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Review

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Evaluation of Phytoremediation Capacity of Guinea grass (*Panicum maximum*): A Focused Review

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A B S T R A C T

Environmental contamination from heavy metals has grown to be a significant problem on a global basis. Due to the mobilisation of heavy metals during ore extraction and subsequent processing for diverse applications, they have been dispersed into the environment. Utilising plants for pollutant extraction, degradation, or volatilization is possible. Using plants and the bacteria that live on them to clean up the environment is known as phytoremediation.
The bioaccumulation of elements in the body tissues of hyperaccumulator plants is used in phytoextraction, phytofiltration, phytostabilization, phytovolatilization, phytodesalination, and phytomining processes. As they move from low trophic levels to high trophic levels, their concentrations rise (a process also named as biomagnification). Recent studies indicate ability of *Panicum maximum* to clean places that have been contaminated with diversified heavy metals and other types of pollution.

1. Introduction

The accumulation of organic sludge, industrial chemicals, heavy metals, and household trash in seas and rivers has led to water pollution, while the emission of harmful gaseous elements from factories and automobiles has led to air pollution (Corami, 2023) and the contamination of water bodies. One of the major environmental issues facing humanity today is the growing discharge of untreated wastewater from mining and industry, as well as excessive fertiliser use for agriculture and soil contamination from heavy metals (Prommarach et al., 2022). Heavy metal pollution is a severe issue for the environment worldwide. Particularly in mining regions, the microbiological life in soil is severely harmed by cadmium (Cd) and lead (Pb) (Xiao et al., 2020). Due to its phytotoxicity, cadmium has generated significant environmental issues requiring for methods to lower its concentration in the environment (Rabelo et al., 2017).

Despite all the financial advantages of cement manufacturing, heavy metals, a byproduct of the process, can pose major risks to the environment and public health. The levels of heavy metals lead (Pb), cadmium (Cd), copper (Cu), chromium (Cr), zinc (Zn), and manganese (Mn) in the factory wastes are higher than allowed (Javanmardi et al., 2022).

A significant amount of coal overburden is produced along with the extraction of coal, and this overburden is piled on the nearby ground in the form of external dumps. Groundwater and surrounding soil contamination brought on by heavy metals, land degradation, and loss of biodiversity are the main issues connected to coal overburden dumps (Kumar et al., 2023).

According to Sajjad et al. (2022), the presence of plastics in soils raises the concentration of potentially harmful metals (As, Zn, Cu, and Pb),

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causes an excessive loss of soil water, and may limit microbial activity. In addition to other organic pollutants, soil pollution caused by explosives is a significant environmental hazard. Ground and surface fluids, soils, and sediments are contaminated by explosive compounds that are entered into the environment during manufacturing, processing, and disposal processes at military facilities (Singh & Mishra, 2014).

While certain agricultural plants are naturally able to tolerate fluoride (F−), most are inhibited in their development and metabolism by excess fluoride (Gadi et al., 2021). Worldwide, P losses from agricultural areas have grown to be a serious environmental issue. Although several methods (including cultural practises like non-till, crop rotation, buffer strips, cover crops, and the application of chemical amendments) have been investigated to decrease P mobility in P-enriched soils, these methods typically do not result in lower in situ soil P concentrations. Several studies have demonstrated that chemical amendments, such as gypsum and materials containing aluminium, can immobilise phosphorus (P) by generating insoluble complexes, hence lowering the likelihood of P movement off-site. But significant problems regarding the stability and liability of P immobilised by soil amendments over the long run remain unsolved (Silveira et al., 2013).

In 31 nations around the world, there are operational nuclear power reactors. The primary sources to the nuclear waste, outside reactor operating, are mining, fuel manufacture, fuel reprocessing, and military actions. The waste streams could pose a radioactive concern to the environment due to the existence of numerous long-lived radionuclides with different oxidation states, including plutonium (Pu), neptunium (Np), americium (Am), and curium (Cm). Nuclear waste frequently contains significant amounts of cesium (137Cs) and strontium (90Sr). Due to their lengthy half-lives and simple translocation into the human body, these radionuclides are able to cause potential health risks. Along with radionuclides, heavy metal pollution is a significant problem. In small amounts, heavy metals are found naturally in the crust of the planet and are also necessary for life's metabolic processes. These heavy metals' bioaccumulation has dangerous side effects. These contaminants enter into human bodies directly through polluted drinking water or the food chain. Scientists from all over the world are working on environmentally friendly solutions to fix the soil and water supplies because of this issue. The waste can be cleaned by using a variety of physical and chemical approaches, but these processes are highly expensive, difficult, and have several adverse effects. Phytoremediation is one of the effective strategies that has been pursued actively to address these drawbacks. The procedure is simple, easy, and incredibly cost-effective. With this method, low- and moderately contaminated locations are effectively decontaminated using plants and the bacteria they are connected with. For the successful rehabilitation of contaminated water and soil systems, numerous plant species are utilised. Remediation of these systems has become a crucial problem as a result of several human activities that significantly increased the amount of heavy metals and radionuclides in these systems. Additionally, the size of the contaminated sites is growing as a result of these activities (Sharma et al., 2015).

