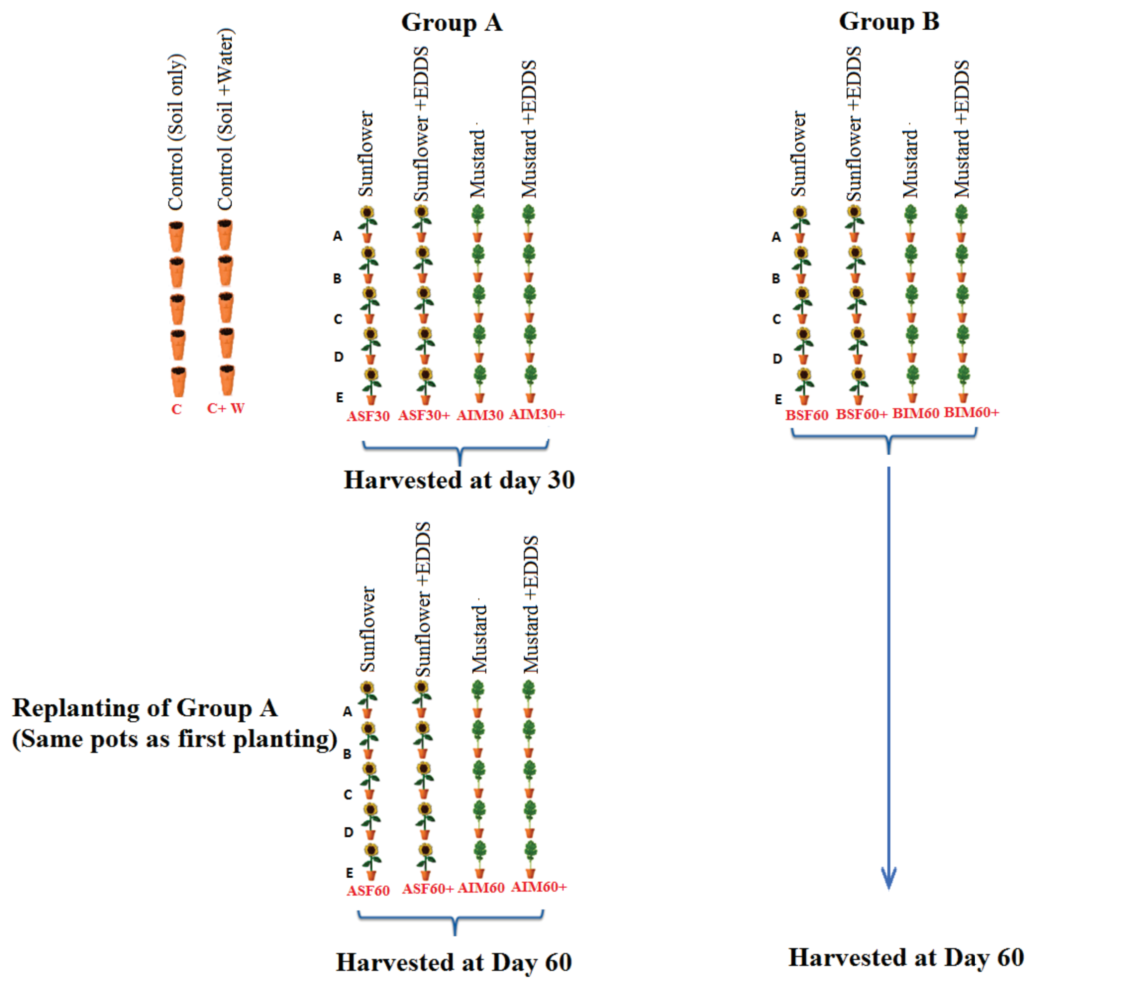

Figure 4 Diagram of Phytoremediation Experimental Design. This study was conducted to determine which treatment provided optimal Pb lead removal (one or two plantings; sunflowers or indian mustard; with or without EDDS). The study consisted of Group A (two crops) and Group B (one crops). which were grown in soil samples taken from the demolished house site in Warren, OH. The control group consisted of unseeded soil in pots (n=5). Both group A and B consisted of 5 pots of *H. annuus* (sunflower), 5 pots of *H. annuus* with EDDS ((S,S)-Ethylenediamine-N,N' – disuccinic acid trisodium salt solution) added 3 days before harvesting, 5 pots of *B. juncea* (Indian mustard), and 5 pots of *B. juncea* also with EDDS added 3 days before harvesting. Group A was planted and harvested at day 30, then the same pots were used for an identical replanting and then subsequently harvested 30 days later (at day 60 of the experiment). Group B was harvested at day 60 and consisted of only one planting.

One seedling was planted into each pot containing ~700 gr lead contaminated soil on June 10. Group A consisted of 4 treatments: either Sunflower or Mustard either with or without (S,S)-Ethylenediamine-N,N' – disuccinic acid trisodium salt solution (EDDS), Aldrich, Lot#BCBP8025V, PCode101579573, MW:358.19 g/mol). Each treatment was conducted in replicates of 5. Group A treatments consisted of two crops; the first crop was harvested after 30 days, followed by a new planting of seedlings which were harvested after another 30 days. Group B treatments were set up at the same time and treated the same as Group A, but were left to grow for the full 60 days as a single crop. The temperature of the greenhouse (Youngstown State University) for this study was maintained at 20 ± 5˚C.

The final molarity of EDDS used in this experiment was 5 mmol/L which required 1.7 ml of the EDDS reagent that was used (Jae-Min Lim, Arthur L. Salido, David J. Butcher, 2013).

CHAPTER 4: RESULTS

4.1 Results summary

The metal (all) concentration analysis of the plant roots (Fig 47 – 56) yielded significance. Two factor ANOVA which was 30 (group A first harvest) versus 60 (Group B) day and Plant type and EDDS combination was used for all metal concentration in root. Both of the treatments were significant (Appendix E). There was a significant difference between the 30 vs 60 days (Appendix E) and significant difference among the treatments (Appendix). The Post Hoc comparisons in root uptake for all metals showed that the two sunflower treatments were different from one another and the Sunflower EDDS was different from the Indian mustard without EDDS. Indian mustard without EDDS was also different from Indian mustard with EDDS so in both cases, EDDS treatments were higher than non EDDS. There is no reason to run Post Hoc for the time because there are only two levels and there was higher metal accumulation in roots after 60 days than after 30. The second ANOVA is two factors as well where treatment is plant X EDDS combination but Indian mustard alone was not present because the plants died in the 2nd 30 days so we have first 30 vs 60 versus 2nd 30 days. In this case, it turned out that only the plant X EDDS combination was significant (Appendix).

There was no statistical significance between control (initial soil) and treatments for the lead concentration (Figures from 6 – 15, 27 – 36). By looking at the averages of the lead level of the shoots (Fig 37 – 46), it's shown that there was minimal accumulation in plant shoots. Pb concentration in the group A (First harvest) was lower than group B and group A second harvest. After running SPSS analysis, results showed that there was no significant difference in time or plant type. However, there was a significant difference in EDDS treatment. It should be noted that statistical analyses of this portion of the experiment are not considered reliable due to the presence of negative values in the metal concentrations of the element chromium and nickel (Cr and Ni) that were determined.

Soil Characteristics

Parameters	Units	Value			
Conductivity	micro Siemens/cm	225			
Organic Matter	%	4.4			
Soil pH		6.8			
*[1]Nitrate-N	ppm	13.4			
*[2]Nitrogen	%	0.14			
*[3]Carbon	%	3.16			
*[4]Exchangeable Cations	(meq/100g)	K 0.2	Mg 1.7	Ca 9.0	CEC 10.9
*[5]Saturation of the CEC	%	K 1.6	Mg 15.6	Ca 82.7	

Figure 5: Selected properties of the initial soil used for this study. Soil nutrient levels of initial samples taken from demolished house site in Warren, OH detailing pH, phosphate levels, additional exchangeable cations, nitrogen, carbon, percentage saturation of CEC and nitrate levels. Results that were obtained through analysis performed by the Agricultural Analytical Services Laboratory at The Pennsylvania State University are indicated with a * (University Park, PA).

Readily Available Metals in Control and in Group B Samples

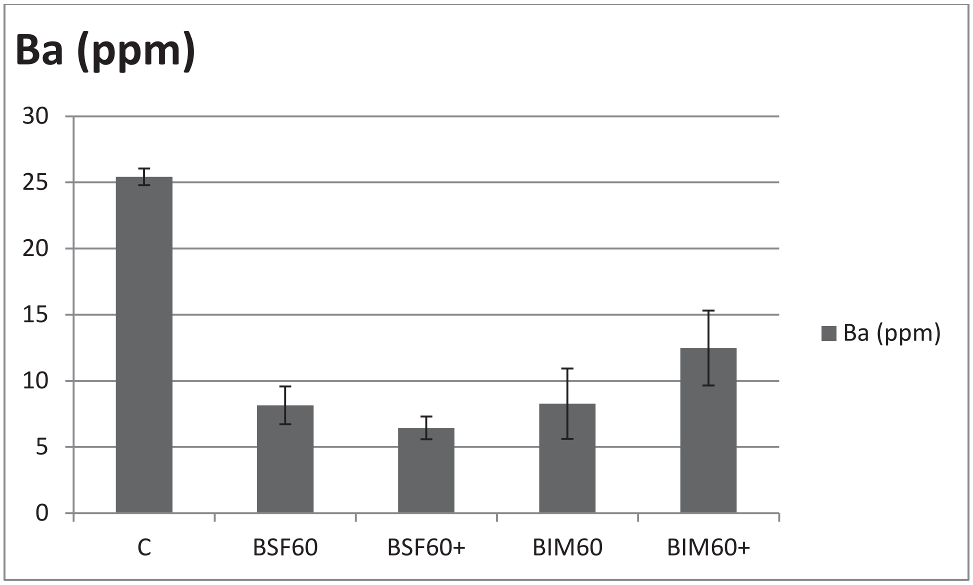

Figure 6: Graph indicating available Ba concentration (ppm) in initial soil Control (C), Group B Sunflower 60 day harvest, Group B Sunflower 60 day harvest +EDDS, Group B Indian Mustard 60 day harvest, Group B Indian Mustard 60 day harvest +EDDS. Error bars indicate standard deviation.

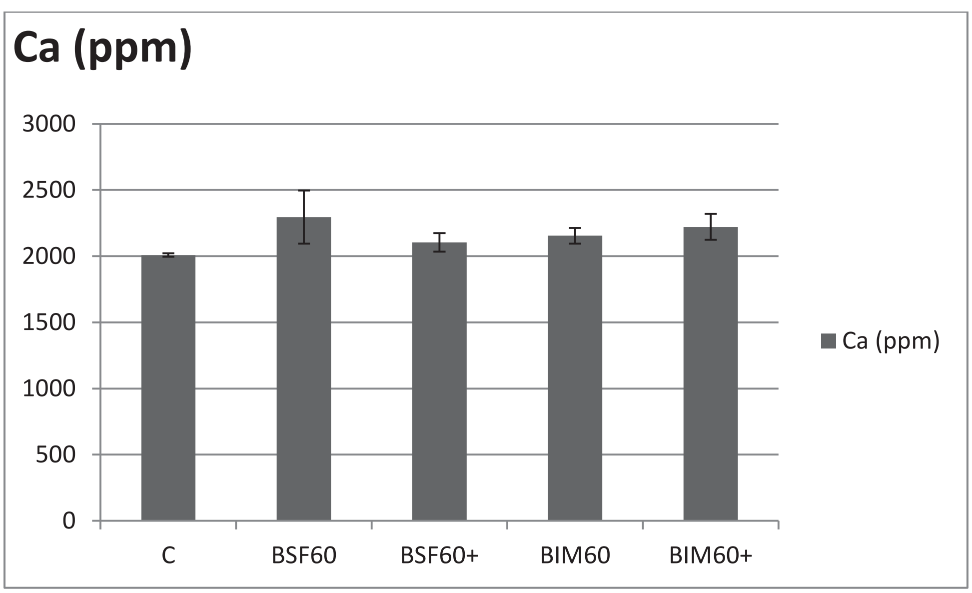

Figure 7: Graph indicating available Ca concentration (ppm) in initial soil Control (C), Group B Sunflower 60 day harvest, Group B Sunflower 60 day harvest +EDDS, Group B Indian Mustard 60 day harvest, Group B Indian Mustard 60 day harvest +EDDS. Error bars indicate standard deviation. It should be noted that concentration values over 1000 ppm obtained throughout this experiment are considered estimates due to the nature of the standards used for instrument calibration.

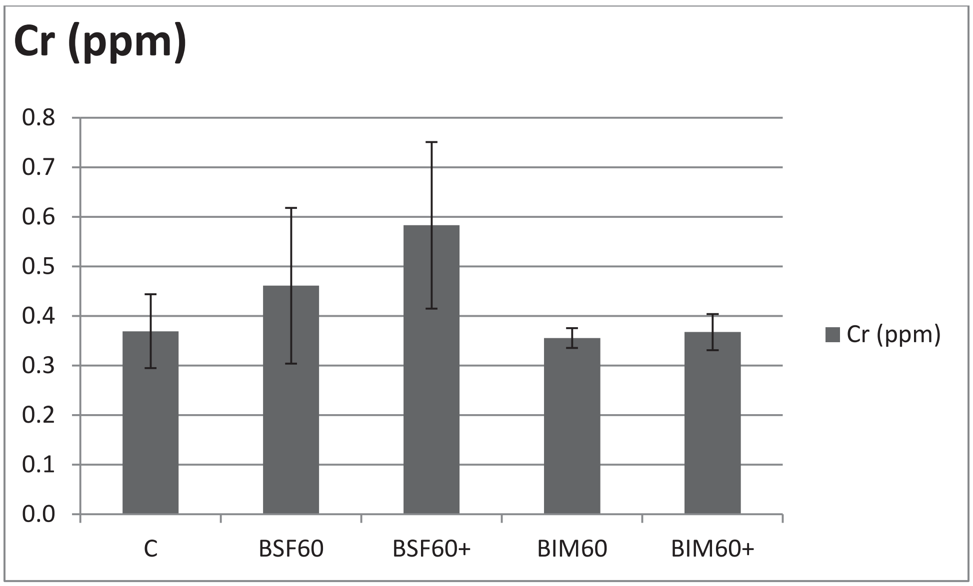

Figure 8: Graph indicating available Cr concentration (ppm) in initial soil Control (C), Group B Sunflower 60 day harvest, Group B Sunflower 60 day harvest +EDDS, Group B Indian Mustard 60 day harvest, Group B Indian Mustard 60 day harvest +EDDS. Error bars indicate standard deviation.

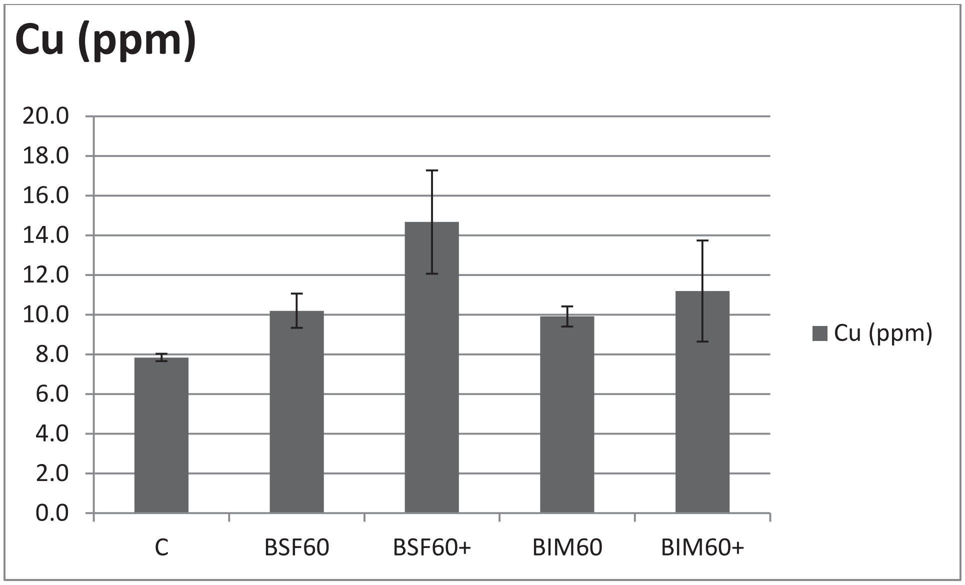

Figure 9: Graph indicating availableCu concentration (ppm) in initial soil Control (C), Group B Sunflower 60 day harvest, Group B Sunflower 60 day harvest +EDDS, Group B Indian Mustard 60 day harvest, Group B Indian Mustard 60 day harvest +EDDS. Error bars indicate standard deviation.

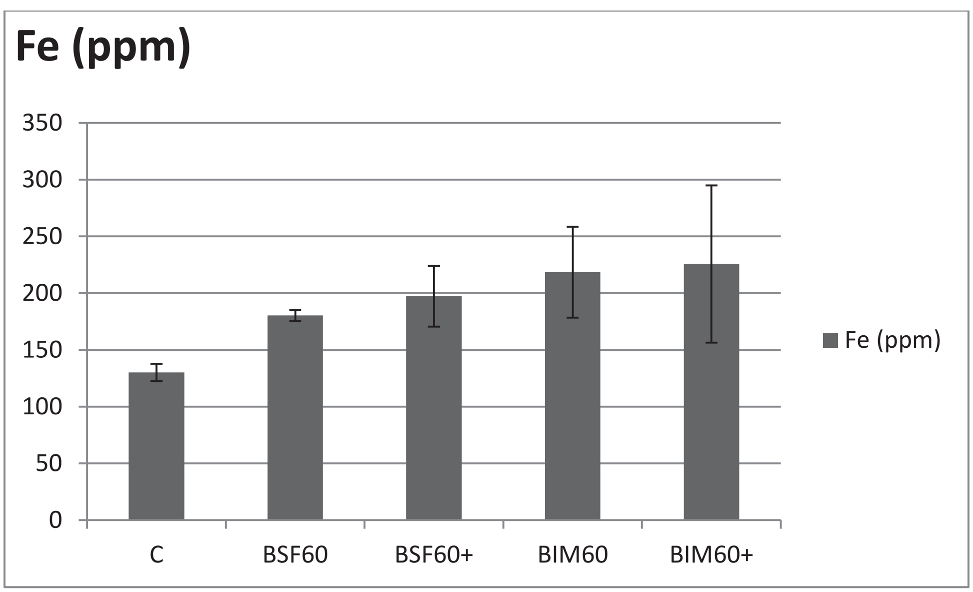

Figure 10: Graph indicating available Fe concentration (ppm) in initial soil Control (C), Group B Sunflower 60 day harvest, Group B Sunflower 60 day harvest +EDDS, Group B Indian Mustard 60 day harvest, Group B Indian Mustard 60 day harvest +EDDS. Error bars indicate standard deviation.

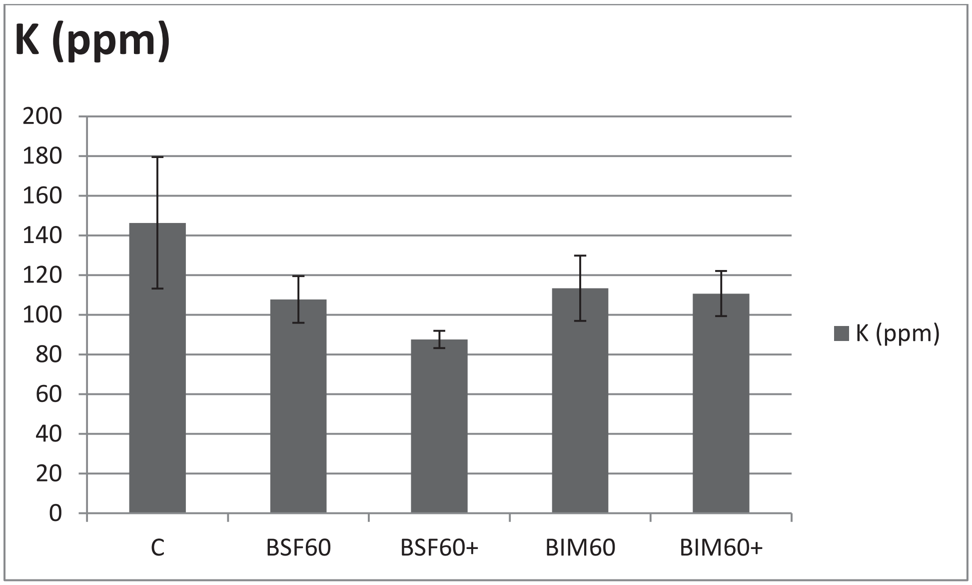

Figure 11: Graph indicating available K concentration (ppm) in initial soil Control (C), Group B Sunflower 60 day harvest, Group B Sunflower 60 day harvest +EDDS, Group B Indian Mustard 60 day harvest, Group B Indian Mustard 60 day harvest +EDDS. Error bars indicate standard deviation.

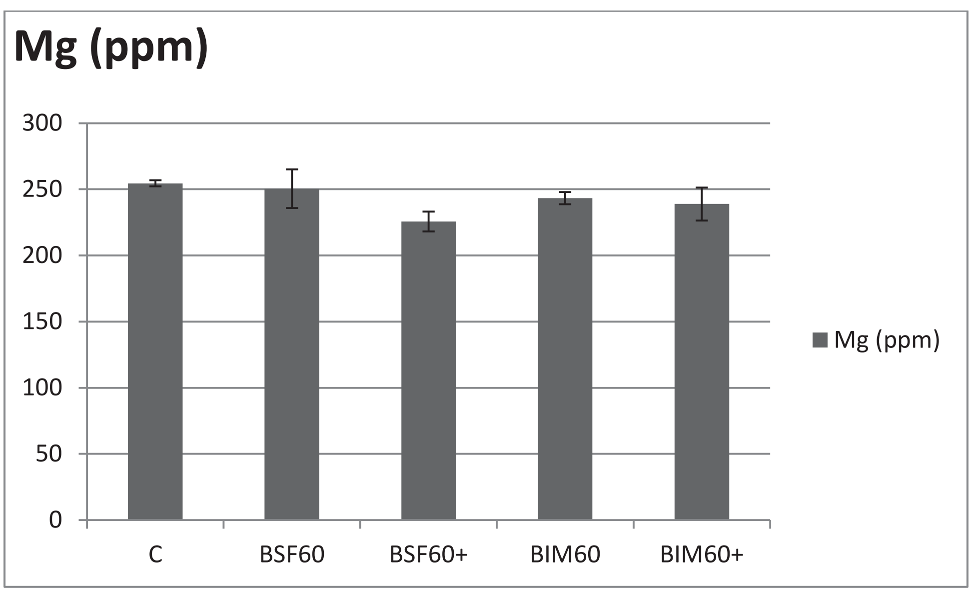

Figure 12: Graph indicating available Mg concentration (ppm) in initial soil Control (C), Group B Sunflower 60 day harvest, Group B Sunflower 60 day harvest +EDDS, Group B Indian Mustard 60 day harvest, Group B Indian Mustard 60 day harvest +EDDS. Error bars indicate standard deviation.

