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Phytoremediation Potential of *Chrysopogon zizanioides* for Toxic Elements in Contaminated Matrices

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Abstract

Many researchers have demonstrated the advantages of plants in the phytoremediation of soils and waters contaminated with heavy metals, herbicides, pesticides, leachates, etc. The unique morphological characteristics of *Chrysopogon zizanioides*, commonly known as vetiver, make it a hyperaccumulator of metals; its roots can store high concentrations of heavy metals such as As, Cd, Cr, Cu, Hg, Ni, Pb, Se, and Zn, and it has thus been successfully used in the field of environmental protection. This chapter presents the importance of vetiver, its characterization, and its potential use as phytoremediation potential for toxic elements in contaminated matrices.

Keywords: vetiver, leachate, phytoremediation, metals, hyperaccumulation

1. Introduction

Heavy metals are natural elements that have a high atomic weight and a density at least five times that of water, due to their high degree of toxicity, some such as Arsenic (As), Cadmium (Cd), Chromium (Cr), Lead (Pb), Copper (Cu), nickel (Ni), selenium (Se) Zinc (Zn) and Mercury (Hg) are considered harmful to health and the environment, raising concerns for setting up adequate prevention or restoration measures that reduce these risks. A special topic of global interest is the residual concentrations of heavy metals since some studies have shown that heavy metals, especially because are considered bioaccumulative in various matrices (range from ng kg^{-1} to less than 10 mg kg^{-1}) [1].

These last components are generated mainly by human activities such as mining, emissions, agriculture, and industrial waste; some studies mention that in high concentrations heavy metals such as Cd, Cr, and Pb can have potential toxic effects, for example, some studies they have observed that they could interact with the to the growth and general metabolism of humans and animals [2]. Also, it was reported

that mean concentrations of heavy metals could affect the biodiversity through their bioaccumulation in different organisms, although it has been observed that this also depends on the type of ecosystem, the exposure time and other environmental factors [3]; such as, some reports suggest that the disposal mechanisms could also depend on the balance between sorption and desorption, as well as the natural dynamics of the soils on which they are deposited, the soil constituents (inorganic and organic), and the chemical nature of the soil. Compound [4].

Many studies have found that waste dumps are sources of heavy metals, most have reported As, Cd, Cr, Cu, Hg, Ni, Pb, and Zn, although the receptor organs are diverse, due to the conditions of storage, disposal, and importance in food production, the treatment of soils and aquifers contaminated by these compounds has gained interest in the last decade [5–7]. The disposition that each of them could have to the environment, can be measured in terms of leachates, whose composition varies from one site to another since they regularly are created by the biodegradation of waste, in some cases, depending on their diffusion capacity in the soil, they could pollute both groundwater and surface water [8]. Numerous studies have emphasized the importance of remediating these sites, mentioning that feasible and long-term alternatives must be created, especially, that guarantee low exposure of these pollutants in places that have a population immersed or that are destined for activities of the primary sector [5].

Heavy metal contamination and pesticides is a serious problem worldwide due to their toxicity, furthermore, assessing the impacts is very complex due to the fact that many species have cumulative and non-biodegradable properties, but cases have been reported, in which certain species of plants could be indicators of these pollutants [6, 8]; also, although some organisms usually transport or extract them from a matrix, they only transform it to other oxidation states in the soil, in terms of bioremediation, some technologies take advantage of this behavior to reduce their mobility and toxicity, however, if they are not remediated sites, metals can reach humans [9–11].

However, although it has been shown that these methods tend to control various types of organic or inorganic pollutants in the long term [12–14], some studies have warned about the risk factor of those plant species that tend to be hyperaccumulative and can also be a food source for some grazing or wild species (it has been reported that the concentration of Cd or Pb metals in hyperaccumulating plants is usually between 10 and 100 times higher than that of the soil) [15, 16].

Vetiver grass is a perennial herb of the Poaceae family, native to India. It is a plant that has been cultivated for many years in Asia, especially in India [17], can grow in a wide range of climatic conditions, and if planted correctly can be used anywhere in tropical, subtropical or Mediterranean climates [18].

