



SYNGONIUM PODOPHYLLUM'S REMEDIATION OF SURFACE LAYERS IN SOILS CONTAMINATED WITH TOXIC METALS

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ABSTRACT

Objective: The aim of this study is to investigate the hyperaccumulation capacity of the native plant *Syngonium podophyllum* in order to remediate an environmental liability contaminated with toxic metals.

Theoretical Framework: This topic presents the main concepts and theories underpinning the research. Phytoremediation and the main characteristics of *Syngonium podophyllum* are highlighted, providing a solid basis for understanding the context of the research.

Method: The methodology adopted for this research comprised the acquisition of *Syngonium podophyllum*, planting it in contaminated soil with a view to hyperaccumulation by the plant, comparing the seedlings in control soil and contaminated soil and analyzing the metal content in the soil and in the seedlings used. Data was collected by means of a statistical analysis carried out on the roots, stem and leaves to check for growth inhibition and whether phytoremediation is a viable alternative.

Results and Discussion: The results obtained revealed that although the stem of the plant, in contaminated soil, showed growth inhibition, its leaves and stem showed an increase, which was significant for the leaves, so the application of *Syngonium podophyllum* as a phytoremediation plant is satisfactory. In the discussion section, these results are contextualized in the light of the theoretical framework, highlighting the implications and relationships identified. Possible discrepancies and limitations of the study are also considered in this section.

Research Implications: The practical and theoretical implications of this research are discussed, providing insights into how the results can be applied or influence practices in the field of environmental management. These implications may cover agronomy, agriculture, soil remediation and ecology.

Originality/Value: This study contributes to the literature by validating the importance of native flora in combating soil degradation and regeneration. The relevance and value of this research is evidenced by the fact that the remediation of an environmental liability brings a contribution to society.

Keywords: Management of Environmental Liabilities, Solid Waste, *Syngonium Podophyllum*, Toxic Metals.

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REMEDIÇÃO DE CAMADAS SUPERFICIAIS POR *SYNGONIUM PODOPHYLLUM* EM SOLOS CONTAMINADOS COM METAIS TÓXICOS

RESUMO

Objetivo: O objetivo deste estudo é investigar a capacidade de hiperacumulação da planta nativa *Syngonium podophyllum*, com o intuito de realizar a remediação de um passivo ambiental contaminado com metais tóxicos.

Referencial Teórico: Neste tópico, são apresentados os principais conceitos e teorias que fundamentam a pesquisa. Destacam-se fitorremediação e principais características da *Syngonium podophyllum*, fornecendo uma base sólida para a compreensão do contexto da investigação.

Método: A metodologia adotada para esta pesquisa compreende a aquisição de *Syngonium podophyllum*, realizando o plantio em solo contaminado, visando a hiperacumulação pela planta, a comparação das mudas em solo controle e solo contaminado e a análise de teor de metais no solo e nas mudas utilizadas. A coleta de dados foi realizada por meio de uma análise estatística realizada nas raízes, caule e folhas, para verificar se inibição do crescimento e se a fitorremediação é uma alternativa viável.

Resultados e Discussão: Os resultados obtidos revelaram que apesar do caule da planta, em solo contaminado, apresentar inibição do crescimento, suas folhas e caule apresentaram um aumento, sendo este significativo para as folhas, assim a aplicação da *Syngonium podophyllum* como uma planta fitorremediadora é satisfatória. Na seção de discussão, esses resultados são contextualizados à luz do referencial teórico, destacando-se as implicações e relações identificadas. Possíveis discrepâncias e limitações do estudo também são consideradas nesta seção.

Implicações da Pesquisa: As implicações práticas e teóricas desta pesquisa são discutidas, fornecendo insights sobre como os resultados podem ser aplicados ou influenciar práticas no campo da gestão ambiental. Essas implicações podem abranger agronomia, agricultura, remediação de solos e ecologia.

Originalidade/Valor: Este estudo contribui para a literatura ao validar a importância da flora nativa no combate à degradação e regeneração de solos. A relevância e o valor desta pesquisa são evidenciados pelo fato de que a remediação de um passivo ambiental traz uma contribuição à sociedade.