2. Phytoremediation

Heavy metal accumulation in the environment is attracting the attention of the scientific community, which is looking for alternatives that may minimise the effects that are brought on by this process (Carrasco-Gil et al., 2012). In order to replace the harmful components with biocompatible, non-toxic, and environmentally friendly materials, scientists are developing green synthesis techniques. The ability of plants to endure dangerous soil minerals and organic compounds as well as their capacity to defend themselves against environmental dangers are well established. For protection against chemicals, plants have a variety of defense mechanisms. Hazardous metals can have their redox states changed into non-toxic ones by using reducing enzymes and proteins that sequester toxic metals (Oza et al., 2020). The cultivation of metal-accumulating plants, which encourage the uptake and accumulation of soil pollutants in their biomass, is one of these solutions (Pramanik et al., 2018).

In Phytoremediation, plants are utilised to decrease the negative effects of heavy metals in the environment (Ashraf et al., 2019). Phytoremediation is a new alternative technology to traditional remediation methods, has the benefit of being both economically and environmentally sustainable (Hasan et al., 2019). Two of the most often applied phytoremediation techniques for heavy metal-contaminated soils are phytoextraction and phytostabilization (Yan et al., 2020). Fastly growing plants that can withstand high metal concentrations in their aboveground tissues are employed in phytoextraction. Plants with a strong potential to decrease metal mobility in the soil are utilised in phytostabilization (Wei et al., 2021). In contrast to phytostabilization, which keeps metals underground, phytoextraction is thought to be a permanent solution for the uptake of heavy metals (assuming it involves the final disposal of avoveground biomass) (Yan et al., 2020). For phytoextraction to be successful, a plant must have high aboveground biomass output, high tolerance, and the capacity to extract, transmit, and accumulate metals. Hyperaccumulator plants, which are accumulator plants with high biomass production, are the most suitable for phytoremediation in this regard. Although they may have low production, hyperaccumulator plants can accumulate over hundred times the typical amounts of accumulated metals or metalloids in their aboveground biomass without displaying any symptoms of phytotoxicity (Chamba-Eras et al., 2022). The prevailing consensus is that species utilised in phytoremediation with high biomass production capacity can compensate their comparatively low metal accumulation capability (Ali et al., 2013). The adoption of species that are not just tolerant but also capable of showing quick development, large biomass yield, and the capacity to concentrate the toxic element is essential to the success of this technique (Cheng et al., 2016).

The improper disposal of industrial and municipal waste, the use of phosphate fertilisers, and the application of sewage sludge, among other things, have all contributed to an increase in the concentration of cadmium in the environment over the past several decades. Given that Cadmium (Cd) is hazardous to plants, animals, and people, this fact poses a serious socioeconomic issue (Stritsis and Claassen, 2013). Because of this, a number of methods to lower the amount of Cd in the environment were researched, most notably phytoextraction (Sheoran et al., 2016). But, there are currently only a few types of plants known to be Cd hyperaccumulators, which encourages research on other plants, such as forage grasses. In phytoremediation, the grasses (ex: *Panicum maximum*, *Urochola maxima*, *Chromolaena odorata*, *Lolium multiflorum*, *Zea mays* and *Mirabilis Jalapa*) have been tested with favorable results (Yavari et al., 2015). Plant growth may be hampered by soil pollution brought on by inappropriate waste disposal. Tropical fodder plants grow quickly, produce considerable amounts of biomass, and grow up strongly (Gonçalves & Monteiro 2023).

When grown in soils with metal contamination, hyperaccumulators concentrate trace and heavy metals in their shoots; these trace metal-loaded plants can be eliminated by harvesting the fields. The invention of phytoextraction is a result of studies examining the usefulness of these hyperaccumulators for environmental cleanup (Sheoran et al., 2016). There are, however, only a few known plant species that are Cd hyperaccumulators as of right now, which encourages research on other plants such forage grasses. The increased biomass of these plants, when grown with an appropriate supply of sulphur (S), can compensate the lower proportional Cd accumulation (Rabêlo et al., 2017a). Sulphur of amino acids reduced phytochelatins (PCs) and glutathione (GSH) that work to chelate and prevent harm from Cd, and an appropriate application of this nutrient can raise the Cd extraction capacity (Seth et al., 2012).

