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Lead Phytoremediation in Contaminated Soils Using Ornamental Landscape Plants

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Abstract

Lead (Pb) in the urban environment can have a negative effect on human health, especially children's health. Reducing elevated Pb exposure in the home landscape is essential. The purpose of this study was to determine which ornamental groundcover landscape plants uptake Pb from contaminated soil. Plants for both shade and sun were selected. Plants for shade [Brake fern (*Pteris vittata*), Asian Jasmine (*Trachelospermum asiaticum*), "Big Blue" Liriope (*Liriope muscari*), and St. Augustinegrass (*Stenotaphrum secundatum*)] and sun [Variegated Liriope (*Liriope muscari* "*Variegata*"), Asian Jasmine (*Trachelospermum asiaticum*), Asparagus Fern (*Asparagus setaceus*), and Bermudagrass (*Cynodon dactylon*)] adapted landscape groundcover plants successfully assimilated Pb grown in soil containing 250 ppm and 500 ppm Pb concentrations. Additionally, soil movement at both 25 mph and 50 mph wind speed was significantly different, with increased soil movement at 50 mph. Therefore, it was determined that landscape plants adapted to both sun and shade can help remove Pb from contaminated soils and stabilize soil particles reducing the movement of soil and be aesthetically pleasing.

Keywords

Soil Heavy Metals, Remediation, Soil Health, Urban Horticulture, Phytoextraction

1. Introduction

Lead (Pb) is a natural element occurring in soil frequently combined with other elements to form a variety of minerals (Kinder, 1997). In New Orleans, it has been discovered that two third of homes and yards have an elevated concentration of Pb. Any soil containing > 400 ppm in a home landscape environment where children play was defined as above normal by the Environmental Protection Agency (Schleifstein, 2011). Lead is a potentially toxic metal that has been a component of manmade-products in the past such as paint, metal water pipes and gasoline. The most common sources of Pb were paint containing Pb and gasoline fumes. When high Pb levels were determined to be harmful, the government banned their use in many everyday products, but the past consumption has left a large quantity of Pb residue in the environment (Mayo Foundation, 2019). Removing Pb from soil can be a very expensive and laborious process. A natural alternative remediation process is removing contaminated soil using phytoremediation. Phytoremediation involves the use of plants to extract contaminants from the soil (Rock, 2000). Researchers and the government have informed the public about the effects of exposure to Pb. Lead exposure has been linked to developmental issues in children. These developmental issues can later turn into behavior problems, which may cause learning difficulties, and eventually even a life of crime (Adelson, 2016). High concentrations of Pb in the blood can have negative effects on the central nervous system, the kidneys, and the blood cells. The effects include reduced IQ scores, hyperactivity, reduced stature, hearing problems, and reoccurring headaches (Schleifstein, 2011). Lead poisoning is an environmental and public health issue across the world (Kinder, 1997). Lead poisoning is an issue in the United States of America to many different degrees (Mayo Foundation, 2019). Lead-polluted soil is a very common cause of Pb ingestion by children (Adelson, 2016). Pre-school age children were determined to have a significant relationship between soil Pb bioaccessibility and blood Pb, as their behaviors place them at greatest risk of soil Pb toxicity (Ren et al., 2006).

Populations of plants, microorganisms, and invertebrates can be affected by Pb concentrations above five hundred parts per million. When living organisms are eliminated by sufficient Pb concentrations, it allows more lead-tolerant species to take their place. No matter the level of Pb added to areas exposed to living organisms, the Pb contamination can alter living entities. Specifically, Pb can alter the biochemical process that purifies and re-purifies the calcium pool in grazing animals and decomposing organisms (Greene, 1993). Plants play a major role in stabilization of soil and items in or above the soil. The above ground vegetation and below the soil roots of the plants combined helps to physically protect soil from eroding (Ford et al., 2016). Soil pollution occurs when harmful chemicals, heavy metals, and other contaminants are present in the soil at concentration levels high enough to be a risk to plants, wildlife, humans, and the soil itself. Soil pollution can cause several negative effects on ecosystems and human, plant, and animal health. The harmful effects caused by soil pollution can result from direct contact with contaminated soil, but it can also be from contact with water or food exposed to polluted sources (Science Communication Unit, 2013). Soil does not need to have a high concentration of a pollutant for it to cause negative effects on humans (Science Communication Unit, 2013). The Environmental Protection Agency (EPA) creates actionable regulations to help keep our environment safe and healthy. The mission of the

