

Employing indigenous flora for the phytoremediation of agricultural soil contaminated by cadmium.

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Abstract— Elevated concentrations of the heavy metal cadmium (Cd) in the soil might adversely affect the health of both the soil and vegetation. The objective of this descriptive study was to examine the ability of certain local plants to stabilize cadmium. A farming production site located in Batu City, East Java, Indonesia, was used for the research. This study was segmented into two stages: (1) an examination of nutrient and heavy metal contamination, and (2) a phytoremediation trial using five distinct species of indigenous flora. Three iterations of the experiment were conducted with a completely randomized design (CRD). Subsequent to the harvesting of the plants, an analysis was conducted on the concentration of heavy metals remaining in the soil and taken up by the plants. Atomic Absorption Spectrometry (AAS) was used for the determination of heavy metal concentration. Before phytoremediation, the initial concentration of heavy metal cadmium in the soil surpassed the limit of 2.26 mg kg⁻¹. Notably, during the fourth week post-planting, the five indigenous plants assessed in the contaminated soil exhibited robust development. This specific plant had an average efficacy of 71.2% in reducing the heavy element cadmium. *Vetiveria zizanioides* (71.2%), *Eleusine indica*, L. (58.9%), *Ageratum conyzoides* L. (52.2%), *Euphorbia hirta* (51.8%), and *Chromolaena odorata* (22.1%) were the species that mitigated the heavy metal cadmium.

Keywords— *Phytoremediation, contaminated land, heavy metal Cd, indigenous plants*

INTRODUCTION

The use of agrochemicals such as fertilizers and herbicides has resulted in a significant increase in cadmium (Cd) pollution in the soil ecosystem in recent years. The majority consensus is that phosphatic fertilizers are the primary source of cadmium contamination in agricultural soils (Grey et al., 1999). The manufacturing procedure results in phosphate fertilizer with a somewhat elevated concentration of Cd (up to 500 mg kg⁻¹) as a trace element (Loganathan et al., 2003). Consequently, elevated concentrations of cadmium contamination in the soil may result from the extensive use of phosphate fertilizers (Tijani et al., 2008; Zeng et al., 2007). The use of organic fertilizers, such as farmyard manure, is believed to contribute to soil contamination with cadmium. Alloway (1995) states that the typical quantity of cadmium in agricultural manure ranges from 0.3 to 1.8 mg kg⁻¹. A significant contributor to Cd pollution in the soils was the substantial annual application of farmyard manure (35 Mg of fresh manure per hectare) (Alloway, 1995). To enhance crop production, agrochemicals are widely used in the Indonesian city of Batu as a result of agricultural advancements. Nevertheless, the extensive use of agrochemicals is expected to pollute the soil with heavy metals and trace elements (Alloway, 1995). Agriculturalists in the municipality of Batu often use phosphate fertilizers and pesticides. The soil cadmium concentration exceeds the threshold limit of 2.26 mg kg⁻¹, as per the latest soil assessment from the first phase of this experiment in Batu. Excessive amounts of cadmium in soils not only adversely affect plants but may also lead to secondary problems including soil acidification (Loganathan, 2003). Considering the potential for Cd contamination in the soil, it is imperative that farmers use appropriate soil remediation techniques to mitigate damage to both soil and plants. The use of indigenous hyperaccumulator plants for the phytoremediation of cadmium is among the proposed techniques for soil restoration. In comparison to other physical or chemical soil cleanup techniques, phytoremediation, which employs natural hyperaccumulator flora, is regarded as the most economical option (McMohan, 2000). The phytostabilization process (Ogundiran and Osibanjo, 2008; Robinson et al., 2009) suggests that indigenous hyperaccumulator

flora may reduce the mobility of Cd within the soil matrix. Research conducted by Hamzah et al. (2012) indicates that natural hyperaccumulator plants may stabilize heavy metals and remediate contaminated soil, rendering it suitable for agricultural use once again. This study seeks to delineate the prospective ability of some indigenous flora to immobilize cadmium in contaminated agricultural soils inside the Indonesian city of Batu.