Utilising bioenergy crops to remove excess soil P is a contemporary alternative technique to alleviate environmental issues caused by P transport from agricultural soils. The expense of plant-based P remediation solutions can be mitigated in addition to the positive effects of P mitigation when harvested biomass is used as a renewable energy source (Silveira et al., 2013). Significant levels of P can be removed from P-enriched soils through phosphorus remediation utilising forage crops, according to findings (Newman et al., 2009). Due to their persistent nature, relatively high dry matter yields, and lengthy growth season, perennial warm-season grasses offer a potential alternative to reduce excess soil P. Additionally, the properties of their roots and growth help reduce surface runoff and soil erosion (Delorme et al., 2000, Surmen et al., 2018).

Since most commercially grown crops only remove small amounts of phosphorus, it will take decades for plant-based remediation solutions to bring phosphorus levels down to levels that are safe for the environment. The disposal of the harvested plant biomass and the high expense of crop establishment, care, and production are two additional drawbacks of using phytoremediation technologies to reduce excess soil P. A more modern alternative to phytoremediation is the production of bioenergy from plants. Even though the synergies between phytoremediation and bioenergy production have not been thoroughly examined, particularly for the phytoremediation of P, previous researches have shown that metal-accumulating plants can be used for bioenergy generation (Van Ginneken et al., 2007). Some perennial bioenergy crops, as opposed to annual crops, may require less N fertiliser to maintain yields (McLaughlin & Kszos, 2005), adding to the viability of plant-based P remediation solutions (Silveira et al., 2013).

Nano-bioremediation is removing or decreasing environmental contaminants from contaminated locations, such as heavy metals, e-waste, inorganic, and organic pollutants, using nanoparticles formed by bacteria, fungi, and algae with the use of nanotechnology. It is referred to as nano-phytoremediation when such environmental toxins are reduced or eliminated using nanoparticles made by or involving higher plants. Nanoparticles are extremely small atomic or molecule aggregates that range in size between 1-100 nm and can dramatically alter the physico-chemical characteristics of a substance as compared to bulk material. Some types of nanoparticles are: natural nanoparticles (volcanic dusts), and mineral composites; incidental nanoparticles (welding fumes), coal combustion, diesel exhaust; and engineered nanoparticles (nanogold, nanozinc, titanium dioxide and nanoaluminium). Similar to phytoremediation, nano-phytoremediation uses a variety of processes. Accordingly, depending on the processes involved, there may be nano-phytostabilization, nano-phytodegradation, nano-phytovolatilization, nano-rhizofilteration, nano-phytoaccumulation, and nano-phytohydraulics. By enabling access to previously inaccessible locations and encouraging in-situ repair, among other things, nanotechnology improves phytoremediation efficiency. By combining the functions of microorganisms and plants and enhancing them with nanoencapsulated enzymes, nano-phytoremediation makes it easier to break down complex organic chemicals that are resistant to degradation into simpler ones. Nanoparticles with high affinity for metal/metalliod absorption include nanosized zero valent iron (nZVI), titanium oxides, manganese oxides, cerium oxides, and zinc oxides. They are effective for remediation of various contaminants, including 2,4,6-trinitrotoluene (TNT explosive), e-wastes (electronic wastes), heavy metals, polychlorinated biphenyls, endosulfan, and others due to this affinity, their many active surface sites, and high surface area (Nwadinigwe & Ugwu, 2018).

3. Phytoremediation by Guinea grass (*Panicum maximum*)

In addition to their high biomass production (often greater than 20 t DW ha-1 year-1), forage grasses typically have a deeper root system, low requirements for soil fertility, higher adaptation to soil and climatic adversities (Rabêlo et al., 2018a). These traits make them perfect for phytoextraction (Vangronsveld et al., 2009). As a result, numerous studies using forage grasses have been carried out to evaluate its ability for accumulating heavy metals and its potential for phytoextraction (Marzban et al., 2017; Rabêlo et al., 2017b, c, 2018c, d).

Recent studies has shown that *Panicum maximum* has the capacity to clean up sites that are contaminated with copper, cadmium, and barium (Monteiro et al., 2011; Gilabel et al., 2014; Silva et al., 2016). Because of its ability to regenerate, tolerance to biotic and abiotic stressors, and favourable response to fertilisation, this grass is simple to produce and has a high production potential (Silva et al., 2016).

Fakayode and Onianwa (2002) conducted research on Guinea grass (Panicum maximum) in the area of Ikeja Industrial Estate in Lagos, Nigeria. They found highly significant relationships between the soil and grass levels of Mn (0.94), Cd (0.83), Ni (0.90), and Pb (0.73). Cr (23), Cd (34.1), Ni (23.4), and Mn (12.3) had greater accumulation factors (indicating the ratio of average metal concentrations at the contaminated site to that of the control site) than Pb (9.8), Zn (7.2) and Cu (8.7) in the panicum maximum.