Environmental Protection Agency is to protect human health and the environment (United States Environmental Protection Agency, 2017b). A program established by the Environmental Protection Agency called the Lead Residential Lead-Based Paint Disclosure Program requires that "potential buyers and renters of housing built prior to 1978 receive information about Pb and Pb hazards prior to buying or renting and provides opportunity for independent Pb inspections for buyers." The goal of this program is to inform the buyer of the presence of Pb and resolve the issues (United States Environmental Protection Agency, 2017a).

A Pb concentration of 500 ppm can be a level at which management should be considered in an urban environment (United States Environmental Protection Agency, 2017a). Remarkably, researchers found that the average Pb concentration in the soil has gradually decreased from 560 ppm in 1998 to 408.1 ppm in 2000, but it continues to be an issue. The age of a home is the most common indicator of Pb concentration levels (Schleifstein, 2011). Lead pollution is especially an issue in the New Orleans area. Many homes in historical New Orleans were built before the ban of Pb paint in 1978. The climate is hot and humid which means there is a lot of moisture. This moisture can cause the Pb paint to chip off and contaminate soil. After Hurricane Katrina, Pb contamination from older buildings polluted surrounding areas after being remodeled (Mielke et al., 2019). Lead can move into and through different ecosystems, resulting in Pb dispersed from vehicle emissions, paint chips, used ammunition, fertilizers, pesticides, and Pb-acid batteries contaminating surrounding areas. Pb commonly accumulates on the soil surface, where it can remain for up to 2000 years (Greene, 1993). In cultivated soil, Pb can be incorporated into the plant's root zone resulting in plant uptake. Because of the chemistry of Pb, the Environmental Protection Agency suggests that an uneven distribution of Pb in ecosystems can disturb other metals from the binding site on the organic matter (Greene, 1993). Lead is not an essential element within a plant, however it can be easily accumulated and absorbed in certain plants (Sharma & Dubey, 2005).

Phytoremediation and phytoextraction are useful tools for sites containing large, low contaminant concentrations at shallow depths where other methods are not justified (Sharma & Dubey, 2005). Phytoremediation can also be a much cheaper method of removing Pb from soil (Peuke & Rehnenberg, 2005). Additionally, phytoremediation reduces secondary contaminated airborne wastes because the plants provide groundcover, which stabilizes the soil and prevents it from going elsewhere (Lew, 2021). Most scientific and mainstream interest in phytoremediation focuses on phytoextraction and phytodegradation, which use specific plant species grown on contaminated soils (Peuke & Rehnenberg, 2005). Phytoextraction is defined as the plants ability to convert insoluble heavy metal contaminates from insoluble forms of metals into water soluble forms (Ghori et al., 2016). Phytoremediation makes contaminated sites more aesthetically pleasing, by turning "brownfields" into "greenfields" by putting more plants into the landscape. Many people are open to the idea of phytoremediation because of the relationships humans have developed with plants, due to our evolutionary past (Lew, 2021). Phytostabilization is also a useful tool that involves the establishment of plant cover with the purpose of reducing the mobility of contaminants within the vadose zone reducing offsite contamination (Bolan et al., 2011). Dense growth of leaves, stolons, roots, and rhizomes can stabilize soil reducing soil movement. Contaminated dust in the home can expose children to Pb (United States Environmental Protection Agency, 2021). Phytoremediation appears to have public support for removing the pollutants from contaminated soils (Oseni et al., 2020). As soil Pb levels decreased in topsoil, Pb levels decreased in children's blood levels (Mielke et al. 2019). Combining phytoremediation and phytostabilization can be an effective combination used in the Urban Environment.