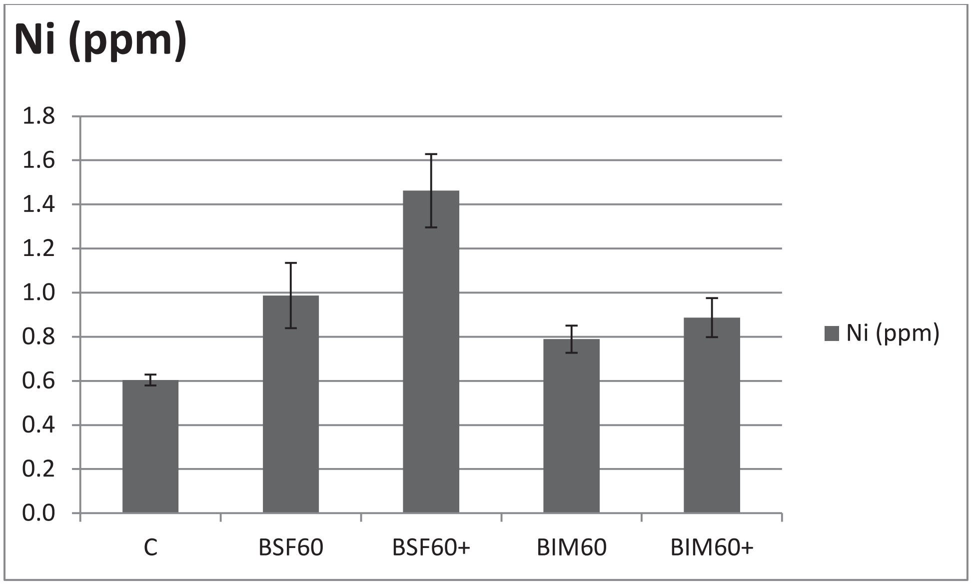

Figure 13: Graph indicating available Ni concentration (ppm) in initial soil Control (C), Group B Sunflower 60 day harvest, Group B Sunflower 60 day harvest +EDDS, Group B Indian Mustard 60 day harvest, Group B Indian Mustard 60 day harvest +EDDS. Error bars indicate standard deviation.

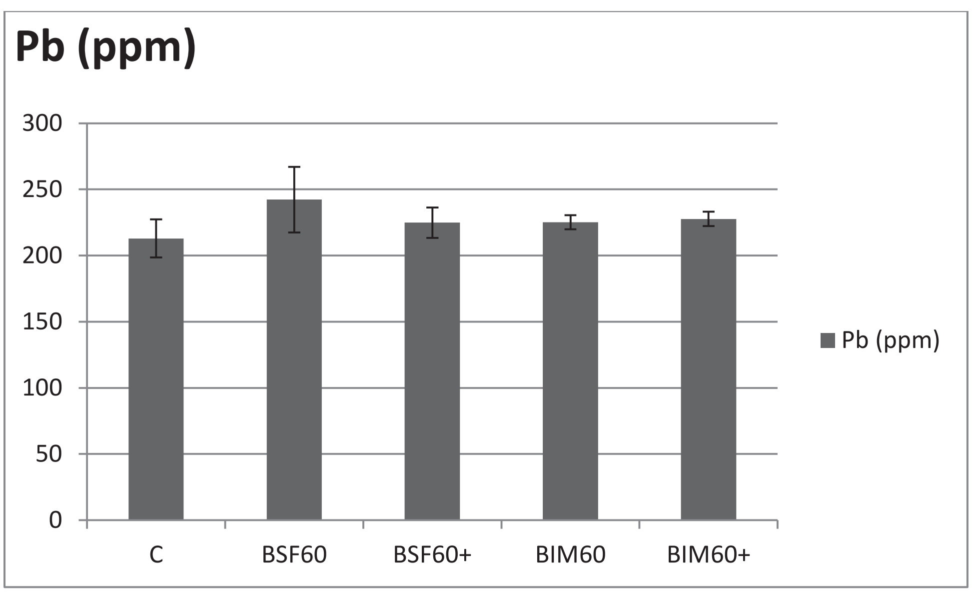

Figure 14: Graph indicating available Pb concentration (ppm) in initial soil Control (C), Group B Sunflower 60 day harvest, Group B Sunflower 60 day harvest +EDDS, Group B

Indian Mustard 60 day harvest, Group B Indian Mustard 60 day harvest +EDDS. Error bars indicate standard deviation.

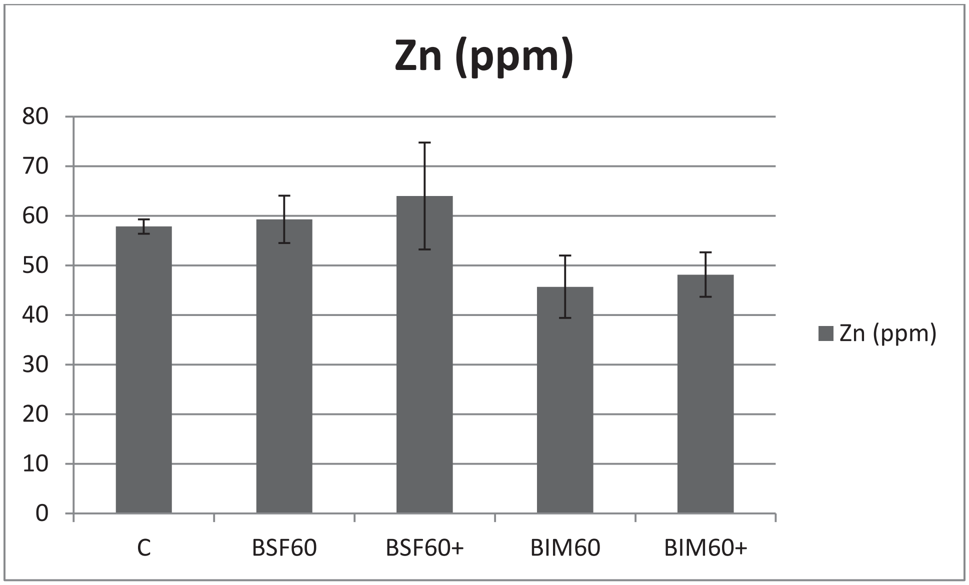

Figure 15: Graph indicating available Zn concentration (ppm) in initial soil Control (C), Group B Sunflower 60 day harvest, Group B Sunflower 60 day harvest +EDDS, Group B Indian Mustard 60 day harvest, Group B Indian Mustard 60 day harvest +EDDS. Error bars indicate standard deviation.

Bar graphs Plant weights (shoots and roots)

Group A plants (harvested at day 30, Sunflower (ASF30), Sunflower +EDDS (ASF30+), Indian mustard (AIM30), Indian mustard +EDDS (AIM30+)); the average of dried weight of the ASF30, ASF30+, AIM30 and AIM30+ were respectively 0.8, 0.7, 1.5 and 1.4 which shows us Indian mustard grew twice better than Sunflower.

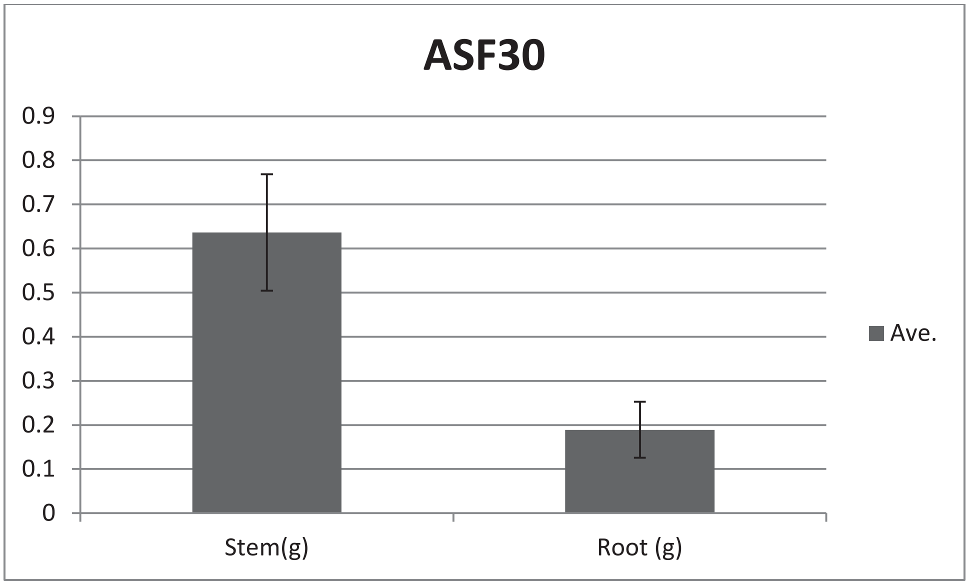

Figure 16: Plant weight (Averaged stem and root weight in grams) data obtained from Group A Sunflower samples that were harvested at day 30 in the study. Error bars represent standard deviation.

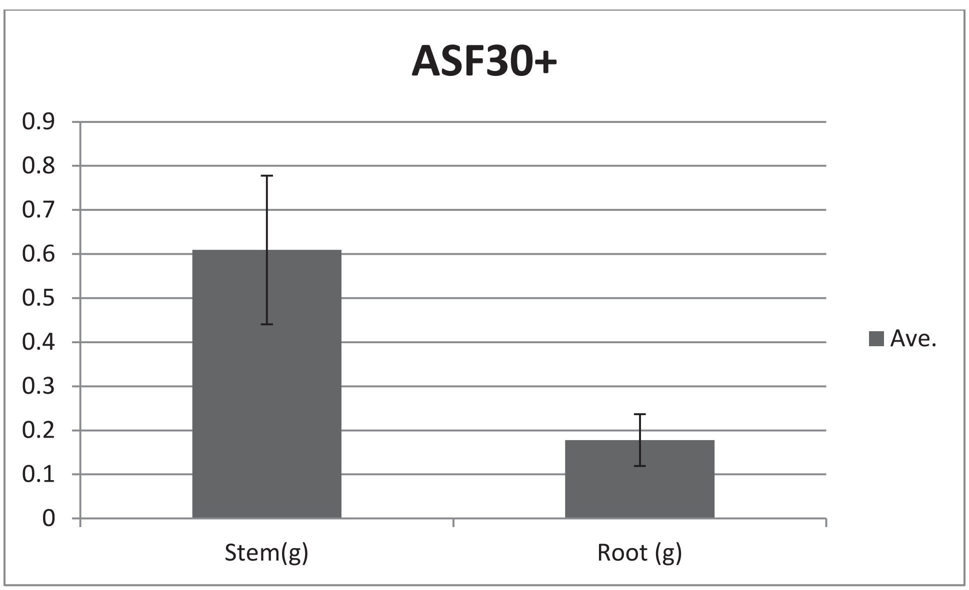

Figure 17: Plant weight (Averaged stem and root weight in grams) data obtained from Group A Sunflower samples supplemented with EDDS that were harvested at day 30 in the study. Error bars represent standard deviation.

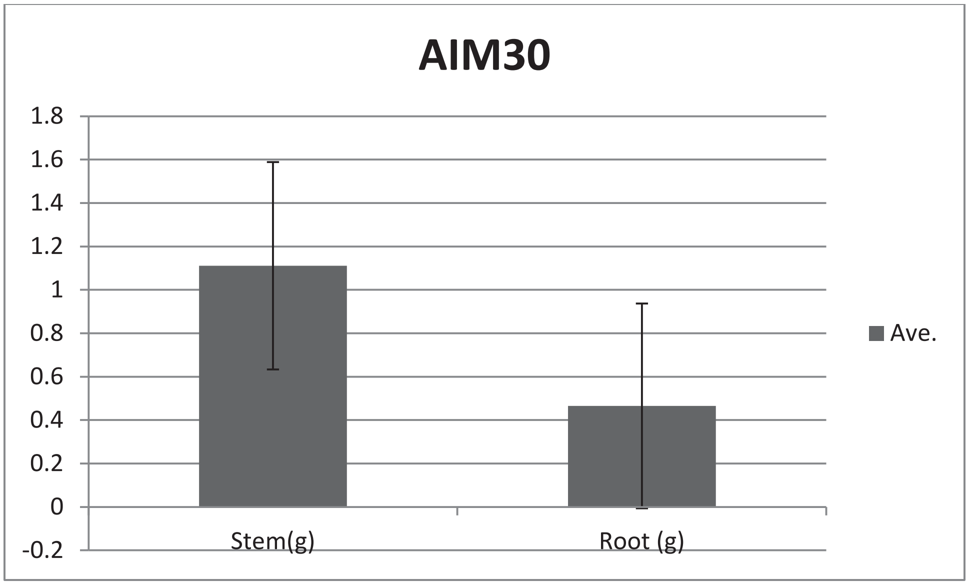

Figure 18: Plant weight (Averaged stem and root weight in grams) data obtained from Group A Indian mustard samples that were harvested at day 30 in the study. Error bars represent standard deviation.

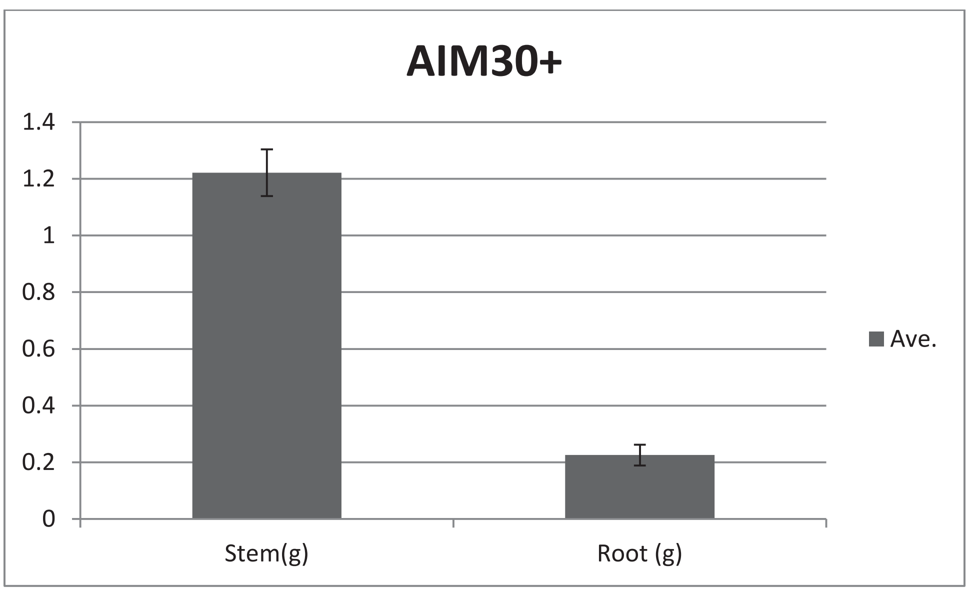

Figure 19: Plant weight (Averaged stem and root weight in grams) data obtained from Group A Indian mustard samples supplemented with EDDS that were harvested at day 30 in the study. Error bars represent standard deviation.

Group B plants (harvested at day 60, Sunflower (BSF30), Sunflower +EDDS (BSF60+), Indian mustard (BIM60), Indian mustard +EDDS (BIM60+)); The average of dried weight of the BSF60, BSF60+, BIM60 and BIM60+ were respectively 4.3, 3.4, 2.1 and 2.6 which shows us Sunflower grew twice better than Indian mustard.

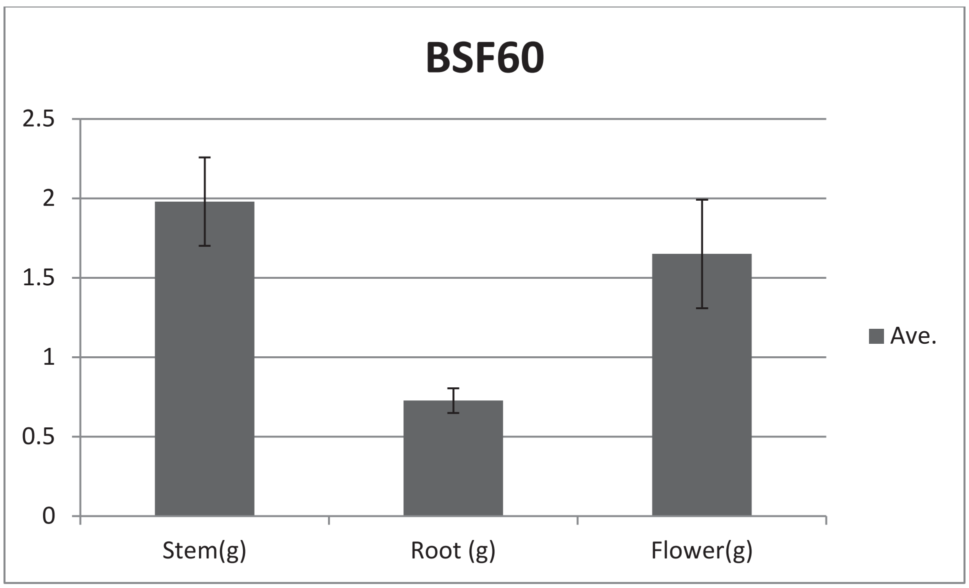

Figure 20: Plant weight (Averaged stem, root and flower weight in grams) data obtained from Group B Sunflower samples that were harvested at day 60 in the study. Error bars represent standard deviation.

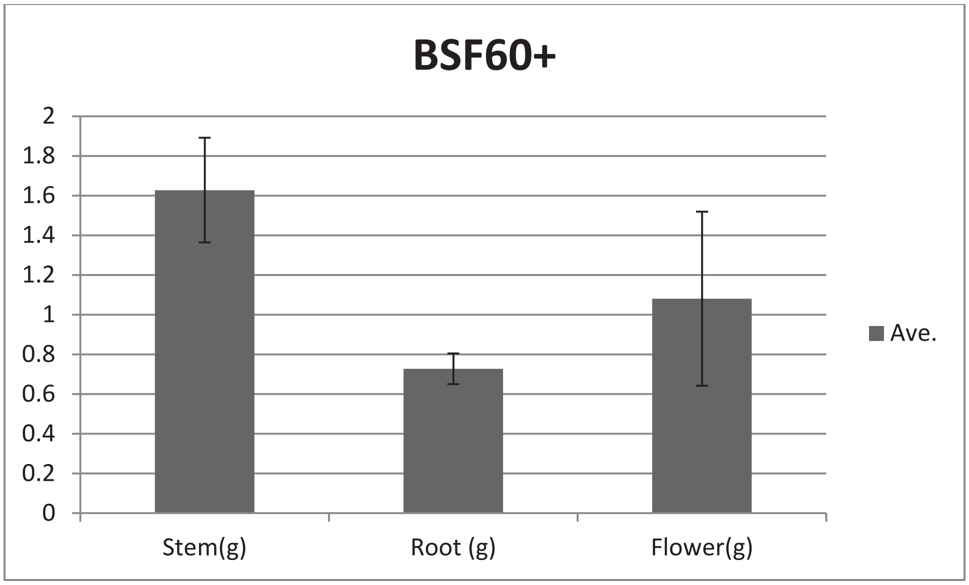

Figure 21: Plant weight (Averaged stem, root and flower weight in grams) data obtained from Group B Sunflower samples supplemented with EDDS that were harvested at day 60 in the study. Error bars represent standard deviation.

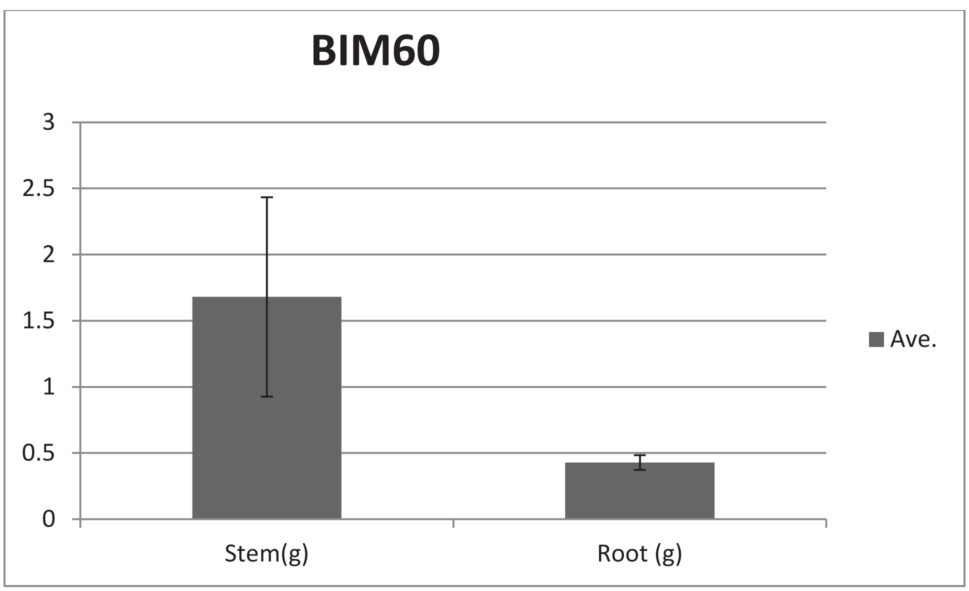

Figure 22: Plant weight (Averaged stem, root and flower weight in grams) data obtained from Group B Indian mustard samples that were harvested at day 60 in the study. Error bars represent standard deviation.

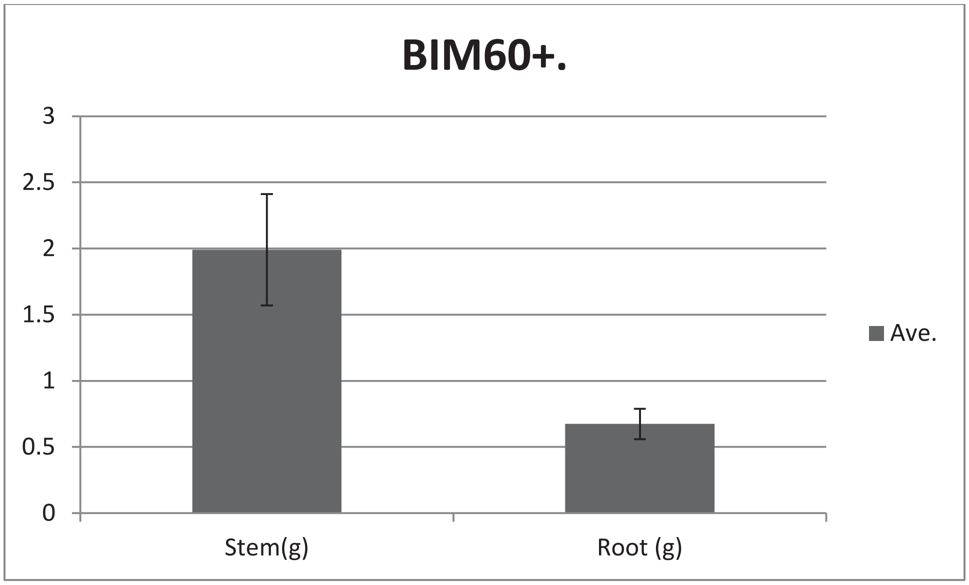

Figure 23: Plant weight (Averaged stem, root and flower weight in grams) data obtained from Group B Indian mustard samples supplemented with EDDS that were harvested at day 60 in the study. Error bars represent standard deviation.

