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Assessment of Sunflower (*Helianthus annuus* L.) for Phytoremediation of Heavy Metal Polluted Mine Tailings—A Case Study of Nampundwe Mine Tailings Dam, Zambia

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Abstract

Mining activities have led to a generation of large quantities of heavy metals laden wastes which are released into the environment in an unsustainable way causing the contamination of the ecosystems and posing a risk to human health. Most mining companies have not employed any rehabilitation or remediation program of the heavy metal laden waste. The aim of this study was to assess the potential of sunflower for phytoremediation of heavy metal polluted mine tailings. Phytoremediation is an emerging technology in the remediation of mine tailings that uses tolerant plant species to clean up contaminated sites. It uses plants with high biomass and sunflower has been identified as such. These plants can extract, transfer, sequester and stabilize a variety of metals through mechanisms such as phytoextraction, phytostabilization, phytoaccumulation and phytovolatilization. Pot experiments were conducted by growing sunflower (*Helianthus annuus* L.) in pyrite mine tailings and in agricultural soil as a control. The study showed that the concentration of Cu reduced from 40.76 mg/kg to 36.59 mg/kg, Zn reduced from 3.58 mg/kg to 3.49 mg/kg and Fe reduced from 23.70 mg/kg to 10 mg/kg respectively in the mine tailings after 6 weeks. Analysis of harvested sunflower (roots, stems, leaves) showed that sunflower could remove heavy metals from the tailings and the highest removal efficiency was 53.7% and the highest translocation factor was 0.25. It was concluded that sunflower has the potential to remediate contaminated mine tailings and that phytoremediation is a viable and efficient technology to treat soils contaminated with heavy metals.

Keywords

Phytoremediation, Translocation Factor, Metal Removal Efficiency,

Helianthus annuus

1. Introduction

Heavy metal contamination of soils has now become a growing challenge in developing countries. Not only does it hinder sustainable development but also poses a threat to the local environment, ecosystems, and human health [1]. Toxic heavy metals such as copper (Cu), iron (Fe), cadmium (Cd), lead (Pb) are the most common and dangerous contaminants [2]. Contaminated soils create lack of arable land, depriving local communities of land for economic agriculture activities as well as posing a health risk [3].

Zambia is an example of a developing country where industrial activities have polluted the soil and continue to do so. The most polluting industrial activities are exploration, mining extraction and mineral beneficiation processes such as smelting, concentrating and refining [4]. The mining and beneficiation processes generate mine waste and acid mine drainage (AMD) which contaminate the soil and ecosystems [5]. The global demand for metals and minerals observed in the recent past has also led to an increased generation of mine waste. The decreasing metals ore grades in Zambia are also increasing the amount of mine waste generated hence increasing soil contaminants [6] [7]. Currently mine waste accounts for 90% of the total solid waste generated annually in Zambia [6]. It contains heavy metals such as lead (Pb), arsenic (As), zinc (Zn), copper (Cu), nickel (Ni), chromium (Cr), cobalt (Co), cadmium (Cd) and mercury (Hg) [8] which contaminates the soil and freshwater ecosystems. Heavy metals are considered as toxic pollutants because they are persistent in the environment [9] and not only pollute the atmosphere, food crops, and degrade the quality of freshwater ecosystems but also affect health of human beings through accumulation in the food chain [8]. Considering the adverse effects of mine waste on the terrestrial and aquatic ecosystems there is a need for the remediation of heavy metal polluted waste from mining activities.

To mitigate the effects of mine waste, different soil remediation technologies have been developed in the last couple of decades. These technologies aim at reducing the bioavailability fractions of heavy metals in soils and their consequent accumulation in the food chain [10]. The conventional techniques of remediating soils are mostly based on physical, chemical and biological methods. Most of these technologies are costly, take time and lead to environmental degradation [2]. These financial and environmental complexities make the implementation of conventional soil remediation technologies a challenge.