An urban environment is a unique manmade landscape based on aesthetics, adaptability, and utility. Horticultural ornamental plants are commercially available from an assortment of vendors. Woody ornamental plant availability throughout the United States has expanded to make hundreds of plant species available for the consumer. These plants provide materials landscape contractors and homeowners use in the urban environment to enhance their homes. Research has established that landscaping increases the value of homes significantly (Shahli et al., 2014). Phytoremediation usually occurs in remediation sites with uninhabited areas with plants such as Indian mustard (Goldowitz & Goldowitz, 2006) and sunflower (Alaboudi et al., 2018), that are not suitable perennial landscape plants. The purpose of this experiment was to determine if various landscape plants are useful for phytoremediation and soil-stabilization in Pb contaminated soils while providing aesthetic landscapes.

2. Materials and Methods

For this experiment, *Pteris vittata* (Brake Fern), *Liriope muscari* ("Big Blue" Liriope), *Stenotaphrum secundatum* (St. Augustinegrass) sod, *Trachelospermum asiaticum* (Asian Jasmine), *Asparagus setaceus* (Asparagus Fern), *Liriope muscari* "*Variegata*" (Variegated Liriope), and *Cynodon dactylon* (Bermudagrass) plants were planted in separate pots. The pots were then dispersed using the randomized complete block design (RCBD) method amongst six plastic deep trays with drainage attached to collect the excess water. All plants were established into containers for 28 days before Pb treatments were applied. On the 29th day, the Olivier silt loam soil was spiked with either a 0-ppm Pb (control), 250 ppm Pb or 500 ppm Pb solution. Plants selected for this experiment were categorized by their light tolerance, either shade or sun loving, giving homeowners an option for either landscape situation. Shade adapted plants included Brake fern, Asian Jasmine, "Big Blue" Liriope, and St. Augustinegrass. Sun adapted plants included Asparagus Fern, Variegated Liriope, Asian Jasmine, and Bermudagrass. These sun-adapted plants followed the same procedure as the shade trial. The plants were watered daily for 52 days, then the plants were harvested and submitted to the LSU soil testing lab where an inductively coupled plasma

(ICP) device was used to measure the leaf tissue quantity. The procedure consisted of harvesting plant tops at the termination of the project and dried at 60˚C for 48 hours. One gram of ground plant material was transferred into a 20 ml scintillation vial and placed in an oven at 50˚C for 1 h to remove residual moisture. Vials were then transferred to desiccators for 1 h to further remove moisture and cool the sample to room temperature. The caps of each sample were tightened upon removal from the desiccators to prevent moisture from re-entering. The machine was calibrated using 5 National Institute of Standards and Technology (NIST) apple tissue samples and 5 blank samples. Elements were analyzed by placing 0.5 g of tissue into a 50 ml tube (SCP Scientific digiTUBE). Funnels were placed in each tube, and samples were placed into an automatic digester (Thomas Cain, DEENA) for digestion using nitric acid. During the digestion, the samples are heated for 6 s at 60˚C and 2.2 ml of distilled water is added. After 2 m, 5 ml nitric acid (SCP Science, 67% to 70% HNO_3, reagent grade) was dispensed into each tube, and the temperature was increased 10˚C every 10 m from 60˚C to 110˚C. The temperature was increased to 125˚C and held for 45 m, and then held for 50 m at 128˚C, and cooled for 2 m. One ml of hydrogen peroxide (Macron Fine chemicals, 30% solution) was dispensed into each tube, cooled for 5 m, and reheated for 5 m to 128˚C. One ml of hydrogen peroxide was dispensed into each tube. Samples were cooled for 5 m and heated for 30 m at 122˚C, cooled for 6 seconds to 20˚C and cooled for one more minute. The volume of each sample was brought to 20 ml using distilled water. Samples were removed from the digester and vacuum filtered using a 1.0-micron Teflon membrane filter (SCP Science) into another 20 ml tube. ICP was performed for Pb using a Spectro Arcos according to the LSU Soil Testing and Plant Analysis Lab's AgMetals procedure. The instrument was calibrated using one blank and 6 standard samples. Samples were run in sets of 60 (2 blanks included) with two National Institute of Standards and Technology (NIST) peach samples and an internal standard every 20 samples. The data was verified to ensure it was within the tolerant ranges of the NIST and internal standards. Lead levels were reported as ppm (mg/kg) leaf dry weight.