Palavras-chave: Gestão de Passivos Ambientais, Resíduos Sólidos, *Syngonium podophyllum*, Metais Tóxicos.

REMEDIACIÓN DE CAPAS SUPERFICIALES CON *SYNGONIUM PODOPHYLLUM* EN SUELOS CONTAMINADOS CON METALES TÓXICOS

RESUMEN

Objetivo: El objetivo de este estudio es investigar la capacidad de hiperacumulación de la planta autóctona *Syngonium podophyllum* para remediar un pasivo ambiental contaminado con metales tóxicos.

Marco teórico: En este tema se presentan los principales conceptos y teorías que sustentan la investigación. Se destacan la fitorremediación y las principales características de *Syngonium podophyllum*, proporcionando una base sólida para comprender el contexto de la investigación.

Método: La metodología adoptada para esta investigación incluye la adquisición de *Syngonium podophyllum*, su plantación en suelo contaminado para detectar la hiperacumulación por parte de la planta, la comparación de las plántulas en suelo control y suelo contaminado y el análisis del contenido de metales en el suelo y en las plántulas utilizadas. Los datos se recogieron mediante un análisis estadístico realizado en las raíces, el tallo y las hojas para comprobar la inhibición del crecimiento y si la fitorremediación es una alternativa viable.

Resultados y Discusión: Los resultados obtenidos revelaron que aunque el tallo de la planta, en suelo contaminado, mostró inhibición del crecimiento, sus hojas y tallo mostraron un incremento, que fue significativo para las hojas, por lo que la aplicación de *Syngonium podophyllum* como planta fitorremediadora es satisfactoria. En la sección de discusión, estos resultados se contextualizan a la luz del marco teórico, destacando las implicaciones y relaciones identificadas. También se consideran en esta sección las posibles discrepancias y limitaciones del estudio.



Implicaciones de la investigación: Se discuten las implicaciones prácticas y teóricas de esta investigación, aportando ideas sobre cómo pueden aplicarse los resultados o influir en las prácticas en el ámbito de la gestión medioambiental. Estas implicaciones pueden abarcar la agronomía, la agricultura, la recuperación de suelos y la ecología.

Originalidad/Valor: Este estudio contribuye a la literatura al validar la importancia de la flora nativa en la lucha contra la degradación y regeneración del suelo. La relevancia y el valor de esta investigación se evidencian por el hecho de que la remediación de un pasivo ambiental trae una contribución a la sociedad.

Palabras clave: Gestión de Pasivos Ambientales, Residuos Sólidos, *Syngonium podophyllum*, Metales Tóxicos.

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1 INTRODUCTION

Population growth and environmental exploitation are among the main causes of incorrect disposal of polluting compounds in soils and waterways. One example is the traditional agriculture, which produces large amounts of food using agricultural pesticides, containing emulsifying compounds and surfactants that may contain toxic metals (TM) in their composition (Steffen *et al.*, 2011; Leite *et al.*, 2019). In urban areas, the incorrect disposal of industrial waste, which can include metals such as copper (Cu), lead (Pb) and cadmium (Cd), are important sources of these contaminants on soil surface, often becoming industrial liabilities (Alexandre, 2023; Dinu *et al.*, 2021; Cheng *et al.*, 2020). In Brazil, although regulated by specific legislation, the disposal of different types of urban or industrial solid waste, the use of agrochemicals and waste from basic sanitation, are still done incorrectly (Dos Santos *et al.*, 2022). So, it is evident the urgency of enforcing the public policies and the proposition of efficient means of managing wastes from human activities, containing polluting substances, which often become environmental liabilities. Furthermore, contamination does not only cause damage at the place of origin, but also, through runoff and leaching, it can compromise receiving bodies of water in other areas (Stefanoski *et al.*, 2013; Núñez *et al.*, 1999).

