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Growth Response of Phytoremediator Plants as an Adaptation Indicator in Phytoremediation Efforts for Mercury (Hg) Contaminated Soil in Sekotong

Amarrusli Ali Amri[1*], I. G. M. Kusnarta[1], A. A. Sudarmawan[1] , I Wayan Sutresna[1], Suwardji[1]

[1] Master of Dryland Agriculture Study Program, Postgraduate, University of Mataram, Mataram, Indonesia.

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Corresponding Author:
Amarrusli Ali Amri
rusliali059@gmail.com

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Abstract: Soil contamination by mercury (Hg) due to artisanal gold mining activities in Sekotong District, West Lombok Regency, poses a serious threat to the ecosystem and land productivity. This research aims to examine the growth response of three phytoremediator plants, namely *Vetiveria zizanioides*, *Ipomoea carnea* L., and *Crotalaria juncea* L., in Hg-contaminated soil as an indicator of their ability to adapt to heavy metal stress. The research was conducted experimentally in situ at two locations with different Hg concentrations (2.49 ppm and 17.71 ppm) using a Nested Design. Parameters observed included plant height and flowering age, analyzed by ANOVA. The results showed that the level of Hg contamination significantly affected the growth and generative phase of plants. *Ipomoea carnea* L. and *Crotalaria juncea* L. grew faster under low contamination conditions, but showed decreased growth and accelerated flowering phase at locations with high contamination. In contrast, *Vetiveria zizanioides* maintained more stable vegetative growth at both locations. These findings suggest that plant tolerance to Hg and its physiological characteristics determine the effectiveness of phytoremediation. *Vetiveria zizanioides* has high potential for long-term and sustainable remediation of mercury-contaminated soils.

Keywords: Mercury, Adaptation, *Vetiveria Zizanioides*, *Crotalaria Juncea* L, *Ipomoea Carnea* L.

Introduction

Environmental pollution from industrial activities, mining, and the use of hazardous chemicals is a growing global issue and poses a serious threat to ecosystem sustainability and human health. These activities produce waste containing heavy metals that are toxic, persistent, and difficult to degrade in the environment (Mosquera et al., 2024), which have the potential to cause long-term impacts on soil, water, and living organisms (Ali et al., 2019). Among the various heavy metals, mercury (Hg) is classified as one of the most dangerous pollutants due to its high mobility in the environment, its ability to transform into highly toxic methylmercury, and its easy accumulation and biomagnification in the food chain (Ray et al., 2025). Exposure to Hg, whether through soil, water, or biota, has been reported to cause serious disruptions to the overall ecosystem balance (UNEP, 2019).

In Indonesia, mercury pollution remains a significant environmental problem, particularly related to small-scale gold mining activities that extensively utilize mercury in the amalgamation process (Nuryanty et al., 2024; Raoilimanantsoa et al., 2026). Uncontrolled Hg use and minimal waste management lead to contamination of soil, surface water, and sediments around mining areas, increasing the risk of long-term environmental exposure (UNEP, 2019; Agustiani et al., 2025). One area significantly impacted by these activities is Sekotong District, West Lombok Regency, West Nusa Tenggara Province. Long-standing artisanal gold mining activities in this region have contributed to the accumulation of mercury in the environment, particularly in the soil and water media around processing areas and mine waste disposal sites. This condition not only accelerates environmental degradation but also increases the risk of mercury exposure to terrestrial ecosystems and local communities dependent on land and water resources in the region.

The impact of mercury pollution in artisanal mining areas not only results in ecosystem damage but

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also poses a serious threat to public health due to the consumption of contaminated water and food (Mahar et al., 2016; Agustiani et al., 2025). Ecologically, mercury-contaminated soil experiences a decline in physical, chemical, and biological quality, which directly impacts ecosystem function and land productivity (Angon et al., 2024). The presence of Hg in the soil can inhibit plant growth through disrupted physiological processes, reduced activity of soil microorganisms, and impaired absorption and availability of essential nutrients. This condition ultimately leads to decreased soil fertility and can affect overall land productivity (Yadav et al., 2025).