Soil movement due to wind speed was evaluated using a modified wind tunnel to ascertain soil loss from wind erosion. Six trays were filled with an Olivier silt loam soil, three of which were covered with St. Augustinegrass and grown for 28 days before applying wind treatments (0, 25, 50 mph). An anemometer was used to establish wind speeds prior to experimentation. After grass establishment, an 18" by 24" plenum directed wind onto the surface for one minute. A cloth bag made of fine mesh cotton collected displaced soil, which was measured to the nearest gram. Data was analyzed using an analysis of variance at the 0.05 level.

3. Results and Discussion

All plants assimilated Pb to some extent regardless of light exposure. Shade loving plants such as brake fern, liriope and Asian jasmine grew successfully in all Pb treatments. Brake fern successfully assimilated Pb in significantly increasing amounts respective to Pb soil concentrations (**Figure 1**). Leaves of brake fern accumulated nearly 450 ppm in dried leaf tissue. This species has historically been documented as a hyperaccumulator in previous research (Rozas et al., 2006). The importance of this is that it gives homeowners a shade loving plant that can be planted in deep shade near a tree where grass does not receive enough light to thrive. As previously stated, soil stabilization is just as important as phytoremediation reducing contaminated dust movement. Asian Jasmine leaf Pb content grown in control soil was significantly less than both the 250 and 500 ppm Pb soil treatments. Plant leaves assimilated low levels (<30 ppm) of Pb but did establish and grow successfully (**Figure 2**). Liriope "Big Blue" significantly assimilated Pb as soil rates increased. Leaf tissue accumulation remained below 15 ppm. All plants successfully grew regardless of Pb treatment (**Figure 3**). St. Augustinegrass successfully assimilated Pb from the contaminated soil. Leaf tissue Pb content approached 150 ppm when grown in 500 ppm contaminated soil. All rates were significantly different from each other with the highest content in 500 ppm soil (**Figure 4**). St. Augustinegrass is considered the most shade tolerant lawngrass in Louisiana. Turfgrass is an excellent groundcover in urban landscapes and resists erosion.

Variegated liriope plants successfully assimilated Pb from the soil. Plants assimilated between 50 and 60 ppm Pb for the 250 and 500 ppm Pb soil treatments, and both were statistically similar (**Figure 5**). Both treatments were greater than the control plants. Asian jasmine plants grown in control soil had significantly lower Pb levels compared to the 250 and 500 ppm Pb soil treatments. Plant leaves assimilated low levels of Pb (20 to 30 ppm) and established and grew successfully (**Figure 6**). Asparagus fern accumulated low levels (5 - 10 ppm) of Pb in fronds for 250 and 500 ppm soil Pb soil treatments (**Figure 7**). The control fronds accumulated significantly less Pb than all other soil treatments. All plants established and grew successfully regardless of soil Pb levels. Bermudagrass established and grew in all soil Pb treatments (**Figure 8**). The control accumulated significantly lower levels of tissue Pb. Soil treatments (250 and 500 ppm) accumulated statistically similar concentrations (20 - 25 ppm) of leaf tissue Pb.

