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Phytoremediation of lead by Chinese tallow (Sapium sebiferum) plant

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PHYTOREMEDIATION OF LEAD BY CHINESE TALLOW (*SAPIUM SEBIFERUM*) PLANT

A THESIS

Presented to the

Honors College at Southern University
Baton, Rouge, Louisiana

In Partial Fulfillment of the Requirements for the
Honors College Degree

By

Oluwaseun A. Odebunmi

December 2001

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Baton Rouge, Louisiana

CERTIFICATE OF APPROVAL

HONORS THESIS

This is to certify that the Honors Thesis of Oluwaseun Odebunmi has been approved by the examining committee for the thesis requirement for the Honors College degree in Biology

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ABSTRACT

Over the past several decades, health and environmental risks of pollution have become apparent. As a result, environmental regulations have been created to remediate areas where environmental contamination is tremendous, therefore, a low-cost alternative to the already existing technology is needed. Using plants to eliminate hazardous organic compounds from contaminated soils has been proposed as an efficient means of remediation. Phytoremediation is the direct use of living green plants to remediate soil, sludge, sediments and ground water contaminated with toxic compounds. The four processes of phytoremediation are rhizofiltration, phytoextraction, phytostabilization and phytodegradation. As they grow and develop, plants will use one of these processes to take in dissolved organic contaminants. Phytoremediation has several advantages over traditional procedures such as on-site management and excavation. It is an inexpensive, non-intrusive process that requires little input past the initial seeding and establishment and may be more effective than unvegetated bioremediation. Some plants have a natural ability to absorb and hyperaccumulate trace elements in their tissues. This ability is being harnessed to remove toxic heavy metals and trace elements from contaminated soils and water. The purpose of this research is to determine which process of phytoremediation the Chinese Tallow plant uses to uptake lead by exposing the plant to different concentrations of the metal, and analyzing the parts of the plant (roots, stems, leaves, soil) using atomic absorption. The results of this study reveal that the Chinese Tallow plant uses the process of rhizofiltration to remediate soils contaminated with lead when exposed to high concentrations of the metal.

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CHAPTER I
BACKGROUND OF THE STUDY

INTRODUCTION

Bioremediation, the systemic use of microorganisms for environmental contaminant treatment, is a developing technology that is currently used (though on a relatively small scale) to clean up some of the halogenated and nonhalogenated volatile and semivolatile organic compounds and petroleum hydrocarbons. The contaminants are degraded by naturally occurring microbes that are stimulated by introducing nutrients, oxygen, and other amendments to the soil or water (EPA, 1998). Considerable research is being done on this technology, and the potential market for well-developed techniques is large (Cunningham, 1993). The bioremediation market in North America and Europe is projected to be at least $1 billion a year by the end of the century, while the use of phytoremediation against toxic metal contamination is expected to be worth around $400 million a year as companies and government agencies (including Exxon Corp. and Dupont) move away from present methods (Miller, 2001).

Another potential biobased low-cost alternative technology is phytoremediation. Phytoremediation is the direct use of living green plants to remediate soil, sludge, sediments and ground water contaminated with toxic compounds from industrial or agricultural sites. Plants will utilize contaminated water and soil for growth and development, and in the process they will take in dissolved organic contaminants. Complex organic compounds will be degraded both in plants and through enhanced microbial activity. Phytoremediation can be used to clean up metals, pesticides, solvents, explosives, crude oil, polyaromatic hydrocarbons, and landfill leachates. Besides being cheap, phytoremediation has other advantages. It does not involve heavy machinery that produces air pollution, and it can reduce the amount of contaminated material dumped in landfills (Cunningham et al., 1998). In addition, topsoil remains in place for reuse, metals absorbed in the plants may be able to be recycled safely, and residents near a toxic site see plants or flowers growing instead of workers using noisy excavating equipment and blowing around contaminated dust. At a former manufacturing site in Detroit, for example,. Daimler Chrysler engineers used sunflowers and mustard plants to reduce 5,750 cubic yards of plant material, which was then landfilled (EPA, 1998).

However, phytoremediation does have its limitations. One of them is slow pace. Depending on the contaminant, it can take several growing seasons to clean a site- much longer than the conventional methods. It is also only effective at depths that plant roots can reach, making it useless against deep-lying contamination unless the contaminated soils are excavated. In addition, it is possible that animals may ingest pollutants by eating the leaves of plants in some projects (Bower, 2000).

In the USA, remediation is usually required when total soil lead exceeds 300 to 500 mg kg [sup-1] in residential soils, or 2000 mg kg [sup-1] in soils used for industrial purposes (EPA, 1998). Current remediation methods for lead-contaminated soils are often expensive and disruptive to the site. In-situ remediation techniques usually involve physical stabilization (e.g. mixing soils with cement or other solidifying agent or installation of soil or asphalt caps) and/or chemical amendment with lime or phosphate fertilizer (Cooper, 1999). None of these techniques actually removes lead from the soil, which usually requires soil washing with strong acids that may have drastic and undesirable effects on soil properties.

The phytoremediation of lead-contaminated soils is particularly challenging due to the low mobility and generally low bioavailability of this widespread contaminant in soils (Kumar et al., 1995). In addition, few species worldwide have been found that accumulate high levels of lead (greater or equal to 1000 mg/kg dry wt.) in aboveground tissues (Klassen et al., 2000). Most plants are highly sensitive to heavy metals and cannot endure even low concentrations in soils (Larcher, 1980), but environments with high concentrations of heavy metals can be colonized by plants that are metal resistant (Shaw, 1990). Metal resistance can be achieved through a variety of mechanisms that can be defined as either mechanisms of avoidance or tolerance (Levitt, 1980). Levitt defines avoidance as the ability to prevent excessive metals that are excessively accumulated in some past of the plant. Plants that use mechanisms of avoidance are often referred to as metal excluders, and metal tolerant plants as metal accumulators.