2 THEORETICAL FRAMEWORK

It is currently known that it is possible not only to treat, but also to decontaminate areas of environmental liabilities, in a process called remediation, restoring the natural fauna and flora in a healthy way and consequently, bringing benefits to human health (Ding *et al.*, 2014). Thus, phytoremediation has been studied as an alternative for managing soil contaminated by



metals, due to potential for retaining these elements and capacity of adapting of certain species to the contaminated matrix (Bhat *et al.*, 2022). These plants require nutrients present in organic matter, and so the TM become more bioavailable and assimilable by their roots when present in contaminated matrices (Tiodar *et al.*, 2021; Liu *et al.*, 2018). The absorption of these metals as cations species by the roots occurs by the action of enzymes present in plants, through association with microorganisms (Liu *et al.*, 2018; Ribeiro; Österreicher-Cunha; Silva, 2015) or carried by sorbents (Lia *et al.*, 2015; Wang *et al.*, 2020). When bio absorbed by sensitive plants, metals as cations can induce the formation of free radicals (FR), causing metabolic disorders (Ferreira *et al.*, 2020; Rodrigues *et al.*, 2016; Schutzendubel; Polle, 2002), changes in the synthesis of proteins and natural pigments, such as chlorophyll (Hodzic *et al.*, 2021; Piacentini *et al.*, 2020; Mouro, 2018; Vieira *et al.*, 2010).

Depending on vegetal specie, soil pH, chemical element and content, lethal or sublethal effects may occur, such as changes in its physiological and/or biochemical behavior (Barbosa *et al.*, 2013; Tchounwou *et al.*, 2012; Lima, Merçon, 2011; Duffus, 2002). Adaptive processes of bioaccumulatory plant reduce damage caused by metallic contaminants (Alexandre, 2023).

Plants with phytoremediation properties, on the other hand, have an interrelated and sophisticated network of strategies to tolerate these cations toxicity and facilitate vegetative detoxification, as the formation of complexes from the root system, after a a short exposure time (El-Mahrouk *et al.*, 2019). These natural chelators, such as the phytochelatins and metallothionein can bind to metallic contaminants and direct them to the less metabolic important structures of cells plant, such as the vacuoles, where they are confined, without interfering with its other metabolic functions (Sousa, 2020; Mirza *et al.*, 2014; Ali; Khan; Sajad, 2013). This property of certain plant species makes them interesting for the phytoremediation process (Viehweger, 2014; Manara, 2012).

Syngonium podophyllum is an ornamental plant, from the Araceae family, belonging to the *Syngonium podophyllum* genus that has 33 species, originating from Mexico (Hossain *et al.*, 2017), and is considered a phytoremediator (Souza *et al.*, 2018; Barbosa *et al.*, 2013). The robust root system, rapid growth, good resistance to pests are desirable characteristics for its use as a TM phytoextractor (Prabakaran *et al.*, 2019; Gupta; Huang; Corpas, 2013). This study began from the interest in contributing to the solution of an old demand in the municipality of Sorocaba/SP, Brazil, which was an area contaminated by metals from an environmental liability of more than 20 years of existence. The objective was to propose a simple, low-cost and environmentally appropriate method for the remediation of contaminated soils from industrial liabilities.



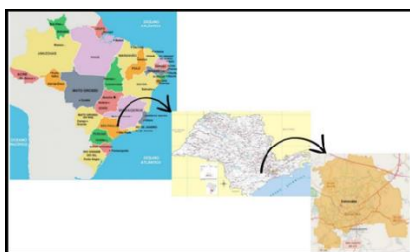
3 METHODOLOGY

3.1 SCENARIO

The industrial liability (Figure 1) is in an industrial neighborhood in Sorocaba City, State of São Paulo - Brazil, whose contamination occurred due to the bankruptcy of the electric accumulator industry, around 20 years ago, since the closure of factory activities.

Figure 1

The industrial liability located in an industrial neighborhood in Sorocaba City, State of São Paulo – Brazil.