Increased wind speed significantly displaced soil at both 25 and 50 mph compared to the control (**Figure 9**). Soil accumulated from the unplanted soil treatment at 50 mph wind speed resulted in greater than 11 times more than the 25 mph unplanted treatment. St. Augustinegrass planted trays lost less than 1 g of soil and less soil was accumulated at both wind speeds compared to the soil treatment. Although this was only a single wind event, it shows the effectiveness of planting groundcovers to stabilize soil movement. This is critically important in an urban landscape, especially where soils are deemed contaminated. A dense sward of grass deeply rooted provided leaves, stolons and fine roots protecting the soil surface from erosion.

There are many previous studies that have documented plant uptake of Pb from contaminated soils (Goldowitz & Goldowitz, 2006; Alaboudi et al., 2018).

The use of landscape plants in this study did show successful assimilation of Pb into leaf tissue (**Figures 1-8**). Industrial phytoremediation and phytoextraction succeed using trees in deeply contaminated aquifers (Fontenot et al., 2014). The importance of this is that integrating landscape plants into the urban landscape accomplishes both phytoremediation and aesthetics. Equally important is the ability of plants serving to stabilize soil resisting wind and water erosion. Fontenot et al. (2015) determined that swards of turfgrass in a brine field increased plant coverage, therefore reducing dust and soil movement. Both grass species tested were adapted to a highly saline brine yard solid waste surface impoundment. Plant adaptability to specific harsh environments is often the reason specific species are selected. The United States Environmental Protection Agency (2017a) does require safe soil levels to be below 400 ppm Pb in the urban environment; however, managing dust and reducing erosion in the urban environment is an expectation of any home landscaper. The use of multiple species to reduce nutrient movement has been demonstrated to be effective (Koonce & Bush, 2019). Combining the use of ornamental trees, shrubs, grasses, and groundcovers capable of soil stabilization and phytoremediation would be helpful in reducing the movement of contaminated soil. Reducing contaminated dust that can enter the home and expose young children to Pb is a benefit of phytostabilization (United States Environmental Protection Agency, 2021). Environmental efforts have been used successfully to reduce Pb contaminated sites using plants (United States Environmental Protection Agency, 1999). Bush et al. (2015) determined that grass rooting strength and penetration force was increased using a coastal grass (*Spartina sp*.). Successful soil stabilization using St. Augustinegrass is an example of an ornamental grass plant that significantly reduces wind-blown soil (**Figure 9**). Bush et al. (2001) did show that with increased Zn rates trees assimilated increased concentrations. Combining the use of ornamental plants capable of soil extraction, phytoremediation, and stabilization with home landscape aesthetics could prove to be as effective as non-ornamental phytoremediation species used in the past for waste site remediation.

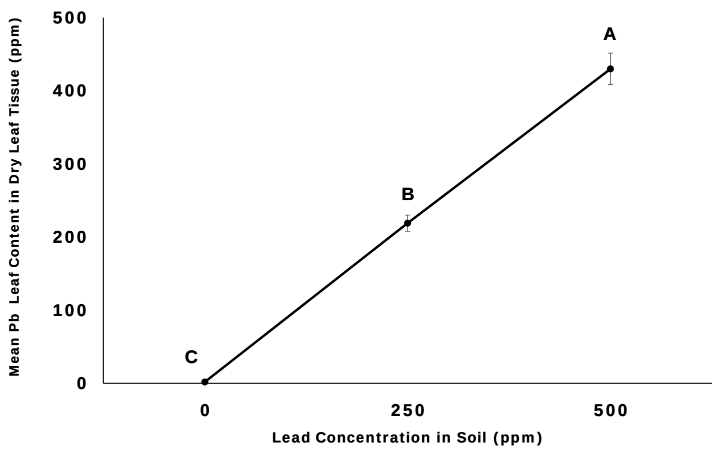

Figure 1. Brake fern (*Pteris vittata*) accumulation of Pb after 52 days.