The initial emphasis in phytoremediation has been on a small number of wild plants termed hyperaccumulators that are able to accumulate high concentrations of specific metals in aboveground tissues (Baker et al., 1994). Many of these species are slow growing requirements, making them less suitable for use in phytoremediation.

Statement of the Problem

The most common heavy metals at hazardous waste sites are cadmium, lead, copper, mercury, nickel and zinc. Of these, lead is one of the most significant contaminants (EPA, 2000). The contamination of soil by lead from anthropogenic activities such as mining, use of leaded gasoline, and the manufacture and testing of lead-based explosives is a worldwide environmental concern. Soils polluted with lead pose health threats to humans as well as plants and animals, often necessitating rather extensive and costly site remediation practices. Research is still needed to determine the most successful soil management practices, types, rates, methods of application of chelates, and combinations of plants for successful remediation of lead-contaminated soils. The purpose of this project is to determine if Chinese Tallow can be utilized to phytoremediate lead. Plants such as Chinese Tallow are very proliferative and can grow in any area under many environmental conditions (Farris, 2000). The Chinese Tallow plant will be tested to determine which of the four phytoremediation processes (rhizofiltration, phytoextraction, phytostabilization, and phytodegradation) are occurring, by determining the concentration or amount of lead taken up by different parts of the plant (roots, stems, leaves, etc.) by ICP atomic absorption

Hypothesis

Lead accumulation in the aboveground plant tissues sampled from an abandoned mine site in Utah was studied by Klassen (1998). Mean lead concentrations in young woody stems of river birch, and in the shoots of a common sedge, were 887 and 485 mg/kg, respectively. We hypothesize that the Chinese Tallow plant will utilize the contaminated water and soil for growth and development, and in the process they will take in dissolved organic contaminants using one of the four technologies of phytoremediation This plant will be able to clean up metals, pesticides, solvents, explosives, crude oil, polyaromatic hydrocarbon, and landfill leachates.

CHAPTER II
REVIEW OF LITERATURE

Risks of Pollution

Health and environmental risks of pollution have become increasingly apparent throughout the world over the past several decades. According to the U.S. Environmental Protection Agency, there are more than 200,000 contaminated sites in the United States. Air, water, and soil contaminants include numerous organic and inorganic substances, such as municipal waste and sewage, various gaseous emissions, fertilizers, pesticides, chemicals, heavy metals, and radionucleotides (radioactive substances). Contaminants can cause land and groundwater to be unusable (EPA, 1998). Animals and insects may come in contact with a contaminant, thus introducing a toxic substance into the food chain. Because of increased public awareness and concern, environmental regulations have been created to not only prevent pollution, but also to remediate areas where environmental contamination has occurred. As a result, environmental remediation is a rapidly developing multibillion-dollar industry (EPA, 1998).

Cost of Environmental Cleanup

The economic cost of environmental remediation can be tremendous. Various studies have estimated that cleanup of current hazardous waste sites with conventional technologies would cost from $400 to $700 billion in the United States alone (Salt et al., 1995). Over the next 5 years, remediation of U.S. sites contaminated with heavy metals and organics could cost another $35 billion (Brown, 1995) Remediation of radionucleotides from soil and water at identified U S. Department of Energy and Department of Defense sites could cost over $10 billion using current treatment technologies. Bioremediation techniques have been successfully employed at more than 400 cleanup sites throughout the USA at a cost approximately 80-90 per cent lower than other cleanup technologies (Miller, 2001).

Chinese Tallow

The Chinese tallow plant is both an invasive and ornamental plant. It is found in the coastal region from Houston, Texas to Florida and up to North Carolina. This plant rapidly displaces native plants and trees, radically altering marsh, forest, and coastal prairie ecosystems. In the coastal prairie (central Louisiana to southern Texas) tallows threaten restoration. Less than 1 percent of the original coastal prairie remains (Farris, 2000).

On the other hand, Chinese tallow is a popular ornamental because of its attractive foliage, which becomes yellow to red in the fall and it is resistant to pests. Its leaves are simple, alternate, deciduous and broad. The leaf blades are pinnately-veined and broadly ovate, with broadly rounded bases. The inflorescences are very attractive to bees and other insects. Chinese tallow gives a fixed oil which envelopes the seeds. The tallow occurs in hard brittle opaque white masses. The oil is used for lighting and the waste from the nuts is used for fuel and manure (Univ. of Fla., 2001).

Chinese tallow is classified as an hyperaccumulator, a plant that possesses the ability to accumulate high levels of metals in its shoots. Examples of common hyperaccumulators are poplar, mustard and mulberry. The reason some plants should develop a liking for adding large doses of metal to their diet is now thought to be that its presence in their stems and leaves protects them against certain fungal diseases and chewing insects. But how plants do it is still a mystery However, a recent discovery by researchers at the Plant Gene

Expression Center in Albany, California, may have revealed the key in a gene for heavy metal tolerance which was found in a yeast, and dubbed 'html' (Miller, 2001). Many plants produce molecules called peptides that bind metals for storage in cell compartments called vacuoles, where plants either store things they need or dump things they don't. However, metal-loving plants also use organic acids (e.g. citric acid) to bind high levels of metals. The html gene appears to prompt the manufacture of a protein that pumps more bound metals into vacuoles, like a sort of efficiency booster (Miller, 2001). Plants such as Chinese Tallow are very proliferative and can grow in any area under many environmental conditions. The plant may provide an inexpensive alternative method to process and clean contaminated soil.