Material and Method

2.1 Soil sampling and initial chemical analysis

Descriptive study was conducted in the field located at Bumiaji Village, Batu City, East Java, Indonesia. The soil's chemical properties were analyzed prior to the planting of a selected indigenous species. The soil analysis encompasses pH (H₂O), soil organic carbon (C) determined via the Walkley and Black method, total nitrogen (N) assessed through the Kjeldahl method, total phosphorus (P) evaluated using the Olsen method, total potassium (K), and total soil Cation Exchange Capacity (soil CEC) measured with 1 M ammonium acetate (NH₄OAc) at a pH of 7.0. Atomic Absorption Spectrometry (AAS) was used to evaluate the overall cadmium content in the soil.

In the Indonesian locality of Bumiaji, Batu, three agricultural establishments were randomly chosen to provide soil specimens. Shallots and produce such as potatoes and carrots were the main crops cultivated on the farms. To create a composite soil medium, soil samples were extracted from the upper 10 cm of soil depth and amalgamated with samples from other locations. This composite soil medium is designed to examine the efficacy of some native plants in stabilizing cadmium.

Descriptive experiment: investigating the ability of selected indigenous plants in stabilizing Cd from contaminated soil

This descriptive study selected five plants: two hyperaccumulators often found in the Indonesian locality of Bumiaji, Batu, and three indigenous species. *Eleusine indica*, L. (KB-1), *Ageratum conyzoides*, L. (KB-2), and *Euphorbia hirta* (KB-3) were the trio of indigenous flora selected. *Vetiveria zizanioides* L. (KB-4) and *Chromolaena odorata* (KB-5) are two hyperaccumulating flora often found in the Bumiaji hamlet. Each plant was cultivated in an individual container with ten kg of composite soil material. Weekly assessments of the flora were performed until they reached three months of age. The characteristics observed were plant growth and the concentration of Cd in the roots, stems, and leaves. The plants' roots, stems, and leaves were segregated after reaching three months of age. Following the elimination of excess soil with distilled water, the botanical specimens were subjected to an oven drying process for 72 hours at 600 degrees Celsius. The dried plant samples were analyzed for the presence of Cd metal using an Atomic Absorption Spectrophotometer (AAS).

2.2 Cadmium concentration analysis

The methodology described by AOAC (1990) was used to evaluate the total Cd concentrations in the soil and plant specimens. A digestion vessel comprising 1 ml of concentrated nitric acid (HNO₃) and 5 ml of 70% perchlorate acid (HClO₄) is packed with dry soil and plant specimens (1 g each) and allowed to sit overnight. The specimens were then subjected to heating for one hour and thirty minutes at 100°C, followed by an extra hour at 130°C. The temperature was raised to 150°C for the second digestion, lasting two hours and thirty minutes, or until the complete consumption of the yellow steam. The temperature was further elevated to 170°C for one hour after the complete emission of the yellow vapor. The substance was processed at a concluding temperature of 200°C for a duration of one hour, resulting in the emission of white vapor. The digestion of the sample was complete at the emergence of a white precipitate and one milliliter of transparent solution. Subsequent to digestion, samples were subjected to filtration using MM 640 W Whatman filter paper following the addition of up to 10 ml of distilled water. Atomic absorption spectrophotometry (AAS) was used to assess the overall Cd concentration in each extract, using several Cd reference solutions for comparison.

2.3 Transfer factor (FT) and Bio-concentration Factor (BCF)

The Transfer factor (FT) was calculated to evaluate the rate of Cd transfer between plant roots and shoot. The bio-concentration factor (BCF) indicates the ability of selected indigenous plant in absorbing Cd from the contaminated soil.

$$FT = \frac{\text{Total Cd concentration in above ground biomass (shoot + leaves)}}{\text{Total Cd concentration in roots}}$$

$$BCF = \frac{\text{Total Cd concentration in plants}}{\text{Total Cd concentration in soil}}$$

RESULTS AND DISCUSSION

3.1 Soil characteristics and heavy metal contamination

Table 1 displays the initial soil analysis data used in this descriptive experiment. The sandy loam composition of the soil extracted from Bumiaji Village in Batu, Indonesia, consists of 56% sand, 8% dust, and 35% clay. The soil exhibits minimal nutrient content (0.13% nitrogen, 0.64 cmol kg⁻¹ of accessible phosphorus, and 0.03 cmol kg⁻¹ of potassium) and maintains a neutral pH of 6.22. The soil exhibits a diminished Cation Exchange Capacity (CEC) of 6 cmol kg⁻¹ and a meager organic matter concentration of 1.73% organic carbon. The total concentration of Cd in the soil was 2.26 mg per kg. Furthermore, Tresnawati et al. (2014) found that some farms in Bumiaji Village exhibited soil with 4.22 mg Cd kg⁻¹, significantly above the agricultural soil limit of 1 mg Cd kg⁻¹ (Alloway, 1995).