According to Paquin et al. (2004), *Panicum maximum* was a successful species for the elimination of RDX (an explosive) (1,3,5-trinitro-1,3,5-triazinane) in Hawaii. According to Lamichhane et al. (2012), the phytoremediation of "RDX explosive" by Panicum maximum was accelerated in the presence of molass and led to RDX disappearance mostly in the root zone.

A possible energy crop that needs additional research is the tropical forage Panicum maximum, which has high biomass, rapid growth, and low humidity content (Ram, 2009). Maximum CV for panicum. Massai (Massai grass) has demonstrated exceptional resilience in surviving at concentrations of 0.1 mmol L-1 Cd in the nutrient solution, even at Cd concentrations in their shoot exceeding 100 mg kg1 DW. This shows that this species may be used for Cadmium phytoextraction (Rabêlo et al., 2018b, c, d). The Massai grass can be used as a model plant in this regard to determine the main plant processes that lead to cadmium accumulation in fodder grasses. According to Gallego et al. (2012), a number of factors, including the plant's nutritional status and its ability to transfer Cadmium from roots to shoots, synthesise Cadmium chelators like glutathione and phytochelatins, and reduce the oxidative stress caused by Cadmium are linked to Cadmium accumulation. However, according to Rabêlo et al. (2018a), we are unsure which of these plant responses is in fact more connected to Cadmium accumulation in fodder grasses. In order to choose forage grasses with a true capacity for Cadmium phytoextraction, it is imperative to establish the primary plant responses connected to Cd accumulation (Rabêlo et al., 2019).

Malondialdehyde levels in tissues was shown to rise when P. maximum Jacq. cv. Massai was exposed to cadmium, according to Rabêlo et al. (2018). Malondialdehyde is a naturally occurring chemical molecule and a sign of oxidative stress with the molecular formula CH2(CHO).

Trinitrotoluene (the explosive used in TNT explosives) can be removed from polluted soil through a novel technique called nanophytoremediation, which was developed by Jiamjitrpanich et al. (2012). This technique combines phytoremediation with nanoscale zero valent Fe (iron) (nZVI). In this study, the purple guinea grass was employed for nano-phytoremediation of soil contaminated with a TNT/nZVI ratio of 100 mg/kg TNT concentration, and it was shown that the remediation of the TNT had been finished in 60 days.

4. Effect of plant nutrition level on phytoremedition

According to de Souza Cardoso and Monteiro (2002), sulphur (S) can play crucial roles in defending plants against abiotic stresses, such as the toxicity of heavy metals. A promising strategy in phytoremediation is the assessment of the impacts of S supply since S can reduce the phytotoxicity brought on by heavy metals (Rabelo et al., 2017).

The simultaneous uptake of NO3 (nitrate) and $NH4^{+}$ (ammonium) by plants is advantageous because it can affect heavy metal bioaccumulation (de Sousa Leite & Monteiro, 2019).

It has been demonstrated that the beneficial element silicon (Si) increases plants' ability to tolerate excess metal in a particular growing media. The effectiveness of Si in reducing Cu toxicity in plants may, however, differ depending on the plant types and the Cu concentration in the soil or other media. Supplying Si to Tanzanian guinea grass can counteract the negative effects of Cu excess. In both growth periods, plant yields increased by Si supplies and decreased with an increase in Cu rates. In contrast to other combinations, plants subjected to Cu at a concentration of 750 mol L-1 without Si treatment had higher copper concentrations in diagnostic leaves (DL), roots, and shoots, as well as increased copper content in these tissues. The primary role of Si was to inhibit the movement of copper (Cu) from roots to shoots, allowing for successive harvesting and reducing the level of Cu in plant tissues (Vieira Filho & Monteiro, 2020).

High amount of potassium supply to Cd exposed plants promoted high levels of shoot drymass production, which decreased the concentrations of this metal in the photosynthetic tissue (indicating remarkable plant tolerance) and harvestable shoots. Thus, K makes Tanzanian guinea grass more capable of phytoextracting Cd (de Anicésio & Monteiro, 2019).

5. Conclusions

A new remediation technique called phytoremediation uses plants and bacteria to purify contaminated air, soil, and water. Long plant growing seasons and higher soil temperatures in tropical and subtropical regions might speed up phytoremediation processes. The selection of promising plants is critical to success of phytoremediation. In addition to their high biomass production, forage grasses typically have a deep root system, low requirements for soil fertility, adaptation to soil and climatic adversities, and successive emissions of shoot apical meristem after the harvest of shoots. Recent studies have shown that Panicum maximum has the capacity to effectively clean-up sites that are contaminated with copper, cadmium, barium, RDX and TNT explosives. Sulphur supply can reduce the phytotoxicity stress sourced from heavy metals during the soil clean up.

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