Sources of Lead

Lead is a bluish-grey metal that occurs naturally in minute amounts within the Earth's crust. It has also been referred to as plumbum, lead metal, and pigment metal (Environment Writer, 2000). Frequent use in many industrial processes is the main reason for lead contamination of the environment. There are a variety of industrial processes that involve the use of lead such as mining, smelting, manufacture of pesticides and fertilizers, dumping of municipal sewage and the burning of fossil fuels that contain a lead additive. Many commercial products and materials also contain lead including paints, ceramic glazes, television glass, ammunition, batteries, medical equipment (i.e., xray shields, fetal monitors), and electrical equipment The uses of lead for roofing and the production of ammunition has increased from previous years On average, recycled lead products only satisfy half of the nation's lead requirements (Meagher, 1998).

Forms of Lead

Ionic lead, lead oxides and hydroxides and lead-metal oxyanion complexes are the general forms of lead that are released into the soil, groundwater and surface waters. The most stable forms of lead are ionic lead and lead-hydroxy complexes. Ionic lead is the most common and reactive form of lead, forming mononuclear and polynuclear oxides and hydroxides (GWRTAC, 1997). The predominant insoluble lead compounds are lead phosphates, lead carbonates (form when the pH is above 6) and lead hydroxides (Raskin, 2000). Lead sulfide is the most stable solid form within the soil matrix and forms under reducing conditions when increased concentrations of sulfide are present. Under anaerobic conditions a volatile organolead (tetramethyl lead) can be formed due to microbial alkylation (GWRTAC, 1997).

Health Effects of Lead

Lead has been listed as a potential carcinogen in the EPA Toxic Release Inventory (TRI) (Environment Writer, 2000). Inhalation and ingestion are the two routes of exposure, and the effects from both are the same. Lead accumulates in the body organs, which may lead to poisoning (plumbism) or even death. The gastrointestinal tract, kidneys, and central nervous system are also affected by the presence of lead. Children exposed to lead are at risk for impaired development, lower IQ, shortened attention span, hyperactivity, and mental deterioration, with children under the age of six being at a more substantial risk. Adults usually experience decreased reaction time, loss of memory, nausea, insomnia, anorexia, and weakness of the joints when exposed to lead (Environment Writer, 2000).

Processes of Phytoremediation

The four main technologies of phytoremediation are: rhizofiltration, phytoextraction, phytostabilization and phytodegradation. Rhizofiltration is the adsorption or precipitation onto plant roots or absorption into the roots of contaminants that are in solution surrounding the root zone. As the roots become saturated with contaminants, they are harvested. For example, sunflowers were used successfully to remove radioactive contaminants from pond water in Chernobyl, Ukraine (Adler, 1996).

Phytoextraction, also called phytoaccumulation, uses plants to absorb contaminants from the soil into the aboveground portions of the plants to reduce the contaminants mobility Hyperaccumulators, certain plants that absorb unusually large amounts of metals in comparison to other plants, are planted at a particular site based on the metals present. These plants are allowed to grow, and harvested to recycle the metals. This procedure may be repeated as necessary to bring soil contamination to levels down to allowable limits.

Phytostabilization is the use of certain plant species to immobilize contaminants in the soil and ground water through absorption and accumulation by roots, adsorption onto roots, or precipitation within the root zone of plants. This process reduces the mobility of the contaminant and prevents migration to the ground water or air, and it reduces bioavailability for entry into the food chain. This technique can be used to reestablish a vegetative cover at sites where natural vegetation is lacking due to high metal concentrations in surface soils or physical disturbances to surficial materials (EPA, 1998).

Phytodegradation, also called phytotransformation, is plant assisted bioremediation in which degradation of contaminants, such as various organic compounds, occurs during a plant's metabolic processes or the breakdown of contaminants external to the plant through the effect of compounds such as enzymes produced by the plants. It is influenced by plant-root and soil microbial activity (rhizodegradation) (EPA, 1998).

Hydraulic Control of Contaminants

Plants can act as hydraulic pumps when their roots reach down toward the water table and establish a dense root mass that takes up large quantities of water. Poplar trees, for example can transpire between 50 and 300 gallons of water per day out of the ground. The water consumption by the plants decreases the tendency of surface contaminants to move towards ground water and into drinking water. The use of plants to rapidly uptake large volumes of water to contain or control the migration of subsurface water is known as hydraulic control There are several applications that use plants for this purpose, such as riparian corridors/buffer strips and vegetative caps (EPA, 1998)

Riparian corridors

The term riparian means located on the bank of a river. Riparian corridors/buffer strips are applications of phytoremediation that also may incorporate aspects of phytodegradation, phytovolatilization, and rhizodegradation to control, intercept, or remediate contamination entering a river or ground-water plume Riparian corridor refers to plants that may be applied along a stream or river bank, while buffer strips may be applied around the perimeter of landfills. Applications of these systems prevent contamination from spreading into surface water and/or ground water (EPA, 1998).

Vegetative Cover

Vegetative cover is a long-term, self-sustaining cap composed of soil and plants growing in and/or over waste in a landfill. This type of cover is an alternative to composite clay or plastic layer caps. Plants control erosion and minimize seepage of water that could otherwise percolate through the landfill and form contaminated leachate. In addition, vegetative caps can be designed not only to control erosion and seepage of water, but to enhance the degradation of underlying materials in the landfill (EPA, 1998).

Recent Phytoremediation Projects

Phytoremediation has been successfully tested in many locations, but full-scale applications are still limited. Private companies such as Exxon Corp and DuPont are testing a variety of plants to see if they can do the dirty work of cleaning up pollutants. In Maryland at a U.S. Army testing facility, hybrid poplar trees were planted in a one acre area over a shallow ground water plume contaminated with organics from several toxic disposal pits (Bower, 2000). The poplar trees act as hydraulic pumps to prevent the spread of contaminants to a nearby marsh. In addition to hydraulic control, researchers have determined that phytovolatilization and rhizofiltration are other mechanisms by which the system is treating the contaminated plume In addition, preliminary results have indicated that the poplar trees are degrading the contaminants in the ground water plume. Table 1lists some sites demonstrating phytoremediation (EPA, 1998).