Phytoremediation is an innovative and green technology that uses plants to clean up contaminated environments [11] [12]. This is an emerging technology that has proven to be less expensive than the conventional technologies and is also more sustainable in that it encourages site restorations. Phytoremediation technologies include phytoextraction, Phytostabilization, Phytofiltration and Phytovolatilization [13]. This technology uses plants species with the following characteristics: a profuse root system, ability to grow fast, heavy biomass, tolerance to high concentrations of metals and high metal-accumulation capability [14]. This enables adsorption, absorption and accumulation of contaminants in their tissues for the remediation [15]. The plants used are known as hyperaccumulators because of their ability to accumulate high concentrations of metals in their tissues [14]. According to Lasat [16], approximately 400 plant species from at least 45 families have been identified as hyperaccumulators of metals. Some plants used for remediation include Indian mustard which remediates Cd, Pb, Se, Zn, Hg and Cu, white willow which remediates Cd, Ni and Pb and sunflower which remediates Pb, Zn, Cu and Mn [1]. Poplar tree is used to remediate chlorinated solvents and Indian grass is used to remediate pesticides and herbicides [1] [15]. Sunflower (*Helianthus annuus* L.) has been identified as a fast growing industrial oil crop with high biomass and the fact that it is capable of hyper accumulating heavy metals in its harvestable parts such as roots leaves and stems [17]. Sunflower is one of the most studied species for phytoremediation of heavy metals and is considered as the most ideal plant because of its greater potential for heavy metal uptake and tolerance [18]. This plant grows in different soil types and the stem can grow as high as 3 m tall with the flower head growing up to 30 cm in diameter with very large seeds [14] [19].

This study aims at investigating the possibility of using sunflower as a green technology for the phytoremediation of mine tailings dumps contaminated with heavy metals from a pyrite mine. This study will use Nampundwe Mine Tailings Dam as a case study. The study will evaluate the potential and efficiency of sunflower for the remediation of mine tailings contaminated with pyritic heavy metals.

2. Methodology

Experiments were conducted on tailings collected from the Nampundwe tailings dumps as well as agricultural soil obtained locally from Nampundwe. Sunflower seedlings were obtained from Seedco, a local company which sells seeds. Soil samples were taken about 5 km from the tailings dumps to help determine the percentage of heavy metals in the pristine environment. The sampling area was divided into uniform sampling areas. A soil probe was used to collect samples at a depth of 20 cm. Tailings collected from the tailings dump using a shovel were stored in buckets. Part of the collected tailings and agricultural soil were submitted for laboratory analysis to establish the initial heavy metal content (copper, zinc and iron). Sunflower seedlings were thereafter planted in buckets containing the remaining 100% tailings and 100% agriculture soil (as a control) and their growth monitored. After six weeks the sunflower was harvested, and the samples from tailings and agricultural soil were taken andanalysed for heavy metals. For analysis of concentration of metals, the roots, shoots, and leaves of sunflower were analysed separately to determine which part of the plant absorbed most of the heavy metals. After the quantification of metal concentrations in the roots, leaves, and shoots as well as the tailings and agricultural soil, the metal removal efficiency (MRE) was determined using Equation (1) [3].

$$\mathrm{MRE} = \left(\mathrm{C}_1 - \mathrm{C}_2\right) / \mathrm{C}_1 \times 100 \quad (1)$$

where C_1 is the concentration of heavy metals in soil/tailings before planting and C_2 is the concentration of heavy metals in soil/tailings after harvesting.

Equation (1) was used to determine the efficiency of sunflower for the remediation of mine tailings contaminated with pyritic heavy metals. In order to establish which method of phytoremediation to use for sunflower the translocation factor (TF) was determined. The translocation factor (TF) is the capability of the plant to move a metal throughout the plant [20]. The greater the value the more ease with which the plant moves the metal. TF is the concentration of metals in the shoots of the sunflower in relation to the roots [3].

$$\mathrm{TF} = \text{concentration of heavy metals in shoots} / \text{concentration of metal in roots} \quad (2)$$

In order to determine the contaminant uptake, the translocation factor of the plant was determined for the plant samples. The initial concentration of heavy metals in the tailings was compared to the concentration obtained after the sunflower was harvested to determine how much was absorbed.

3. Results

Figure 1 shows a comparison between heavy metal content in the agricultural soils and the tailings and it can be seen that iron is lower than that in the agricultural soil as it is extracted as pyrite (Fe_2S) whereas copper and zinc contents are higher in the tailings due to the extraction processes employed were iron is