Efforts to remediate mercury-contaminated land require alternative approaches that are more environmentally friendly, economical, and applicable on a large scale. In this context, phytoremediation has emerged as a sustainable technology for remediating contaminated land (Shen et al., 2022). Phytoremediation utilizes the ability of plants to absorb, translocate, stabilize, or accumulate pollutants, including mercury, through mechanisms such as phytoextraction and phytostabilization (Machhi et al., 2025; Kafle et al., 2022). This approach not only has the potential to reduce the mobility and toxicity of mercury in the environment but also supports soil quality improvement and ecosystem restoration of contaminated land (Yan et al., 2020). Furthermore, Kumar et al. (2024) emphasized that phytoremediation has the advantages of being relatively low cost, capable of being applied over large areas, and not causing significant disturbances to soil structure and function, making it relevant for application to mercury-contaminated land in the Sekotong region.

Plant selection is a key factor in the success of phytoremediation, especially in mercury-contaminated land. The plants used must have a high tolerance to heavy metal stress and the ability to absorb, retain, or translocate Hg without experiencing significant growth decline. Several plants have been reported to have good mercury tolerance and accumulation capabilities, including vetiver (*Vetiveria zizanioides*), pink morning glory (*Ipomoea carnea* L.), and sunn hemp (*Crotalaria juncea* L.). Vetiver is known to have a deep and massive root system, making it effective in stabilizing heavy metals in the root zone (Machhi et al., 2025). Meanwhile, pink morning glory has a fast growth rate and high tolerance to polluted environments, while sunn hemp, as a legume, has the potential to support soil fertility restoration through nitrogen fixation (Arone et al., 2024).

The success of phytoremediation is greatly influenced by the ability of plants to adapt to polluted environmental conditions. Therefore, this research was conducted to examine the growth response of three types of phytoremediator plants on mercury-contaminated soil in Sekotong District, which are used as the main indicators in evaluating the ability of plants to adapt to the phytoremediation process. The objectives of this research are to analyze the growth response of phytoremediator plants (vetiver, pink morning glory, and sunn hemp) on mercury (Hg)-contaminated soil in Sekotong District as an indicator of the ability of plants to adapt to heavy metal contamination and to evaluate the potential of the three types of plants in supporting the phytoremediation process of mercury-contaminated soil based on plant growth parameters as a basis for selecting adaptive and effective species.

Method

The method used was an experimental in situ soil remediation approach to assess the growth response of photoremediator plants in direct remediation efforts under actual environmental conditions. This research was conducted from January to April 2025. The research location was in an inactive post-gold mining area in Sekotong District, West Lombok Regency. The research was conducted at two locations: Location 1 in Kayu Putih Hamlet, Pelangan Village, and Location 2 in Labuan Petung Hamlet, Pesisir Emas Village.

The tools used in this research included a watering can, a hoe, a sickle, and a ruler or measuring tape. The materials used included, compost, rice husks, Phonska 16-16-16 fertilizer, vetiver clumps (*Vetiveria zizanioides*), pink morning glory (*Ipomoea carnea* L.) stem cuttings, and sunn hemp (*Crotalaria juncea* L.) seeds.

This research used a nested design with location as the main treatment and plant species as nested treatments within the location. The two research locations had different levels of mercury (Hg) contamination: Location 1 (L1) with an Hg concentration of 2.49 ppm and Location 2 (L2) with an Hg concentration of 17.71 ppm. At each location, three types of phytoremediator plants were planted: vetiver (*Vetiveria zizanioides*), pink morning glory (*Ipomoea carnea* L.), and sunn hemp (*Crotalaria juncea* L.). Each location consisted of three replications (blocks), resulting in nine experimental plots per location. One sample plant was planted in each plot, and the observation values were averaged as one unit of analysis. In total, there were 18 experimental units (2 locations × 3 plant types × 3 ref).

The experiment included land preparation, planting, fertilization, plant care, and harvesting. Observed parameters were plant height and flowering time, measured weekly throughout the research period. Observational data were analyzed using *analysis of variance* (ANOVA) in a nested design at a 5% significance level. If the analysis showed significant differences, the test was continued with an Honestly Significant Difference (HSD) test at the same significance level.

Result and Discussion

Plant Height Growth Rate

The following is a summary table of the results of the analysis of variance (ANOVA) on weekly growth rates in three species of phytoremediator plants.

