

## The Effect of Giving Gamal Leaf Bokashi (*Gliricidia Sepium*) on Various Depths of Mercury-Contaminated Soil and Its Accumulation in Plant Tissue

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### Abstract

*Mercury (Hg) contamination in soils affected by small-scale gold processing may reduce soil quality and create a pathway for heavy metal transfer into plant tissues. This study assessed the role of kirinyu bokashi (*Chromolaena odorata* L.) in regulating Hg distribution in contaminated soil and Hg accumulation in maize tissues across different soil depths. The greenhouse experiment was conducted at the Faculty of Agriculture, Tadulako University, using Hg-contaminated soil collected from the Poboya gold-processing area, Palu City. A factorial experiment in a randomized block design was applied with two factors: soil depth (0-10 cm, 11-20 cm, and 21-30 cm) and bokashi dosage (0, 15, 30, and 45 t ha<sup>-1</sup>). Each treatment combination was replicated three times, resulting in 36 experimental units. Observed variables included soil Hg, plant Hg, plant Hg uptake, soil pH, organic C, and cation exchange capacity. The results indicated that kirinyu bokashi altered Hg distribution in contaminated soil, reduced Hg concentration in plant tissues, and improved selected soil chemical properties, particularly organic C and cation exchange capacity. The 45 t ha<sup>-1</sup> treatment showed the strongest tendency to suppress soil and plant Hg, although the magnitude varied among depths. These findings suggest that *gliricidia sepium* bokashi has potential as an organic amendment for managing Hg-contaminated soil.*

**Keywords:** *Organic Amendment; Gliricidia Sepium Bokashi; Mercury; Contaminated Soil; Plant Tissue; Maize; Soil Depth*

### INTRODUCTION

Soil is both the primary medium for crop production and a reservoir for the accumulation of various pollutants. In agricultural systems, soil degradation not only impacts plant growth but can also compromise food security, as hazardous elements stored in the soil can be absorbed by



roots and transferred to other plant parts. One pollutant that requires serious attention is mercury (Hg), particularly in areas adjacent to artisanal gold processing operations.

In small-scale gold mining areas, mercury is often used in the amalgamation process. Waste from this process can remain in tailings, be carried by surface runoff, or re-enter the environment through evaporation and deposition. High levels of Hg in the soil can affect soil chemistry and increase the risk of accumulation in plants. This situation is relevant to the soil in the Poboya area of Palu City, which has been widely associated with pollution from gold processing.

Efforts to remediate heavy metal-contaminated soil can be achieved through an amelioration approach, which involves applying soil amendments that improve the soil's chemical properties while simultaneously reducing metal availability. Organic matter is one option because it contains functional groups that can interact with metal cations, forming organometallic complexes, increasing cation exchange capacity, and helping stabilize heavy metals in the soil. Thus, the addition of organic matter has the potential to reduce Hg mobility and limit its transfer to plants.

Bokashi (*Gliricidia sepium*) is a local organic material that can be used as a source of carbon and nutrients. After decomposition, bokashi produces organic compounds that can contribute to humus formation, increase organic carbon, and enhance the soil's ability to absorb metal ions. Furthermore, the presence of organic matter can influence soil reaction or pH, which is a factor controlling the chemical behavior of heavy metals.

Soil depth needs to be considered in Hg studies because heavy metal concentrations are not always uniform across layers. Topsoil layers are generally closer to sources of contamination and surface activity, while deeper layers may exhibit different accumulation patterns due to leaching, binding by soil materials, or differences in organic matter content. Therefore, observations at multiple depths are necessary to more fully understand Hg distribution.

Based on this rationale, this study examines the effect of organic matter in the form of bokashi on the distribution of Hg in contaminated soil and its accumulation in corn plant tissues at various depths. This study also assesses changes in pH, organic carbon, and CEC as supporting indicators in explaining changes in Hg behavior in the soil-plant system.