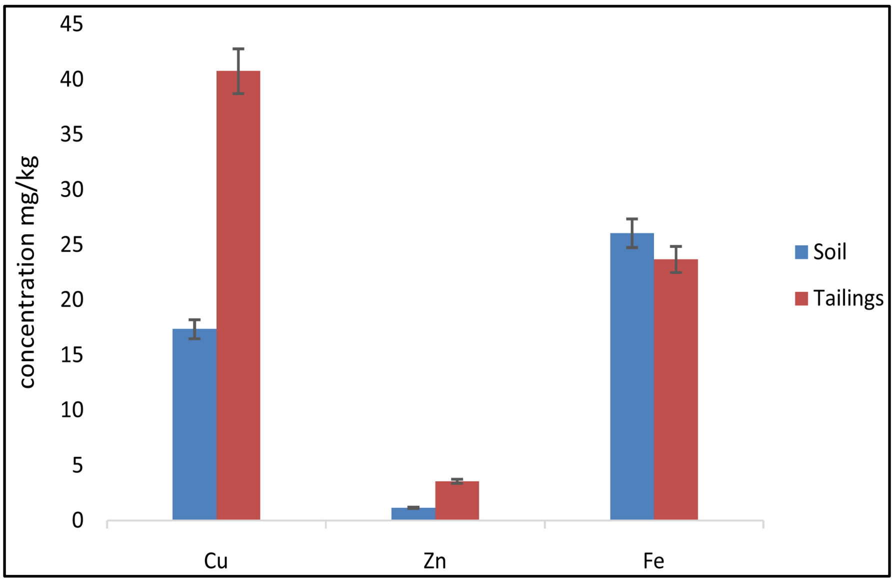

Figure 1. Comparison of concentration of heavy metals in soil and tailings before planting of sunflower.

processed as a pyrite concentrate and the rest of the metals in the ore report to the tailings. The metal concentration in the agriculture soil was found to be lower than that found in the tailings as shown in **Table 1**. These were consistent with metal concentration found in soils and water in mining areas of Zambia [21]. In Zambia, heavy metal pollution in agricultural soils differs according to the region. Geographical areas where mining activities take place have a higher concentration of heavy metals in soils while areas which are distant from mining activities have moderate or low heavy metals in their soils [21]. Furthermore results obtained (**Table 1**) show that copper and iron were the most dominant heavy metals in the soil and tailings. However, the concentration of copper and zinc in the tailings was higher than in the soil while the concentration of iron was higher in the soil than in the tailings. It should be noted that this was expected as iron is predominant in this region as evidenced by the presences of a pyrite (Fe_2S) mine and an iron mine.

4. Evaluation of the Potential and Efficiency of Sunflower for the Remediation of Mine Tailings Contaminated with Pyritic Heavy Metals

The concentration of heavy metals in tailings is reduced after harvesting of the sunflower. The amount of copper reduced from 40.76 mg/kg to 36.59 mg/kg while zinc reduced from 3.58 mg/kg to 3.49 mg/kg and iron reduced from 23.70 mg/kg to 10.97 mg/kg (**Table 1** and **Table 2**) respectively, after six weeks. The concentrations of Cu, Zn and Fe significantly reduced in the tailings as the same increased in the sunflower. The reduction of heavy metal concentration was also observed in the soil which was a control in this research. The data obtained shows that the sunflower was able to uptake heavy metals from the contaminated tailings. These results of heavy metals in the soil and tailings before planting and after harvesting are shown in **Table 1** and **Table 2** respectively.

Figure 2 and **Figure 3** show the concentration of heavy metals in the soil and tailings before planting and after harvesting the sunflower. It was observed that

Table 1. Initial Cu, Zn and Fe content in both the Nampundwe agricultural soil and tailings before planting the sunflower.

Concentration before planting (mg/kg)					
Tails			Soil		
Cu	Zn	Fe	Cu	Zn	Fe
41.92	2.46	16.40	14.38	0.30	24.14
43.66	3.08	17.64	19.84	0.96	26.56
35.24	1.88	17.06	14.48	1.76	24.78
42.52	4.96	16.10	19.38	1.02	24.32
40.48	5.56	51.30	18.76	1.76	30.56
40.76 ± 3.29	3.58 ± 1.60	23.70 ± 15.44	17.37 ± 2.71	1.16 ± 0.62	26.07 ± 2.69

Table 2. Cu, Zn and Fe content in both the soil and tailings after harvesting the sunflower.