3.2 PROCEDURE WITH SYNGONIUM PODOPHYLLUM

Sixty *Syngonium podophyllum* seedlings were purchased from a local flower shop and identified by roots, stems and leaves and were adapted for 20 days at the experiment site. After this period, three random samples of the terrestrial and aerial of the seedlings were separated and washed with running water, followed by deionized water. The roots, stems and leaves were dried naturally, bagged, identified and sent to the laboratory where analyzes for metal determination were carried out in accordance with the recommendation of the EPA's Test Methods for Evaluating Solid Waste standard, called SW 846, method 3050B (EPA, 2022). The control soil used was composed of vermicompost (40%), ash (35%) and solid cattle manure (25%) and the seedlings were planted in 30 pots measuring 25 cm in diameter and 40 cm high.

3.3 SAMPLE COLLECTION

By the collecting the contaminated soil, debris was removed from the upper layers of the soil with the help of an excavator and, at a depth of 40 cm, around 40 kg of soil were removed for the study. This sample was transported to the laboratory, and 100g was separated



and sent to carry out preliminary analyzes to characterize the soil and determine metal content. The analyzes were carried out in a certified laboratory in the city of São Paulo, capital, and followed the recommendations of the EPA's Test Methods for Evaluating Solid Waste standard, called SW 846, method 3050B (EPA, 2022).

3.4 EXPERIMENT SETUP

Thirty *Syngonium podophyllum* seedlings were adapted in control soil for 20 days, after that, the adult plants were selected, ensuring that they were as similar as possible in root, stem and leaf size. The initial length of each plant was measured and they were inserted in new pots containing 200g of contaminated soil. Other samples were separated using the same criteria in pots containing only fertilized soil and were considered controls. All plants remained in a natural environment during the period of experiment.

At the end of the established period of 30 days, the soil and plant samples were removed. The general conditions of the plants were evaluated and recorded, observing the presence or absence of damage or pests, after which they were measured again to compare with the initial measurement. Three samples of exposed plants were sent for determination of metal content in the same laboratory. All procedures were repeated after 60 days.

All the measures of the stems, leaves and roots, initial, after 30 days and 60 days, were analyzed by Prism 5.0 Tukey's Multiple Comparison Test analysis with significance $p > 0,05$.

4 RESULTS AND DISCUSSIONS

Despite the soil having metal contents within legal limits, it was classified as an environmental liability by the Environmental Company of the State of São Paulo, Brazil (CETESB), according to a 2020 report, in the public domain on the page of the Environmental Agency of the state of São Paulo.

At the site under study, intense degradation of the landscape was observed, sometimes it was possible to observe points of spontaneous combustion, probably resulting from the leak of sulfuric acid to the lower layers of the soil and groundwater which, in contact with organic matter, heated up to the point of combustion. It was also observed a strong odor and, upon visual analysis, its appearance was quite dry and reddish in color. Table 1 shows the results of metal determinations in soil from environmental liabilities at the time of collection and after



phytoremediation treatment for 30 and 60 days. The elements Barium (Ba), Lead (Pb) and Copper (Cu) stand out.

Table 1

Comparative analysis of the soil at different times of phytoremediation (mg. Kg-1).

Metal	Inicial	30 days	60 days	CONAMA* 420/2009
Antimony	< 0.500	< 0.500	< 0.500	25
Arsenic	< 0.500	< 0.500	< 0.500	150
Barium (Ba)	77.232	23.665	48.748	750
Boron	< 20.000	< 20.000	< 20.000	-
Cadmium	< 0.100	< 0.100	< 0.100	20
Lead (Pb)	252.491	6.555	3.525	900
Cobalt	< 2.000	< 2.000	< 2.000	90
Copper (Cu)	62.38	8.545	12.525	600
Cromium	< 0.500	7.454	18.151	400
Iron	347.355	19.999	29.625	-
Mercury	< 0.100	< 0.100	< 0.100	70
Molibdenum	< 3.000	< 3.000	< 3.000	120
Nickel	1.999	4.515	< 2.000	130
Silver	< 0.500	< 0.500	< 0.500	100
Selenium	< 0.500	< 0.500	< 0.500	-
Zinc	27.405	64.585	< 10.000	2000

Based on the data in Table 1, it is observed that the elements Ba, Pb and Cu were reduced in the first 30 days of analysis, with no additional effect after 60 days.