Compiled by Méndez-Cano [19]; the plant vetiver is a perennial herb that forms dense clumps **Figure 1**; it has sterile inflorescences and seeds and reproduces vegetatively. It can withstand extreme droughts due to the high salt content in the sap of its leaves, it can withstand extreme droughts due to the high salt content in the sap of its leaves and also flooding for long periods. It grows in a wide range of soils with different levels of fertility, it is tolerant to extreme climatic variations, such as prolonged droughts, floods and temperatures ranging from -9 – 55°C . It grows in soils, including rocky soils, and can also be grown in hydroponic conditions. It tolerates pH levels between 3.3 and 12.5, as well as saline, acidic, alkaline and sodic media with a high load of nutrients and heavy metals. It is classified as a C4 type plant due to its high atmospheric CO₂ fixation capacity.

Recent research compares the variability in biomechanical properties of *Chrysopogon zizanioides*, including tensile strength, Young's modulus and strain at break, which have a direct implication to root reinforcement to slope [20], interesting studies reveal that biomass extracted from the roots of the species can be used as

Figure 1.
Chrysopogon zizanioides.

activated carbon. This work offers an innovative and environmentally safe approach to control porosity in biomass-derived activated carbon (BAC) materials for energy storage applications [21]. Natural fibers as compared to synthetic fibers are having higher strength, rigidity and also in supporting the structural load of matrix. Vetiver fiber is used as reinforcement for the polymer composites with polypropylene and polyethylene as matrix material [22].

Authors demonstrate the application of vetiver grass has been widely promoted in tropical regions as a cost-effective and environmental-friendly solution for slope stabilization and erosion control for many years. Despite its potential, vetiver grass utilization has not been widely accepted by disadvantaged agricultural communities at landslide hazard areas [23].

Also floating Hydroponic System (FHS) is a potential and cost-effective technique for wastewater treatment. Vetiver is a more efficacious material for phytoremediation due to its physiological and morphological properties [24].

Although there are reports of several species discovered with high potential for phytoremediation, vetiver is a grass species that meets all the criteria required to eliminate contaminants in water and soil, but are few reports of use [12]; an important point is that this plant can survive under hydroponic conditions, has been used for a long time in water and soil conservation [25–27], in the rehabilitation and restoration of landfills, as in the phytoremediation of leachates, it survives under hydroponic conditions [28]. Many species have been reported as metal phytoremediators but few have been reported to be able to adapt to extreme altitude, climate, variable pH, and exposure conditions in eutrophic systems; thus, it is of great importance to continue studying native species to identify potential alternative phytoremediators

[29]. For these reasons, in this study, we present a review of the importance of vetiver, its characterization, and its potential use as a remediation alternative.

2. General characteristics of vetiver (*Chrysopogon zizanioides*)

Vetiver belonging to the Poaceae family, native to India [19]. Is one of the few species of grass that meets all the criteria necessary to eliminate contaminants [28]. Regarding its morphological characteristics, it's a tall grass (1–2 m) with abundant vegetative growth, characterized by a massive, finely structured and deep root apparatus, capable of reaching 3–4 m deep in the first year [27]. For this trait, vetiver grass is well known for its effectiveness in controlling erosion and sediments [30].

It has long, narrow leaves that produce a thick growth barrier that cuts and separates runoff water. This type of growth also allows vetiver to act as an effective filter by trapping sediments and contaminants linked to them such as heavy metals and some pesticide residues [31]. One of the most useful physiological characteristics of vetiver is its high tolerance to high concentrations of heavy metals such as Al, B, Ba, Be, Co, Cr, Cu, Fe, Mg, Mn, Ni, Pb, S, Se, Tl, V, and Zn [12, 13, 19, 31, 32]. In **Figure 2**, shows a summary of the morphological characteristics of vetiver plant, and heavy metals to tolerant.

Some studies mention that the dense and finely structured root of this plant creates an ideal environment for microbiological processes in the rhizosphere, these characteristics also make vetiver a good alternative for stabilizing river banks and road embankments and preventing erosion [31]. However, the efficiency and cost-effectiveness in water and soil conservation, particularly in the treatment of wastewater, were only recognized in the decade of the 80s when its outstanding physiological and morphological characteristics were identified [31], but these distinctive features, make it an effective phytoremediator species for the treatment of various types of contaminants; also these attributes, together with its high biomass production, type of reproduction, and adaptations to climate changes, also make vetiver an ideal species for the phytoremediation not only of soil but also of artificial systems such as wetlands [12].

Figure 2.
Morphological characteristics of vetiver (*C. zizainoides*).

3. Methods for the characterization of heavy metals in phytoremediation

The different techniques applied for the characterization of heavy metals are presented in **Table 1**.