Concentration after harvesting (mg/kg)					
Tails			Soil		
Cu	Zn	Fe	Cu	Zn	Fe
38.78	2.96	11.2	12.12	0.74	13.42
38.00	3.24	7.60	11.16	0.58	12.60
38.04	3.08	7.76	11.18	0.64	13.00
35.88	3.98	12.98	9.26	1.22	10.68
32.26	4.22	15.30	8.24	0.24	11.10
36.59 ± 2.65	3.49 ± 0.57	10.97 ± 3.34	10.39 ± 1.59	0.68 ± 0.35	12.16 ± 1.20

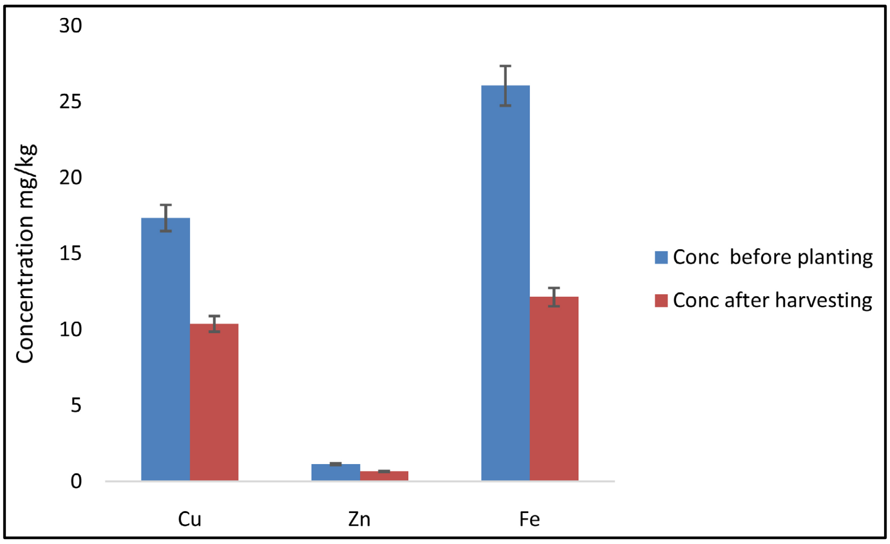

Figure 2. Concentration of heavy metals in the agricultural soil before planting and after harvesting the sunflower.

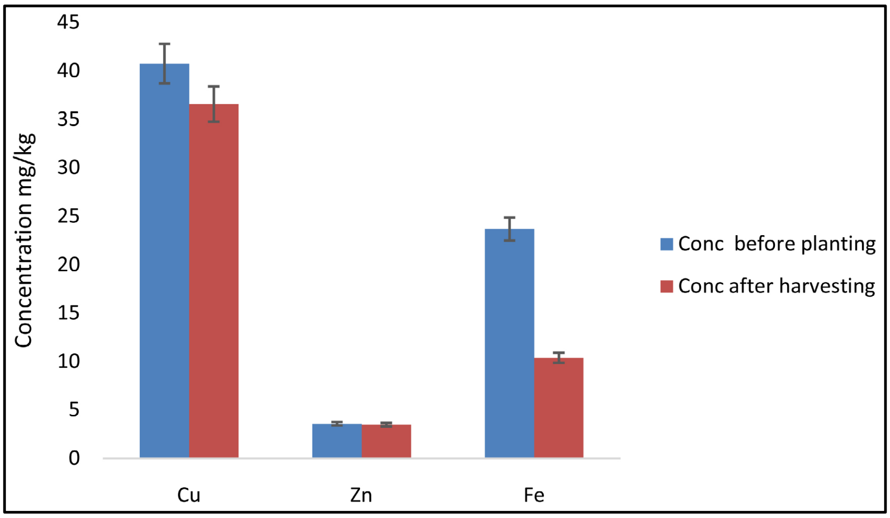

Figure 3. Concentration of heavy metals in the tailings before and after harvesting the sunflower.

the concentration of heavy metals reduced significantly in the tailings and soil after harvesting the sunflower.

5. Determination of the Efficiency of Sunflower to Remediate Mine Tailings Contaminated with Heavy Metals

For sunflower planted in the tailings the metal recovery efficiency (MRE) was 10.23% for Cu, 2.5% for Zn and 53.7% for Fe while for the control sample the MRE for Cu was 40%, Zn was 41.3% and Fe was 53%. From these results, we can conclude that sunflowers are effective in removing heavy metals from tailings. The removal efficiency of 53.7% shows that it is a good accumulator of iron. After harvesting the sunflower plants copper and iron were found to be the most accumulated in the plant parts after the six (6) weeks planting period. It was also observed that most of the heavy metals were absorbed in the roots and leaves. This is evident in both the control (soil) and the tailings. Results of metal concentration in individual plant parts showed a higher concentration in the roots followed by leaves and lastly the stems. Table 3 and Table 4 show the concentrations in the roots, stems, and the leaves after harvesting from the agricultural soil and the tailings.

