PHYTOREMEDIATION OF CONTAMINATED SOIL USING NO-EDIBLE PLANTS

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Abstract

Waste disposal in the environment has become a menace to various communities and their inhabitants especially in developing countries. Heavy metals being widespread and persistent pollutants have the tendency to concentrate in the environment and enter the human body. In this research, the remediation was monitored for 4 weeks during which the plants were grown in soils contaminated with Cd and Pb (heavy metals) at 0.1M, 0.05M and 0.025M concentrations of the metals. They were analyzed biweekly to check the ability of these plants to effect remediation and the rate at which the remediation was done. The digested plant and soil samples were analysed using Atomic Absorption Spectrophotometer. The results showed that the remediation abilities of the plants on the Pb contaminated soils were in this order, Amaranthus spinosus> Cynodon dactylon; and their remediation abilities on Cd contaminated soil were Cynodon dactylon> Amaranthus spinosus. It can then be stated that Cynodan dactylon and Amaranthus spinosus were good at remediating Pb and Cd contaminated soils; but Amaranthus spinosus was better for the remediation of Pb contaminated processes. It is therefore recommended that Amaranthus spinosus and Cynodon dactylon be used to remediate Pb and Cd contaminated soils since they are capable, can create green areas in the environment and the process is cost effective especially for third world nations.

1.0 INTRODUCTION

Waste disposal in the environment has become a menace to various environments and their surrounding inhabitants especially in developing nations. This threat could be seen in the form of contamination of the soil where large amount of toxic wastes are dumped. The contaminated soil exposes everyone around to health dangers like cancer; thus poor quality of life. These disposed wastes, usually solids and liquids, may contain both biodegradable and non-biodegradable materials. The non-biodegradable materials contaminate the environment by releasing their constituent elements which may be toxic (like heavy metals) to human and animals.

1.1 Heavy metals

Heavy metals are metals with atomic masses between 54.63 and 200.59 and densities greater than 5g/cm^3 (Dias, 2002). They are natural components of the earth's crust which are released into the environment due to the natural and human activities. They have toxic effects especially when they are in high concentrations. Examples of these metals includes arsenic (As), cadmium (Cd), chromium (Cr), cobalt (Co), copper (Cu), Mercury (Hg), nickel (Ni), manganese (Mn), lead(Pb), selenium(Se), zinc(Zn), etc. due to the numerous uses of heavy metals in several applications, they are widely distributed in the soil and waste water.

Trace elements especially the heavy metals remain in the soil nearly indefinitely. These heavy metals are widespread and persistent pollutants, thus they have the tendency to concentrate in the human body. Human exposure to metals and their compounds in the environment are through food, drinks, water and via skin contact. However, over a period of time, adverse toxic effects may occur as a result of long-term low level exposure (Ewers, 1991). At high concentrations, microbial population can either be completely inhibited by inhibiting their various metabolic activities; or organisms can develop resistance to the elevated levels of these metals (Shukla et al., 2010). For this reason, a suitable measure to eliminate or reduce these heavy metals from the environment should be adopted. These metals cannot be degraded biologically nor chemically; but can be transformed into other forms. Thus the environmental risk is dependent on its toxicity, oxidation state and level of concentration (Brady and Weil, 2008). Environmental pollution by heavy metals can inhibit the actions of micro organisms by blocking essential functional groups, displace essential metal ions or modify the active conformations of biological molecules (Doelman et al., 1994, Gadd and Grifftiths, 1978). These micro organisms help in plant growth, thus keeping the ecosystem balanced.

1.2 Economic importance of Heavy Metals

.Lead: Lead in the environment arises from both natural and anthropogenic sources. Its exposure can occur through drinking water, food, air, soil and dust from old paint which contains lead. In humans, exposure to lead can result in a wide range of biological effects depending on the level and duration of exposure. Various effects can be seen over a broad range of doses, with the developing foetus and infant being more sensitive (causing premature deliveries and spontaneous abortions in humans, as well as chromosome aberration (Csuros and Csuros, 2002) than adults. High levels of exposure may result to toxic biochemical effects on humans which in turn cause problems in the synthesis of haemoglobin, kidneys (causing tubular dysfunction or nephrotoxicity (Csuros and Csuros, 2002)), gastrointestinal tract, joints and reproductive system, and acute or chronic damage to the nervous system. Lead is readily absorbed through intestinal tract and deposited in the central nervous system. The presence of lead in the body is indicated by blood lead levels, expressed as micrograms of lead per deciliter of blood (g/di). Blood lead levels of 10ug/dl and higher may contributed to decreased cognition, nervous system damage and stunted growth.