## METHOD

The research was conducted in the greenhouse of the Department of Agricultural Cultivation, Faculty of Agriculture, Tadulako University. Soil and plant analysis were conducted in the Natural Resources and Environmental Analysis Laboratory, Faculty of Agriculture,



Tadulako University. The soil used was from the Poboya gold mine processing area, Palu City, Central Sulawesi. The test plant used was sweet corn variety Bonanza F1. The bokashi materials applied were gamal leaves *Gliricidia sepium*, EM4, rice bran, sugar, urea, and water.

The experiment was arranged in a factorial randomized block design. The first factor was soil depth, which consisted of three levels: 0-10 cm, 11-20 cm, and 21-30 cm. The second factor was the dose of bokashi kirinyu, which consisted of four levels: 0 t ha<sup>-1</sup>, 15 t ha<sup>-1</sup>, 30 t ha<sup>-1</sup>, and 45 t ha<sup>-1</sup>. Each treatment combination was repeated three times, resulting in a total of 3 x 4 x 3 = 36 experimental units. If the analysis of variance showed a significant effect, the test was continued with the Honestly Significant Difference (HSD) test.

The soil from each layer was air-dried, cleaned of coarse material, and then weighed to a volume of 10 kg per polybag. Bokashi kirinyu was mixed according to the treatment dosage, and the medium was incubated before planting. Two corn seeds were planted in each polybag and thinned 14 days after planting. Observations were made until the maximum vegetative phase, after which the soil and plant tissues were analyzed in the laboratory.

Observed variables included soil chemical properties and indicators of Hg contamination, namely soil Hg concentration, Hg in plant tissue, plant Hg uptake, soil pH, organic carbon, CEC, and the chemical composition of bokashi. Data were analyzed using analysis of variance according to the experimental design. Results are presented in tabular form to show the response pattern between organic matter dose and soil depth

## RESULTS AND DISCUSSION

### Chemical Characteristics of Bokashi *Gliricidia sepium*

Initial analysis of *Gliricidia sepium* bokashi indicates that this organic material has a high organic carbon content and a relatively favorable C/N ratio for decomposition. The high organic carbon content is an important source of humic compounds, while the N, P, and K contents indicate that bokashi functions not only as an ameliorant but also as a nutrient contributor to contaminated soil.

**Table 1. Chemical composition of bokashi leaves of gamal *Gliricidia sepium***

| Type of material | Parameter | Content (%) | C/N   |
|------------------|-----------|-------------|-------|
| Gamal Leaves     | C-organic | 34.52       | 11.51 |
|                  | N         | 3.00        |       |
|                  | P         | 0.83        |       |
|                  | K         | 6.05        |       |

Source: Natural Resources and Environmental Analysis Laboratory, Faculty of Agriculture, Tadulako University (2016).

### Distribution of Mercury (Hg) in Contaminated Soil

Soil Hg concentrations showed a decreasing trend with increasing bokashi dosage. In the treatment without organic matter, soil Hg levels remained high at all depths. After bokashi was added, soil Hg levels decreased, with the lowest value recorded at a dosage of 45 t ha<sup>-1</sup> at a depth of 20 cm, at 575.43 ppm. This pattern indicates that organic matter plays a role in suppressing dissolved Hg or mobile Hg in the soil medium.

**Table 2. Soil Hg concentration at various bokashi doses and soil depths**

| Bokashi dose (t ha <sup>-1</sup> ) | 0-10 cm | 11-20 cm | 21-30 cm |
|------------------------------------|---------|----------|----------|
| 0                                  | 589.04  | 588.34   | 586.97   |
| 15                                 | 586.34  | 586.28   | 585.11   |
| 30                                 | 583.88  | 583.10   | 583.30   |
| 45                                 | 580.65  | 575.43   | 580.45   |

Note: values are expressed in ppm.

The decrease in soil Hg can be explained by the ability of organic matter to form complex bonds with heavy metals. Carboxyl, phenolic, and other charged groups in organic matter contribute to the adsorption of metal cations. The higher the bokashi dose, the greater the chance of organometallic bonds forming, which makes Hg less available to plants. Thus, changes in soil Hg levels are influenced not only by the initial Hg amount but also by the quality of the gamal leaf bokashi and the chemical conditions of the soil at each depth.