6. Translocation Factor (TF)

The translocation factor of heavy metals from the tailings was calculated from the roots to the shoots. The translocation factor for copper from the root to shoot system for sunflower planted in the tailings was 0.22 and 0.16 for the sunflower planted in the soil respectively. However, the TF for iron was 0.25 for sunflower planted in the tailings and 0.225 for sunflower planted in the agricultural soils respectively. The TF factor of 0.25 from the roots to the shoots for sunflower planted in the tailings was the highest. Plants have a natural ability to

Table 3. Concentrations of heavy metals in the roots, stems and leaves of harvested sunflower from tailings.

Tailings	Roots	Leaves	Stems
Copper (Cu) mg/kg	1.8	0.8	0.4
Zinc (Zn) mg/kg	0.04	Not detected	Not detected
Iron (Fe) mg/kg	6	2	1.5

Table 4. Concentrations of heavy metals in the roots, stems, and leaves of harvested sunflower from agricultural soil.

Soil	Roots	Leaves	Stems
Copper (Cu) mg/kg	3.7	1.1	0.6
Zinc (Zn) mg/kg	0.13	ND	0.03
Iron (Fe) mg/kg	8	3	1.8

uptake elements from soil through biological processes [22] and translocate them between roots and shoot systems. Heavy metals can also be taken up and transported to different parts of the plant and findings from this research indicate that sunflower has the capability to translocate heavy metals throughout the plant [23]. Relative to copper and iron, zinc was not taken up as much from the soil and this can be attributed to its low concentration in the tailings. Previous studies have indicated that low concentrations of heavy metals affect the rate of translocation [24].

From this study, we can infer that sunflowers can bioaccumulate copper, zinc, and iron. These findings agree with Adesodun *et al.* [14] who concluded from an experiment carried out on two different species of sunflower that it is effective in cleaning up heavy metal contaminated soils; however, they argued that the efficiency of sunflower was at the early stages of its growth. He suggested that sunflowers should be harvested after four weeks and seedlings replanted for another cycle of cleanup process [14]. This finding was consistent with other studies which suggested that exposure time influences the uptake of metals by sunflower [18]. Rizwan *et al.* [18], also argues that heavy metal accumulation in sunflower species reaches its maximum at four weeks after planting. It can be concluded that the uptake and cleaning of contaminated soils by sunflower is dependent on the type of metal [25] and the exposure time to the contaminated sites [18].

It can be seen that the sunflower planted in tailings exhibited a stunted growth (**Figure 4**) as compared to the one planted in agricultural soil (**Figure 5**). Several

Figure 4. Sunflower planted in tailings at three weeks.

Figure 5. Sunflower planted in agriculture soil at three weeks.

studies have shown that heavy metals impact negatively on biomass yield and sunflower growth [18]. Considering the fact that higher biomass accumulation is an important factor in enhancing efficiency of phytoremediation [26], soil amendments can be used to promote high biomass yield [27]. However, measures should be taken to avoid reintroducing of heavy metals in the soil [27]. Studies have shown that nitrogen fertilizers [28] and EDTA improved the phytoremediation of sunflower in heavy metal contaminated soils [27]. Similarly, it was observed that the shoot length of sunflower differed significantly between the sunflower in the tailings and that planted in agricultural soil which entails that an increase in heavy metal concentration affects the growth of the sunflower [18] [20]. Furthermore, increased concentrations of heavy metals reduced the leaf area, plant height and biomass of sunflower seedlings [18] as observed between the plant in the tailings and those in the soil. It is therefore imperative to determine the concentration levels of heavy metals in contaminated soils to help determine if sunflower can be used for remediation. For highly contaminated sites, other remediation methods can be used to reduce the bioavailability and toxicity of the heavy metals [29] there after sunflower can be planted for phytoremediation to gradually cleanup and restore the ecosystem of the contaminated soils [30].

7. Conclusion

The potential and efficiency of sunflower for remediation of mine tailings contaminated with pyritic heavy metals were assessed. It was found that sunflower has the potential to remediate contaminated soils. Sunflower exhibited ability to effectively remove multiple heavy metals from mine tailings as the removal efficiency of iron by sunflower reached 53.7% in the tailings after six weeks. Most of the heavy metals were found to be in the roots and leaves of the sunflower showing that sunflower can remediate heavy metals through phytostabilization and phytoextraction. Higher concentrations of heavy metals in the tailings were found to negatively affect the shoot lengths, leaf area and biomass yield of the sunflower.

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Conflicts of Interest

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

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