TABLE 1
SOIL CHEMICAL PROPERTIES

Element	Chemical Properties
pH (H ₂ O)	6.22
Organik C (%)	1.73
Total N (%)	0.13
C/N	13.31
P-olsen (cmol kg ⁻¹)	0.64
K (cmol kg ⁻¹)	0.03
CEC (cmol kg ⁻¹)	6.00
Cd (mg kg ⁻¹)	2.26

The widespread use of agrochemicals, including fungicides and phosphorus fertilizers, could have led to the elevated levels of total soil cadmium in the soil employed for this study. Fungicides and pesticides often include cadmium compounds as a key component (Environmental Agency, 2009; Lahuddin, 2007). As expected, the rigorous application of insecticides and fungicides might elevate the levels of Cd in the soil. An discussion with the farmers in Bumiaji Village reveals that around 80% of them use fungicides almost throughout the whole year, potentially leading to considerable Cd residue in the soil. The majority consensus is that phosphatic fertilizers are the primary source of cadmium contamination in agricultural soils (Grey et al., 1999). The phosphosites (rock phosphate) used for the production of P fertilizers have comparatively elevated levels of Cd (<500 mg/kg). Phosphorus fertilizers, often SP-36 (36% P) and NPK (10% P), are regularly provided to the agriculturalists in Bumiaji Village. The overall concentration of soil cadmium is expected to increase with the heavy use of phosphorus fertilizers due to the elevated levels of trace metals, including cadmium, present in these fertilizers. Moreover, in comparison to other soil metals, Cd is taken by plants with greater ease (Widaningrum et al., 2007; Subowo et al., 1999). Additional examination of the active constituents of P fertilizers and fungicides used by the farmers is necessary to ascertain the quantity of Cd introduced to the soil, hence elucidating the forecast of anthropogenic Cd sources in Bumiaji Village.

3.2 Descriptive experiment: investigating the ability of selected indigenous plants in stabilizing Cd from contaminated soil

Over the course of the eight-week trial, all five of the native plants included in this descriptive study showed comparatively strong development (Figure 1). Of the three native plants examined in this study, *Ageratum conyzoides*, L. (KB-2) and *Eleusine indica*, L. (KB-1) both exhibit superior growth in comparison to *Euphorbia hirta* (KB-3) (Figure 1a). In comparison to *Euphorbia hirta* (KB-3), *Vetiveria zizanioides* L. (KB-4), and *Chromolaena odorata* (KB-5), *Eleusine indica*, L. (KB-1) and *Ageratum conyzoides*, L. (KB-2) had the tallest plants at the conclusion of the trial.

Eleusine indica, L. (KB-1) and *Ageratum conyzoides*, L. (KB-2) similarly had the most leaves when compared to the other plants, in line with measurements of plant height (Figure 1b). *Eleusine indica*, L. (KB-1) and *Ageratum conyzoides*, L. (KB-2) are tolerant of the high soil total Cd level, as shown by the increased plant growth and leaf output. Additionally, both plants exhibit superior development compared to the experiment's known hyperaccumulator plants (KB-4 and KB-5). The capacity of plants to take nutrients from the soil is connected with their height and leaf output (Sastroutomo, 1990). Therefore, our findings may suggest that *Eleusine indica*, L. (KB-1) and *Ageratum conyzoides*, L. (KB-2) are not only tolerant of high soil Cd concentration but may also be hyperaccumulator plants that stabilise Cd in contaminated soil.