It can also reduce intelligence, delay motor development, impair memory and cause problems with hearing and balancing in children. In adults, in increases blood pressure (Microsoft Encarta, 2009).

Cadmium: Cadmium is produced as an inevitable by-product of zinc refining. Since the metal may occur naturally within the raw ore, the most significant use of cadmium is in nickel/cadmium batteries; as rechargeable or secondary power source exhibiting high output, long life, low maintenance and high tolerance to physical and electrical stress (Turer et al., 2001). Cadmium coatings provide good corrosion resistance, particularly in high stress environment such as marine and aerospace applications where high safety and reliability is required. Other uses of cadmium are as pigments, stabilizers for polyvinyl chloride and in alloys and electronic compounds.

Cadmium derives its toxicological properties from its chemical similarity with zinc which is an essential micronutrient for plants, animals and human. The metal (Cd) is bio persistent and once absorbed by an organisms, remains resident for many years, although it may be eventually excreted. Uptake of cadmium by plants is greatest from soils and varies with soil properties especially those that control adsorption and also with the plant species and the source of cadmium. The average daily intake for humans is estimated as 0.15ug from air and 1ug from water. Smoking a packet of cigarette can lead to the inhalation of around 2-4ug of cadmium (WHO, 2005). Oral absorption is very low. The effects of exposure to cadmium include vomiting, increased salivation, abdominal pain, and diarrhea. Acute inhalation is characterized by coughing and tightness in the chest. Chronic exposure produces a variety of effects on kidneys, lungs, heart, hones, and gonads. Cadmium fumes can damages the olfactory organs. It has also been shown experimentally that Cd poisoning have cardiovascular effects like increased blood pressure, anaemia, cardiomyopathy, effects on the reproductive system in both sexes and skeletal system. No relevance has been found with Cd in biological cells. It is extremely toxic when it contaminates food. It can cause inflammation and cancer when inhaled or enteropathy and nutrient and nutrient mal-absorption syndromes when ingested (Frustaci et al, 2000, Microsoft Encarta, 2009).

2.0 Phytoremediation

Phytoremediation involves the use of plants to remove pollutants from the environment. It can be described as the ability of some plants to concentrate heavy metals and nuclides in their biomass thus, cleaning up soil and water contaminated with inorganics and/or organics (Prasad, 2011). It is a promising, relatively new technology for cleaning heavy metal contaminated sites (Ajaz et al, 2010). This process can help reduce the amount of toxic metals in the soil and those leaching into ground water. Plants use solar energy (through photosynthesis) to extract chemicals from the soil ad deposit them in the above ground part of their bodies, or convert them to a less toxic form. These plants can then be harvested and treated, removing the pollutants (Anon, 2006). It is well suited for use at very large field sites where other methods remediation are not cost effective or practicable and at sites with low concentration of contaminants where treatment is required over long periods of time (Prasad, 2011). Phytoremediation is slow compared to microbial method of bioremediation (Philip et al, 2002). Soil clean up can be accomplished to certain depths below ground level, within the reach of plant roots. Sites under remediation need to be maintained (water, and monitored). Again, a living plant may continue to absorb contaminants until it is harvested (Shukla et al, 2010). An ideal phytoremediator (plant for phytoremediation) would have: high tolerance to the pollutant, the ability to either degrade or concentrate the contaminant at high levels in the biomass, extensive root system, the capacity to absorb large amounts of water from the soil, fast growth rates and high level of biomass (Anon, 2006).

2.1 Mechanisms in Phytoremediation

These mechanisms are in the sequence of how contaminants come in contact with the plant system, rhizosphere and then the transportation process. They are interrelated and dependent on plant physiological processes driven by solar energy, rhizospheric processes and other available precursors (Prasad, 2011). These mechanisms include:

a. **Phytosequestration** is the process of reducing the mobility of the contaminants thereby preventing their migration into the soil, water and air. Phytosequestration can be achieved by phytochemical complexation in the root zone, contaminants being sequestered into the vacuoles of the root cell and transport protein inhibition on the root membrane.

b. **Phytodegradation** (**Phytotransformation**) refers to the uptake of contaminants with subsequent breakdown, mineralization or metabolization by the plant itself through various internal enzymatic reactions and metabolic processes (Prasad, 2011). The various enzymes which are responsible for these activities and functions are produced by the plants.

c. **Phytovolatilization** is the volatilization of contaminants from the plant either from the leaf stomata or from plant stems (Anon, 2009). In some cases, a breakdown product derived from the rhizodegradation and/or phytodegradation of the parent contaminant along the transpiration pathway may be the phytovolatilized constituent (Prasad, 2011). An example is the tobacco plants which have been modified to be able to take up the highly toxic elemental mercury into the atmosphere (Prasad, 2011).