One of the techniques that can be used for the identification of heavy metals is Atomic Absorption Spectroscopy (AAS), this analytical technique is widely used to determine more than 70 elements in solution and in different matrices, in quantities as low as 10–14 g with reasonable selectivity, little manipulation, and minimum sample size. It can indirectly identify anions and organic compounds [33, 34]. This technique is older than ICP-OES (Inductively Coupled Plasma Optical Emission Spectroscopy), and various authors have reported studies comparative with other methods cited in environmental regulations [12, 28, 38], some mention that it makes it possible to quantitatively determine the chemical elements that constitute a material quickly, precisely, and accurately [7, 13, 39].

To convert solid and liquid samples into aqueous solutions for analysis with ICP-OES and AAS, it is necessary to eliminate all organic material to avoid interferences and obtain the analytes of interest at detectable concentrations [12, 38, 40–43]. Acid digestion is a necessary process in the identification of metals, which is done by acid decomposition at high temperatures [36] or using mixtures of HNO₃ and H₂O₂ [37].

Another method used is X-Ray Fluorescence spectroscopy (XRF). It can identify analytes or other components of interest and it is thus very useful for qualitative analysis. It is currently used in the fields of archeology, forensic sciences, medicine, geology, coatings, materials, electronics, pharmaceuticals and environmental sciences, used this method to perform qualitative and quantitative analyses of heavy metals [35, 44].

Technique	Characteristics	References
Atomic Absorption Spectroscopy (AAS)	Identify at least 70 elements in quantities as low as 10–14 g, high selectivity.	[33, 34]
Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES)	Quantify chemical elements that constitute a material quickly, accurately.	[7, 13, 35]
X-Ray Fluorescence spectroscopy (XRF)	Identify analytes or other components of interest, is very useful for qualitative analysis.	[36, 37]

Table 1.
Techniques for characterization of heavy metals.

4. Vetiver: potential use in phytoremediation

Several authors have achieved the mitigation of different types of heavy metals using vetiver grass (**Table 2**) and determined the amount of Cr absorbed from the residual sludge of a tanning facility and found a concentration of 596.92 mg kg⁻¹ in the leaf tissue [38], others studies showed that the effect on vetiver of having a concentration of As of 225 mg kg⁻¹ is a slight yellowing of the leaves and a small decrease in biomass [36]; these results confirm that this grass can survive successfully in soils moderately contaminated by As [31].

The capacity of vetiver to remove contaminants has also been tested using compost leachate, an experiment that was allowed to stand for 112 days without

Heavy metals	Origin	References
Cr	Residual sludge tannery	[39]
Cd, Cu, Fe, and Pb	Compost leach	[38]
As, Cd, Ni, Pb, and Zn	Ash remediation	[28]
Al, Cr, Cu, Fe, Mn, Ni, and Zn	Rehabilitation of iron mine	[13]
Cu, Fe, Mn, Pb, and Zn	Water polluted with heavy metals	[12]
Cr, Cu, Pb, and Zn	Soil contaminated with heavy metals	[38]
Cu, Fe, Mn, Pb, and Zn	Industrial waters	[24]
B	Industrial waters	[44]

Table 2.
Heavy metals absorbed for vetiver grass.

aeration, showed that the concentration of Cd, Cu, Fe, and Pb decreased after the treatment with vetiver, and therefore can be used to for the bio-purification of compost leachate [42]; others study evaluated the efficiency of vetiver in the absorption of metals based on the translocation and bioaccumulation factors, the results revealed that roots have a high uptake capacity for Cd, Pb, and Zn, however, there was a low translocation of metals such as Cd, As, Ni, and Pb towards the aerial part of the plant and accumulation of Zn in the roots was the highest at 100% [28].

However, some similar reports found a highs amount of Fe accumulated in the roots, despite this, the results show that vetiver is a good phythostabilizer and potential accumulator of heavy metals since in the roots they also found the presence of Al, Cu, Mn, Zn, Cr, and Ni, but in concentrations, inferiors to Fe [13]. In research similar, the absorbed metals were found to be in order $Fe > Pb > Cu > Mn > Zn$, the results also showed that as the length and density of the roots increases, so does the absorption of heavy metals, but suggest being careful if in the site intends to develop other species, due to the competition of Fe and its importance in the physiological processes of plants [12].