Table 1. Results of analysis of variance (ANOVA) of weekly plant height growth rate parameters.

No	Plant Height	Significance	
		L	P(L)
1.	2 WAP	ns	s
2.	4 WAP	ns	s
3.	6 WAP	s	s
4.	8 WAP	s	s
5.	10 WAP	s	s
6.	12 WAP	s	s

Description: WAP = weeks after planting, L = location, P(L) = plants nested within location, s = significant and ns = non-significant

Based on Table 1, the growth rate response of plant height parameters in the three species showed a significant influence, both on location factors and on the plant species nested within the location. This finding indicates variations in growth response influenced by differences in concentration levels and contamination characteristics at each location.

Table 2. Average total weekly plant height at the location

Location	Plant height at each location (L) / L (WAP)					
	2	4	6	8	10	12
L1	44,36^a	72,20^a	111,75^b	161,78^b	199,49^b	239,66^b
L2	33,18^a	53,32^a	83,75^a	124,26^a	157,27^a	183,64^a

Description: The numbers in each column are followed by the same letter, not significant in the BNJ test at the 5% level, at L1= Location 1, L2= Location 2, at each WAP.

Table. 3. weekly plant height of plantings at each location.

WAP	Plant height (P) nested within the location (L) / P(L)					
	L1			L2		
	V	I	C	V	I	C
2	50,71 bc	48,81 bc	33,87 ab	58,00 c	24,03 a	17,50 a
4	66,14 bc	78,60 bc	77,57 bc	84,03 c	45,48 ab	30,45 a
6	85,60 a	107,30 a	148,15 b	103,23 a	73,36 a	74,65 a
8	111,80 a	146,32 a	232,78 b	138,89 a	96,57 a	137,32 a
10	143,52 ab	177,51 b	282,22 b	170,30 ab	117,95 a	183,56 c
12	196,79 ab	227,55 b	319,19 c	193,57 ab	135,69 a	185,80 ab

Description: The numbers in each column followed by the same letter are not significant in the BNJ test at 5% level, L1= location 1, L2= location 2, V= vetiver, I= ipomoea and C= crotalaria.

As shown in Table 2, the average plant height at site 1 was consistently higher than at site 2, confirming that the contamination conditions at the site were the main factor influencing the growth of phytoremediation plants. As reported by Asghar et al. (2025), Hg^{2+} exposure causes physiological stress in plants, thus inhibiting growth through disruption of cell division activity.

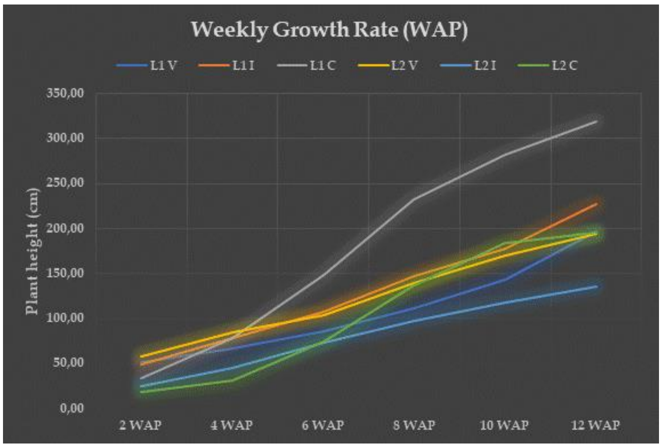

Figure 1. Weekly plant height growth rate

The data presented in Table 3 and Figure 1 show that plant height increased consistently from 2 to 12 weeks after planting (WAP) across all treatments, indicating that the three phytoremediator plants were able to adapt and grow throughout the observation period. However, growth responses differed significantly between plant species and locations, confirming the influence of species and contamination conditions on plant vegetative growth.

Pink morning glory (*Ipomoea carnea* L.) and sunn hemp (*Crotalaria juncea* L.) exhibit faster height growth and greater final height, with characteristic woody stem morphology that produces bast fiber (Soni et al., 2024; Saha et al., 2022), compared to vetiver (*Vetiveria zizanioides*), which has a clump-forming morphological structure (bush), especially at location 1. This difference reflects the differences in morphological characteristics between woody plants and shrubs (Treml et al., 2019). In addition, physiological aspects of each plant, such as nutrient uptake efficiency and tolerance to heavy metal stress, also play an important role in determining plant growth performance (Yan et al., 2020).