### Accumulation and Absorption of Mercury in Corn Plants

Plant responses to Hg are reflected in two indicators: plant Hg uptake and Hg concentration in plant tissue. Hg uptake data show that uptake values increase at higher bokashi doses. However, plant tissue Hg concentrations actually decrease with increasing bokashi doses. This difference in direction may occur because total uptake is related to biomass growth, while tissue concentration reflects the Hg content per unit of plant tissue.

**Table 3. Hg absorption of corn plants at various bokashi doses and soil depths**

| <b>Bokashi dose (t ha<sup>-1</sup>)</b> | <b>0-10 cm</b> | <b>11-20 cm</b> | <b>21-30 cm</b> |
|-----------------------------------------|----------------|-----------------|-----------------|
| <b>0</b>                                | 0.65           | 0.63            | 0.53            |
| <b>15</b>                               | 0.76           | 0.77            | 0.74            |
| <b>30</b>                               | 1.00           | 0.95            | 0.94            |
| <b>45</b>                               | 1.42           | 1.36            | 1.33            |

*Note: The value follows the Hg absorption units of plants in the source text.*

**Table 4. Hg concentration in corn plant tissue at various bokashi doses and soil depths**

| <b>Bokashi dose (t ha<sup>-1</sup>)</b> | <b>0-10 cm</b> | <b>11-20 cm</b> | <b>21-30 cm</b> |
|-----------------------------------------|----------------|-----------------|-----------------|
| <b>0</b>                                | 41.09          | 41.55           | 39.94           |
| <b>15</b>                               | 37.58          | 37.62           | 37.64           |
| <b>30</b>                               | 36.07          | 34.37           | 34.01           |
| <b>45</b>                               | 33.53          | 33.04           | 31.84           |

*Note: values are expressed in ppm.*

The highest plant Hg concentration was found in the treatment without bokashi, while the lowest value was found in the 45 t ha<sup>-1</sup> treatment at a depth of 30 cm. This indicates that kirinyu bokashi can suppress Hg levels in plant tissues. Physiologically, heavy metals present in the soil solution can be absorbed by the roots and then translocated to other plant parts through the transport network. When organic matter reduces Hg availability in the growing medium, Hg transfer to plant tissues can also be suppressed.

### Changes in Soil pH due to Bokashi Application

The soil pH was in the neutral range and showed a slight decrease with increasing bokashi dosage. The treatment without bokashi had a pH of 7.08, while the 45 t ha<sup>-1</sup> dosage had a pH of 6.83. This change may be related to the decomposition of organic matter, which produces certain organic compounds. Despite the decrease in pH, this range still reflects relatively neutral soil conditions.

**Table 5. Soil pH values at various doses of bokashi**

| <b>Bokashi dose (t ha<sup>-1</sup>)</b> | <b>soil pH</b> |
|-----------------------------------------|----------------|
| <b>0</b>                                | 7.08           |
| <b>15</b>                               | 7.05           |

|           |      |
|-----------|------|
| <b>30</b> | 6.98 |
| <b>45</b> | 6.83 |

pH is a crucial factor in Hg behavior because it affects the solubility, adsorption, and formation of metal complexes. In soils with higher organic matter, the effect of pH is not independent, but rather works in conjunction with the increase in active organic matter groups and the soil's adsorption capacity. Therefore, even if the pH decreases slightly, increasing organic matter can still enhance the soil's ability to bind metals.

### Soil Organic C Changes

Bokashi application increased soil organic carbon content at all depths. At a dose of 45 t ha<sup>-1</sup>, organic carbon reached its highest value, particularly in the 0-10 cm layer. This increase indicates that bokashi addition acts as a direct carbon source for contaminated soil. This increase in organic carbon is crucial because organic carbon forms the basis for humus formation and plays a role in heavy metal stabilization.