a) Plants Growth

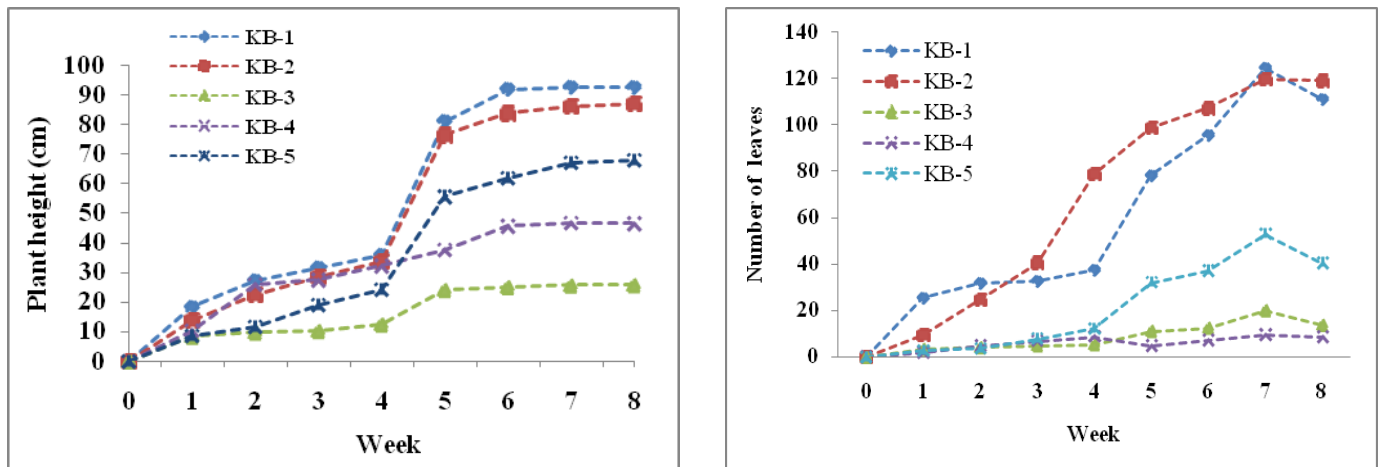


FIGURE 1. A) PLANT HEIGHT AND B) NUMBER OF LEAVES DURING THE 8 WEEKS OF EXPERIMENT
KB-1= *Eleusine indica* KB-2 = *Ageratum conyzoides* KB-3 = *Euphorbia hirta* KB-4 = *Vetiveria zizanioides*
KB-5 = *Chromolaena odorata*

Figure 2 illustrates the fundamental characteristics of plants' roots, including root length and root dry biomass. *Eleusine indica* L. (KB-1) and *Chromolaena odorata* (KB-3), two of the selected native species, exhibited greater root lengths (63.0–65.1 cm cm⁻³) compared to *Ageratum conyzoides*, L. (KB-2) (38 cm cm⁻³). Similar to the assessment of root length, KB-1 and KB-3 exhibited greater root dry mass compared to KB-2. *Vetiveria zizanioides* L. (KB-4) had a reduced root length compared to *Chromolaena odorata* (KB-5) among the identified hyperaccumulator species analyzed in this study (Figure 2a). Unlike KB-5, the shortened roots of KB-4 did not lead to a reduction in root dry mass. Relative to the other plants, KB-4 exhibited the highest biomass (90 g pot⁻¹), as determined by root dry matter assessment (Figure 2b). As to Garbisu et al. (2002), hyperaccumulator plants are characterized by their capacity to: (i) withstand elevated metal concentrations in the soil; (ii) extract or assimilate metals from the soil; (iii) exhibit rapid growth; (iv) generate substantial biomass; and (v) possess a robust root system. The existence of many bacteria that are crucial for the degradation of pollutants in the rhizosphere is directly linked to the vast root systems of hyperaccumulator plants (Alkorta et al., 2004; Krämer et al., 2010). This microorganism will facilitate the decomposition of heavy metal complexes, enabling roots to assimilate them, hence increasing the quantity of metals that hyperaccumulator plants may extract from the soil.