Previous Phytoremediation Research

Several phytoremediation studies have examined the potential of different plant species to reduce concentrations of organic contaminants. Variability exists among plant species for degradation of various toxic compounds, with perennial forage, grasses and legumes among the most effective (Wiltse, 1998). Recently, efforts have been directed toward finding remediation strategies for lead-contaminated soils that are less expensive and less damaging to soil properties than current approaches. One such method is phytoextraction, in which plant uptake is used to remove lead or other metals from the soil, followed by harvesting the aboveground biomass, which is then either disposed of in a landfill or treated to recover the metals (Cunningham et al., 1995). Many metals of environmental concern are taken up in very small amounts by plants. For lead, plants rarely accumulate more than 100 mg kg [sup-1] (Cooper, 1999). Plants known to naturally accumulate unusually large amounts of lead or other metals are often small and slow growing; hence, the total lead removed in harvested biomass still may be low even if lead concentrations in the plants are very high (Cooper, 1999). The potential of duckweed to accumulate lead was examined, and it was determined to be a poor accumulator of lead (Zayed, 1998). This study aims to determine the effectiveness of the Chinese Tallow plant, a very proliferative hyperaccumulator, in the phytoremediation of lead

Table 1. Examples of Sites Demonstrating Phytoremediation

Location	Application	Contaminants	Medium	Plant(s)
Edgewood, MD	Phytovolatilization Rhizofiltration Hydraulic control	Chlorinated solvents	Ground water	Hybrid poplar
Fort Worth, TX	Phytodegradation Phytovolatilization Rhizodegradation Hydraulic control	Chlorinated solvents	Ground water	Eastern cottonwood
New Gretna, NJ	Phytodegradation Hydraulic control	Chlorinated solvents	Ground water	Hybrid poplar
Ogden, UT	Phytoextraction Rhizodegradation	Petroleum hydrocarbons	Soil Ground water	Alfalfa Poplar Juniper Fescue
Portsmouth, VA	Phytodegradation Rhizodegradation	Petroleum	Soil	Grasses Clover
Portland, OR	Phytodegradation	PCP PAHs	Soil	Ryegrass
Trenton, NJ	Phytoextraction	Heavy metals Radionuclides	Soil	Indian mustard
Anderson, SC	Phytostabilization	Heavy metals	Soil	Hybrid polar Grasses
Chernobyl, Ukraine	Rhizofiltration	Radionuclides	Ground water	Sunflower
Ashtabula, OH	Rhizofiltration	Radionuclides	Ground water	Sunflower
Upton, NY	Phytoextraction	Radionuclides	Soil	Indian mustard
Milan, TN	Phytodegradation	Explosives wastes	Ground water	Duckweed Parrotfeather
Beaverton, OR	Vegetative cover	Metals Nitrates BOD	Not Applicable	Cottonwood
Texas City, TX	Vegetative cover Rhizodegradation	PAHs	Soil	Mulberry
Amana, IA	Riparian corridor Phytodegradation	Nitrates	Ground water	Hybrid poplar