Group A plants (harvested at day 60, Sunflower (ASF60), Sunflower +EDDS (ASF60+), Indian mustard (AIM60), Indian mustard +EDDS (AIM60+)); the average of dried weight of the ASF60, ASF60+, AIM60 and AIM60+ were respectively 0.1, 0.5, died and 0.1 which shows us they all grew very poorly.

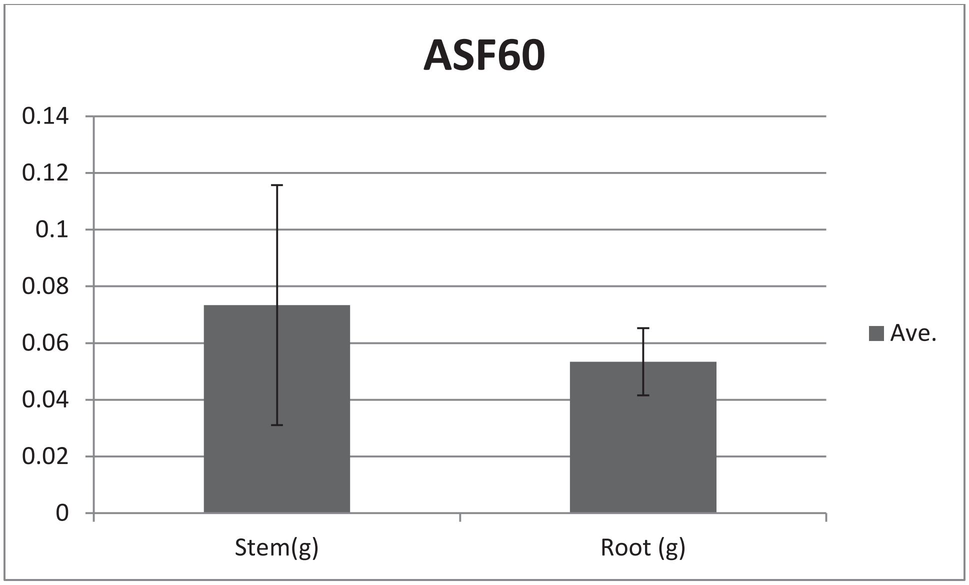

Figure 24: Plant weight (Averaged stem and root weight in grams) data obtained from Group A Sunflower samples that were harvested at day 60 in the study. Error bars represent standard deviation.

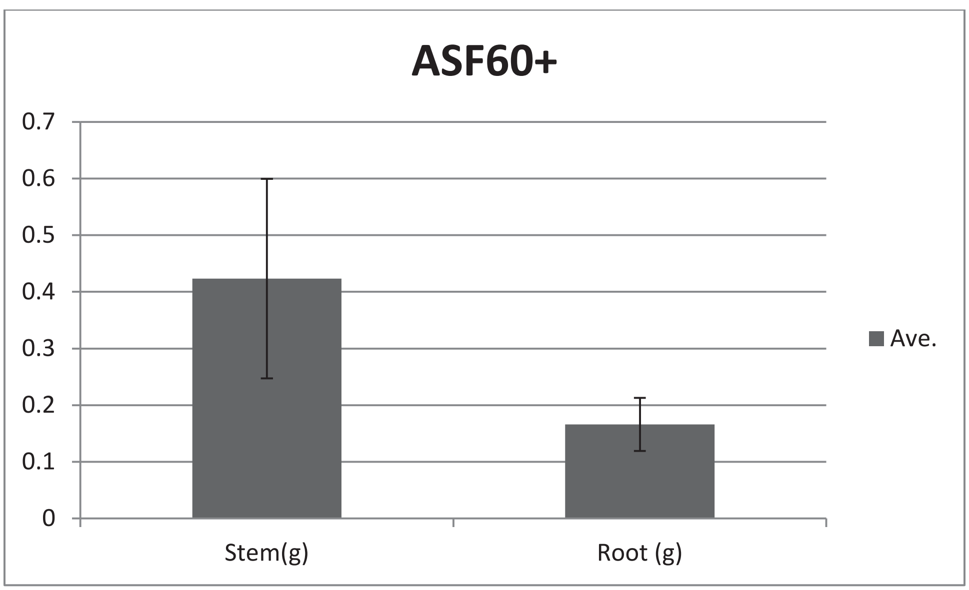

Figure 25: Plant weight (Averaged stem and root weight in grams) data obtained from Group A Sunflower samples supplemented with EDDS that were harvested at day 60 in the study. Error bars represent standard deviation.

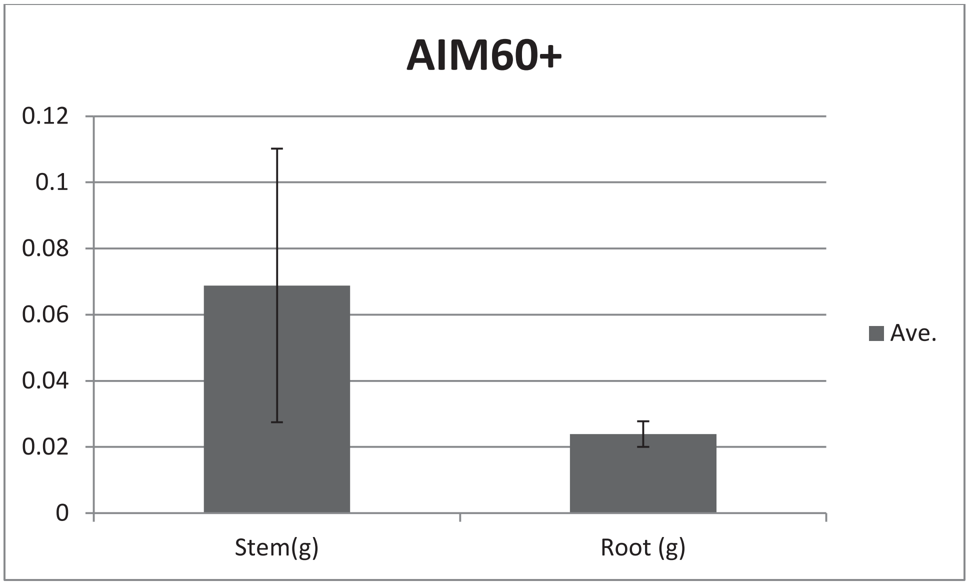

Figure 26: Plant weight (Averaged stem and root weight in grams) data obtained from Group A Indian mustard samples supplemented with EDDS that were harvested at day 30 in the study. Error bars represent standard deviation.

Bar Graphs of Soil metal data (total concentrations)

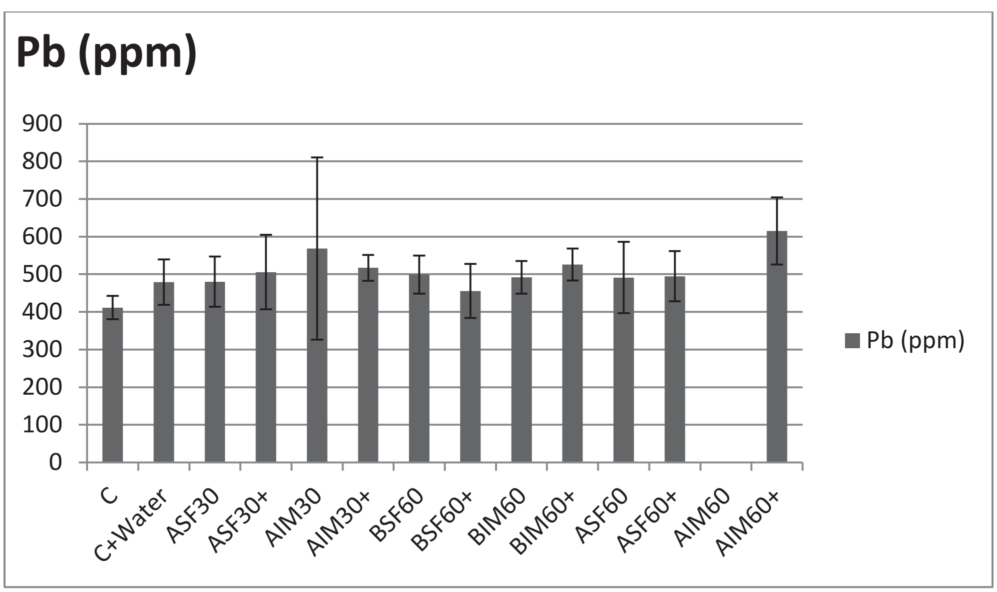

Figure 27: Soil metal concentration of Pb (ppm) in each of the experimental groups in the study. The groups include initial soil Control +Water (C+Water), Group A Sunflower 30 day harvest (ASF30), Group A Sunflower + EDDS 30 day harvest (ASF30+), Group A Indian Mustard 30 day harvest (AIM30), Group A Indian Mustard + EDDS 30 day harvest (AIM30+), Group B Sunflower 60 day harvest (BSF60), Group B Sunflower + EDDS 60 day harvest (BSF60+), Group B Indian Mustard 60 day harvest (BIM60), Group B Indian Mustard + EDDS 60 day harvest (BIM60+), Group A Sunflower 60 day harvest (ASF60), Group A Sunflower + EDDS 60 day harvest (ASF60+), Group A Indian Mustard 60 day harvest (AIM60), Group A Indian Mustard + EDDS 60 day harvest (AIM60+). The AIM60 group did not survive the experiment and yielded no data. Error bars represent standard deviation.

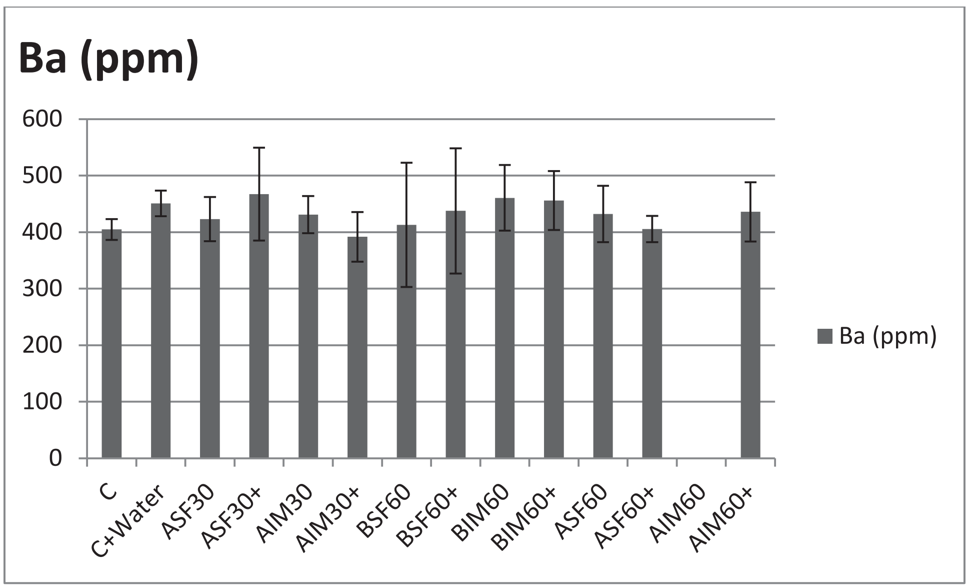

Figure 28: Soil metal concentration of Ba (ppm) in each of the experimental groups in the study. The groups include initial soil Control +Water (C+Water), Group A Sunflower 30 day harvest (ASF30), Group A Sunflower + EDDS 30 day harvest (ASF30+), Group A Indian Mustard 30 day harvest (AIM30), Group A Indian Mustard + EDDS 30 day harvest (AIM30+), Group B Sunflower 60 day harvest (BSF60), Group B Sunflower + EDDS 60 day harvest (BSF60+), Group B Indian Mustard 60 day harvest (BIM60), Group B Indian Mustard + EDDS 60 day harvest (BIM60+), Group A Sunflower 60 day harvest (ASF60), Group A Sunflower + EDDS 60 day harvest (ASF60+), Group A Indian Mustard 60 day harvest (AIM60), Group A Indian Mustard + EDDS 60 day harvest (AIM60+). The AIM60 group did not survive the experiment and yielded no data. Error bars represent standard deviation.

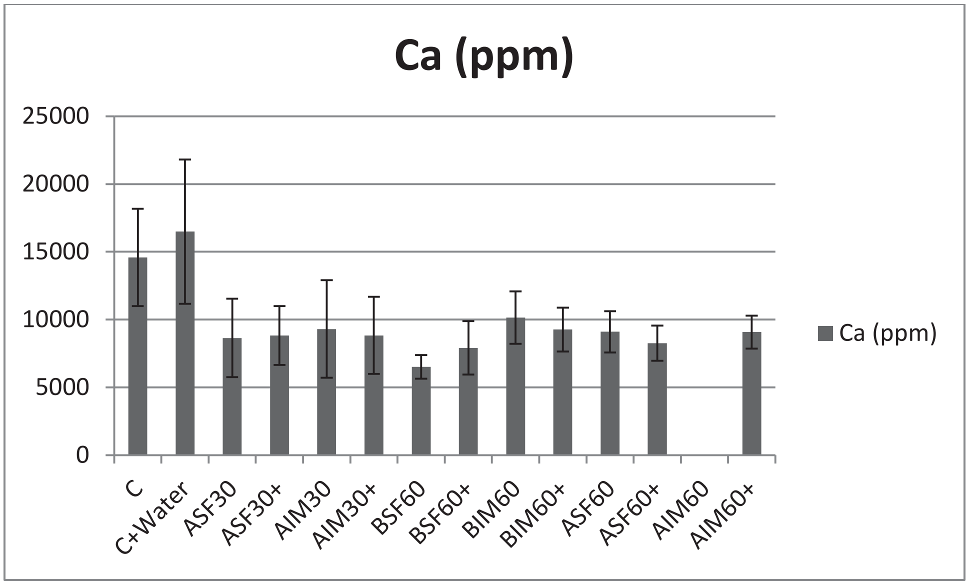

Figure 29: Soil metal concentration of Ca (ppm) in each of the experimental groups in the study. The groups include initial soil Control +Water (C+Water), Group A Sunflower 30 day harvest (ASF30), Group A Sunflower + EDDS 30 day harvest (ASF30+), Group A Indian Mustard 30 day harvest (AIM30), Group A Indian Mustard + EDDS 30 day harvest (AIM30+), Group B Sunflower 60 day harvest (BSF60), Group B Sunflower + EDDS 60 day harvest (BSF60+), Group B Indian Mustard 60 day harvest (BIM60), Group B Indian Mustard + EDDS 60 day harvest (BIM60+), Group A Sunflower 60 day harvest (ASF60), Group A Sunflower + EDDS 60 day harvest (ASF60+), Group A Indian Mustard 60 day harvest (AIM60), Group A Indian Mustard + EDDS 60 day harvest (AIM60+). The AIM60 group did not survive the experiment and yielded no data. Error bars represent standard deviation. It should be noted that concentration values over 1000 ppm obtained throughout this experiment are considered estimates due to the nature of the standards used for instrument calibration.

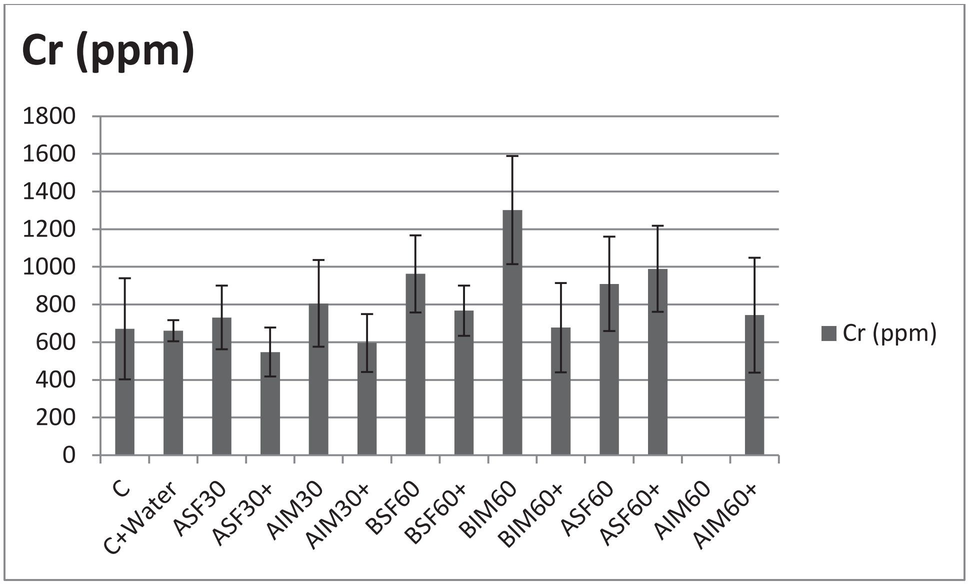

Figure 30: Soil metal concentration of Cr (ppm) in each of the experimental groups in the study. The groups include initial soil Control +Water (C+Water), Group A Sunflower 30 day harvest (ASF30), Group A Sunflower + EDDS 30 day harvest (ASF30+), Group A Indian Mustard 30 day harvest (AIM30), Group A Indian Mustard + EDDS 30 day harvest (AIM30+), Group B Sunflower 60 day harvest (BSF60), Group B Sunflower + EDDS 60 day harvest (BSF60+), Group B Indian Mustard 60 day harvest (BIM60), Group B Indian Mustard + EDDS 60 day harvest (BIM60+), Group A Sunflower 60 day harvest (ASF60), Group A Sunflower + EDDS 60 day harvest (ASF60+), Group A Indian Mustard 60 day harvest (AIM60), Group A Indian Mustard + EDDS 60 day harvest (AIM60+). The AIM60 group did not survive the experiment and yielded no data. Error bars represent standard deviation. It should be noted that concentration values over 1000 ppm obtained throughout this experiment are considered estimates due to the nature of the standards used for instrument calibration.

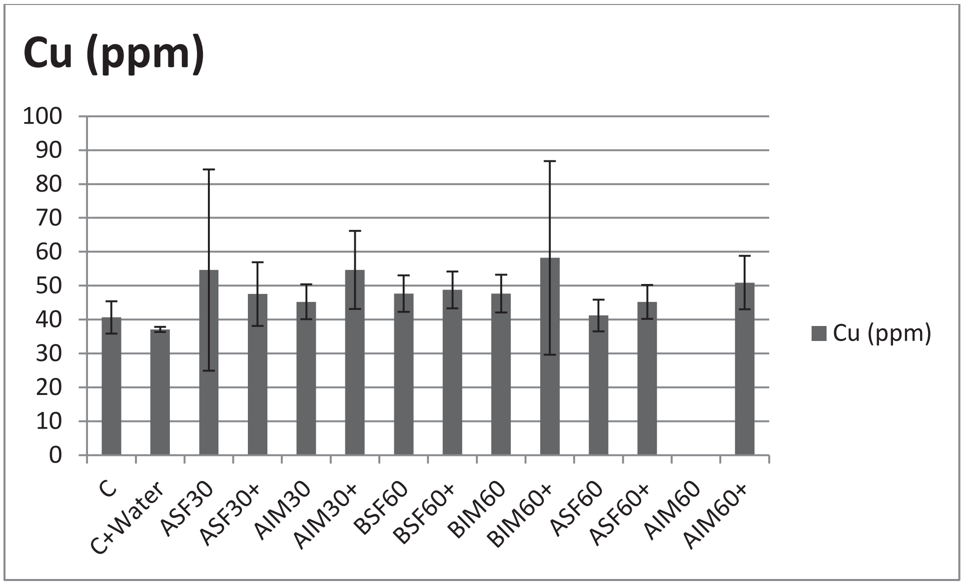

Figure 31: Soil metal concentration of Cu (ppm) in each of the experimental groups in the study. The groups include initial soil Control +Water (C+Water), Group A Sunflower 30 day harvest (ASF30), Group A Sunflower + EDDS 30 day harvest (ASF30+), Group A Indian Mustard 30 day harvest (AIM30), Group A Indian Mustard + EDDS 30 day harvest (AIM30+), Group B Sunflower 60 day harvest (BSF60), Group B Sunflower + EDDS 60 day harvest (BSF60+), Group B Indian Mustard 60 day harvest (BIM60), Group B Indian Mustard + EDDS 60 day harvest (BIM60+), Group A Sunflower 60 day harvest (ASF60), Group A Sunflower + EDDS 60 day harvest (ASF60+), Group A Indian Mustard 60 day harvest (AIM60), Group A Indian Mustard + EDDS 60 day harvest (AIM60+). The AIM60 group did not survive the experiment and yielded no data. Error bars represent standard deviation.

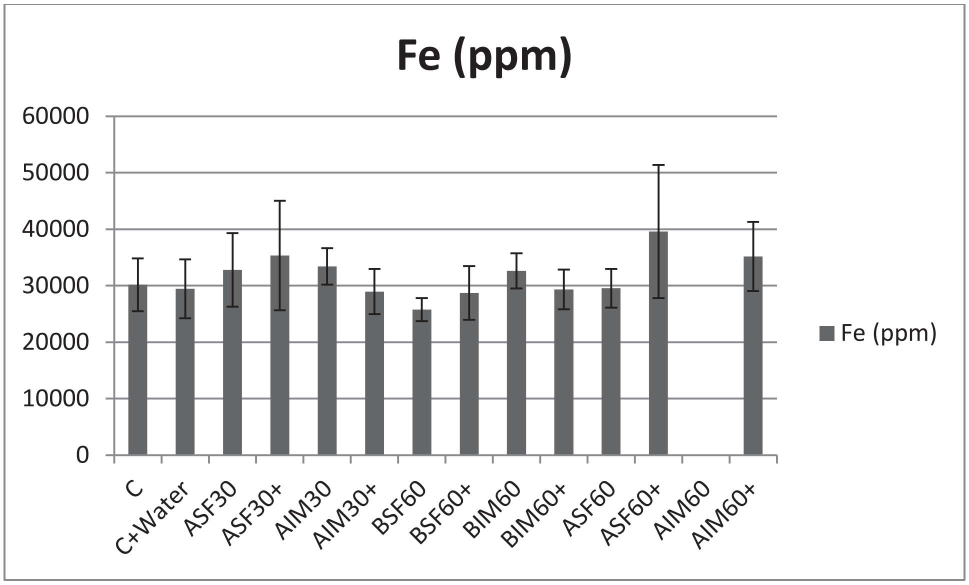

Figure 32: Soil metal concentration of Fe (ppm) in each of the experimental groups in the study. The groups include initial soil Control +Water (C+Water), Group A Sunflower 30 day harvest (ASF30), Group A Sunflower + EDDS 30 day harvest (ASF30+), Group A Indian Mustard 30 day harvest (AIM30), Group A Indian Mustard + EDDS 30 day harvest (AIM30+), Group B Sunflower 60 day harvest (BSF60), Group B Sunflower + EDDS 60 day harvest (BSF60+), Group B Indian Mustard 60 day harvest (BIM60), Group B Indian Mustard + EDDS 60 day harvest (BIM60+), Group A Sunflower 60 day harvest (ASF60), Group A Sunflower + EDDS 60 day harvest (ASF60+), Group A Indian Mustard 60 day harvest (AIM60), Group A Indian Mustard + EDDS 60 day harvest (AIM60+). The AIM60 group did not survive the experiment and yielded no data. Error bars represent standard deviation. It should be noted that concentration values over 1000 ppm obtained throughout this experiment are considered estimates due to the nature of the standards used for instrument calibration.