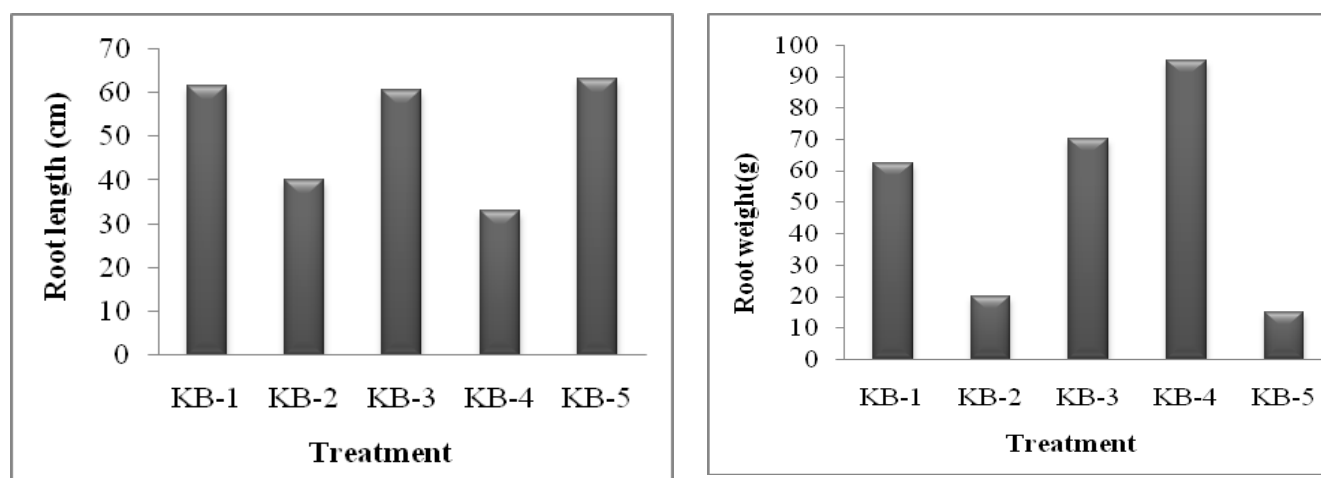


FIGURE 2. A.) PLANTS ROOT LENGTH AND B.) DRY ROOT WEIGHT AFTER 8 WEEKS OF EXPERIMENT

KB-1= *Eleusine indica* KB-2 = *Ageratum conyzoides* KB-3 = *Euphorbia hirta*
KB-4 = *Vetiveria zizanioides* KB-5 = *Chromolaena odorata*

b) Cadmium absorption by plants

Using plants to recover metals from polluted soil is the most accepted way; this remediation process is called phytoremediation. This technique makes use of plants' capacity to absorb, collect, and/or break down components found in soil and water environments. Certain plants are known as "heavy metal hyperaccumulators" because of their capacity to retain significant concentrations of these metals that don't seem to be used by them. In phytoremediation of elemental contaminants, plants either sequester the element in their roots to stop it from seeping from the site or extract and translocate a hazardous cation or oxyanion to above-ground tissues for later harvest.

While some plants that accumulate heavy metals prefer to store them in their roots, others move them into their shoots and/or leaves. Heavy metal accumulation in plant tissues is often assessed using the translocation factor (TF), where $TF > 1$ denotes the efficient transfer of heavy metals from roots to shoots (Fayiga and Ma, 2006; Rezvani and Zaefarian, 2011). With the exception of *Eleusine indica* L. (KB-1), the majority of native plants had TF values more than 1, according to the results of this descriptive experiment (Table 2). When compared to the other plants examined, *Vetiveria zizanioides* L. (KB-4) had the lowest TF (Table 2), which suggests that this plant prefers to store Cd in its roots.

TABLE 2

CADMIUM CONCENTRATION IN PLANT ROOTS, UPPER PART OF PLANTS, TRANSLOCATION FACTOR (TF), AND BIOCONCENTRATION FACTOR (BCF) IN EACH PLANT.

Treatment	Cd concentration in roots (mg kg^{-1})	Cd concentration in upper part of plants (mg kg^{-1})	Total Cd concentration (mg kg^{-1})	TF	BCF
<i>E. indica</i>	0.6	0.3	0.9	0.6	0.4
<i>A. conyzoides</i>	0.5	0.6	1.1	1.2	0.5
<i>E. hirta</i>	0.5	0.6	1.1	1.3	0.5
<i>V. zizanioides</i>	0.4	0.2	0.6	0.5	0.3
<i>C. odorata</i>	0.8	0.9	1.8	1.1	0.8