In contrast, all plants grown at location 2 showed lower plant heights compared to location 1. This decreased growth is thought to be related to higher levels of mercury (Hg) contamination, as heavy metals can inhibit cell division and elongation, reduce photosynthetic activity, and disrupt plant nutrient uptake (Patnaik et al., 2025; Umar et al., 2025). Despite experiencing decreased growth, vetiver (*Vetiveria zizanioides*) showed relatively stable growth at both locations. This indicates that vetiver has a better tolerance level to polluted soil conditions and supports its role as a phytoremediator plant (Destri et al., 2024).

Age of Flowering Plants

Table 4. Age of flowering plants at each location

Location	Plant	Flowering Age (WAP)					
		2	4	6	8	10	12
L1	V	-	-	-	-	-	
	I	-	-	-	-	-	
	C	-	-	-	-	-	
L2	V	-	-	-			
	I	-	-				
	C	-	-	-			

Descrip.: L1= location 1, L2= location 2, V= vetiver, I= ipomoea, C = crotalaria and colored column = time of flower appearance

Based on Table 4, descriptively, it is known that at higher levels of contamination, especially at location 2, there are differences in the timing of the emergence of the generative phase between plant species. pink morning glory (*Ipomoea carnea* L.) began to enter the flowering phase earlier, namely at 6 WAP, while vetiver (*Vetiveria zizanioides*) and sunn hemp (*Crotalaria juncea* L.) only showed the flowering phase at 8 WAP. This difference indicates a different physiological response to environmental stress, especially exposure to the heavy metal mercury (Hg)

Accelerated flowering in *Ipomoea carnea* L. in locations with higher contamination is thought to be an adaptation mechanism to environmental stress. Plants experiencing heavy metal stress tend to accelerate the transition from the vegetative to the generative phase as a survival strategy to ensure continued reproduction before environmental conditions worsen (Jorjani & Pehlivan Karakaş, 2024). This phenomenon is common in plants that are relatively sensitive to heavy metal stress.

Figure 2. Ipomoea 6 WAP

Figure 3. Vertiver 8 WAP

Figure 4. *Crotalaria* 8 WAP

In contrast, delayed flowering in vetiver (*Vetiveria zizanioides*) and sunn hemp (*Crotalaria juncea* L.) indicates that these two plants have better tolerance to polluted conditions (Destri et al., 2024). Plants with high tolerance levels tend to maintain a longer vegetative phase to support biomass accumulation (Jorjani & Pehlivan Karakaş, 2024).

This difference in flowering time has important implications for the effectiveness of phytoremediation. Plants that flower earlier generally experience reduced vegetative growth and shoot biomass (Shavrukov et al., 2017), thus reducing the potential for heavy metal accumulation. Conversely, plants that delay the generative phase have the potential to produce greater biomass and increase the efficiency of heavy metal remediation in polluted environments (Shen et al., 2022).

Figures 5 and 6 of the phytoremediator plants aged 12 WAP, the differences in plant height parameters at each location are clearly visible, and are closely related to the different concentrations of mercury contamination.