**Table 6. Soil organic C content at various bokashi doses and soil depths**

| <b>Bokashi dose (t ha<sup>-1</sup>)</b> | <b>0-10 cm</b> | <b>11-20 cm</b> | <b>21-30 cm</b> |
|-----------------------------------------|----------------|-----------------|-----------------|
| <b>0</b>                                | 1.16           | 1.14            | 1.12            |
| <b>15</b>                               | 1.64           | 1.47            | 1.32            |
| <b>30</b>                               | 1.94           | 1.69            | 1.47            |
| <b>45</b>                               | 2.10           | 1.81            | 1.52            |

*Note: values are expressed in percentage (%).*

The highest organic carbon content in the surface layer indicates that organic matter plays a greater role in the zone directly treated. The deeper the soil layer, the lower the organic carbon content. This pattern is important in explaining why Hg responses can differ across depths. Layers with higher organic carbon potentially have a greater capacity to adsorb and stabilize Hg.

### Changes in Cation Exchange Capacity (CEC)

Soil CEC (Central Tolerance Concentration) increased with increasing bokashi dosage. The lowest CEC value was found in the 0 t ha<sup>-1</sup> treatment, while the highest value was found in the 45 t ha<sup>-1</sup> treatment. The increase in CEC indicates an increase in the soil's negative charge, which

can retain cations, including heavy metal cations. With increased CEC, Hg is more likely to be retained in the soil sorption complex and becomes less mobile.

**Table 7. Cation exchange capacity of soil at various doses of bokashi**

| Bokashi dose (t ha <sup>-1</sup> ) | Soil CEC (me 100 g <sup>-1</sup> ) |
|------------------------------------|------------------------------------|
| 0                                  | 10.71                              |
| 15                                 | 11.44                              |
| 30                                 | 11.87                              |
| 45                                 | 12.04                              |

Increasing the CEC also strengthens bokashi's ameliorative function. Soils with higher CEC have a better ability to retain nutrients and metals, so changes in CEC can be understood as one mechanism explaining the decrease in soil Hg and plant tissue Hg. In other words, bokashi not only adds organic matter but also alters the soil's chemical properties, thus creating a more stable root environment.

### Synthesis of Discussion

Overall, the application of bokashi leaves (*Gliricidia sepium*) resulted in three main patterns. First, bokashi reduced soil Hg concentrations, especially at high doses. Second, Hg concentrations in corn plant tissues decreased with increasing bokashi doses. Third, soil chemical quality improved through increased organic carbon and CEC. These three patterns are interrelated because organic matter can increase sorption sites, form complexes with heavy metals, and reduce Hg mobility in the soil-plant system.

Depth remains a crucial factor because Hg and organic matter are not distributed uniformly within the soil profile. Different soil layers exhibit different responses to bokashi treatments. Therefore, management of Hg-contaminated soil requires considering not only the organic matter dose but also the characteristics of the soil layer targeted for remediation. In the context of contaminated soil from the Poboya area, approaches based on local organic matter, such as bokashi (*Gliricidia sepium*), could be an initial alternative to reduce Hg risks. Although comprehensive remediation still requires source management and long-term monitoring.

### CONCLUSION

Application of gamal leaf bokashi (*Gliricidia sepium*) has been shown to reduce mercury (Hg) concentrations in contaminated soil and reduce Hg accumulation in corn plant tissues,



especially at a dose of 45 t ha<sup>-1</sup>. This effect is related to increased organic carbon and cation exchange capacity, which strengthens the adsorption mechanism and the formation of organometallic complexes, thereby suppressing Hg mobility in the soil-plant system. Furthermore, Hg distribution varies across soil depths, with the most pronounced response occurring in layers with higher organic matter content. Practically, these results indicate that gamal leaf bokashi has the potential to be used as an effective local ameliorant for the initial rehabilitation of Hg-contaminated soil, particularly in agricultural lands surrounding artisanal gold mining areas.

However, this study has limitations, including being conducted in a greenhouse, which does not fully represent field dynamics. It also failed to evaluate long-term changes in Hg levels and the nature of chemical speciation. Furthermore, this study used only one indicator plant, thus limiting generalizability to other commodities. Therefore, further research is recommended at the field scale with longer observation periods, encompassing various plant species, and examining the interaction of Hg with organic matter fractions and soil microorganisms. Practical implications suggest that the use of bokashi needs to be combined with pollution source management and integrated remediation strategies to ensure the effectiveness of Hg risk reduction is sustainable and safe for agricultural production systems.

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