The capacity of certain plants to remove heavy metals from the soil is assessed using the bioconcentration factor value (BCF) (Ma et al., 2001). Table 2 displays the BCF for a few native species used in this investigation. Plants are classified as hyperaccumulators if their BCF value is more than 1 mg kg^{-1} , and as heavy metal accumulators if their BCF value is less than 1 mg kg^{-1} (Mellem et al., 2009; 2012). Every plant examined in this experiment had a BCF value less than 1. These plants are thus regarded as Cd accumulators. *Chromolaena odorata* (KB-5) accumulated the most Cd, whereas *Vetiveria zizanioides* L. (KB-4) accumulated the least (Table 2). The following factors affected the rate of Cd uptake from soil to plant tissue: (1) the rate at which Cd moved from the soil to the root surface; (2) the concentration of Cd ions on the root surface; (3) metal transport from the root surface into the

root; (4) contact time; and (5) translocation from the roots to the plant canopy (Alloway, 1995; Brown et al., 1995). The low ion concentration of Cd on the root surface and the contact period may have contributed to the experiment's low BCF result. To validate these ideas, further research on the rhizosphere's Cd content is required. All five of the plants evaluated in this descriptive experiment were able to lower the soil Cd levels, according to the soil analysis conducted six weeks into the experiment (Figure 3). It is noteworthy, nonetheless, that although the other plants were able to extract up to 50% of the Cd from the soil, *Chromolaena odorata* (KB-5) was only able to collect 22.1% (Figure 3). Although *Chromolaena odorata* has been shown to be an excellent remediator plant (mostly Hg and Pb) (Hamzah et al., 2012), the low soil Cd reduction seen in the *Chromolaena odorata* (KB-5) suggests that it was not suited for Cd remediation. Metal accumulator plants draw metal—in this example, cadmium—from polluted soils and store it in their canopy for later processing or disposal (Chaney et al., 2008). *Eleusine indica* L. (KB-1) is the best plant for stabilising Cd in Bumiaji Village based on characteristics of metal accumulator plants. *Eleusine indica* L. (KB-1) has shown the capacity to lower accessible Cd from a polluted soil, develop high root biomass, and be tolerant of high soil Cd concentrations. To determine how well *Eleusine indica* L. (KB-1) extracts Cd from soil, further research is required.

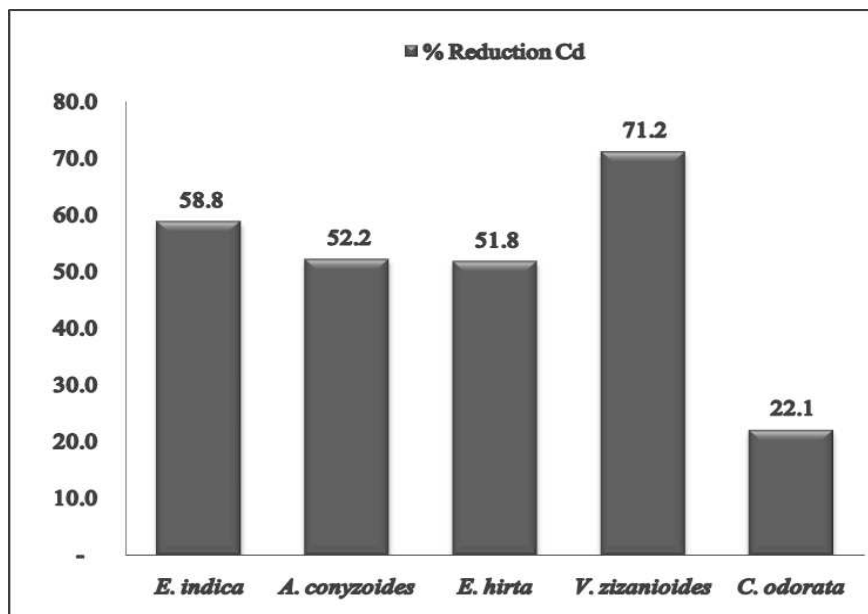


FIGURE 3. PERCENTAGE OF CD REDUCTION ON EACH PLANT

CONCLUSION

The soil at the Bumiaji Village research location in Batu Regency, Indonesia, had low fertility and contained higher amounts of Cd than permissible for agricultural use. The capacity of three indigenous plants—*Eleusine indica* L., *Ageratum conyzoides* L., and *Euphorbia hirta* L.—to immobilize cadmium from contaminated agricultural soil has been examined. Both *Ageratum conyzoides* L. and *Euphorbia hirta* L. sequester Cd in their stems and foliage, but *Eleusine indica* L. has the ability to concentrate Cd in its root system. *Eleusine indica* L. had the highest resilience among the three native plants studied in this experiment and was identified as a suitable species for reducing soil Cd levels.

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