In 2007, a study assessed the efficiency of the vetiver grass in the phytoextraction of Cr, Cu, Pb, and Zn in order to establish whether this plant could be considered a good hyperaccumulator of those heavy metals. Phytoextraction experiments showed that vetiver was little efficient in the uptake of Cr and Cu (less than 0.1% in shoots and roots after 30 days for both metals), but highly efficient in the uptake of Pb and Zn (0.4% in shoots and 1% in roots for Pb and 1% in both shoots and roots for Zn, after 30 days), for these reasons, vetiver grass can be considered a good enough “hyperaccumulator” of Pb and Zn [41].

In 2013, other researchers measured the ability to remove heavy metals from industrial wastewater. Vetiver were grown on four samples of industrial wastewater taken from a milk factory, a battery manufacturing plant, an electric lamp plant, and an ink manufacturing plant, the results indicated that could tolerate and grow in wastewater [24].

On the other hand, some studies have evaluated the efficiency of vetiver in the treatment of leachates with the aim of reducing chemical oxygen demand, total suspended solids, total dissolved solids and total organic carbon in municipal landfill leachates. The results revealed a removal efficiency of approximately 90% [45]. A relevant study evaluated the differences in tolerance and accumulation of boron between reed (*Phragmites australis* L.), cattail (*T. latifolia* L.) and vetiver, these plants survived concentrations of B of up to 250, 500, and 750 mg L⁻¹, respectively, therefore, vetiver showed the highest tolerance to B [40]. Thus, the evidence described above confirms the phytoremediation potential of the vetiver

grass, the findings of different studies have confirmed the potential of vetiver as a phytoremediation plant for use in the removal of heavy metals from contaminated soils [12, 46, 47] and in the rehabilitation of landfills [35]. Although it is not an aquatic plant, vetiver can grow and survive under hydroponic conditions [48] and can be used to remediate eutrophic waters, wastewater from pig farms [49], and waste leachates [50].

Further studies could focus on increasing the uptake of heavy metals using, for example, chelating agents [41] and explore the ability of vetiver to participate in the remediation of other pollutants such as endosulfan [49]. The dense growth of vetiver roots can prevent erosion and landslides and act as a natural barrier that could be used in landfill cells to prevent leachates from infiltrating the aquatic mantle, regardless of the impermeable barrier (geomembrane) that is commonly used in landfills.

5. Conclusions

The new trends in the restoration of degraded soils, wastewater and even leachates generated from urban waste include phyto-management as part of a Circular Economy model which is an attractive and viable alternative that is already being explored by different companies; it is based on the principles of preservation and optimization of natural resources, as well as improving the efficiency of production systems by eliminating or reducing environmental contaminants. Therefore, phytoremediation can be considered a circular economy strategy because it aims to reduce both the entry of materials and the production of waste.

In different matrices water, soil, air there are inorganic contaminants which include trace elements that are essential for the growth and development of plants, heavy metals and some non-metallic elements such as As and B are also included. Toxicity varies according to many factors, such as the chemical form of the elements, concentration, persistence among other factors, some compounds can be transformed to their less toxic forms such as Cr. *Chrysopogon zizanioides* is a hyper-accumulator species with a sometimes unpleasant appearance and its growth capacity makes it ideal for phytoremediation.

Based on group experience we know that this species can survive, tolerate, absorb and transform. Also based on the literature we know that there must be periods of acclimatization of the species for its transformation and or ideal absorption of the compounds. Due to previous knowledge about the phytoremediation process, which is an integral methodology where at the same time the species phytovolatilizes, rhizofiltration, phytodegrades. Due to the characteristics of the species, it can be a permeable membrane to prevent or sequester toxic elements to the water table, but thanks to the life cycle of this species it can absorb significantly contaminated by its modular growth. However, dead leaves may contain some compounds that cannot be degraded and these should be confined or incinerated to ensure that they do not return to the soil.

The essential oil extracted from vetiver roots can be used in the perfume industry, vetiver leaves can be used for roofing of rustic houses and the plant is already used as a fire barrier because it keeps growing even after being burned. In addition, the use of vetiver has the purpose of improving the management of degraded spaces and their restoration through innovative phytoremediation techniques. Vetiver could be used in many countries throughout the world due to its economical accessibility and ability to adapt to different climatic conditions, as well as its capacity to remove different types of pollutants as has already been evidenced.

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Conflicts of interest

The authors declare no conflict of interest.

Nomenclature

Al	aluminum
B	boron
Ba	barium
Be	beryllium
Cd	cadmium
Co	cobalt
Cr	chromium
Cu	copper
Fe	iron
Mg	magnesium
Mn	manganese
Ni	nickel
Pb	lead
S	sulfur
Se	selenium
Tl	thallium
V	vanadium
Zn	zinc

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