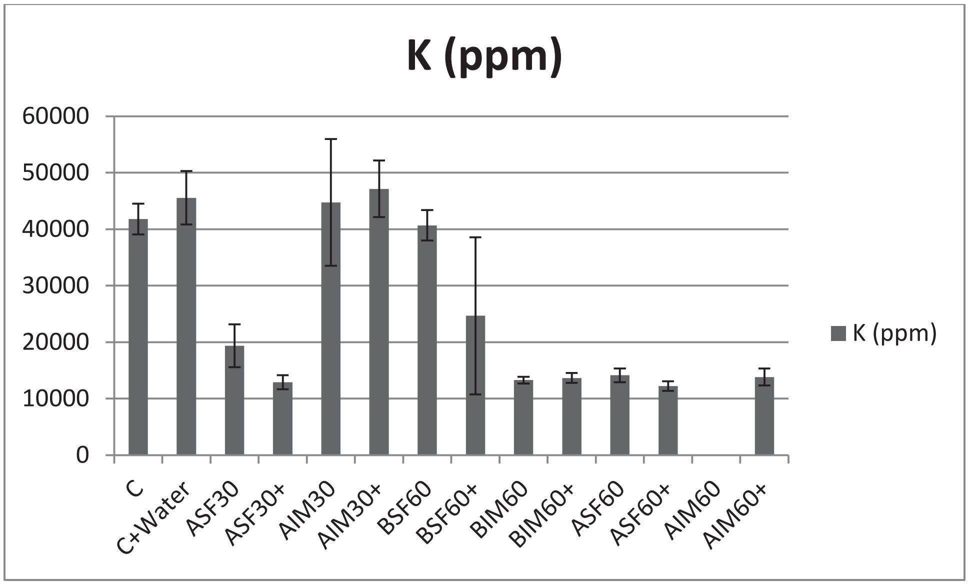

Figure 33: Soil metal concentration of K (ppm) in each of the experimental groups in the study. The groups include initial soil Control +Water (C+Water), Group A Sunflower 30 day harvest (ASF30), Group A Sunflower + EDDS 30 day harvest (ASF30+), Group A Indian Mustard 30 day harvest (AIM30), Group A Indian Mustard + EDDS 30 day harvest (AIM30+), Group B Sunflower 60 day harvest (BSF60), Group B Sunflower + EDDS 60 day harvest (BSF60+), Group B Indian Mustard 60 day harvest (BIM60), Group B Indian Mustard + EDDS 60 day harvest (BIM60+), Group A Sunflower 60 day harvest (ASF60), Group A Sunflower + EDDS 60 day harvest (ASF60+), Group A Indian Mustard 60 day harvest (AIM60), Group A Indian Mustard + EDDS 60 day harvest (AIM60+). The AIM60 group did not survive the experiment and yielded no data. Error bars represent standard deviation. It should be noted that concentration values over 1000 ppm obtained throughout this experiment are considered estimates due to the nature of the standards used for instrument calibration.

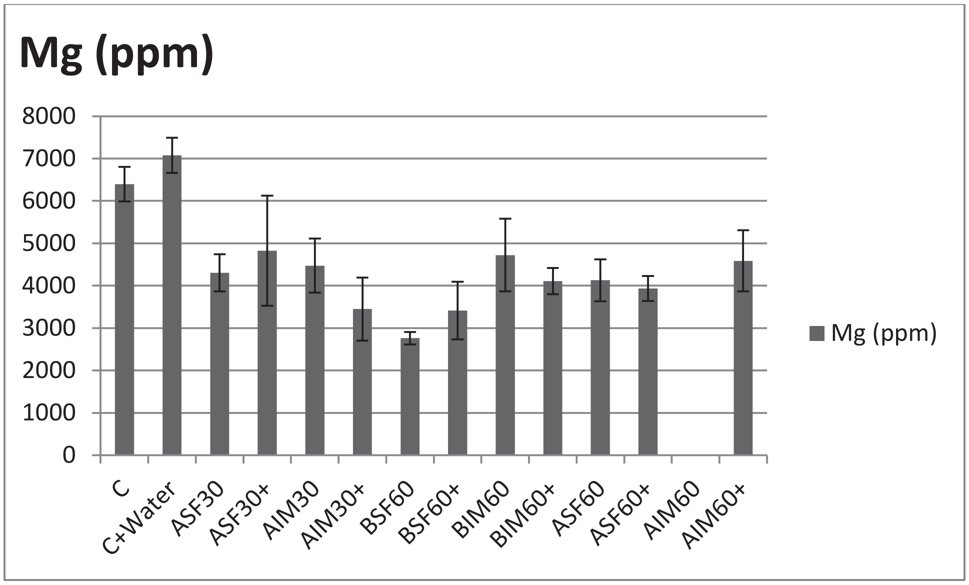

Figure 34: Soil metal concentration of Mg (ppm) in each of the experimental groups in the study. The groups include initial soil Control +Water (C+Water), Group A Sunflower 30 day harvest (ASF30), Group A Sunflower + EDDS 30 day harvest (ASF30+), Group A Indian Mustard 30 day harvest (AIM30), Group A Indian Mustard + EDDS 30 day harvest (AIM30+), Group B Sunflower 60 day harvest (BSF60), Group B Sunflower + EDDS 60 day harvest (BSF60+), Group B Indian Mustard 60 day harvest (BIM60), Group B Indian Mustard + EDDS 60 day harvest (BIM60+), Group A Sunflower 60 day harvest (ASF60), Group A Sunflower + EDDS 60 day harvest (ASF60+), Group A Indian Mustard 60 day harvest (AIM60), Group A Indian Mustard + EDDS 60 day harvest (AIM60+). The AIM60 group did not survive the experiment and yielded no data. Error bars represent standard deviation. It should be noted that concentration values over 1000 ppm obtained throughout this experiment are considered estimates due to the nature of the standards used for instrument calibration.

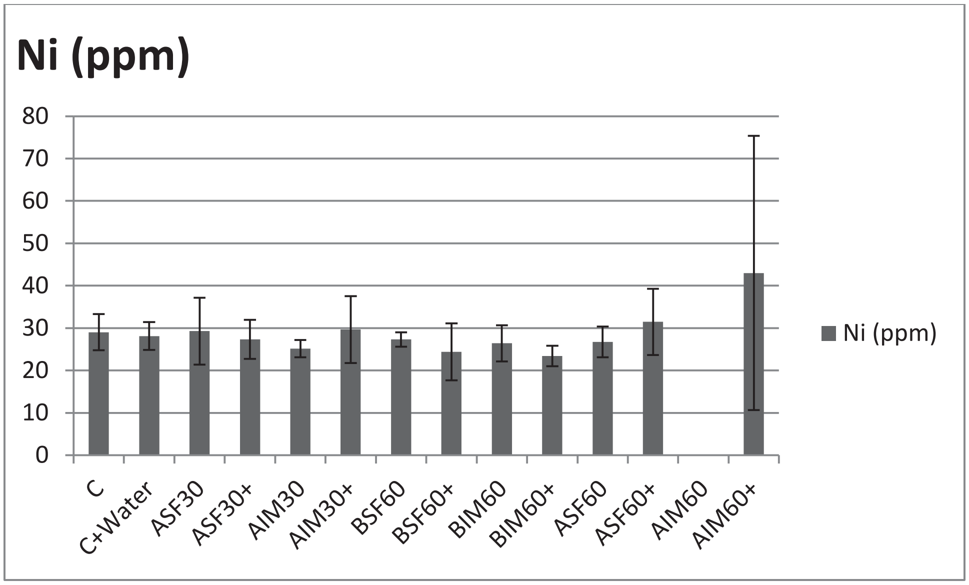

Figure 35: Soil metal concentration of Ni (ppm) in each of the experimental groups in the study. The groups include initial soil Control +Water (C+Water), Group A Sunflower 30 day harvest (ASF30), Group A Sunflower + EDDS 30 day harvest (ASF30+), Group A Indian Mustard 30 day harvest (AIM30), Group A Indian Mustard + EDDS 30 day harvest (AIM30+), Group B Sunflower 60 day harvest (BSF60), Group B Sunflower + EDDS 60 day harvest (BSF60+), Group B Indian Mustard 60 day harvest (BIM60), Group B Indian Mustard + EDDS 60 day harvest (BIM60+), Group A Sunflower 60 day harvest (ASF60), Group A Sunflower + EDDS 60 day harvest (ASF60+), Group A Indian Mustard 60 day harvest (AIM60), Group A Indian Mustard + EDDS 60 day harvest (AIM60+). The AIM60 group did not survive the experiment and yielded no data. Error bars represent standard deviation.

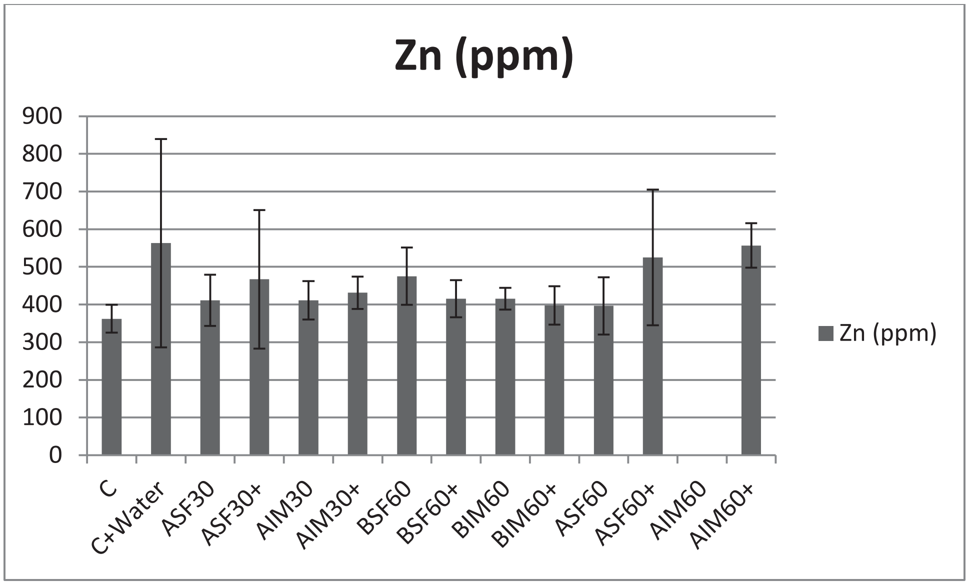

Figure 36: Soil metal concentration of Zn (ppm) in each of the experimental groups in the study. The groups include initial soil Control +Water (C+Water), Group A Sunflower 30 day harvest (ASF30), Group A Sunflower + EDDS 30 day harvest (ASF30+), Group A Indian Mustard 30 day harvest (AIM30), Group A Indian Mustard + EDDS 30 day harvest (AIM30+), Group B Sunflower 60 day harvest (BSF60), Group B Sunflower + EDDS 60 day harvest (BSF60+), Group B Indian Mustard 60 day harvest (BIM60), Group B Indian Mustard + EDDS 60 day harvest (BIM60+), Group A Sunflower 60 day harvest (ASF60), Group A Sunflower + EDDS 60 day harvest (ASF60+), Group A Indian Mustard 60 day harvest (AIM60), Group A Indian Mustard + EDDS 60 day harvest (AIM60+). The AIM60 group did not survive the experiment and yielded no data. Error bars represent standard deviation.

Bar Graphs of Plant Shoot's metal data

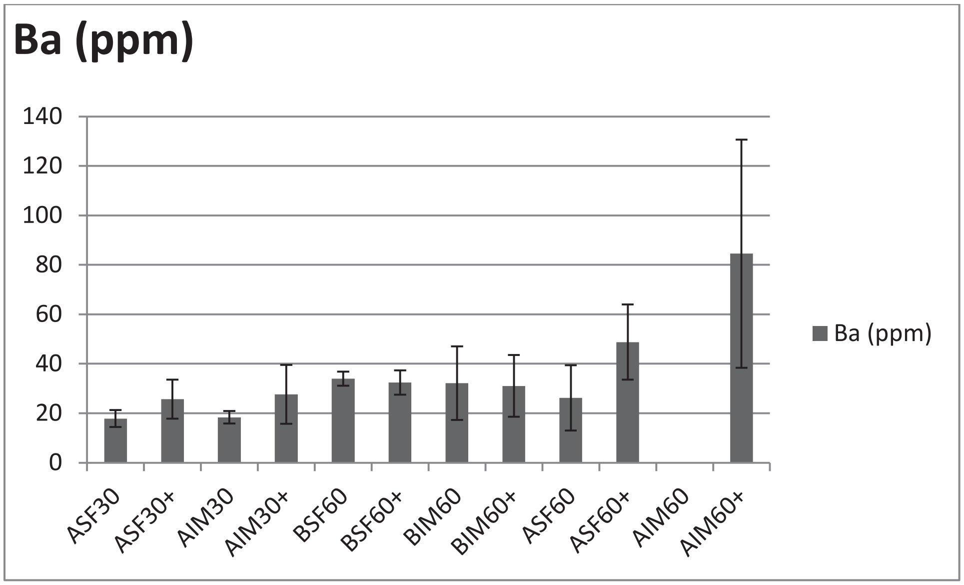

Figure 37: Shoots metal concentration of Ba (ppm) in each of the experimental groups in the study. The groups include, Group A Sunflower 30 day harvest (ASF30), Group A Sunflower + EDDS 30 day harvest (ASF30+), Group A Indian Mustard 30 day harvest (AIM30), Group A Indian Mustard + EDDS 30 day harvest (AIM30+), Group B Sunflower 60 day harvest (BSF60), Group B Sunflower + EDDS 60 day harvest (BSF60+), Group B Indian Mustard 60 day harvest (BIM60), Group B Indian Mustard + EDDS 60 day harvest (BIM60+), Group A Sunflower 60 day harvest (ASF60), Group A Sunflower + EDDS 60 day harvest (ASF60+), Group A Indian Mustard 60 day harvest (AIM60), Group A Indian Mustard + EDDS 60 day harvest (AIM60+). The AIM60 group did not survive the experiment and yielded no data. Error bars represent standard deviation.

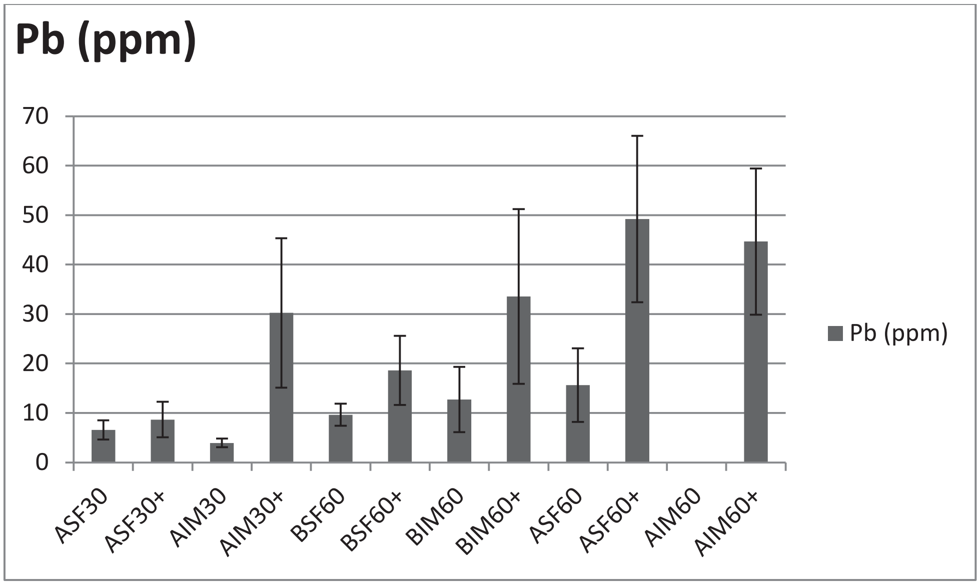

Figure 38: Shoots metal concentration of Pb (ppm) in each of the experimental groups in the study. The groups include, Group A Sunflower 30 day harvest (ASF30), Group A Sunflower + EDDS 30 day harvest (ASF30+), Group A Indian Mustard 30 day harvest (AIM30), Group A Indian Mustard + EDDS 30 day harvest (AIM30+), Group B Sunflower 60 day harvest (BSF60), Group B Sunflower + EDDS 60 day harvest (BSF60+), Group B Indian Mustard 60 day harvest (BIM60), Group B Indian Mustard + EDDS 60 day harvest (BIM60+), Group A Sunflower 60 day harvest (ASF60), Group A Sunflower + EDDS 60 day harvest (ASF60+), Group A Indian Mustard 60 day harvest (AIM60), Group A Indian Mustard + EDDS 60 day harvest (AIM60+). The AIM60 group did not survive the experiment and yielded no data. Error bars represent standard deviation.

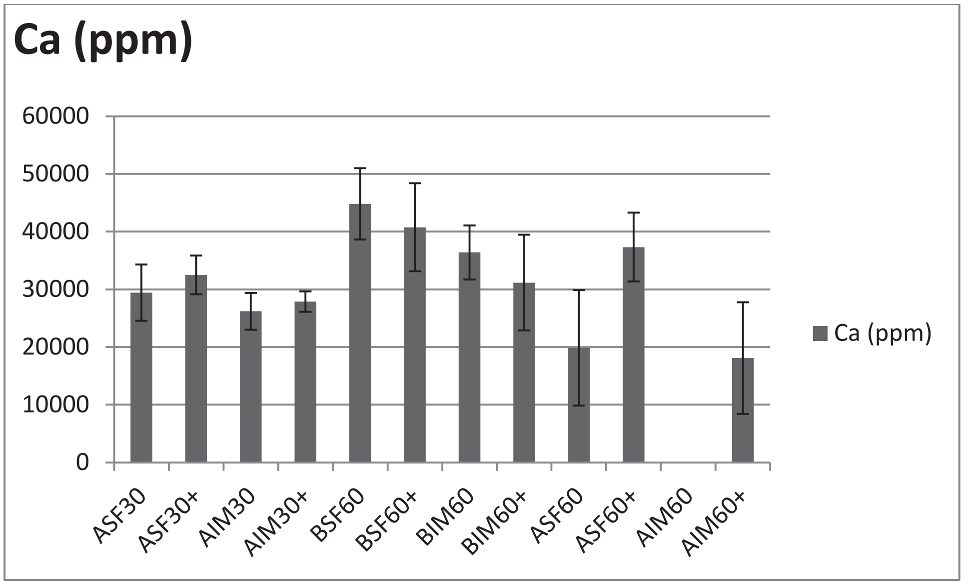

Figure 39: Shoots metal concentration of Ca (ppm) in each of the experimental groups in the study. The groups include, Group A Sunflower 30 day harvest (ASF30), Group A Sunflower + EDDS 30 day harvest (ASF30+), Group A Indian Mustard 30 day harvest (AIM30), Group A Indian Mustard + EDDS 30 day harvest (AIM30+), Group B Sunflower 60 day harvest (BSF60), Group B Sunflower + EDDS 60 day harvest (BSF60+), Group B Indian Mustard 60 day harvest (BIM60), Group B Indian Mustard + EDDS 60 day harvest (BIM60+), Group A Sunflower 60 day harvest (ASF60), Group A Sunflower + EDDS 60 day harvest (ASF60+), Group A Indian Mustard 60 day harvest (AIM60), Group A Indian Mustard + EDDS 60 day harvest (AIM60+). The AIM60 group did not survive the experiment and yielded no data. Error bars represent standard deviation. It should be noted that concentration values over 1000 ppm obtained throughout this experiment are considered estimates due to the nature of the standards used for instrument calibration.

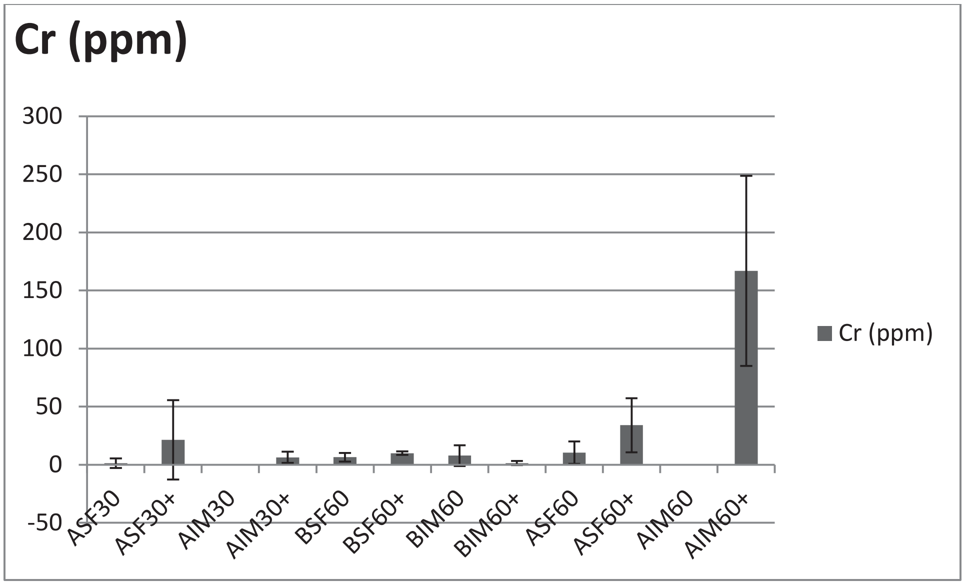

Figure 40: Shoots metal concentration of Cr (ppm) in each of the experimental groups in the study. The groups include, Group A Sunflower 30 day harvest (ASF30), Group A Sunflower + EDDS 30 day harvest (ASF30+), Group A Indian Mustard 30 day harvest (AIM30), Group A Indian Mustard + EDDS 30 day harvest (AIM30+), Group B Sunflower 60 day harvest (BSF60), Group B Sunflower + EDDS 60 day harvest (BSF60+), Group B Indian Mustard 60 day harvest (BIM60), Group B Indian Mustard + EDDS 60 day harvest (BIM60+), Group A Sunflower 60 day harvest (ASF60), Group A Sunflower + EDDS 60 day harvest (ASF60+), Group A Indian Mustard 60 day harvest (AIM60), Group A Indian Mustard + EDDS 60 day harvest (AIM60+). The AIM60 group did not survive the experiment and yielded no data. Error bars represent standard deviation.