The application of the phytoremediation process by means of *Syngonium podophyllum* inserted in soil contaminated by metals, presented satisfactory results, due to the observed reduction in metal contents, notably Ba, Cu and Pb, in the contaminated industrial soil, with correspondent accumulation of these elements in plant tissues (Table 2). A reduction of 36.88% of Ba, 98.6% of Pb and 79.92% of Cu (Table 1) in the soil was observed, through the phytoextraction process, without observable damage to the plants.

Analysis of the aerial parts and roots of the vegetables (Table 2) shows that multimetals were accumulated in all regions of the vegetable over a period of 30 days, with no increase in the subsequent 30 days, considered the period necessary for maximum response of the phytoremediator. The presence of some toxic metals such as Pb and Cu before phytoremediation is probably due to atmospheric pollution, as previously observed by other authors (Lima *et al.*, 2022; Serbula *et al.*, 2012). After 30 days, the accumulation of metals in plant tissues corresponded to a total of 1276.801 mg of metals per kilogram of vegetable mass.



Table 2

Presence of metals in the vegetative parts, for the period studied (in mg. Kg⁻¹).

Metals	Root 0	Root 30	Root 60	Stem 0	Stem 30	Stem 60	Leaf 0	Leaf 30	Leaf 60
Antimony	< 0.500	< 0.500	< 0.500	< 0.500	< 0.500	< 0.500	< 0.500	< 0.500	< 0.500
Arsenic	< 0.500	< 0.500	< 0.500	< 0.500	< 0.500	< 0.500	< 0.500	< 0.500	< 0.500
Barium (Ba)	< 0.500	39.128	28.585	< 0.500	33.941	29.585	< 0.500	70.998	61.215
Boron	< 20.000	< 20.000	< 20.000	< 20.000	< 20.000	< 20.000	< 20.000	< 20.000	< 20.000
Cadmium	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100
Lead (Pb)	2.625	203.538	215.155	4.915	439.957	215.144	3.210	< 0.100	<1.000
Cobalt	< 0.200	< 0.200	< 0.200	< 0.200	< 0.200	< 0.200	< 0.200	< 0.200	< 2,000
Copper (Cu)	4.914	42.399	31.525	2.594	48.764	37.848	2.697	51.099	41.525
Chromium	< 0.500	66.256	56.252	<0.500	29.001	21.515	< 0.500	68.278	55.262
Iron	41.145	218.838	185,855	29.598	35.338	33.202	29.598	< 20.000	< 20.000
Mercury	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100
Molybdenum	< 3.000	< 3.000	< 3.000	< 3.000	< 3.000	< 3.000	< 3.000	< 3.000	< 3.000
Nickel	2.302	107.503	85.958	4.5911	75.939	52.121	2.497	< 2.000	< 2.000
Silver	< 0.500	< 0.500	< 0.500	< 0.500	< 0.500	< 0.500	< 0.500	< 0.500	< 0.500
Selenium	< 0.500	< 0.500	< 0.500	< 0.500	< 0.500	< 0.500	< 0.500	< 0.500	< 0.500
Zinc	14.515	21.077	15.141	17.004	24.274	21.515	9.007	28.866	19.585



The seedlings removed from the pots over a period of 30 days and the control pot shown difference in root dimensions at the beginning and in the end of phytoextraction and in the controls. It is observed that plant control has a longer and more branched root than those that were harvested after 30 days of exposure. In addition to the difference in the root system, the species showed an increase in aerial development, showing an increase in the number of leaves, more intense colors and an increase in aerial biomass.