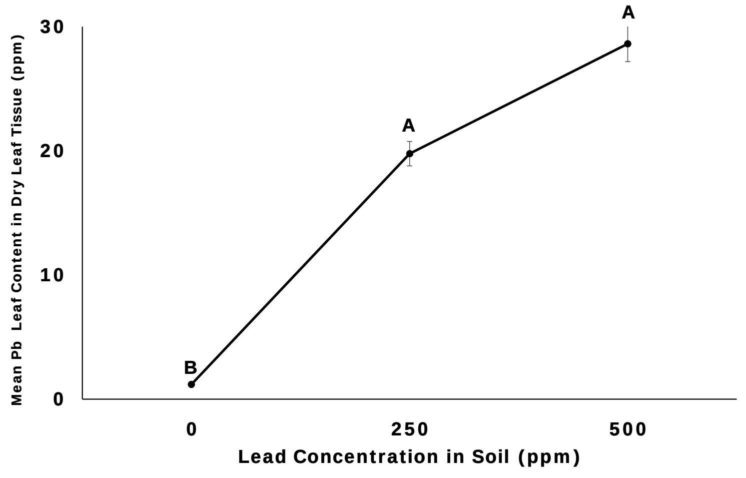

Figure 2. Asian Jasmine (*Trachelospermum asiaticum*) accumulation of Pb after 52 days.

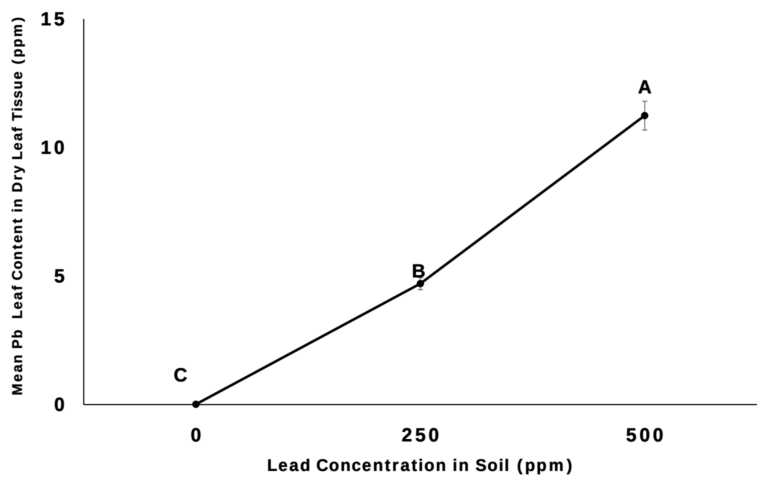

Figure 3. "Big Blue" Liriope (*Liriope muscari*) accumulation of Pb after 52 days.

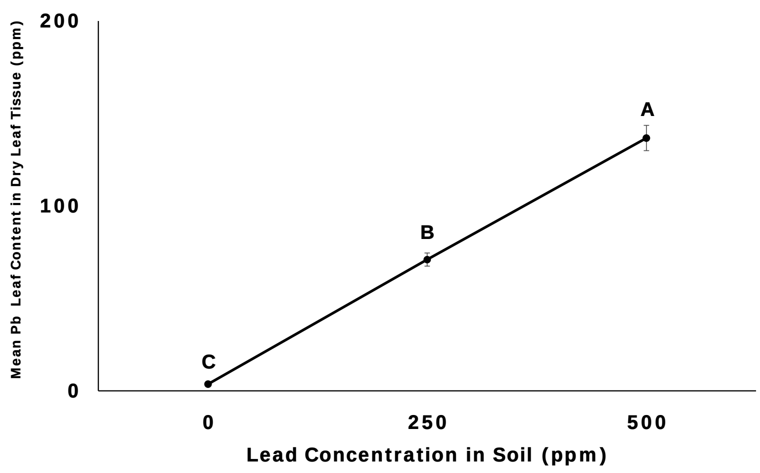

Figure 4. St. Augustinegrass (*Stenotaphrum secundatum*) accumulation of Pb after 52 days.