FIGURE 1. A YOUNG CHINESE TALLOW TREE

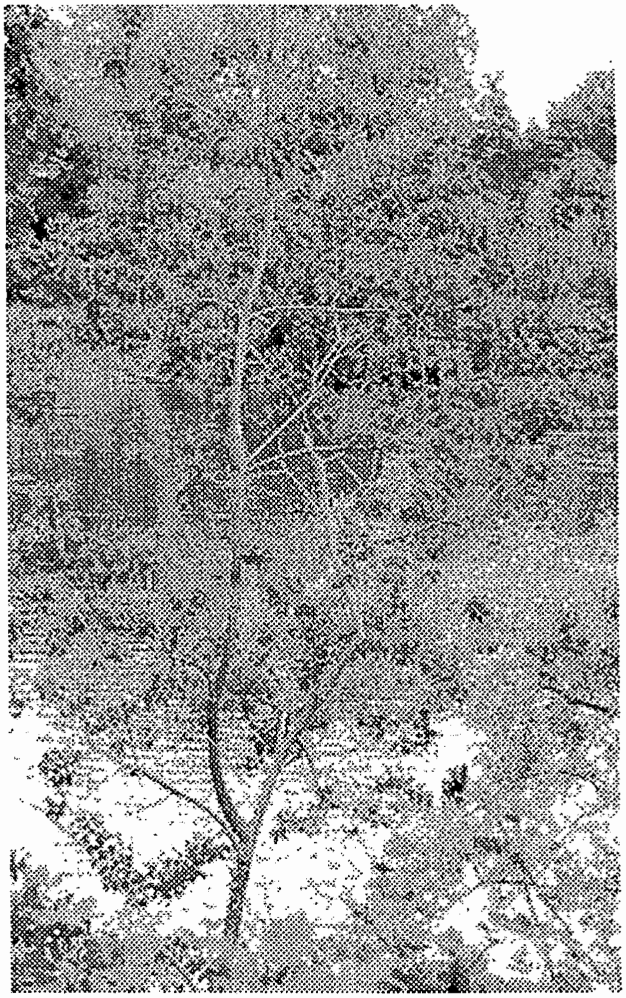


FIGURE 2. AN INFESTATION

FIGURE 3. RIPE CHINESE

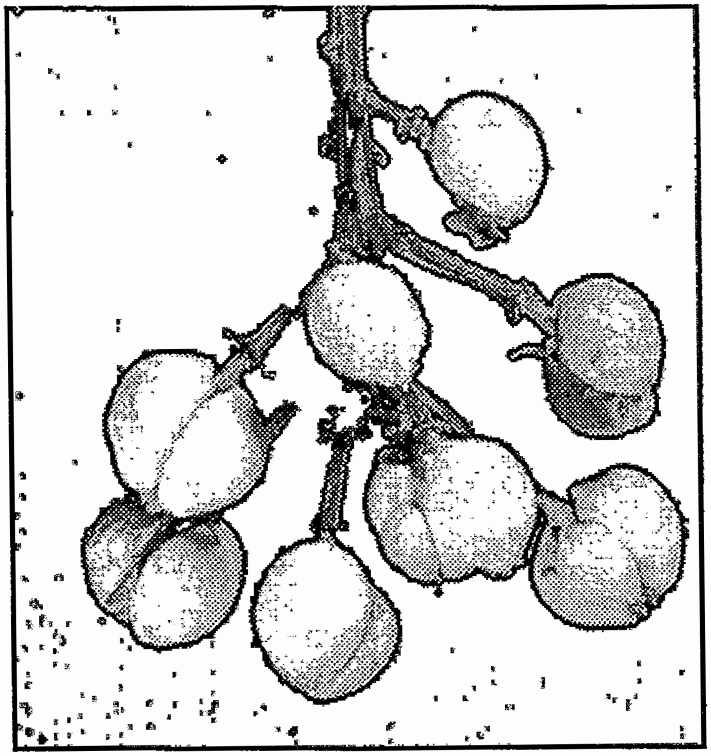


FIGURE 4 UPTAKE OF METALS BY PHYTOEXTRACTION

Figure 1. Uptake of Metals (Nickel) by Phytoextraction

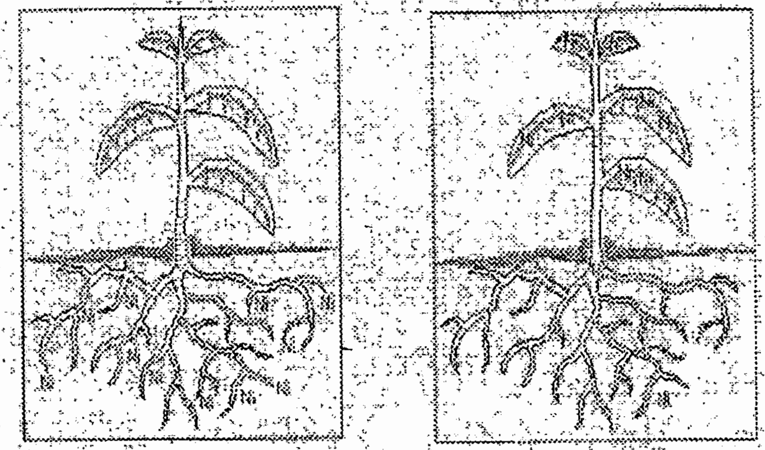
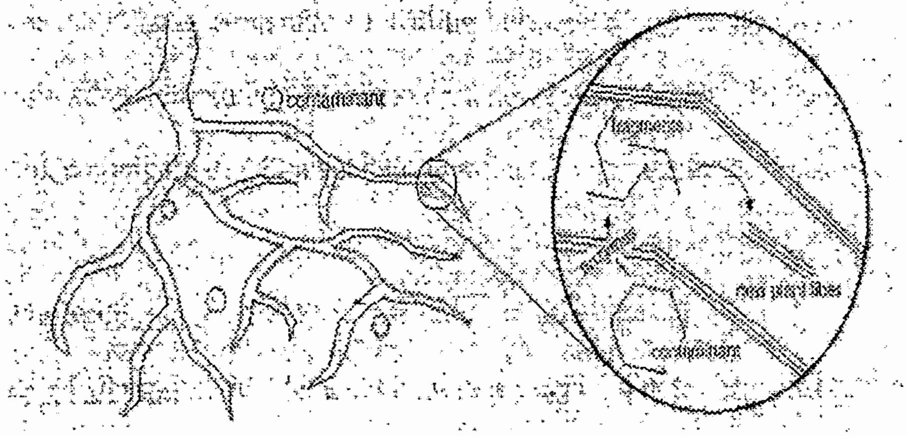


FIGURE 5 DESTRUCTION OF ORGANIC CONTAMINANTS BY PHYTODEGRADATION

Figure 2. Destruction of Organic Contaminants by Phytodegradation



CHAPTER III
EXPERIMENTAL DESIGN

Information concerning growth, development, propagation, and phytoremediation potential of Chinese tallow will be obtained via literature searches. Selected new plants will be obtained from uncontaminated areas. These plants will be grown in the lab in pots and beds and experiments utilizing contaminants will be performed in a green house. Their roots, stems, leaves will be placed into separate containers (plastic bags). The samples will be analyzed for toxic compounds. The specific methods for the above procedures are as follows:

Materials and Methods

Collection of Plants. The Chinese tallow seedlings used for this study will be collected from the Jean Lafitte National Historical Park and Preserve in New Orleans, Louisiana. The plants will be transported to the greenhouse on the Agricultural Farm at Southern University. The plants will be grown in pots containing Miracle Gro potting soil, and the pots will be placed in racks designed to allow for adequate drainage. The plants will be allowed to acclimate for 2-3 weeks before being exposed to the heavy metal (lead).

Preparation of Lead Solutions. A 1% stock solution of lead will be prepared by adding 1 gram of lead nitrate to an Erlenmeyer flask, and diluting it to a volume of 100 ml by adding distilled water. To make a 1000 ppm solution, 10 ml of the stock solution was diluted with 90 ml of water, for a 100 ppm solution, 10 ml of the 1000 ppm solution was diluted with 90 ml of water, and for a 10 ppm solution, 10 ml of the 100 ppm solution was diluted with 90 ml of water. 1 ppm, 0.1 ppm, and 0.01 ppm solutions were prepared using the same dilution procedures.