Treatment was established within the optimal period of 30 days of exposure to multiple contaminants and the reduction of metal contents contributes to the soil restoration process. Data from measurements of individual parts of exposed plants are presented in Table 3. It is observed that there was a significant reduction in root length by after 30 days of insertion of contaminated soil (Figure 2A). However, there was an increase in stem size and a significant increase in leaf size respectively (Figures 2 B and C). This decrease in the root system in the presence of metals has been observed in previous works (Gianello et. al., 2011; Alva; Huang; Paramasivam, 2000). This damage caused by multiple metals can be explained by the inhibition of cellular processes, damage to the structures and oxidation of protein molecules in this structure of the plant (Ferreira et. al., 2020; Sposito, 1989; Reilly; Reilly, 1973). The interaction with the walls of root cells that are in contact with metallic cations could direct the harmful potential to the aerial parts, but the phytochelatin and TM complexation reduces the harmful potential to the upper parts of the plant (Rodrigues *et al.*, 2016, Dos Santos *et al.*, 2011). In the case of Pb, it can be exchanged with Ca, facilitating its mobilization in plant tissues (Matias, 2011).

Table 3

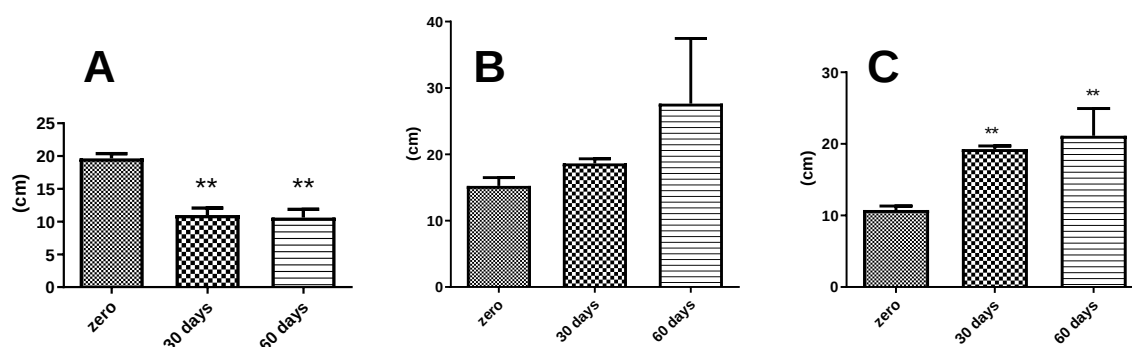
Measurements of Syngonium podophyllum, (in cm) after 30 days of contact with soil containing TM.

Plant	CONTROL			EXPOSED		
	Root	Stem	Leaf	Root	Stem	Leaf
1	18,6	15	13,5	13,1	17,5	20,1
2	10,20	14,30	9,50	10,10	19,90	18,60
3	32,30	14,2	11,30	11,20	22,20	16,20
Media±DVP	20,37±7,96	14,65±0,35	11,43±1,38	11,47±1,09	21,05±1,15	18,30±1,40



Figure 2

Measurements of the vegetative species during the studied period. In A, roots measurements. In B, stems measurements. C, leaves measurements.



5 CONCLUSION

It was demonstrated that it is possible to decontaminate an industrial area in 30 days of insertion of a single plant species, in a degraded soil with multiple metals, pointing to a viable solution for treating environmental liabilities, that is, a tool for management of solid waste in a sustainable and low-cost way, using a fast-growing and shallow shrub phytoextractor.

The *Syngonium podophyllum* as a phytoremediation tool for soils contaminated by metals, it was possible to do the reimplantation of other species and the reintroduction of fauna or flora, restoring the ecosystem, in addition to improving the local visual aspect, improving the functionalities of this land. It is a frugal innovation product with the possibility of immediate application on similar soil conditions.

Finally, as a contribution to society, the study demonstrated that phytoremediation is an interesting and viable methodology for different types of environmental matrices. By inserting phytoremediation plants into soils with anthropogenic degradation, the landscape is vastly improved, in addition to reducing site erosion. As advantage, this species does not suffer serious damage, unlike other less evolved plants. Phytoremediation is one of the technologies recommended by environmental agencies to treat contaminated areas.



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