d. **Phytostabiization** refers to the holding of contaminated soils and sediments in a place by vegetation; and to immobilize toxic contaminants in soils (Prasad, 2011). In other words, phytostabilization is the use of plant roots to reduce the mobility or bioavailability of pollutants in the environment (Pulford and Watson, 2003). Contaminants are absorbed and accumulated by roots, adsorbed onto the roots, or precipitated in the rhizosphere. This reduces or even prevents the mobility of the contaminants, preventing migration into the groundwater or air, and reduces the bioavailability of the contaminant thus preventing the spread through the food chain. This process is usually applied for metal contaminated waste sites where it is important to hold the contaminants in a place since metals do not degrade.

e. **Phytoextraction** refers to the ability of plants to take up contaminants into the roots and translocate them to the shoots or leaves. In other words, Phytoextration can be described as the use of plant roots to absorb, concentrate and precipitate toxic metals from soils into the harvestable portions of roots and surface biomass (shoots, leaves etc). For contaminants to be extracted by plants, the constituent must be dissolved in the soil water and come into contact with the plant roots through the transpiration stream (Prasad, 2011). The plant may store the chemicals taken in its biomass through lignification (covalent bonding of chemical to the lignin of the plant); or sequester it into the cell vacuoles of short tissues. Generally, Cd, As, Ni, Cu, Se and Zn are readily bioavailable for plant to take up shoot whereas Cr, Pb and U are not easily bioavailable.

f. **Rhizofiltration** can be defined as the use of plant roots to absorb, concentrate and/or precipitate hazardous compounds, particularly heavy metals or radio-nuclides from aqueous solutions (Prasad, 2011). Unlike phytoextraction, metals are primarily retained in the root system, and not moved into the plant shoots. Roots of plants can sorb large amounts of Pb and Cr from soil water or water flowing through the root zone of densely growing vegetation. These plants are harvested and replaced as they grow older. Generally, all these applications use phytohydraulic mechanisms since it brings the contaminants into the root zone. The depth of plant root penetration is a very important factor for successful phytoremediation.

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3.1 *Amaranthus spinosus*

Fig 1: *Amaranthus spinosus* (Source: Wikipedia, 2011)

Amaranthus spinosus, thorny amaranth, spiny amaranth or prickly amaranth is native to the tropical Americas, but it is present on most continents as an introduced species and sometimes a noxious weed especially of rice cultivation in Asia. It had many other uses which also include food and as herbs that stop bleeding. They are grown for their brilliant foliage, curious flowers and adaptability to hot and dry weather conditions. They are popular bedding plants, with large and attractively coloured leaves and minute flowers borne in drooping tassel-like spikes (Burnie *et al.*, 2004).

3.2 *Cynodon dactylon*

Fig 2: *Cynodon dactylon* (Source: Wikipedia, 2011)

Cynodon dactylon is known by many names which include Bermuda grass, Dog's Tooth grass, Bahama grass, etc. It is a grass, native to north and east Africa, Asia and Australia. Although it is not native to Bermuda, it is an abundant invasive species there. It is a perennial grass, forming thick mats by means of stolons and rhizomes (Gibbs Russell *et al.,* 1991). The blades are grey-green in colour and are short, usually 2–15 centimetres long with rough edges. The erect stems can grow 1–30cm tall. The seed heads are produced in a cluster of 2–6 spikes together at the top of the stem, each spike 2–5cm long. It has a deep root system. In drought situations with penetrable soil, the root system can grow to over 2m deep, though most of the root mass is less than 60cm under the surface (Wikipedia, 2011). The grass creeps along the ground and roots wherever a node touches the ground, forming a dense mat. *Cynodon dactylon* is propagated through seeds, runners and rhizomes. In winter, the grass becomes dormant and turns brown. Growth is promoted by full sun. It is fast-growing and tough, making it popular and useful for sports fields, as when damaged it will recover quickly. *Cynodon dactylon* is not overly vulnerable to diseases; rather it suffers from exposure to cold weather (Burnie *et al*., 2004). It is a highly desirable lawn grass in warm climates. Its heat and drought tolerance enable it to survive where few other grasses do. It has a relatively coarse-bladed form with numerous cultivars selected for different turf requirements. It is also highly aggressive, crowding out most other grasses and invading other habitats. It has become a hard-to-eradicate weed in some areas. This weedy nature leads some gardeners to give it the name of "devil grass". Bermuda grass has been cultivated on saline soils in California's Central Valley which are too salt-damaged to support agricultural crops; it was successfully irrigated with saline water and used to graze cattle. *Cynodon dactylon* plays an important role in conservation, because it prevents soil erosion.