Sun Trial Results:

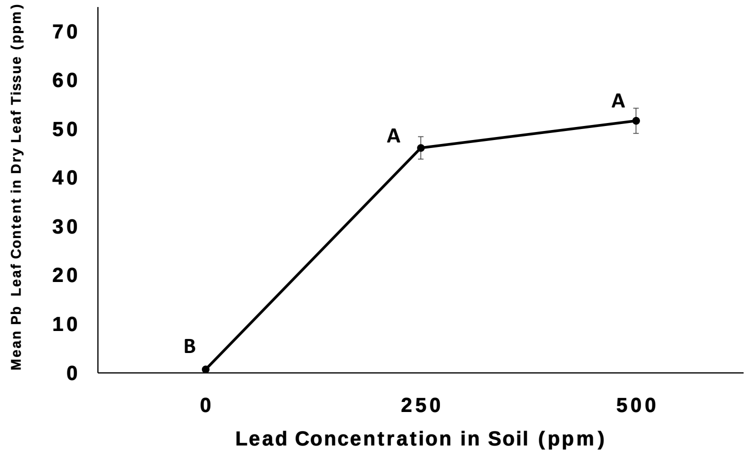

Figure 5. Variegated Liriope (*Liriope muscari* "*Variegata*") accumulation of Pb after 52 days.

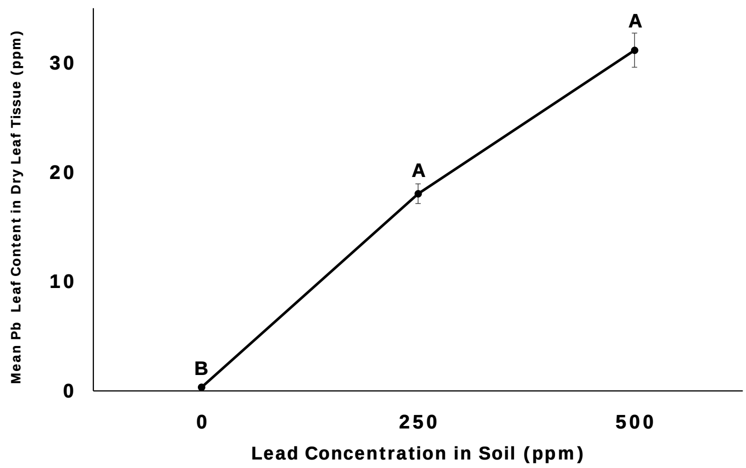

Figure 6. Asian Jasmine *(Trachelospermum asiaticum*) accumulation of Pb after 52 days.

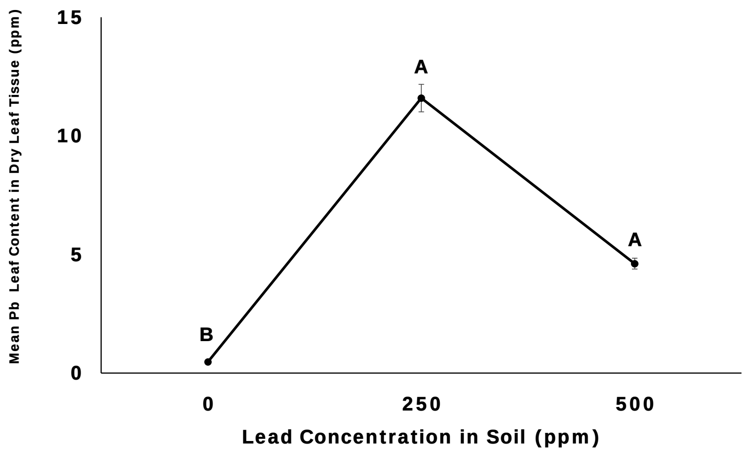

Figure 7. Asparagus Fern (*Asparagus setaceus*) accumulation of Pb after 52 days.