Plant Exposure. When the plants have taken root, they will be exposed in triplicate to 40 ml of the varying concentrations of lead, from 0.01 ppm to 1000 ppm. The control plants will be given 40 ml of water. There will be 21 plants in total. This step will be administered for 24-hour and 48-hour studies. After the allotted times, the plants will be collected from solution, ad the different organs (roots, stems, leaves) and soil, will be placed in plastic Zip-Loc bags.

Acid Digestion of Samples. For the digestion of samples, a representative 1-gram sample is digested with repeated additions of nitric acid and hydrogen peroxide. For GFAA or ICP-MP analysis, the resultant digestate is reduced in volume while heating and then diluted to a final volume of 100 ml. The specific steps we used for the above procedures are as follows:

The samples were mixed thoroughly to achieve homogeneity, and then they were sieved. For each digestion procedure, the samples were weighed to the nearest 0.01 g and transferred to a digestion vessel.

Next, 10 ml of 1:1 nitric acid was added, the slurry was mixed, and covered with a vapor recovery device. The samples were heated at 95 degrees and refluxed for 10 to 15 minutes without boiling. After cooling, 5 ml of concentrated nitric was added, and the samples refluxed for 30 minutes. This step was repeated over and over until no brown fumes were given off by the sample indicating the complete reaction with nitric acid. Using a ribbed watch glass, the solution was allowed to evaporate to approximately 5 ml without boiling. 2 ml of water and 3 ml of 30% hydrogen peroxide was added to the samples, and the samples were warmed on the heating source to start the peroxide reaction. The acid-peroxide digestate was heated until the volume had been reduced to approximately 5 ml. After cooling, the samples were diluted to 100 ml with water. Particulates in the digestate were removed by filtration. Finally, the samples were analyzed using atomic absorption.

CHAPTER IV
RESULTS

The extent of lead removal from the soil depends on the ability of the plant to accumulate lead in the roots, stems, and leaves. Lead absorption in the roots of the Chinese Tallow plant are shown in Table 2 and graphed in Fig. 6.

Plants that were exposed to higher concentrations of lead (100 ppm and 1000 ppm) showed the greatest level of lead concentrated in the roots. There was no significant amount of lead absorption at lower concentrations. Table 3 shows lead absorption in the leaves of the plant. The graph of this data (Fig. 7) reveals a biphasic response, with a significant level of lead absorption at 100 ppm, followed by a sudden decrease at 1000 ppm.

Lead absorptions in the stems of the Chinese Tallow plant are recorded in Table 4. The graph of this data (Fig. 8) shows that negligible amounts of lead was absorbed in the leaves of the tested plants.

Other elements including aluminum, boron, calcium, cadmium, copper, iron, phosphorous, magnesium, manganese, sodium, nickel, potassium, zinc, selenium, and arsenic were also found present in the parts of the Chinese Tallow plant. These results are recorded in table 5.

TABLE 2

Table 2. **Average Lead Absorption in Chinese Tallow Roots.**	
INITIAL LEAD ADDED TO PLANTS (ppm)	***LEAD ABSORPTION IN ROOTS (mg/kg)***
0.0	21.3
0.01	26.82
0.1	27.47
1	14.21
10	17.0
100	80.84
1000	92.13

FIGURE 6. LEAD ABSORPTION IN THE ROOTS OF THE CHINESE TALLOW PLANT.

FIG 6.

Lead Absorption in the Roots of the Chinese Tallow Plant.

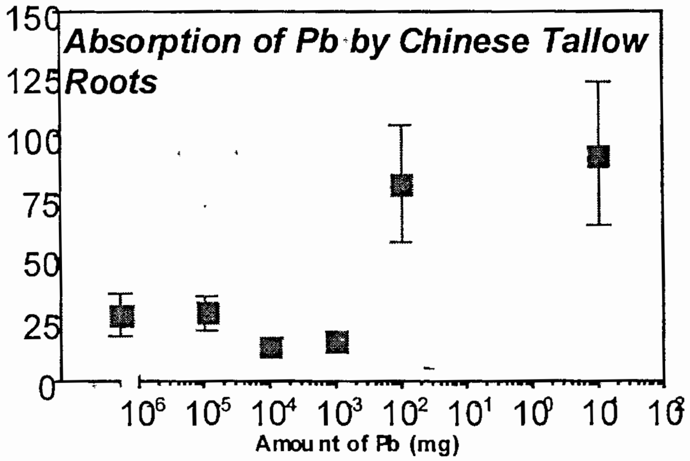


TABLE 3

Table 3.
Average Lead Absorption in Chinese Tallow Leaves

INITIAL LEAD ADDED TO PLANTS (ppm)	***LEAD ABSORPTION IN LEAVES (mg/kg)***
Control	30.43
0.01	32.38
0.1	30.91
1	15.05
10	29.78
100	76.59
1000	41.67