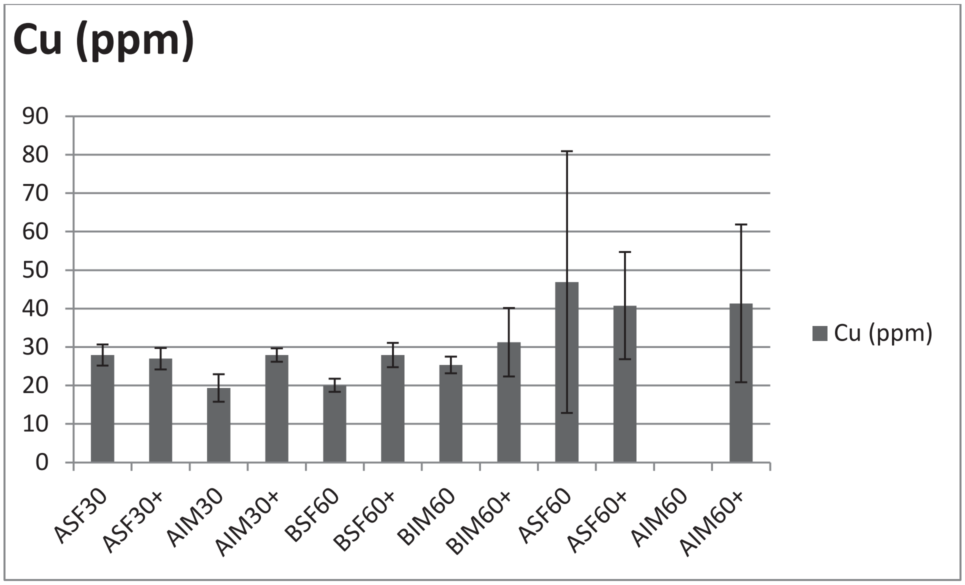

Figure 41: Shoots metal concentration of Cu (ppm) in each of the experimental groups in the study. The groups include, Group A Sunflower 30 day harvest (ASF30), Group A Sunflower + EDDS 30 day harvest (ASF30+), Group A Indian Mustard 30 day harvest (AIM30), Group A Indian Mustard + EDDS 30 day harvest (AIM30+), Group B Sunflower 60 day harvest (BSF60), Group B Sunflower + EDDS 60 day harvest (BSF60+), Group B Indian Mustard 60 day harvest (BIM60), Group B Indian Mustard + EDDS 60 day harvest (BIM60+), Group A Sunflower 60 day harvest (ASF60), Group A Sunflower + EDDS 60 day harvest (ASF60+), Group A Indian Mustard 60 day harvest (AIM60), Group A Indian Mustard + EDDS 60 day harvest (AIM60+). The AIM60 group did not survive the experiment and yielded no data. Error bars represent standard deviation.

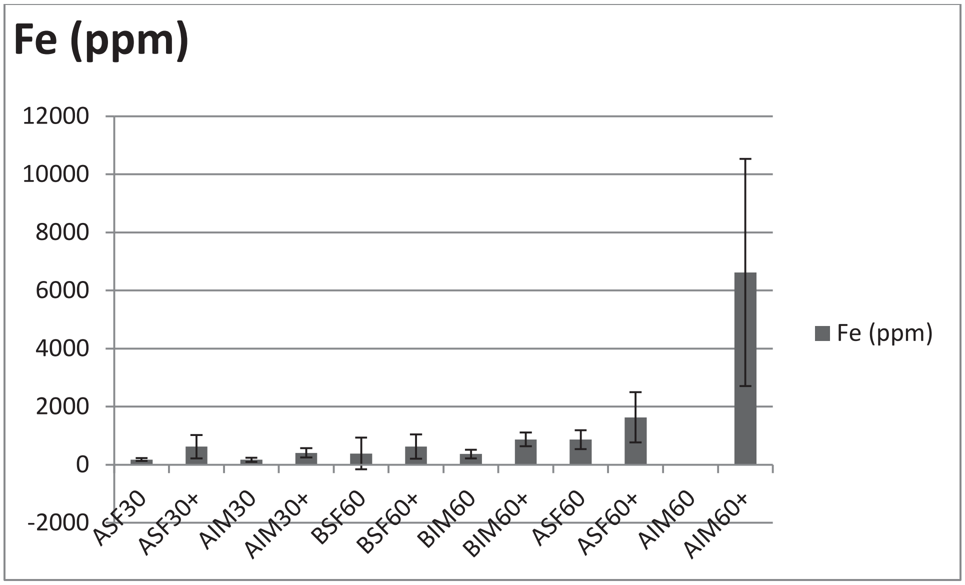

Figure 42: Shoots metal concentration of Fe (ppm) in each of the experimental groups in the study. The groups include, Group A Sunflower 30 day harvest (ASF30), Group A Sunflower + EDDS 30 day harvest (ASF30+), Group A Indian Mustard 30 day harvest (AIM30), Group A Indian Mustard + EDDS 30 day harvest (AIM30+), Group B Sunflower 60 day harvest (BSF60), Group B Sunflower + EDDS 60 day harvest (BSF60+), Group B Indian Mustard 60 day harvest (BIM60), Group B Indian Mustard + EDDS 60 day harvest (BIM60+), Group A Sunflower 60 day harvest (ASF60), Group A Sunflower + EDDS 60 day harvest (ASF60+), Group A Indian Mustard 60 day harvest (AIM60), Group A Indian Mustard + EDDS 60 day harvest (AIM60+). The AIM60 group did not survive the experiment and yielded no data. Error bars represent standard deviation. It should be noted that concentration values over 1000 ppm obtained throughout this experiment are considered estimates due to the nature of the standards used for instrument calibration.

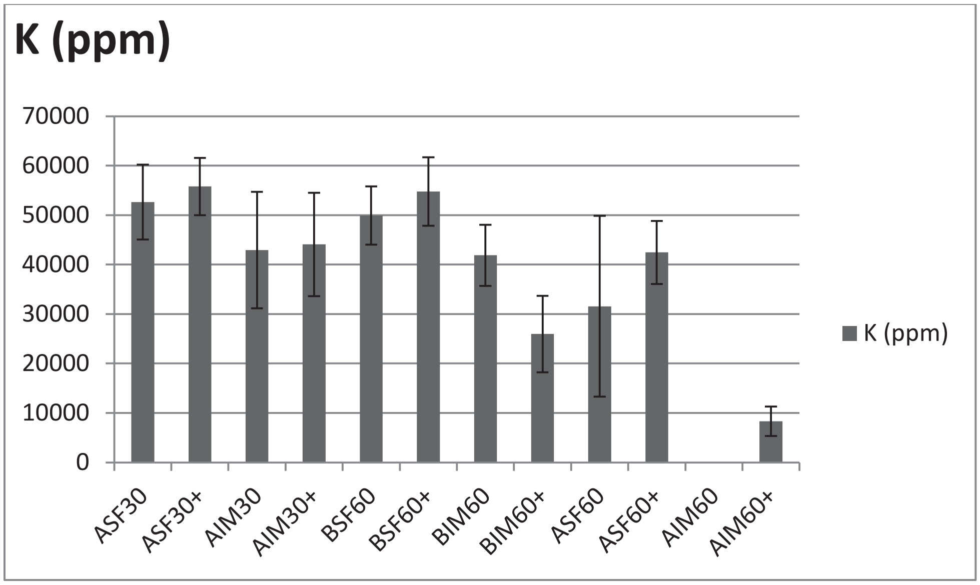

Figure 43: Shoots metal concentration of K (ppm) in each of the experimental groups in the study. The groups include, Group A Sunflower 30 day harvest (ASF30), Group A Sunflower + EDDS 30 day harvest (ASF30+), Group A Indian Mustard 30 day harvest (AIM30), Group A Indian Mustard + EDDS 30 day harvest (AIM30+), Group B Sunflower 60 day harvest (BSF60), Group B Sunflower + EDDS 60 day harvest (BSF60+), Group B Indian Mustard 60 day harvest (BIM60), Group B Indian Mustard + EDDS 60 day harvest (BIM60+), Group A Sunflower 60 day harvest (ASF60), Group A Sunflower + EDDS 60 day harvest (ASF60+), Group A Indian Mustard 60 day harvest (AIM60), Group A Indian Mustard + EDDS 60 day harvest (AIM60+). The AIM60 group did not survive the experiment and yielded no data. Error bars represent standard deviation. It should be noted that concentration values over 1000 ppm obtained throughout this experiment are considered estimates due to the nature of the standards used for instrument calibration.

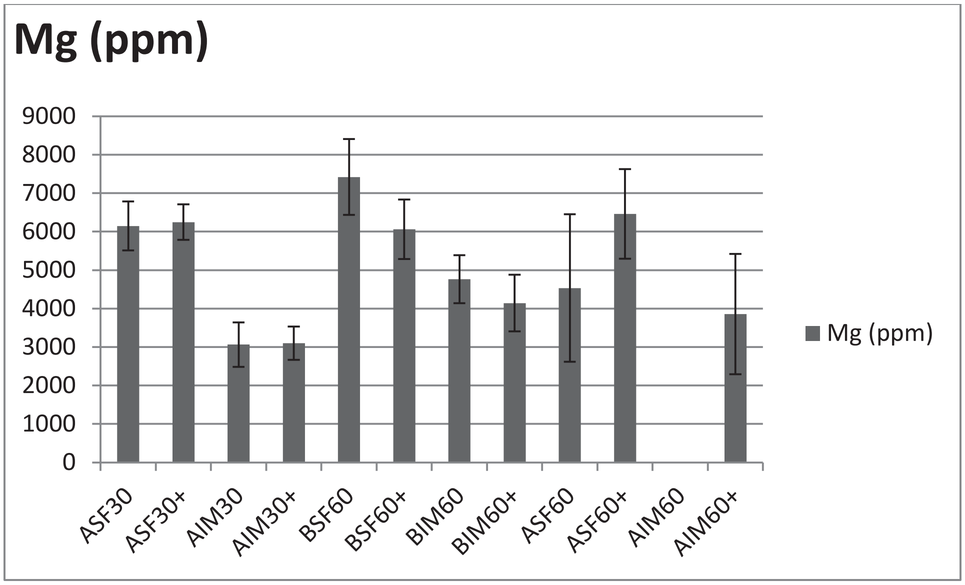

Figure 44: Shoots metal concentration of Mg (ppm) in each of the experimental groups in the study. The groups include, Group A Sunflower 30 day harvest (ASF30), Group A Sunflower + EDDS 30 day harvest (ASF30+), Group A Indian Mustard 30 day harvest (AIM30), Group A Indian Mustard + EDDS 30 day harvest (AIM30+), Group B Sunflower 60 day harvest (BSF60), Group B Sunflower + EDDS 60 day harvest (BSF60+), Group B Indian Mustard 60 day harvest (BIM60), Group B Indian Mustard + EDDS 60 day harvest (BIM60+), Group A Sunflower 60 day harvest (ASF60), Group A Sunflower + EDDS 60 day harvest (ASF60+), Group A Indian Mustard 60 day harvest (AIM60), Group A Indian Mustard + EDDS 60 day harvest (AIM60+). The AIM60 group did not survive the experiment and yielded no data. Error bars represent standard deviation. It should be noted that concentration values over 1000 ppm obtained throughout this experiment are considered estimates due to the nature of the standards used for instrument calibration.

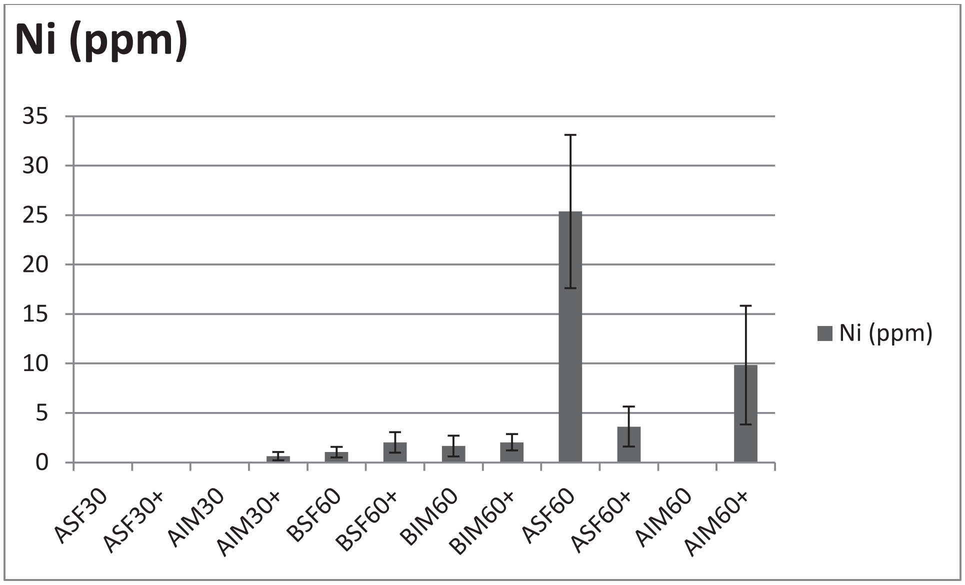

Figure 45: Shoots metal concentration of Ni (ppm) in each of the experimental groups in the study. The groups include, Group A Sunflower 30 day harvest (ASF30), Group A Sunflower + EDDS 30 day harvest (ASF30+), Group A Indian Mustard 30 day harvest (AIM30), Group A Indian Mustard + EDDS 30 day harvest (AIM30+), Group B Sunflower 60 day harvest (BSF60), Group B Sunflower + EDDS 60 day harvest (BSF60+), Group B Indian Mustard 60 day harvest (BIM60), Group B Indian Mustard + EDDS 60 day harvest (BIM60+), Group A Sunflower 60 day harvest (ASF60), Group A Sunflower + EDDS 60 day harvest (ASF60+), Group A Indian Mustard 60 day harvest (AIM60), Group A Indian Mustard + EDDS 60 day harvest (AIM60+). The AIM60 group did not survive the experiment and yielded no data. Error bars represent standard deviation.

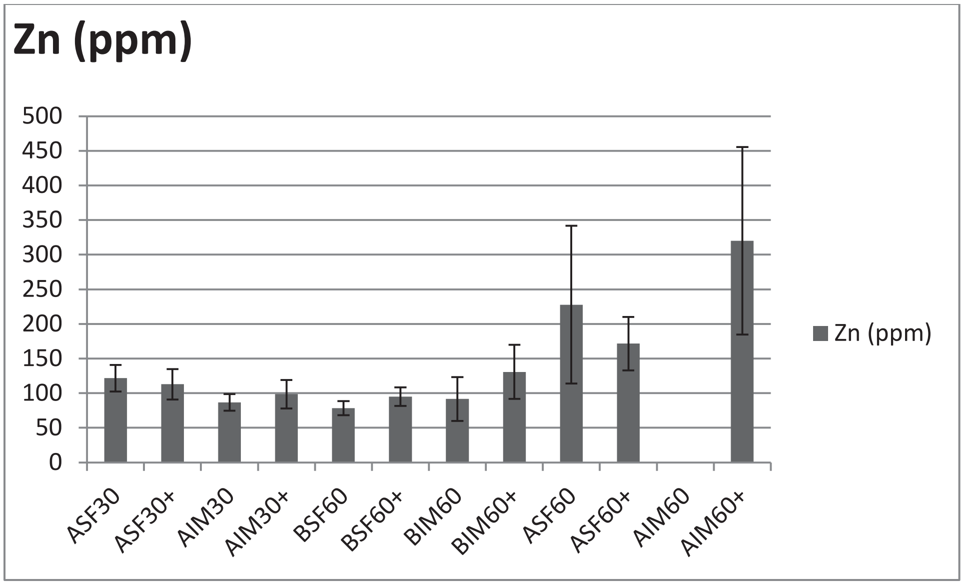

Figure 46: Shoots metal concentration of Zn (ppm) in each of the experimental groups in the study. The groups include, Group A Sunflower 30 day harvest (ASF30), Group A Sunflower + EDDS 30 day harvest (ASF30+), Group A Indian Mustard 30 day harvest (AIM30), Group A Indian Mustard + EDDS 30 day harvest (AIM30+), Group B Sunflower 60 day harvest (BSF60), Group B Sunflower + EDDS 60 day harvest (BSF60+), Group B Indian Mustard 60 day harvest (BIM60), Group B Indian Mustard + EDDS 60 day harvest (BIM60+), Group A Sunflower 60 day harvest (ASF60), Group A Sunflower + EDDS 60 day harvest (ASF60+), Group A Indian Mustard 60 day harvest (AIM60), Group A Indian Mustard + EDDS 60 day harvest (AIM60+). The AIM60 group did not survive the experiment and yielded no data. Error bars represent standard deviation.

Bar Graphs of Plant Root's metal data

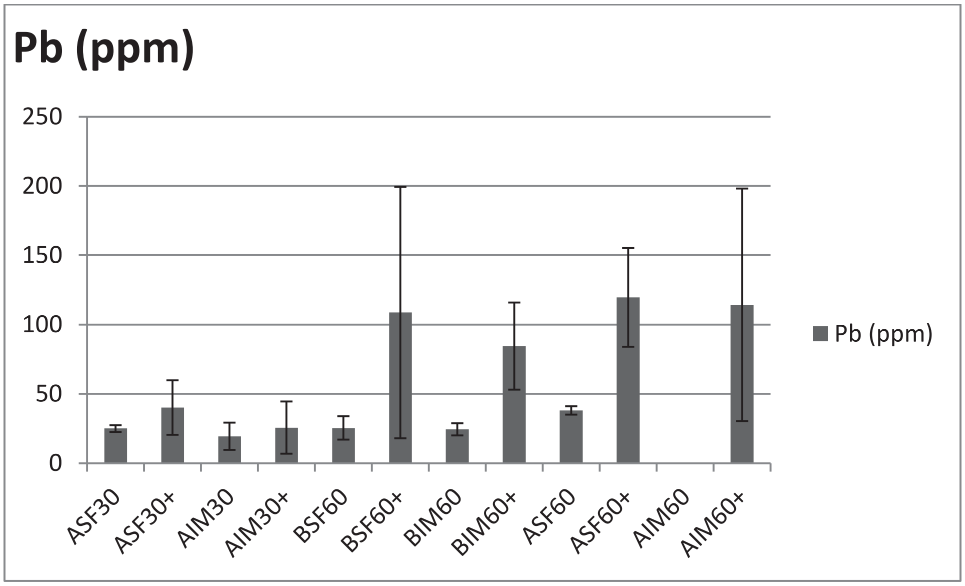

Figure 47: Root metal concentration of Pb (ppm) in each of the experimental groups in the study. The groups include Group A Sunflower 30 day harvest (ASF30), Group A Sunflower + EDDS 30 day harvest (ASF30+), Group A Indian Mustard 30 day harvest (AIM30), Group A Indian Mustard + EDDS 30 day harvest (AIM30+), Group B Sunflower 60 day harvest (BSF60), Group B Sunflower + EDDS 60 day harvest (BSF60+), Group B Indian Mustard 60 day harvest (BIM60), Group B Indian Mustard + EDDS 60 day harvest (BIM60+), Group A Sunflower 60 day harvest (ASF60), Group A Sunflower + EDDS 60 day harvest (ASF60+), Group A Indian Mustard 60 day harvest (AIM60), Group A Indian Mustard + EDDS 60 day harvest (AIM60+). The AIM60 group did not survive the experiment and yielded no data. Error bars represent standard deviation.

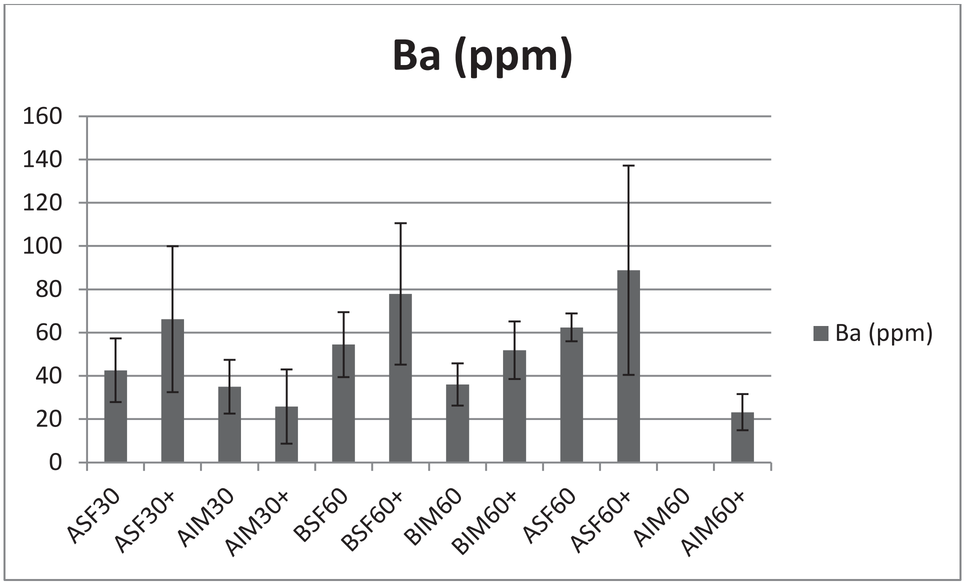

Figure 48: Root metal concentration of Ba (ppm) in each of the experimental groups in the study. The groups include Group A Sunflower 30 day harvest (ASF30), Group A Sunflower + EDDS 30 day harvest (ASF30+), Group A Indian Mustard 30 day harvest (AIM30), Group A Indian Mustard + EDDS 30 day harvest (AIM30+), Group B Sunflower 60 day harvest (BSF60), Group B Sunflower + EDDS 60 day harvest (BSF60+), Group B Indian Mustard 60 day harvest (BIM60), Group B Indian Mustard + EDDS 60 day harvest (BIM60+), Group A Sunflower 60 day harvest (ASF60), Group A Sunflower + EDDS 60 day harvest (ASF60+), Group A Indian Mustard 60 day harvest (AIM60), Group A Indian Mustard + EDDS 60 day harvest (AIM60+). The AIM60 group did not survive the experiment and yielded no data. Error bars represent standard deviation.

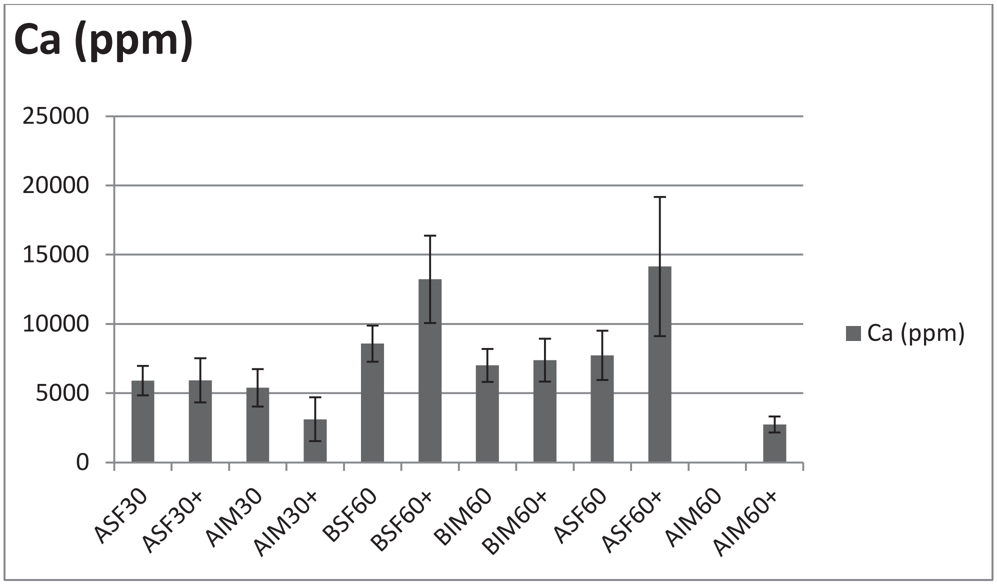

Figure 49: Root metal concentration of Ca (ppm) in each of the experimental groups in the study. The groups include Group A Sunflower 30 day harvest (ASF30), Group A Sunflower + EDDS 30 day harvest (ASF30+), Group A Indian Mustard 30 day harvest (AIM30), Group A Indian Mustard + EDDS 30 day harvest (AIM30+), Group B Sunflower 60 day harvest (BSF60), Group B Sunflower + EDDS 60 day harvest (BSF60+), Group B Indian Mustard 60 day harvest (BIM60), Group B Indian Mustard + EDDS 60 day harvest (BIM60+), Group A Sunflower 60 day harvest (ASF60), Group A Sunflower + EDDS 60 day harvest (ASF60+), Group A Indian Mustard 60 day harvest (AIM60), Group A Indian Mustard + EDDS 60 day harvest (AIM60+). The AIM60 group did not survive the experiment and yielded no data. Error bars represent standard deviation. It should be noted that concentration values over 1000 ppm obtained throughout this experiment are considered estimates due to the nature of the standards used for instrument calibration.