4.0 RESEARCH METHODOLOGY

Soil samples were collected from the Enugu State Waste Management Authority (ESWAMA) dump site opposite St. Patrick's College, Emene, Enugu. The soil was weighed to a mass of about 5kg into different containers. These soil samples were then contaminated by adding 0.1M, 0.05M and 0.025M of each of the metals and the plants were grown in them. A control was also prepared in which there was no additional metal and the same plants were also grown in them. They were then watered and monitored as they grew for 4 weeks. A set of these plants were harvested from each concentration of metal contaminated soil after two and four weeks of their growth, and dried at 40°C.

The harvested plants and the soil samples were then digested and analyzed using AAS to determine the amount of heavy metals in the plants before growing them on the contaminated soil; the amount of heavy metals which the plants were able to take into their biomass within the periods (2weeks and 4weeks); and the amount of heavy metals in the soil before contamination, which served as control. Some of the plants could not live up to 4 weeks in the metal contaminated soils (as was seen with the plants grown on the Cd contaminated soils). The rate of remediation was determined by plotting graphs of concentration against time.

5.0 RESULTS AND DISCUSSION

It was observed that after 2weeks of plants growth, the *Amaranthus spinosus* showed retardation in growth especially on the soils contaminated with Cd. The *Cynodon dactylon* plants showed more resistance to the soils' contamination since they all grew till the end of the investigation period.

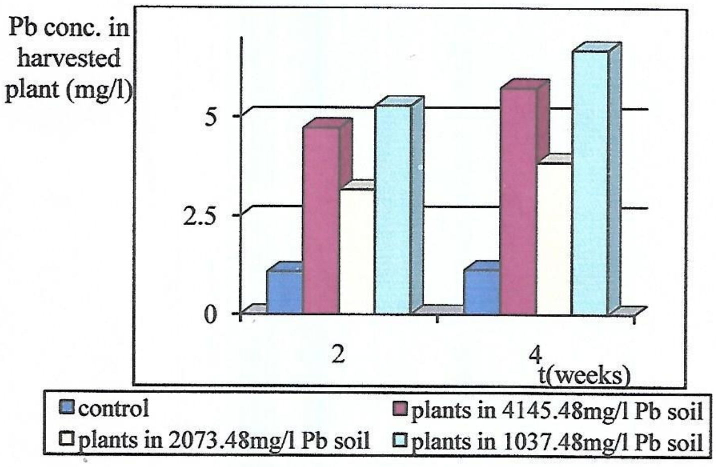

Fig 3: Metal accumulated by *Cynodon dactylon* plants grown on Pb contaminated soil

Cynodon dactylon translocated Pb continuously till the end of 4weeks but the rate reduced with time. This situation was an indication that if *Cynodon dactylon* is allowed to grow on the soil for a longer time, it will get to a point when the plants (*Cynodon dactylon*) will be saturated with Pb and as such may result to death of the plants. This implies that, if *Cynodon dactylon* should be used for phytoremediation of Pb contaminated soil, they will be continually replanted as they die off until the Pb contamination is cleared to the barest minimum. Of course, the dead *Cynodon dactylon* plants could be removed from the site and recycled in order to reclaim the Pb. It was also noticed that the highest amount of Pb (6.69mg/l) translocated was found in plants grown on the soil contaminated with 0.025M solution of Pb which was the soil with the lowest concentration of Pb. In other words, the remediation was more effective on the soil with a lower concentration of Pb.

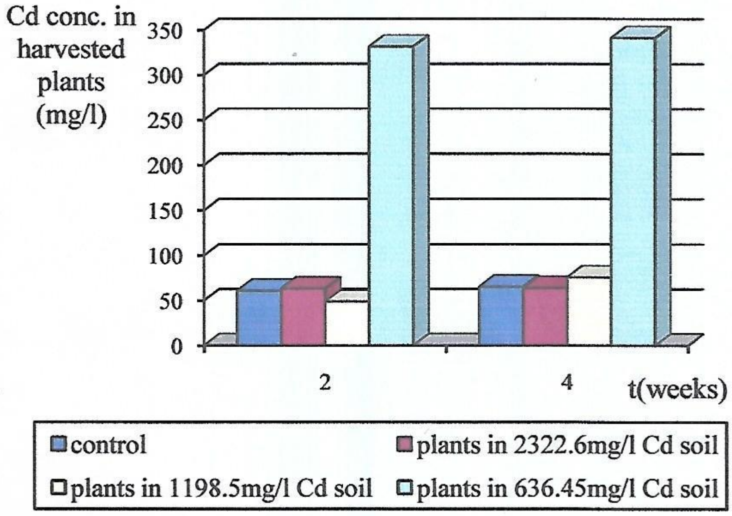

Fig 4: Metal accumulated by *Cynodon dactylon* plants grown on Cd contaminated soil