FIGURE 7 ABSORPTION OF LEAD BY THE LEAVES OF THE CHINESE TALLOW PLANT

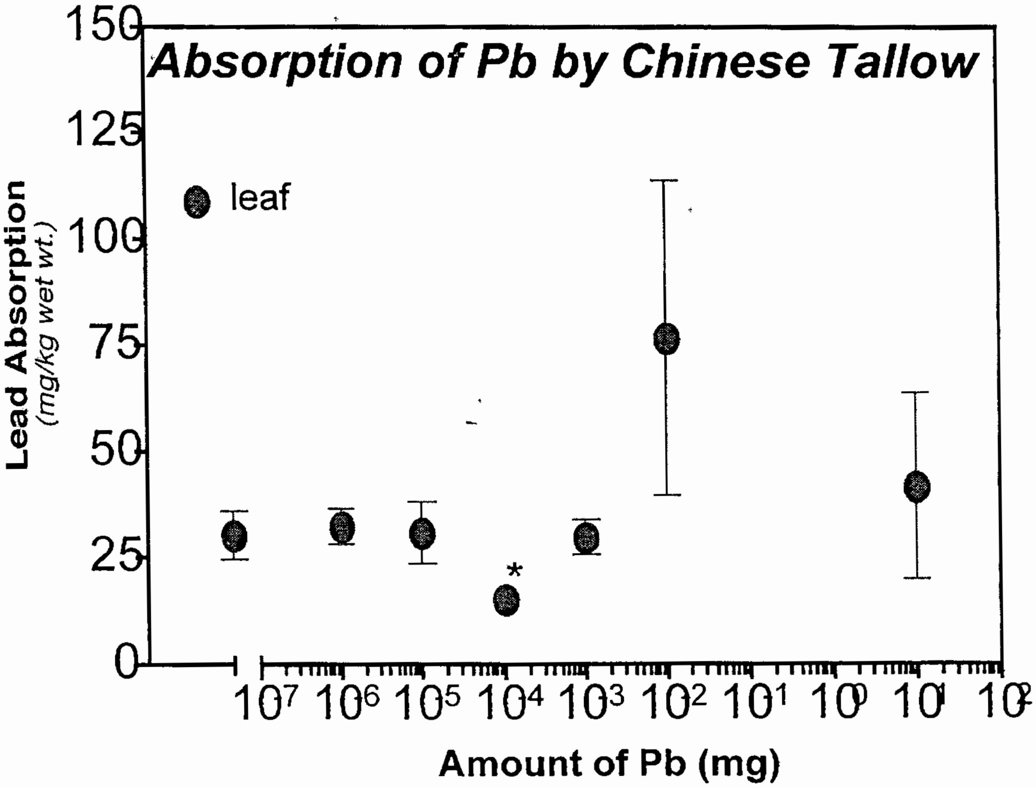


TABLE 4

Table 4.
Average Lead Absorption in Chinese Tallow Stems.

INITIAL LEAD ADDED TO PLANTS (ppm)	*LEAD ABSORPTION IN STEMS (mg/kg)*
Control	9.32
0.01	4.2
0.1	13.28
1	8.71
10	9.18
100	9.68
1000	34.66

TABLE 5. OTHER ELEMENTS ABSORBED BY THE CHINESE TALLOW PLANT.

CONCENTRATION	ORGAN	Al	B	Ca	Cd	Cu	Fe	K
	LEAVES							
.01 ppm		68.9	82.4	4561	0.28	28.21	148.1	25454
		45.6	80	4584	0.12	22.02	136.4	20165
		29.57	55.4	3364	0.31	29.78	84	24819
Average		48.02	72.6	4169.67	0.24	26.67	122.83	23479.33
.1 ppm		60.3	72	7873	0.11	12.7	119.2	18102
		44.93	45.32	6228	0.1	20.02	81.8	19762
		36.39	63.8	3561	0.07	27.53	90.9	18843
Average		47.21	60.37	5887.33	0.09	20.08	97.3	18902.33
1 ppm		47.27	58.7	4896	0.14	24.03	102.8	20211
		72.6	55.5	11606	0.16	30.68	140	16436
		25.12	30.02	6844	0.04	16.93	52.7	13443
Average		48.33	48.07	7782	0.11	23.88	98.5	16696.67
10 ppm		47.5	26.71	7980	0.16	16.17	93.6	9018
		57.5	53.8	11105	0.24	19.12	90.2	18228
		41.88	211.4	11245	0.24	12.94	66.5	17691
Average		48.96	97.3	10110	0.21	16.08	83.43	14979
100 ppm		33.99	63.9	14006	0.29	16.07	86.6	13399
		73	17.22	9506	0.13	17.87	77.5	12361
		56.8	45.35	12847	0.11	25.01	84.6	20725
Average		54.6	42.16	12119.67	0.17	19.65	82.9	15495
1000 ppm		52.6	56.8	9776	0.18	13.48	67.6	20344
		46.01	30.33	10743	0.04	17.96	96.7	15942
		135.5	53.3	10231	0.43	21.96	151.6	21687
Average		78.04	46.81	10250	0.22	17.8	105.3	19324.33
Control		31.61	65.3	6435	0.02	13.4	55.4	22170
		65.1	90.3	12763	0.04	20.98	102.5	19739
		Lost/Burned						
Average		48.36	77.8	9599	0.03	17.19	78.95	20954.5

TABLE 5 CONT.

CONCENTRATION	ORGAN	Al	B	Ca	Cd	Cu	Fe	K
.01 ppm		90	17.46	3107	0	10.79	79.7	7936
		115.1	18.71	3741	0	9.16	100.2	7286
		75.2	20.04	4556	0	12.24	81.8	12495
Average		93.43	18.74	3801.33	0	10.73	87.23	9239
.1 ppm		647	19.16	5464	0	14.99	2083	6223
		372.8	17.87	2941	0	22.13	348.8	8647
		117.2	19.24	2053	0	9.58	84.4	9123
Average		379	18.76	3486	0	15.57	838.73	7997.67
1 ppm		226	10.47	3221	0	11.17	256.3	3659
		364.9	13.52	3771	0	17.47	541	9084
		38.93	11.84	3783	0	11.25	17.65	8351
Average		209.94	11.94	3591.67	0	13.3	271.65	7031.33
10 ppm		58.7	12.95	3241	0	6.9	74.5	4503
		93.7	14.67	4018	0	10.05	69.2	6959
		51.8	17.65	4222	0	12.35	44.67	7111
Average		68.07	15.09	3827	0	9.77	62.79	6191
100 ppm		64	17.22	5053	0	60.4	81.3	8069
		1232	13.38	4036	0	44.73	1200	5701
		69.9	9.76	2997	0	12.85	79.6	7180
Average		1472.01	125.42	26836.33	0.01	110.87	2160.49	54580.17
1000 ppm		174.3	9.48	3478	0	11.4	183.1	3968
		100.3	15.53	4265	1.67	15 34	57.7	7635
		892	13.78	2591	0	35.23	841	5160
Average		388.87	12.93	3444.67	0.56	20.66	360.6	5587.67
Control		1412	11.32	2432	0	31.31	1072	4999
		142.1	16.94	3926	0.08	51.4	107.4	7150
		73.2	19.43	3909	0.08	43.18	98.5	7438
Average		542.43	15.9	3422.33	0.06	41.96	425 97	6529

TABLE 5 CONT.