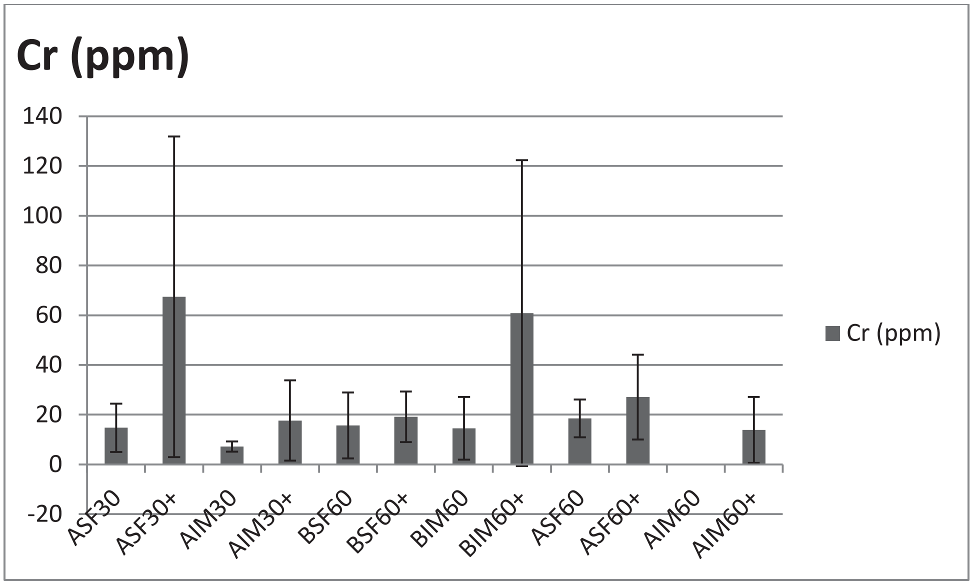

Figure 50: Root metal concentration of Cr (ppm) in each of the experimental groups in the study. The groups include Group A Sunflower 30 day harvest (ASF30), Group A Sunflower + EDDS 30 day harvest (ASF30+), Group A Indian Mustard 30 day harvest (AIM30), Group A Indian Mustard + EDDS 30 day harvest (AIM30+), Group B Sunflower 60 day harvest (BSF60), Group B Sunflower + EDDS 60 day harvest (BSF60+), Group B Indian Mustard 60 day harvest (BIM60), Group B Indian Mustard + EDDS 60 day harvest (BIM60+), Group A Sunflower 60 day harvest (ASF60), Group A Sunflower + EDDS 60 day harvest (ASF60+), Group A Indian Mustard 60 day harvest (AIM60), Group A Indian Mustard + EDDS 60 day harvest (AIM60+). The AIM60 group did not survive the experiment and yielded no data. Error bars represent standard deviation.

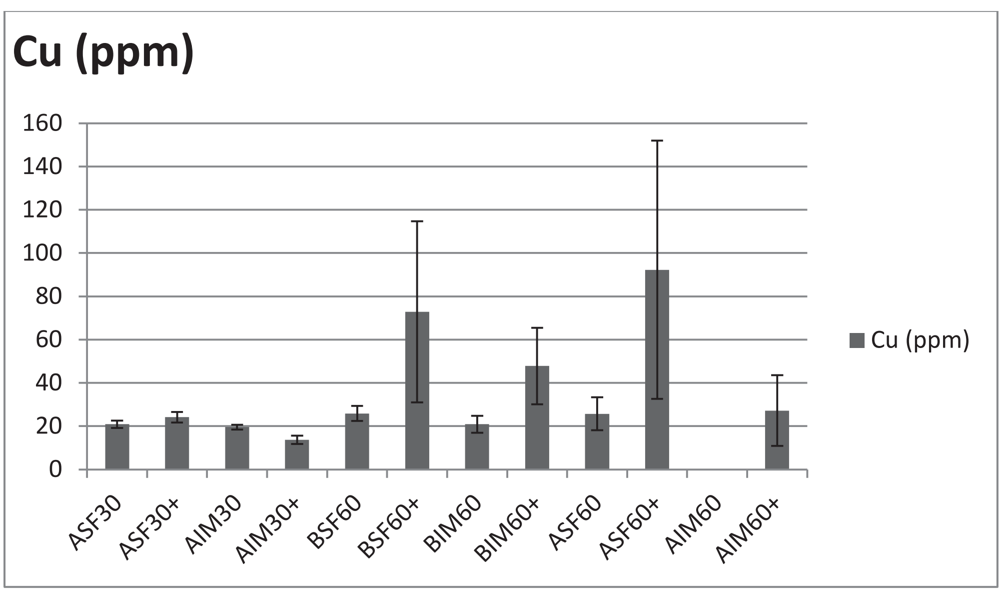

Figure 51: Root metal concentration of Cu (ppm) in each of the experimental groups in the study. The groups include Group A Sunflower 30 day harvest (ASF30), Group A Sunflower + EDDS 30 day harvest (ASF30+), Group A Indian Mustard 30 day harvest (AIM30), Group A Indian Mustard + EDDS 30 day harvest (AIM30+), Group B Sunflower 60 day harvest (BSF60), Group B Sunflower + EDDS 60 day harvest (BSF60+), Group B Indian Mustard 60 day harvest (BIM60), Group B Indian Mustard + EDDS 60 day harvest (BIM60+), Group A Sunflower 60 day harvest (ASF60), Group A Sunflower + EDDS 60 day harvest (ASF60+), Group A Indian Mustard 60 day harvest (AIM60), Group A Indian Mustard + EDDS 60 day harvest (AIM60+). The AIM60 group did not survive the experiment and yielded no data. Error bars represent standard deviation. It should be noted that concentration values over 1000 ppm obtained throughout this experiment are considered estimates due to the nature of the standards used for instrument calibration.

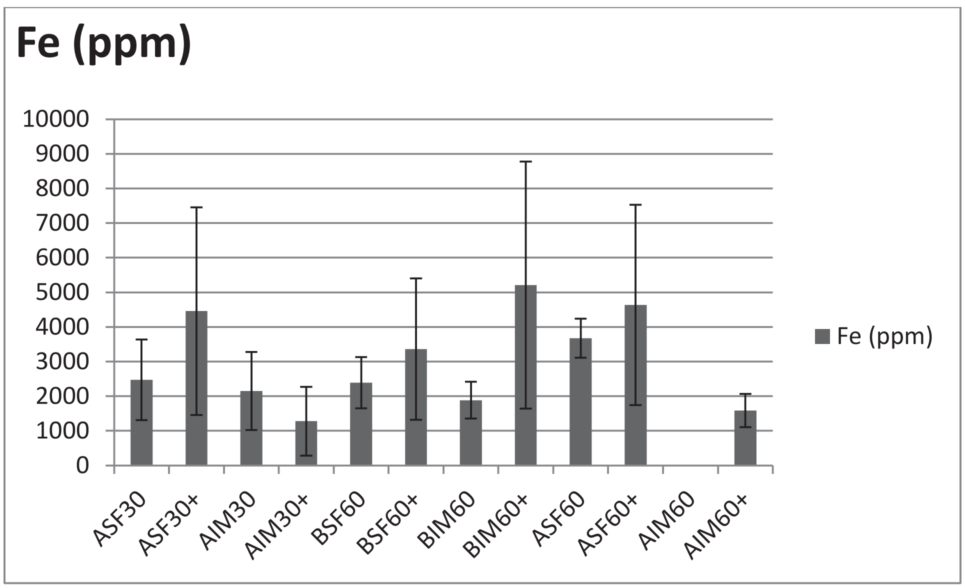

Figure 52: Root metal concentration of Fe (ppm) in each of the experimental groups in the study. The groups include Group A Sunflower 30 day harvest (ASF30), Group A Sunflower + EDDS 30 day harvest (ASF30+), Group A Indian Mustard 30 day harvest (AIM30), Group A Indian Mustard + EDDS 30 day harvest (AIM30+), Group B Sunflower 60 day harvest (BSF60), Group B Sunflower + EDDS 60 day harvest (BSF60+), Group B Indian Mustard 60 day harvest (BIM60), Group B Indian Mustard + EDDS 60 day harvest (BIM60+), Group A Sunflower 60 day harvest (ASF60), Group A Sunflower + EDDS 60 day harvest (ASF60+), Group A Indian Mustard 60 day harvest (AIM60), Group A Indian Mustard + EDDS 60 day harvest (AIM60+). The AIM60 group did not survive the experiment and yielded no data. Error bars represent standard deviation. . It should be noted that concentration values over 1000 ppm obtained

throughout this experiment are considered estimates due to the nature of the standards used for instrument calibration.

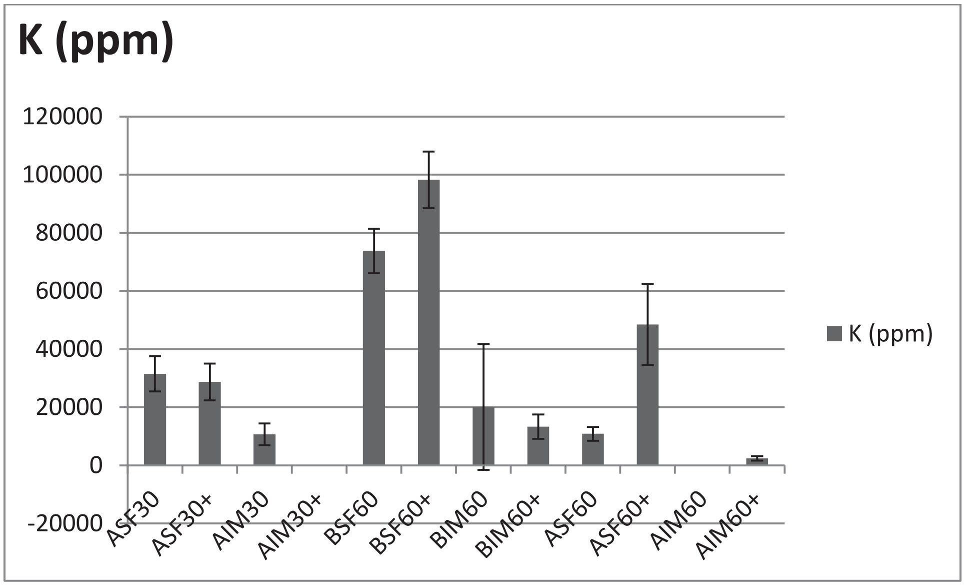

Figure 53: Root metal concentration of K (ppm) in each of the experimental groups in the study. The groups include Group A Sunflower 30 day harvest (ASF30), Group A Sunflower + EDDS 30 day harvest (ASF30+), Group A Indian Mustard 30 day harvest (AIM30), Group A Indian Mustard + EDDS 30 day harvest (AIM30+), Group B Sunflower 60 day harvest (BSF60), Group B Sunflower + EDDS 60 day harvest (BSF60+), Group B Indian Mustard 60 day harvest (BIM60), Group B Indian Mustard + EDDS 60 day harvest (BIM60+), Group A Sunflower 60 day harvest (ASF60), Group A Sunflower + EDDS 60 day harvest (ASF60+), Group A Indian Mustard 60 day harvest (AIM60), Group A Indian Mustard + EDDS 60 day harvest (AIM60+). The AIM60 group did not survive the experiment and yielded no data. Error bars represent standard deviation. It should be noted that concentration values over 1000 ppm obtained throughout this experiment are considered estimates due to the nature of the standards used for instrument calibration.

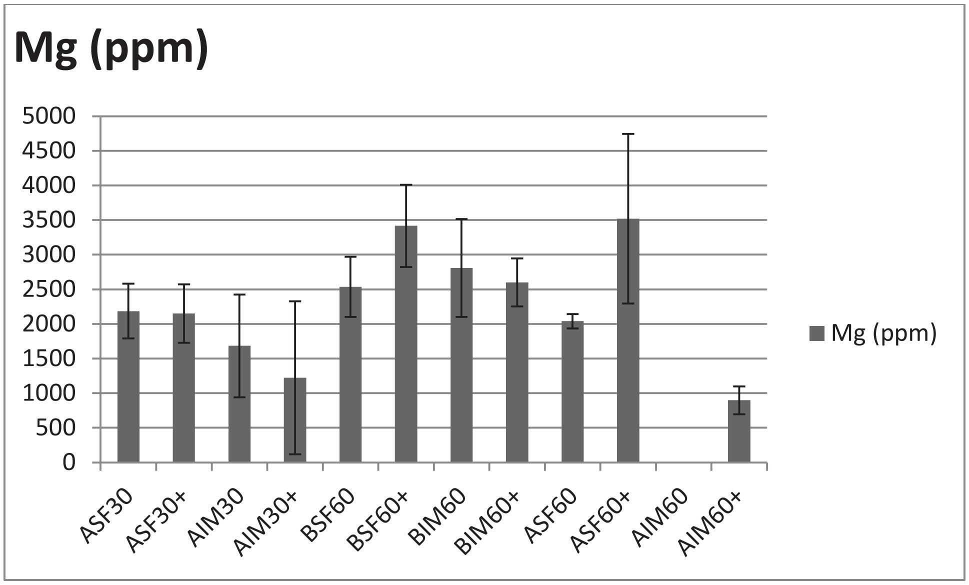

Figure 54: Root metal concentration of Mg (ppm) in each of the experimental groups in the study. The groups include Group A Sunflower 30 day harvest (ASF30), Group A Sunflower + EDDS 30 day harvest (ASF30+), Group A Indian Mustard 30 day harvest (AIM30), Group A Indian Mustard + EDDS 30 day harvest (AIM30+), Group B Sunflower 60 day harvest (BSF60), Group B Sunflower + EDDS 60 day harvest (BSF60+), Group B Indian Mustard 60 day harvest (BIM60), Group B Indian Mustard + EDDS 60 day harvest (BIM60+), Group A Sunflower 60 day harvest (ASF60), Group A Sunflower + EDDS 60 day harvest (ASF60+), Group A Indian Mustard 60 day harvest (AIM60), Group A Indian Mustard + EDDS 60 day harvest (AIM60+). The AIM60 group did not survive the experiment and yielded no data. Error bars represent standard deviation. It should be noted that concentration values over 1000 ppm obtained throughout this experiment are considered estimates due to the nature of the standards used for instrument calibration.

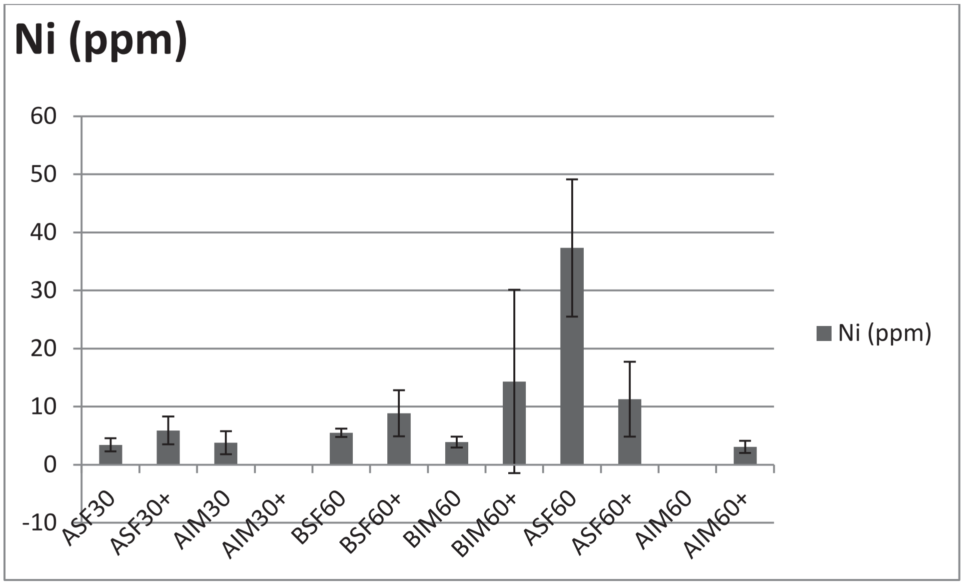

Figure 55: Root metal concentration of Ni (ppm) in each of the experimental groups in the study. The groups include Group A Sunflower 30 day harvest (ASF30), Group A Sunflower + EDDS 30 day harvest (ASF30+), Group A Indian Mustard 30 day harvest (AIM30), Group A Indian Mustard + EDDS 30 day harvest (AIM30+), Group B Sunflower 60 day harvest (BSF60), Group B Sunflower + EDDS 60 day harvest (BSF60+), Group B Indian Mustard 60 day harvest (BIM60), Group B Indian Mustard + EDDS 60 day harvest (BIM60+), Group A Sunflower 60 day harvest (ASF60), Group A Sunflower + EDDS 60 day harvest (ASF60+), Group A Indian Mustard 60 day harvest (AIM60), Group A Indian Mustard + EDDS 60 day harvest (AIM60+). The AIM60 group did not survive the experiment and yielded no data. Error bars represent standard deviation.

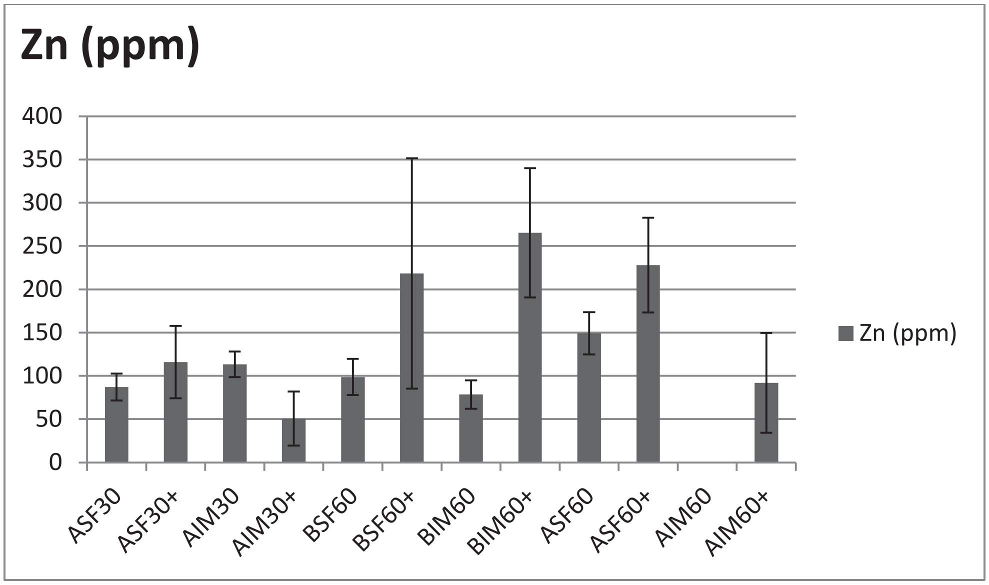

Figure 56: Root metal concentration of Zn (ppm) in each of the experimental groups in the study. The groups include Group A Sunflower 30 day harvest (ASF30), Group A Sunflower + EDDS 30 day harvest (ASF30+), Group A Indian Mustard 30 day harvest (AIM30), Group A Indian Mustard + EDDS 30 day harvest (AIM30+), Group B Sunflower 60 day harvest (BSF60), Group B Sunflower + EDDS 60 day harvest (BSF60+), Group B Indian Mustard 60 day harvest (BIM60), Group B Indian Mustard + EDDS 60 day harvest (BIM60+), Group A Sunflower 60 day harvest (ASF60), Group A Sunflower + EDDS 60 day harvest (ASF60+), Group A Indian Mustard 60 day harvest (AIM60), Group A Indian Mustard + EDDS 60 day harvest (AIM60+). The AIM60 group did not survive the experiment and yielded no data. Error bars represent standard deviation.

CHAPTER 5: DISCUSSION

Statistical analysis of this study's data revealed no significant interactions between soil metal (all) concentration values, treatments, and growth times in the soil and shoot groups. Also, the planting, 30 day growth, harvesting, replanting in the same pots and second 30 day growth that constituted group A did not produce a significant difference in terms of metal concentrations when compared to group B. In the root group, however, significant interactions were found between metal concentrations and the growth times ($\alpha = 0.005$) and between the metal concentrations and the different treatments ($\alpha = 0.004$). For the soil metal concentration group, a lack of significance in terms of decreasing metal concentrations (as would be expected through plant uptake) may have been caused by the brevity of the study. Perhaps a longer study, ranging from months to over a year, would yield results indicating significant decreasing metal concentrations in the soil. Putting aside the presence of negative values (which may have influenced the statistical analyses) the resulting data for shoots may have occurred due to, once again, the shortness of the study. These plants may have revealed higher metal concentrations in their shoots with studies ranging in time from 3 months to over 1 year. Additionally, the necessary dilutions and methods used for extracting the metals from the shoots may not have been ideal. The metal concentration data for the roots indicated that both the duration of the experiments and the treatments (the plant types and the presence or absence of EDDS) were significant in terms of metal concentrations in the roots. First, the roots are in the most direct contact with the soil. Metal accumulation would have to begin in the roots and perhaps the plants, as stated earlier, did not have a long enough growth time for the metals to relocate or travel up to the shoots. Within this data, it can be seen that for the 30 vs. 60 day comparison, higher metal concentrations were present after 60 days. This is simply a factor of time and providing the plants with a longer opportunity to uptake the metals from the soil. For the metal concentration (within plant tissues) vs. treatments comparison, the plants that were treated with EDDS possessed higher metal concentrations that those without EDDS. The chelating agent EDDS produces higher levels of soluble metals within the soil, allowing the plants to uptake the metals more easily. In terms of which plant species was more capable at the uptake of metals, there was not statically significant difference. The presence or absence of EDDS was more significant.