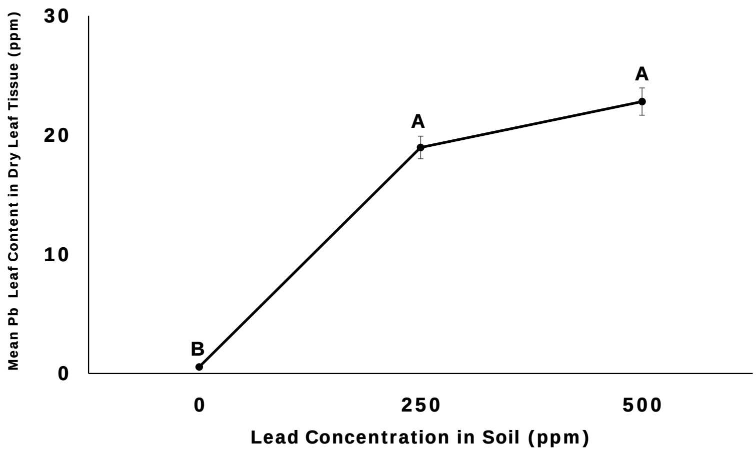

Figure 8. Bermudagrass (*Cynodon dactylon*) accumulation of Pb after 52 days.

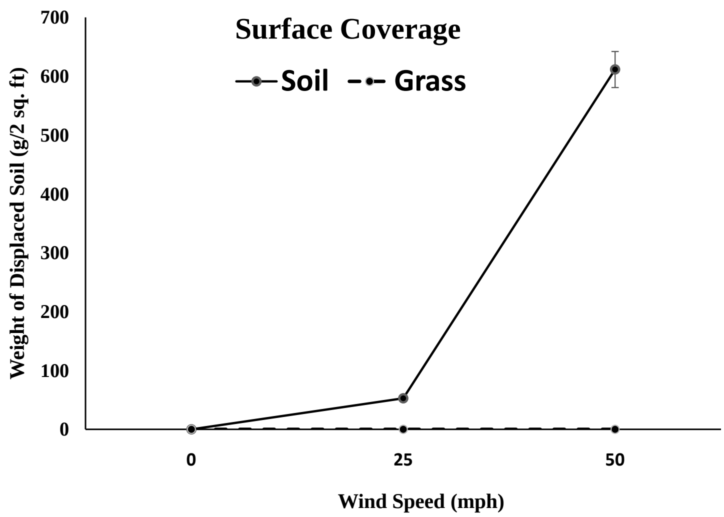

Figure 9. The effect of established plants St. Augustinegrass (*Stenotaphrum secundatum*) on soil stabilization at different wind speeds.

4. Conclusion

The general public benefits from this project because it will have a less expensive and destructive method of reducing regulated elements, such as Pb, from soils above acceptable levels. This research established that all plants assimilated Pb into leaf tissue. Additionally, soil stabilization with dense plant leaf and root systems was shown to reduce the migration of soil particles that can be harmful to humans. Many children play in the soil and constantly put their hands and fingers in their mouth making them prone to heavy metal contamination. In large cities like New Orleans, where elevated Pb levels are detected in soil, this can be harmful to children and could have long-term effects on their health. These plants can be used to remove Pb safely and cheaply from soil particles, avoiding exposure of children and reducing the chance of it being airborne. Integrating aesthetically pleasing landscape plants can achieve both soil stabilization and phytoremediation. Selected plants such as Asian Jasmine and St. Augustinegrass are groundcover plants that can reduce airborne soil particles. Using groundcover plants in large metropolitan areas like New Orleans, Louisiana can reduce Pb human exposure each year. This study indicated that landscape plants can be used to ameliorate soil Pb contamination in the urban landscape environment.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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