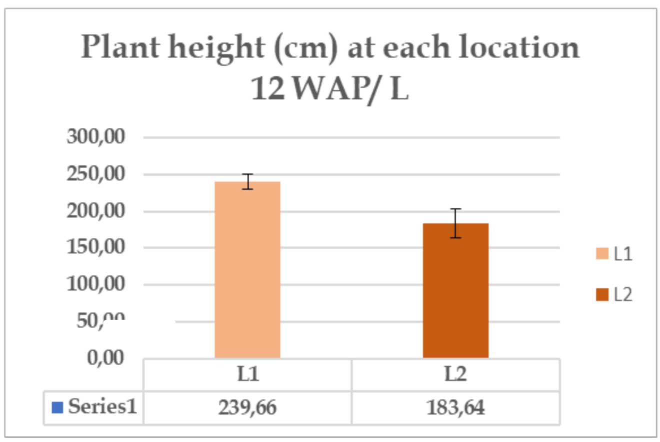

Figure 5. Average total plant height at location age 12 WAP

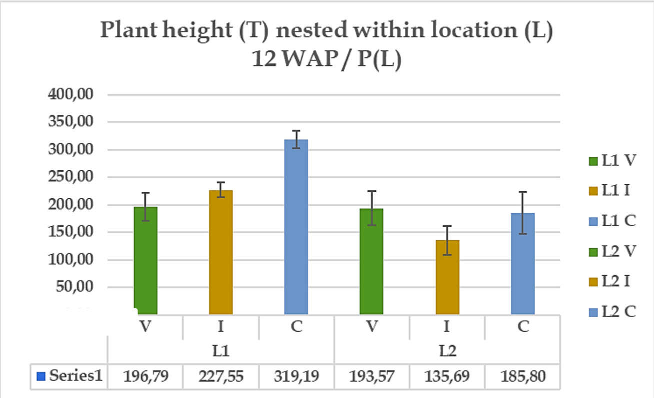

Figure 6. Plant height at 12 WAP at each location

Based on Figure 5, the average plant height at 12 WAP shows a clear difference between locations. Plants grown at location 1 had an average height of 239.66 cm, higher than those at location 2, which only reached 183.64 cm. This difference indicates that environmental conditions at location 2 exerted greater stress on plant growth, which is thought to be related to higher levels of mercury (Hg) contamination. Heavy metals are known to inhibit cell elongation and reduce plant metabolic activity, thus directly impacting vegetative growth (Wang et al., 2023; Patnaik et al., 2025).

Figure 6 shows that the plant growth response at 12 WAP is not only influenced by location, but also by plant type. At location 1, sunn hemp (*Crotalaria juncea* L.) showed the highest plant height (319.19 cm), followed by pink morning glory (*Ipomoea carnea* L.) (227.55 cm) and vetiver (*Vetiveria zizanioides*) (196.79 cm). This pattern indicates that sunn hemp (*Crotalaria juncea* L.) has a high vegetative growth capacity and biomass production under relatively more favorable environmental conditions.

In contrast, at location 2, there was a decrease in plant height across all species, with varying degrees of decline. pink morning glory (*Ipomoea carnea* L.) experienced the most significant decline, reaching a height of only 135.69 cm, while vetiver (*Vetiveria zizanioides*) and sunn hemp (*Crotalaria juncea* L.) reached 193.57 cm and 185.80 cm, respectively. The sharp decline in Ipomoea indicates that this species is relatively more sensitive to Hg pollution stress, while vetiver demonstrated the ability to maintain more stable growth under polluted conditions (Bayani et al., 2024).

These differences in growth responses between species are closely related to plant adaptation strategies to heavy metal stress. Highly tolerant plants, such as vetiver (*Vetiveria zizanioides*), tend to maintain vegetative growth even under polluted conditions (Mouthon et al., 2025). Conversely, more sensitive plants, such as the pink morning glory (*Ipomoea carnea* L.), exhibited significant growth reductions and accelerated generative phases, as indicated by earlier flowering at 6 weeks post-harvest at site 2. This strategy is a common plant response to environmental stress to ensure reproductive success (Jorjani & Pehlivan Karakaş, 2024).

Overall, these results indicate that Hg contamination levels and plant physiological characteristics jointly determine growth patterns, generative transition times, and plant adaptation potential in phytoremediation systems. Vetiver (*Vetiveria zizanioides*) plants with good tolerance capabilities have the potential to be more effective for long-term, sustainable, and environmentally friendly remediation at various mercury (Hg) contamination concentrations (Danur, 2022; Lazuardi et al., 2023).

Conclusion

Based on the results of research and discussion regarding the growth response of three types of phytoremediator plants in two locations with different levels of mercury contamination, the following conclusions can be drawn.

1. The level of mercury (Hg) contamination has been shown to be the main factor determining the ability of plants to adapt to heavy metal stress, which is reflected in the decrease in vegetative growth and changes in the transition time to the generative phase in locations with higher levels of contamination as a form of physiological response of plants to environmental stress.
2. *Vetiveria zizanioides* showed a better level of adaptation and growth stability in mercury-polluted soil conditions, while *Crotalaria juncea* L. and *Ipomoea carnea* L. had higher growth performance in lower contamination conditions but were more sensitive to high contamination levels.

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