This study reveals the potential for plants, especially those supplemented with chelating agents like the biodegradable EDDS, to assist in the bioremediation of contaminated soil sites. While the species of plant did not seem to matter, the key aspects of this study that most likely influenced the results was time and the presence or absence of EDDS. It is likely that a longer study would have perhaps produced more significant data for the metal concentrations found in both the soil and shoots of the plants. Also, we thought there would have been a significantly larger uptake of metal contaminants from the soil when the group A method of planting and replanting in the same soil was used. Additionally, other conditions such as greenhouse temperature, plant strains and organic matter must be considered in terms of their effect on metal uptake. This ended up not being the case however, but it should be noted that the plants in group A's second harvesting grew poorly which might be because of the high temperature and deficiency of nutrients and this most likely affected the outcome of the study. If the study were to be repeated, longer growth times, different metal extraction methods, and more plant samples, perhaps with multiple plants in a single pot or larger plants in general, would be used. Overall, however, this study reveals the significant potential that relatively common plants hold in terms of their ability to aid in the process of bioremediation.

In the future studies, harvesting time can be longer than 60 day in order to absorb more lead from the soil. Also, high biomass hyperaccumulator can be used as well as along with bigger pots.

CHAPTER 6: APPENDICES

Appendix A: Soil metal concentration

Controls	**Ba (mg/kg)**	**Ca (mg/kg)**	**Cr (mg/kg)**	**Cu (mg/kg)**	**Fe (mg/kg)**	**K (mg/kg)**	**Mg (mg/kg)**	**Ni (mg/kg)**	**Pb (mg/kg)**	**Zn (mg/kg)**
Control Soil A	398	14500	947	45	31230	38085	6470	26	445	396
Control Soil B	432	16005	271	48	35015	45930	7120	30	381	415
Control Soil C	399	10210	1038	35	26120	42830	6275	25	365	303
Control Soil D	373	21490	588	39	26205	38710	5725	32	442	342
Control Soil E	407	12120	445	41	37225	41575	6325	36	434	353
Control Soil F	419	13195	739	35	25210	43635	6470	25	403	364
Average	405	14587	671	41	30168	41794	6398	29	412	362
STDEV	19	3579	269	5	4674	2735	409	4	31	37
C Soil+Water A	461	12745	582	36	27870	51100	7545	30	399	360
C Soil+Water B	420	23995	710	38	24005	39535	7145	23	494	375
C Soil+Water C	472	12715	693	38	36445	46015	6535	31	545	954
Average	451	16485	661	37	29440	45550	7075	28	479	563
Stdev	22	5310	57	1	5199	4733	415	3	61	277
GroupA 1st hrvst	**Ba (mg/kg)**	**Ca (mg/kg)**	**Cr (mg/kg)**	**Cu (mg/kg)**	**Fe (mg/kg)**	**K (mg/kg)**	**Mg (mg/kg)**	**Ni (mg/kg)**	**Pb (mg/kg)**	**Zn (mg/kg)**
ASF30 A1	382	8610	635	39	38400	19060	5205	25	437	369
ASF30 A2	485	7230	807	56	49720	26705	4240	30	647	598
ASF30 B1	406	7770	831	46	28265	22810	4138	26	467	409
ASF30 B2	440	7345	703	143	34640	22360	4033	27	493	402
ASF30 C1	441	7970	589	47	29100	21570	4080	34	464	387
ASF30 C2	424	9100	987	42	32475	18230	4874	25	503	376
ASF30 D1	369	6740	740	45	28265	14590	3656	51	427	358
ASF30 D2	490	8205	921	46	31145	18530	4647	28	531	459
ASF30 E1	390	17030	362	40	27040	14200	4119	22	413	368
ASF30 E2	403	6495	742	45	28910	15645	4047	25	421	384
Average	423	8650	732	55	32796	19370	4304	29	480	411
Stdev	39	2896	168	30	6535	3807	439	8	66	68
ASF30+ A1	374	12770	326	37	25470	12960	3654	22	405	334
ASF30+	504	10125	554	44	33635	13285	4629	31	586	412

A2										
ASF30+ B1	388	6710	486	43	27655	10750	3375	24	467	378
ASF30+ B2	431	7195	618	47	33545	13000	4280	27	462	388
ASF30+ C1	388	6020	534	37	24955	11210	3534	21	385	364
ASF30+ C2	402	8410	327	38	30420	12200	3787	23	431	388
ASF30+ D1	633	12380	669	56	42555	15020	7505	33	556	555
ASF30+ D2	480	8840	677	47	31245	12945	5775	27	458	425
ASF30+ E1	507	8470	569	61	49555	12990	5750	32	583	960
ASF30+ E2	566	7335	721	65	54600	14655	5975	33	724	
Average	467	8826	548	48	35364	12902	4826	27	506	467
Stdev	82	2177	130	9	9677	1254	1297	5	99	184
AIM30 A1	465	19245	714	50	35965	12985	5825	26	576	509
AIM30 A2	411	9465	1127	40	30050	44240	4076	28	507	385
AIM30 B1	386	7285	611	39	31050	41200	3606	23	1276	351
AIM30 B2	442	8130	460	37	34630	51400	4604	22	454	380
AIM30 C1	427	7690	1085	49	34780	50500	4251	28	423	414
AIM30 C2	463	11210	708	49	31975	48610	4572	24	575	473
AIM30 D1	366	5750	821	41	28505	44910	3900	22	399	333
AIM30 D2	470	8685	869	51	34380	54350	4888	27	484	437
AIM30 E1	432	6860	1126	51	32305	48740	3903	25	481	435
AIM30 E2	447	8765	542	45	40400	50400	5110	26	508	399
Average	431	9309	806	45	33404	44734	4473	25	568	411
Stdev	33	3603	231	5	3223	11199	636	2	242	51
AIM30+ A1	473	9830	655	79	37060	58300	4765	30	559	453
AIM30+ A2	445	7995	664	42	33910	52200	4202	25	564	428
AIM30+ B1	450	9220	456	73	33260	53450	5035	23	511	395
AIM30+ B2	384	7720	381	70	27115	45445	3337	22	501	376
AIM30+ B3	386	17075	382	46	28750	46200	2887	25	538	457
AIM30+ C1	411	7800	843	52	33035	49265	3444	33	559	492
AIM30+ C2	363	6150	876	57	26530	45115	2987	29	527	482
AIM30+ D1	372	10935	547	50	26025	45090	2948	27	539	472
AIM30+ D2	368	10730	534	46	25330	45430	2896	26	529	445
AIM30+ D3	315	5605	535	52	24605	37995	2405	22	483	402
AIM30+ E1	424	7195	463	49	30605	47915	3556	30	481	467
AIM30+ E2	351	7330	709	49	25440	42785	3184	48	486	389

AIM30+ E3	352	7210	699	45	24875	43665	3186	45	449	349
Average	392	8830	596	55	28965	47143	3448	30	517	431
Stdev	44	2846	154	12	3991	4998	742	8	34	43
Group B	**Ba (mg/kg)**	**Ca (mg/kg)**	**Cr (mg/kg)**	**Cu (mg/kg)**	**Fe (mg/kg)**	**K (mg/kg)**	**Mg (mg/kg)**	**Ni (mg/kg)**	**Pb (mg/kg)**	**Zn (mg/kg)**
BSF60 A1	369	6670	1012	47	26460	41565	2870	29	525	519
BSF60 A2	373	6225	882	46	25145	39995	2694	27	493	434
BSF60 B1	359	7940	862	51	28280	38540	2762	28	458	438
BSF60 B2	381	7800	812	45	24200	37095	2838	26	492	425
BSF60 C1	368	6290	1059	49	27005	40195	2686	28	527	550
BSF60 C2	395	7145	1223	53	26985	44660	3059	30	494	492
BSF60 D1	334	4983	1340	34	22500	37525	2464	23	403	339
BSF60 D2	452	6465	651	50	29100	45750	2822	28	572	586
BSF60 E1	731	5970	735	55	23740	39540	2637	27	574	567
BSF60 E2	368	5605	1056	45	24290	42040	2780	27	454	403
Average	413	6509	963	48	25771	40691	2761	27	499	475
Stdev	110	878	205	5	2018	2712	150	2	50	76
BSF60+ A1	395	5625	714	61	25415	43020	2760	41	397	401
BSF60+ A2	371	5750	948	49	37415	41095	2771	28	559	504
BSF60+ A3	403	5550	701	53	25015	44035	2778	37	359	359
BSF60+ A4	370	5680	943	50	37605	41070	2707	28	562	511
BSF60+ B1	334	5625	616	44	20525	34505	2277	22	403	383
BSF60+ B2	445	8055	782	51	24165	39660	2828	27	486	455
BSF60+ B3	393	7275	753	36	24735	11275	3473	16	349	331
BSF60+ B4	521	10250	954	45	28995	12885	4234	21	419	391
BSF60+ C1	438	9715	719	46	27725	12815	3670	20	429	426
BSF60+ C2	388	7965	560	46	28405	12520	3838	21	395	414
BSF60+ D1	414	9375	944	47	27885	13105	4177	19	458	373
BSF60+ D2	419	8350	679	52	33890	13715	3953	21	532	396
BSF60+ E1	807	11185	841	50	29410	13330	4463	21	556	432
BSF60+ E2	431	10420	595	52	30865	12580	3891	21	476	446
Average	438	7916	768	49	28718	24686	3415	24	456	416
Stdev	111	1967	133	5	4756	13905	682	7	72	49
BIM60 A1	504	9270	1163	56	33285	13105	4339	27	558	456
BIM60 A2	440	8570	768.5	44	33555	13205	4096	22	468	376
BIM60 B1	416	13620	1166	46	32220	14140	6055	25	474	402
BIM60 B2	602	9695	1582	59	31760	13120	4138	35	477	449

BIM60 C1	507	11270	1674		35095	12600	4141	23	444	426
BIM60 C2	451	8895	1461	49	31975	14335	4603	29	536	429
BIM60 D1	424	8375	1176.5	42	39740	13395	4332	33	564	427
BIM60 D2	409	8435	1704	44	27320	12275	3973	23	451	404
BIM60 E1	448	13235	1314	46	29830	13350	4932	23	503	425
BIM60 E2	405		1013.5	44	31590	13385	6630	25	446	361
Average	461	10152	1302	48	32637	13291	4724	26	492	415
Stdev	58	1942	287	6	3105	584	861	4	43	29
BIM60+ A1	413	10605	1112	141	28535	13110	4370	21	498	378
BIM60+ A2	406	10880	961	42	25455	12860	4050	23	477	385
BIM60+ B1	415	8215	400	50	25745	13120	3985	22	533	389
BIM60+ B2	414	6485	499	55	32650	13480	3763	25	487	386
BIM60+ C1	460	11535	666	52	35235	13465	3988	28	520	405
BIM60+ C2	468	9635	569	67	34720	14635	4479	26	586	455
BIM60+ D1	493	7775	418	46	29590	13405	3980	23	610	432
BIM60+ D2	476	10600	575	47	25175	12810	3837	22	527	497
BIM60+ E1	428	7420	602	41	27440	14040	3881	20	478	307
BIM60+ E2	586	9545	977	41	28790	15785	4785	25	543	344
Average	456	9270	678	58	29334	13671	4112	23	526	398
Stdev	52	1613	237	29	3530	878	309	2	42	51
GroupA 2nd hrvst	**Ba (mg/kg)**	**Ca (mg/kg)**	**Cr (mg/kg)**	**Cu (mg/kg)**	**Fe (mg/kg)**	**K (mg/kg)**	**Mg (mg/kg)**	**Ni (mg/kg)**	**Pb (mg/kg)**	**Zn (mg/kg)**
ASF60 A1	470	8530	936	42	36655	14200	4212	22	538	387
ASF60 A2	502	8495	987	39	31560	15255	4587	22	562	391
ASF60 B1	503	8460	1541	45	30975	15165	4526	29	620	406
ASF60 B2	454	9225	1036	43	28535	15440	4875	30	533	372
ASF60 C1	363	6470	972	40	25940	12270	3287	24	374	352
ASF60 C2	442	9695	671	37	30700	13230	3712	25	405	385
ASF60 D1	363	9420	848	39	25530	12765	3951	27	398	328
ASF60 D2	375	10820	604	33	25105	13085	3718	26	346	298
ASF60 E1	419	7670	780	44	28340	14045	3752	29	545	459
ASF60 E2	429	12230	724	51	32050	15895	4657	34	594	587
Average	432	9102	910	41	29539	14135	4128	27	491	396
Stdev	50	1526	251	5	3400	1200	494	4	95	76
ASF60+ A1	370	6715	780	43	29230	10790	3347	22	403	340
ASF60+ A2	387	7815	948	41	65300	11565	3851	38	448	387
ASF60+ B1	428	10135	940	43	28585	12355	3895	25	429	447
ASF60+ B2	366	11440	1110	40	36035	10830	4534	49	438	427

ASF60+ C1	393	7530	621	52	35890	12375	3852	44	511	584
ASF60+ C2	391	9165	884	35	37570	12165	3967	26	405	439
ASF60+ D1	425	8335	1465	45	35355	12575	3985	28	594	443
ASF60+ D2	431	7905	1242	51	34360	13485	4271	32	554	609
ASF60+ D3	437	7770	1234	52	33570	13645	4241	30	521	566
ASF60+ E1	419	7520	812	46	56150	12225	3749	27	519	
ASF60+ E2	418	7480	807	46	55350	12440	3722	26	516	1035
ASF60+ E3	400	7330	1036	48	27605	12355	3767	31	603	497
Average	405	8262	990	45	39583	12234	3932	31	495	525
Stdev	23	1290	228	5	11789	830	294	8	66	180
AIM60+ A1	386	10265	426	53	29635	12750	4834	28	653	520
AIM60+ A2	459	10150	648	57	33995	14845	4535	31	680	568
AIM60+ B1	428	9185	598	40	31550	13385	4371	28	559	514
AIM60+ B2	423	7140	589	41	46665	12250	3596	31	538	490
AIM60+ C1	364	7560	431	42	30415	12545	3813	28	485	496
AIM60+ C2	397	10645	721	43	31220	13340	4893	139	480	532
AIM60+ D1	522	9805	841	59	42700	16235	5700	38	661	663
AIM60+ D2	531	9845	850	58	42885	16350	5765	38	657	651
AIM60+ D3	403	7575	786	56	28680	12020	3711	32	674	532
AIM60+ E1	446	8580	1552	60	33840	14660	4657	37	765	602
Average	436	9075	744	51	35159	13838	4587	43	615	557
Stdev	53	1213	305	8	6128	1513	720	32	89	59

Appendix B: Shoot metal concentration

Group A 1st Harvest	Ba (mg/kg)	Ca (mg/kg)	Cr (mg/kg)	Cu (mg/kg)	Fe (mg/kg)	K (mg/kg)	Mg (mg/kg)	Ni (mg/kg)	Pb (mg/kg)	Zn (mg/kg)
ASF30 shoot Pot A1	14	25480	1	32	254	48680	6790	1	7	144
ASF30 shoot Pot A2	12	21565	1	27	223	43910	5795	0	6	141
ASF30 shoot Pot A3	14	25355	1	35	274	50900	6945	1	7	185
ASF30 shoot Pot B1	15	24415	3	30	136	50250	6020	0	8	118
ASF30 shoot	15	24965	0	29	204	50000	5900	1	6	105

Pot B2										
ASF30 shoot Pot B3	14	24535	1	29	188	49740	5915	0	8	121
ASF30 shoot Pot B4	16	24805	0	30	159	48855	5900	0	9	114
ASF30 shoot Pot C1	18	27065	5	27	127	43710	5020	0	6	101
ASF30 shoot Pot C2	18	29120	2	28	131	46695	5345	1	6	105
ASF30 shoot Pot C3	19	29695	0	28	121	49445	5545	0	7	113
ASF30 shoot Pot C4	19	29840	-2	29	111	48590	5465	1	7	114
ASF30 shoot Pot D2	19	34780	-3	24	160	52700	6970	-1	5	120
ASF30 shoot Pot D3	20	36645	0	25	145	56050	7200	1	5	124
ASF30 shoot Pot D4	17	30440	-3	26	123	46865	6045	0	4	106
ASF30 shoot Pot E1	20	32980	2	24	174	61450	5980	-1	5	112
ASF30 shoot Pot E2	24	38450	-1	28	220	71050	6920	-1	13	128
ASF30 shoot Pot E3	19	32470	17	24	209	60300	5895	-1	5	113
ASF30 shoot Pot E4	26	36940	-2	29	222	68300	6985	-1	6	128
Average	18	29419	1	28	177	52638	6146	0	7	122
Stdev	3	4897	4	3	48	7592	637	1	2	19
ASF30+ Shoot Pot A1	17	30710	0	26	277	62600	6515	-1	5	104
ASF30+ Shoot Pot A2	18	29585	0	26	249	60650	6350	-1	5	112
ASF30+ Shoot Pot A3	17	28865	-1	26	216	59900	6280	-1	5	107
ASF30+ Shoot Pot A4	17	28195	125	28	410	57800	6245	0	6	95
ASF30+ Shoot Pot B1	31	32690	89	32	1194	61450	6805	1	11	142
ASF30+ Shoot Pot B2	26	28670	23	27	788	54750	6020	0	9	128
ASF30+ Shoot Pot B3	21	27170	8	27	666	52050	5745	1	9	125
ASF30+ Shoot Pot B4	26	31860	48	29	1163	59550	6580	0	11	156
ASF30+ Shoot Pot C1	51	33385	28	29	1119	59050	6455	2	17	126
ASF30+ Shoot Pot C2	32	32810	33	28	1090	57550	6345	0	15	106
ASF30+ Shoot Pot C3	30	35315	28	29	1160	62300	6815	0	13	153
ASF30+ Shoot Pot D1	23	34980	-1	25	281	50500	6170	-1	5	101
ASF30+ Shoot Pot D2	24	32605	-4	22	123	43535	5350	-1	6	79
ASF30+ Shoot Pot D3	22	33130	2	21	165	47395	5590	-1	6	84
ASF30+ Shoot Pot D4	22	35835	-1	26	203	51100	6185	-1	6	98

ASF30+ Shoot Pot E1	25	31110	0	25	1110	46260	5400	0	8	82
ASF30+ Shoot Pot E2	33	40105	13	31	501	61000	6990	0	11	116
ASF30+ Shoot Pot E3	27	37925	-2	29	502	56550	6610	0	9	119
Average	26	32497	22	27	623	55777	6247	0	9	113
Stdev	8	3355	34	3	401	5761	461	1	4	22
AIM30 Shoot Pot A1	24	32770	0	22	289	49810	3761	0	6	102
AIM30 Shoot Pot A2	19	28205	-3	19	194	41695	3119	-1	4	90
AIM30 Shoot Pot A3	17	26095	1	14	126	41745	2890	-1	6	88
AIM30 Shoot Pot A4	19	28525	-1	18	158	45200	3216	-1	4	94
AIM30 Shoot Pot B1	16	22820		18	416	41015	3051	0	3	93
AIM30 Shoot Pot B2	16	23355	2	19	132	41750	3030	-1	4	91
AIM30 Shoot Pot B3	15	22200	-1	19	121	39645	2766	-1	3	84
AIM30 Shoot Pot B4	17	24290	1	20	166	45495	3172	-1	4	91
AIM30 Shoot Pot C1	20	25475	-4	22	169	48950	3370	-1	5	86
AIM30 Shoot Pot C2	18	25235	-8	20	178	47950	3552	-1	4	82
AIM30 Shoot Pot C3	18	24725	-1	22	170	47340	3361	-1	4	81
AIM30 Shoot Pot C4	18	22590	-3	20	174	43995	3056	-1	3	75
AIM30 Shoot Pot D1	22	33395	1	26	209	62400	4089	0	5	105
AIM30 Shoot Pot D2	20	30170	-2	24	149	60000	3651	-1	4	104
AIM30 Shoot Pot D3	16	26320	-1	22	141	52700	3261	-1	3	91
AIM30 Shoot Pot D4	15	24450	-2	20	125	47920	2982	-1	4	83
AIM30 Shoot Pot E1	23	28430	-5	18	103	19255	2134	-1	4	87
AIM30 Shoot Pot E3	19	25035	3	11	110	18870	1908	0	4	60
AIM30 Shoot Pot E4	19	23580	5	12	92	19675	1815	0	4	58
Average	18	26193	-1	19	169	42916	3062	-1	4	87
Stdev	2	3181	3	4	73	11767	574	0	1	12
AIM30+ Shoot Pot A1	25	28365	4	24	578	45705	3144	2	30	130
AIM30+ Shoot Pot A2	22	27770	3	29	444	45390	3116	1	33	
AIM30+ Shoot Pot A3	22	26760	6	28	331	46080	3024	0	32	
AIM30+ Shoot Pot A4	22	27000	5	25	282	46765	3058	0	31	99
AIM30+ Shoot Pot B1	30	30900	6	27	639	56950	4037	1	19	136

AIM30+ Shoot Pot B2	27	29600		28	804	53750	3519	1	63	110
AIM30+ Shoot Pot B3	24	29385	6	28	470	54500	3474	0	22	97
AIM30+ Shoot Pot B4	22	27505	4	28	451	51250	3288	1	21	113
AIM30+ Shoot Pot C1	28	25175	7	28	453	26750	2432	1	61	109
AIM30+ Shoot Pot C2	27	27340	5	30	234	29000	2624	1	35	76
AIM30+ Shoot Pot C3	25	24785	0	29	263	26900	2420	0	37	63
AIM30+ Shoot Pot C4	25	26175	8	28	236	27730	2550	1	33	99
AIM30+ Shoot Pot D1	71	30980	22	32	358	51800	3463	0	11	85
AIM30+ Shoot Pot D2	24	27575	8	28	266	48220	3086	0	12	77
AIM30+ Shoot Pot D3	22	28805	6	29	328	50300	3279	1	13	87
Average	28	27875	6	28	409	44073	3101	1	30	98
Stdev	12	1778	5	2	159	10457	435	0	15	20
Group B	**Ba (mg/kg)**	**Ca (mg/kg)**	**Cr (mg/kg)**	**Cu (mg/kg)**	**Fe (mg/kg)**	**K (mg/kg)**	**Mg (mg/kg)**	**Ni (mg/kg)**	**Pb (mg/kg)**	**Zn (mg/kg)**
BSF60 Shoot Pot A1	31	47935	7	19	301	43985	7515	1	8	74
BSF60 Shoot Pot A2	31	47620	9	20	325	44620	7875	1	10	83
BSF60 Shoot Pot A3	35	57000	5	19	364	50400	8780	1	9	86
BSF60 Shoot Pot A4	31	47495	7	19	335	45825	7785	1	9	78
BSF60 Shoot Pot B1	32	36230	4	19	449	39845	6755	0	12	69
BSF60 Shoot Pot B2	35	41780	3	19	596	42735	7595		9	87
BSF60 Shoot Pot B3	34	45545	2	23	401	52100	8320	1	9	75
BSF60 Shoot Pot B4	36	49305	7	21	707	56100	8400	1	13	71
BSF60 Shoot Pot C1	35	48180	7	19	391	54900	8380	1	9	68
BSF60 Shoot Pot C2	35	46110	5	20	432	54050	8010	2	10	93
BSF60 Shoot Pot C3	38	46230	18	21	650	45645	7635	1	10	
BSF60 Shoot Pot C4	41	51450		23	949	50350	7935	2	12	96
BSF60 Shoot Pot D1	30	41530	3	18	284	47650	7190	2	7	66
BSF60 Shoot Pot D2	30	38185	3	18	267	43575	6785	1	7	72
BSF60 Shoot Pot D3	32	42725	3	19	310	48675	7605	1	7	70
BSF60 Shoot Pot D4	35	54900	8	20	387	49690	7980	0	9	76
BSF60 Shoot Pot E1	33	33100	7	20	547	59350	5275	1	7	69