This research has shown that *Cynodon dactylon* was even a better plant for the remediation of Cd contaminated soil. When the plants were growing on the Cd contaminated soil, they grew healthily within the first 2weeks and then started dying gradually. Within the first 2weeks, *Cynodon dactylon* translocated some amount of the Cd into their system with the highest amount found in the plants grown on the soil contaminated with 0.025M Cd which has the value of 341.6mg/l. This was more than half of the total Cd present in the soil. This shows that at lower concentrations, *Cynodon dactylon* can remediate Cd contaminated soils better and at a very fast rate too. But when the soil was highly polluted with Cd, the plants were still able to grow and translocate the Cd but at a slower rate. Therefore *Cynodon dactylon* is a good plant for the remediation of Cd in the soil, but faster when the contamination level is low.

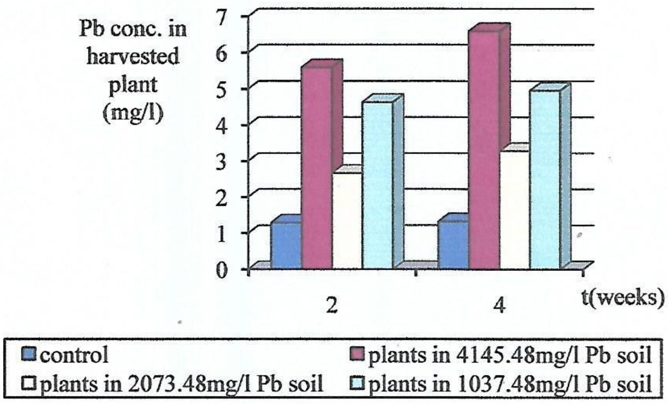

Fig 5: Metal accumulated by *Amaranthus spinosus* plants grown on Pb contaminated soil

Amaranthus spinosus was found to be even more effective in the remediation of Pb contaminated soils as could be seen from the analysis which showed that it was able to remove a maximum of 6.599mg/l of Pb from the soil with 0.1M of Pb within the period. This was almost the same value obtained with *Cynodon* dactylon, but from the soil contaminated with 0.025M of Pb. This indicated that *Amaranthus spinosus* was more effective since it removed more Pb from the soil with a higher concentration of Pb contamination.

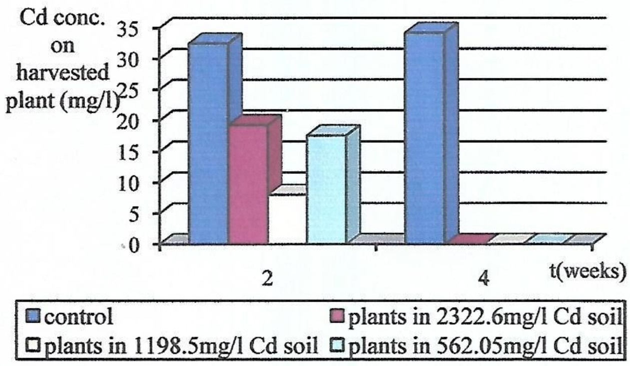

Fig 6: Metal accumulated by *Amaranthus spinosus* plants grown on Cd contaminated soil

In the soil contaminated with Cd, a different situation occurred with *Amaranthus spinosus* where they survived for just 2weeks. Although the plants did not live long on the soil with Cd contamination, they could still be used for the remediation of Cd contaminated soil since they were able to translocate a reasonable amount of Cd into their system. Remediation could be achieved with extra care and monitoring using *Amaranthus spinosus* since there will be continuous planting, harvesting and replanting of the plant as they grow and die until the contamination level is reduced to the barest minimum.

6.0 CONCLUSION AND RECOMMENDATION

It was observed that *Amaranthus spinosus* and *Cynodon dactylon* can be used to remediate soils contaminated with Cd and Pb based on the research done on them. It is therefore recommended that *Amaranthus spinosus* and *Cynodon dactylon* be used to remediate Pb and Cd contaminated soils since it is achievable. In addition to the fact that Phytoremediation cleans up the environment, it also creates green areas, aesthetic advantages in the environment, promotes a balanced ecosystem and cost effective especially for the third world nations.

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