CONCENTRATION	ORGAN	Al	B	Ca	Cd	Cu	Fe	K
	ROOTS							
.01 ppm		6860	16.91	5760	1.98	38.5	6870	6527
		12175	31.53	8100	2.61	51	13430	6852
		11013	29.01	8484	2.24	60.7	12506	6822
Average		10016	25.82	7448	2.28	50.07	10935.33	6733.67
.1 ppm		6709	33.52	6317	1.76	88	14149	8274
		5456	25.42	9492	1.09	83.4	9526	11920
		5106	24.31	5014	0.87	37.95	4607	17442
Average		5757	27.75	6941	1.24	69.78	9427.33	12545.33
1 ppm		2168	23.79	9952	0.79	66	7260	6630
		5920	25.05	5548	5.03	95.5	5315	15114
		2449	17.1	5541	1.71	83.4	4732	9778
Average		3512.33	21.98	7013.67	2.51	81.63	5769	10507.33
10 ppm		6332	26.44	9163	3.66	76.4	6200	11030
		7732	25.84	7493	1.38	61.4	6571	15445
		4042	26.14	10510	0.62	84.9	3747	14217
Average		6035.33	26.14	9055.33	1.89	74.23	5506	13564
100 ppm		2418	24.92	8961	2.39	113.3	2547	14412
		4639	24.14	9866	5.3	68.8	4149	10887
		7369	29.06	11478	0.9	95.6	8776	6574
Average		4808.67	26.04	10101.67	2.87	92.57	5157.33	10624.33
1000 ppm		2923	18.52	6592	1.98	124.3	3738	9431
		5023	26.31	5667	3.75	70.4	12002	5529
		2393	17.89	5863	0.21	57.2	1883	11895
Average		3446.33	20.91	6040.67	1.98	83.97	5874.33	8951.67
Control		7236	20.92	4465	3.28	104.8	5468	15690
		3575	16.5	5561	0.18	66.4	3332	6781
		13849	22.46	5754	1.08	88.8	9784	9249
Average		8220	19.96	5260	1.51	86.67	6194.67	10573.33

CHAPTER V
DISCUSSION AND CONCLUSION

If phytoremediation is to be successful, the plant must be able to accumulate the contaminants in the soil, without dying. The results of this study demonstrate that the Chinese Tallow plant has the ability to absorb lead without a reduction in vigor, productivity, and overall growth.

To determine which of the four processes of phytoremediation (phytodegradation, phytoextraction, phytostabilization, rhizofiltration) is occurring, the lead absorption in the roots, stems, leaves and soil of the plant have to be analyzed. In phytodegradation, the lead in the soil will be transformed into another substance that the plant will use as nutrients, or it will be degraded into gases that are emitted into the atmosphere. If phytodegradation were occurring, there should be no lead present in the roots, stems, or leaves of the plant. However, our results show high amounts of lead absorbed in the roots of the plant, indicating that phytodegradation could not have occurred. In phytoextraction, the contaminant moves from the soil into the roots of the plant, and finally into the aboveground portions of the plant. For phytoextraction to be the process used by the Chinese Tallow plant, there should be a higher level of lead absorption in the aboveground portions (leaves, stems), than in the roots of the plant. Once again, our results indicate that the lead absorption in the roots was higher than the leaves and the stems, which absorbed negligible amounts of lead Phytostabilization immobilizes the contaminant and restricts its movement to the root-zone of the plant. In this case, the contaminant cannot get to the aboveground portions of the plant because it is stabilized in the root-zone. At the present time, it is impossible for us to determine if the Chinese Tallow plant uses the process of phytostabilization to uptake lead because due to time limitations, the samples from the soil could not be analyzed. In rhizofiltration, the contaminants in the soil are sequestered by the roots of the plants, therefore, the roots should have the highest concentrations of the contaminant. Our results reveal this mode of phytoremediation because the highest levels of lead absorption were indeed found in the roots of the plants. In addition, if rhizofiltration were occurring, one would not expect an increase in lead absorption by the stems and leaves of the plants over time because the lead is supposed to be retained in the roots. Figure 6 shows that over time, there was an increase in the amount of lead found in the stems and leaves of the Chinese Tallow plant.

After analyzing the results, we wondered why the lead absorption of the stem was so low compared to that of the leaves. We came up with the hypothesis that since plants have a vascular system, the stem probably had a transport system, moving the lead to the leaves without actually storing the lead

Furthermore, we tried to determine if the Chinese Tallow plant uses rhizofiltration to accumulate other metals. We looked at the absorption of phosphorus by the leaves and the stems of the plant (Fig. 7). The results revealed that there was more phosphorus in the leaves than in the roots, indicating that the Chinese Tallow plant does not use rhizofiltration to remediate phosphorus.

The results of this study indicate that the Chinese Tallow plant can be used to remediate hazardous waste sites that contain high concentrations of lead, using the process of rhizofiltration. The plant can be used to remediate sites contaminated with other metals as well.

Analysis of the soil samples used in this study are necessary to determine if the Chinese Tallow plant uses the process of phytostabilization. Additional studies are necessary to determine if the Chinese Tallow plant will continue to grow and absorb lead at concentrations higher than 1000 ppm. Also, the effect of phytoremediation on the food-chain if herbivores and omnivores ingest the metal-laden foliage is an area that needs further study.

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