BSF60 Shoot Pot E2	37	39440	12	23		61000	5720	2	14	
BSF60 Shoot Pot E3	35	36620	6	21		57700	5385	1	13	99
Average	34	44809	6	20	453	49905	7417	1	10	78
Stdev	3	6198	4	2	177	5876	986	1	2	10
BSF60+ Shoot Pot A2	44	34320	9	32		61450	6150	4	27	98
BSF60+ Shoot Pot A3	32	30100	5	31	800	53450	4893	2	29	82
BSF60+ Shoot Pot A4	38	36020	4	29		59950	5650	2	25	93
BSF60+ Shoot Pot B1	33	56000	3	26	310	55200	7560	1	14	105
BSF60+ Shoot Pot B2	32	50950	0	26	267	54450	7015	2	14	82
BSF60+ Shoot Pot B3	36	58900	5	29	574	59800	7985	2	16	98
BSF60+ Shoot Pot B4	28	42925	7	25	246	49015	6495	1	13	87
BSF60+ Shoot Pot C1	30	45940		24	590	47730	6550	2	10	113
BSF60+ Shoot Pot C2	25	35880	1	23	159	43030	5720	1	10	86
BSF60+ Shoot Pot C3	26	40060	1	24	197	42315	5645	1	13	73
BSF60+ Shoot Pot C4	24	33215	3	23	191	41480	5440	1	10	82
BSF60+ Shoot Pot D1	33	40115	20	32	546	59100	6210	2	15	104
BSF60+ Shoot Pot D2	31	37755	7	30	432	56550	5500	2	14	131
BSF60+ Shoot Pot D3	34	42910	22	32	584	61450	5910	3	20	98
BSF60+ Shoot Pot D4	34	41740	12	32	608	60200	5775	2	17	94
BSF60+ Shoot Pot E1	30	32030	7	27	417	54500	5245	2	24	78
BSF60+ Shoot Pot E2	40	43205	10	29	718	66150	6345	3	25	107
BSF60+ Shoot Pot E3	32	33580	2	26	716	54900	5330	3	35	98
BSF60+ Shoot Pot E4	35	38690		29	706	59950	5770	5	24	99
Average	32	40754	7	28	474	54772	6063	2	19	95
Stdev	5	7638	6	3	206	6896	772	1	7	13
BIM60 Shoot Pot A1	33	41920	1	26	340	51900	4076	1	16	147
BIM60 Shoot Pot A2	75	40785	7	24	485	47900	3837	0	32	122
BIM60 Shoot Pot A3	35	41860	3	25	309	52250	4139	1	13	137
BIM60 Shoot Pot B1	26	33705	28	29	549	46100	5065	2	13	111
BIM60 Shoot Pot B2	28	37800		29	675	51000	5625	2	14	108
BIM60 Shoot Pot B3	31	35825	9	27	628	47530	5245	2	15	88

BIM60 Shoot Pot B4	24	31545	15	25	415	47520	4668	3	14	68
BIM60 Shoot Pot C1	49	37025	5	27		38670	5155	4	17	95
BIM60 Shoot Pot C2	48	36640	6	28		36955	5370	3	14	86
BIM60 Shoot Pot C3	46	35645	8	27		37535	4892	3	16	91
BIM60 Shoot Pot C4	46	36865	34	25		36505	5495	3	13	84
BIM60 Shoot Pot D1	20	37575	1	21	256	38440	4952	2	5	75
BIM60 Shoot Pot D2	39	44770	7	25	303	42750	5595	2	5	165
BIM60 Shoot Pot D3	24	42470	2	22	421	41795	5360	1		68
BIM60 Shoot Pot D4	21	38835	4	23	240	40340	4988	1	6	56
BIM60 Shoot Pot E1	17	29985	4	24	213	34460	3945	1	5	48
BIM60 Shoot Pot E2	17	30625	6	24	275	35410	4172	1	21	74
BIM60 Shoot Pot E3	16	28480	2	26	200	35100	3838	0	6	63
BIM60 Shoot Pot E4	17	29265	-1	25	228	33315	4088	0	5	58
Average	32	36401	8	25	369	41867	4763	2	13	92
Stdev	15	4680	9	2	149	6166	621	1	7	32
BIM60+ Shoot Pot A1	36	31385	4	52	657	32455	4771	3	76	160
BIM60+ Shoot Pot B1	49	42890		29	844	36500	4873	1	33	157
BIM60+ Shoot Pot B2	56	48300		34	1211	38450	5275	1	40	193
BIM60+ Shoot Pot C1	21	27190	-1	28	998	22015	3830	4	41	143
BIM60+ Shoot Pot C2	26	30750	1	23	944	26410	4504	2	31	96
BIM60+ Shoot Pot D1	27	23245	1	36	513	21030	2993	2	28	139
BIM60+ Shoot Pot D2	26	24795	1	35	554	23980	3240	2	27	142
BIM60+ Shoot Pot E1	18	23580	0	20	984	15300	3597	2	12	67
BIM60+ Shoot Pot E2	21	28375	4	24	1139	17535	4178	2	14	80
Average	31	31168	1	31	871	25964	4140	2	34	131
Stdev	13	8271	2	9	235	7731	736	1	18	39
Group A 2nd Harvest	**Ba (mg/kg)**	**Ca (mg/kg)**	**Cr (mg/kg)**	**Cu (mg/kg)**	**Fe (mg/kg)**	**K (mg/kg)**	**Mg (mg/kg)**	**Ni (mg/kg)**	**Pb (mg/kg)**	**Zn (mg/kg)**
ASF60 shoot Pot D1	11	11835	24	16	398	11440	2909	36	6	100
ASF60 shoot Pot E1	25	13780	2	31	1104	27545	3462	18	16	207
ASF60 shoot Pot F1	43	33940	5	94	1090	55700	7225	23	25	377

Average	26	19852	10	47	864	31562	4532	25	16	228
Stdev	13	9994	10	34	330	18291	1918	8	7	114
ASF60+ shoot Pot A1	42	35105	73	29	1537	31840	5705	6	36	117
ASF60+ shoot Pot A2	51	39435	8	32	2060	35295	6175	4	48	142
ASF60+ shoot Pot B1	43	48965	42	31	1239	45125	8895	2	31	184
ASF60+ shoot Pot B2	40	43785	34	30	1384	41510	7760	2	41	160
ASF60+ shoot Pot C1	62	29795		44	2731	42030	4956	6	70	191
ASF60+ shoot Pot C2	89	41325	11	57	3520	55400	6790	7	89	259
ASF60+ shoot Pot D1	41	38065		35	753	49685	7335	1	54	179
ASF60+ shoot Pot D2	33	29325		25	515	43840	5980	1	35	123
ASF60+ shoot Pot E1	40	32030	57	60	1234	40320	5335	3	44	171
ASF60+ shoot Pot E2	47	35350	13	65	1356	39665	5660	4	45	191
Average	49	37318	34	41	1633	42471	6459	4	49	172
Stdev	15	5965	23	14	862	6374	1164	2	17	39
AIM60 shoot Pot A1	DIED									
AIM60+ shoot Pot A1	123	30885	88		6495	8210	4974	16	66	524
AIM60+ shoot Pot B1	25	26025		42		12850	4906	5	44	147
AIM60+ shoot Pot C1	100	9895	279	73	6345	6440	2878	11		331
AIM60+ shoot Pot D1	139	18785	134	32	12340	9990	5290	16	46	278
AIM60+ shoot Pot E1	35	4916		17	1302	4143	1228	1	24	
Average	85	18101	167	41	6620	8327	3855	10	45	320
Stdev	46	9673	82	21	3908	2977	1567	6	15	135

Appendix C: Root metal concentration

Group A 1st Harvest	**Ba (mg/kg)**	**Ca (mg/kg)**	**Cr (mg/kg)**	**Cu (mg/kg)**	**Fe (mg/kg)**	**K (mg/kg)**	**Mg (mg/kg)**	**Ni (mg/kg)**	**Pb (mg/kg)**	**Zn (mg/kg)**
ASF30 root Pot A1	25	4706	4	20	928	20945	1776	2	22	74
ASF30 root Pot B1	25	4395	6	19	943	29185	1895	2	24	63
ASF30 root Pot C1	67	6705	28	19	3708	29550	2454	5	24	98
ASF30 root Pot D1	43	7045	7	23	2871	39565	2557	4	27	99

ASF30 root Pot D2	50	6885	21	23	3787	37325	2705	5	30	107
ASF30 root Pot E1	46	5710	24	21	2602	32430	1731	4	24	82
Average	43	5908	15	21	2473	31500	2186	3	25	87
Stdev	15	1053	10	2	1166	6061	396	1	2	15
ASF30+ root Pot A1	97	5685	105	27	6680	32440	2831	9	33	204
ASF30+ root Pot A2	73	5535	22	23	5550	31545	2527	8	22	96
ASF30+ root Pot B1	35	3747	26	22	2641	31300	1696	4	28	94
ASF30+ root Pot B2	43	4722	18	23	2372	37535	2037	5	23	98
ASF30+ root Pot C1	126	8330	196	27	10320	27755	2344	9	82	140
ASF30+ root Pot D1	66	8230	38	20	2489	23445	2093	4	44	65
ASF30+ root Pot E1	24	5310		25	1141	16785	1526	3	50	115
Average	66	5937	67	24	4456	28686	2150	6	40	116
Stdev	34	1598	64	2	3001	6295	423	2	20	42
AIM30 root Pot A1	32	4124	8	19	2044	6790	1423	4	28	113
AIM30 root Pot A2	60	7785	11	21	3902	10820	3131	7	34	127
AIM30 root Pot B1	29	5735	6	20	968	15540	1182	3	8	90
AIM30 root Pot C1	28	4132	6	20	2849	14170	1577	4	15	106
AIM30 root Pot E1	26	5170	6	18	975	6180	1112	1	13	131
Average	35	5389	7	20	2148	10700	1685	4	19	113
Stdev	12	1348	2	1	1127	3774	742	2	10	15
AIM30+ root Pot A1	47	5675	10	15	2656	-17755	2977	2	58	76
AIM30+ root Pot A2	66	6045	45	16	3559	-19270	3565	3	64	133
AIM30+ root Pot B1	27	3452	14	14	1097	-18280	1190	0	25	38
AIM30+ root Pot B2	31	3427	45	16	1326	-18740	1565	1	30	49
AIM30+ root Pot C1	19	3065	6	15	1183	-17335	749	-1	16	45
AIM30+ root Pot C2	17	2813	6	14	1131	-15190	766	-1	15	43
AIM30+ root Pot D1	18	2611	4	14	648	-16965	589	-1	15	48
AIM30+ root Pot D2	8	1500	2	11	343	-8800	267	-2	16	28
AIM30+ root Pot E1	11	894	33	10	345	-4312	197	-1	9	18
AIM30+ root Pot E2	14	1725	13	12	513	-10065	365	-1	9	27
Average	26	3121	18	14	1280	-14671	1223	0	26	51

Stdev	17	1587	16	2	995	4857	1105	1	19	31
Group B	**Ba (mg/kg)**	**Ca (mg/kg)**	**Cr (mg/kg)**	**Cu (mg/kg)**	**Fe (mg/kg)**	**K (mg/kg)**	**Mg (mg/kg)**	**Ni (mg/kg)**	**Pb (mg/kg)**	**Zn (mg/kg)**
BSF60 root Pot A1	36	7705	10	21	1569	70200	1837	5	15	77
BSF60 root Pot A2	48	9475	11	28	2129	70300	2292	6	24	83
BSF60 root Pot A3	36	7525	8	22	1447	69550	1864	5	20	83
BSF60 root Pot A4	46	9245	7	25	1820	73800	2326	5	18	78
BSF60 root Pot B1	41	6000	10	23	1677	67100	1829	6	28	119
BSF60 root Pot B2	55	8755	10	23	2250	71600	2711	6	22	90
BSF60 root Pot B3	56	8865	15	23	2326	70650	2793	5	26	83
BSF60 root Pot B4	92	10275	13	26	3309	66850	3291	6	42	117
BSF60 root Pot C1	71	8530	15	33	3272	67550	2848	6	38	144
BSF60 root Pot C2	66	8065	10	32	3004	62500	2671	6	31	107
BSF60 root Pot C3	63	8140	10	28	2947	63200	2638	6	33	114
BSF60 root Pot C4	40	5365	9	28	1678	64800	1790	5	28	104
BSF60 root Pot D1	46	9210	23	23	1997	80200	2894	6	15	73
BSF60 root Pot D2	46	8850	11	23	2001	79150	2732	5	16	76
BSF60 root Pot D3	42	8185	12	22	1717	76200	2585	5	15	79
BSF60 root Pot D4	51	9190	10	24	2111	82550	2939	5	19	92
BSF60 root Pot E1	63	9655	48	27	3086	80950	2633	6	26	115
BSF60 root Pot E2	55	8100	13	29	2764	83400	2238	5	30	119
BSF60 root Pot E3	86	11315	59	30	4433	84950	3204	7	42	137
BSF60 root Pot E4	51	9120	8	28	2330	89700	2575	5	19	85
Average	54	8579	16	26	2393	73760	2534	6	25	99
Stdev	15	1298	13	3	740	7693	434	1	8	21
BSF60+ root Pot A1	94	19520	13	66	3767	94000	4515	10	137	216
BSF60+ root Pot A2	61	15420	8	55	2022	85350	3388	6	98	173
BSF60+ root Pot A3	71	16845	13	55	2683	87350	3822	8	132	182
BSF60+ root Pot A4	96	18600	24	52	3895	87150	4376	7	120	187
BSF60+ root Pot B1	43	10360	12	29	1254	89950	3099	5	33	119
BSF60+ root Pot B2	49	10470	11	33	1669	89750	3181	6	33	108

BSF60+ root Pot B3	40	8930	8	32	1320	81900	2712	5	41	98
BSF60+ root Pot B4	35	8785	9	36	1123	86800	2570	4	36	105
BSF60+ root Pot C1	83	10570	22	31	3608	100400	3074	9	32	114
BSF60+ root Pot C2	79	10130	19	31	3402	104450	2962	8	33	120
BSF60+ root Pot C3	73	10405	11	30	2988	102600	2959	8	41	115
BSF60+ root Pot C4	92	9035	41	31	4704	97150	2930	9	55	146
BSF60+ root Pot D1	45	12635	9	138	1432	108300	2765	7	63	205
BSF60+ root Pot D2	59	14265	18	137	2096	108800	3178	7	36	197
BSF60+ root Pot D3	58	14685	14	135	2002	110650	3203	7	87	205
BSF60+ root Pot D4	63	14660	30	119	2283	118250	3301	7	93	213
BSF60+ root Pot E1	114	14285	24	114	5845	102350	3875	16	279	424
BSF60+ root Pot E2	147	15530	34	110	7795	105650	4340	17	267	583
BSF60+ root Pot E3	100	13830	21	112	4929	101100	3706	15	244	417
BSF60+ root Pot E4	157	15475	40	110	8420	102950	4391	18	313	440
Average	78	13222	19	73	3362	98245	3417	9	109	218
Stdev	33	3162	10	42	2042	9739	595	4	91	133
BIM60 root Pot A1	31	6775	9	31	1411	64000	3287	6	25	93
BIM60 root Pot A2	28	6045	11	23	1229	60500	3297	6	23	95
BIM60 root Pot A3	28	6200	8	20	1247	58850	3191	5	23	84
BIM60 root Pot A4	29	5315	6	16	1616	17970	1945	4	29	84
BIM60 root Pot B1	32	6040	14	17	1767	10980	2605	3	27	70
BIM60 root Pot B3	35	6785	50	18	2028	11045	2873	4	29	67
BIM60 root Pot C1	39	6265	5	20	1887	7295	2585	3	23	61
BIM60 root Pot C2	60	7690	6	21	2656	9040	3738	5	30	105
BIM60 root Pot C3	57	7580	13	21	3106	8795	3704	4	30	90
BIM60 root Pot D1	31	6285	18	24	1596	4415	1492	3	27	49
BIM60 root Pot D2	33	6385	20	26	1871	4260	1557	3	23	59
BIM60 root Pot E1	29	8060	34	17	1389	7190	2500	2	17	68
BIM60 root Pot E2	37	9635	2	20	2141	8685	3055	3	19	99
BIM60 root Pot E3	36	9025	6	19	2456	8115	3458	4	17	73
Average	36	7006	14	21	1885	20081	2806	4	24	78

Stdev	10	1190	13	4	533	21683	707	1	4	16
BIM60+ root Pot A1	53	6645	65	51	4242	11560	2663	5	96	204
BIM60+ root Pot A2	60	7445	25	69	3509	12460	3079	7	112	234
BIM60+ root Pot B1	42	6960	47	41	2627	21455	2509	10	93	315
BIM60+ root Pot B2	34	6095	29	37	2809	21090	2439	8	75	245
BIM60+ root Pot C1	56	9755	39	71	3735	12385	2763	15	118	374
BIM60+ root Pot C2	62	10065	23	76	4317	12465	2848	16	133	379
BIM60+ root Pot D1	69	5630	236	35	12325	10545	2040	58	79	243
BIM60+ root Pot D2	68	7440	81	42	12150	11410	2754		67	218
BIM60+ root Pot E1	27	5255	15	20	2421	8120	1964	3	25	130
BIM60+ root Pot E2	48	8535	47	36	3975	11255	2934	7	47	311
Average	52	7383	61	48	5211	13275	2599	14	84	265
Stdev	13	1554	61	18	3568	4179	348	16	31	75
Group B 2nd Harvest	**Ba (mg/kg)**	**Ca (mg/kg)**	**Cr (mg/kg)**	**Cu (mg/kg)**	**Fe (mg/kg)**	**K (mg/kg)**	**Mg (mg/kg)**	**Ni (mg/kg)**	**Pb (mg/kg)**	**Zn (mg/kg)**
ASF60 root Pot D1	66	5240	29	20	4014	8335	1994	39	41	115
ASF60 root Pot E1	68	9210	14	20	4133	10270	2182	51	39	166
ASF60 root Pot F1	53	8760	12	36	2883	13980	1942	22	34	167
Average	62	7737	19	26	3677	10862	2039	37	38	149
Stdev	6	1775	8	8	564	2342	103	12	3	24
ASF60+ root Pot A1	77	18870	23	82	3730	35055	4026	11	122	276
ASF60+ root Pot B1	57	12105	25	56	2756	50200	3495	8	137	211
ASF60+ root Pot C1	84	11575	54	80	4684	31950	2738	11	133	279
ASF60+ root Pot D1	45	7265	6	36	1903	54450	1857	4	51	146
ASF60+ root Pot E1	181	20910		207	10115	70650	5485	23	154	
Average	89	14145	27	92	4638	48461	3520	11	120	228
Stdev	48	5024	17	60	2893	14026	1224	6	36	55
AIM60+ root Pot A1	12	3603	5	55	930	1343	720	4	259	187
AIM60+ root Pot B1	22	2168	4	20	1384	2869	680	2	70	57
AIM60+ root Pot D1	36	2897	33	20	2220	3332	1058	4	72	86
AIM60+ root Pot E1	23	2285		13	1800	2112	1137	2	57	38

Average	23	2738	14	27	1584	2414	899	3	114	92
Stdev	8	571	13	16	479	756	201	1	84	58

Appendix D: Soil available metal concentration for Group B

	Ba (mg/kg)	**Ca (mg/kg)**	**Cr (mg/kg)**	**Cu (mg/kg)**	**Fe (mg/kg)**	**K (mg/kg)**	**Mg (mg/kg)**	**Ni (mg/kg)**	**Pb (mg/kg)**	**Zn (mg/kg)**
C1	25	1993	0	8	130	116	254	1	207	58
C2	25	1996	0	8	127	141	251	1	206	57
C3	27	2017	0	8	123	190	257	1	211	57
C4	26	2030	0	8	127	178	253	1	201	57
C5	25	2006	1	8	145	107	258	1	241	61
Average	25	2008	0	8	130	146	255	1	213	58
Stdev	1	14	0	0	8	33	2	0	14	1
	Ba (mg/kg)	**Ca (mg/kg)**	**Cr (mg/kg)**	**Cu (mg/kg)**	**Fe (mg/kg)**	**K (mg/kg)**	**Mg (mg/kg)**	**Ni (mg/kg)**	**Pb (mg/kg)**	**Zn (mg/kg)**
BSF60 A1	7	2232	0	10	187	108	251	1	246	61
BSF60 B1	9	2126	0	10	184	100	232	1	224	57
BSF60 C1	10	2281	0	10	177	110	249	1	230	58
BSF60 D1	9	2682	1	12	181	128	277	1	289	67
BSF60 E1	6	2160	0	9	172	93	244	1	222	53
Average	8	2296	0	10	180	108	250	1	242	59
Stdev	1	200	0	1	5	12	15	0	25	5
BSF60+ A1	6	2168	0	10	162	91	217	1	215	47
BSF60+ B1	7	2029	1	16	238	86	223	2	225	70
BSF60+ C1	8	2017	1	15	207	80	224	2	232	67
BSF60+ D1	6	2189	1	18	204	89	240	1	242	78
BSF60+ E1	6	2121	0	14	175	92	224	1	211	58
Average	6	2105	1	15	197	88	226	1	225	64
Stdev	1	70	0	3	27	4	8	0	11	11
BIM60 A1	13	2249	0	9	173	92	245	1	230	58
BIM60 B1	6	2167	0	9	180	107	250	1	228	46
BIM60 C1	7	2073	0	10	223	109	236	1	225	42
BIM60 D1	8	2163	0	11	232	117	246	1	229	43
BIM60	6	2119	0	10	284	142	240	1	215	40

E1										
Average	8	2154	0	10	218	113	243	1	225	46
Stdev	3	58	0	1	40	16	5	0	5	6
BIM60+ A1	8	2056	0	9	181	115	222	1	221	46
BIM60+ B1	13	2331	0	10	175	104	239	1	225	57
BIM60+ C1	15	2197	0	15	247	105	236	1	230	44
BIM60+ D1	10	2217	0	9	173	99	237	1	237	48
BIM60+ E1	16	2306	0	13	353	131	261	1	226	46
Average	12	2221	0	11	226	111	239	1	228	48
Stdev	3	97	0	3	69	11	12	0	5	5

Appendix E: Statistical analysis for the all metal concentration of the plant roots

Tests of Between-Subjects Effects

Dependent Variable: REGR factor score 1 for analysis 1

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	10.856[a]	7	1.551	4.348	.002
Intercept	.957	1	.957	2.683	.113
t30vs60days	3.368	1	3.368	9.443	.005
treatment2	6.062	3	2.021	5.665	.004
t30vs60days * treatment2	.978	3	.326	.914	.447
Error	9.987	28	.357		
Total	21.365	36			
Corrected Total	20.842	35			

a. R Squared = .521 (Adjusted R Squared = .401)

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