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# Effect of using ash from waste incineration plants for bio-fertilizer production

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## Abstract

This study aimed to evaluate the effect of using incinerator ash from the waste to energy plant in Luang Prabang Province as a raw material in the production of Bio-fertilizer, and to analyze the chemical composition of the fertilizer at varying ash incorporation ratios, ranging from 0-30%. Each Bio-fertilizer formulation consisted of: cow manure, rice husk charcoal, sawdust, and effective microorganism (EM) extract. The experiment employed a Completely Randomized Design (CRD) with 8 treatments and 3 replications. The Bio-fertilizer production method involved mixing the raw materials according to the designated ratios, followed by a total fermentation period of 45 days under plastic sheeting. After fermentation, the fertilizers were analyzed for chemical components that serve as plant nutrients, namely: pH, Organic Matter (OM), Nitrogen (N), Phosphorus ($P_2O_5$), and Potassium ($K_2O$). The chemical analysis results showed that the treatments incorporating incinerator ash resulted in statistically significant differences in the chemical composition of the plant nutrients, at a level of $p<0.05$. Specifically, Treatment T3 performed best among the experimental groups, leading to an increase in Organic Matter (OM) from 3.50 to 4.37%. This level is significantly high when compared to the established standard for fertilizer (≥3%). Additionally, it resulted in a 0.5 time increase in $P_2O_5$ compared to the formulation without ash. Furthermore, increasing the amount of ash led to a sequential increase in the $K_2O$ value, indicating that ash significantly influences the $K_2O$ content, particularly in Treatment T8.

**Keywords:** Ash; Bio-Fertilizer; Nutrient Elements Value; Incineration plants

## 1. Introduction

Currently, the management of waste residues from biomass and municipal incineration specifically ash, which remains in large quantities has become a significant environmental challenge in the Lao PDR and the broader region. Without proper management, the disposal of this ash can lead to severe environmental impacts, such as heavy metal contamination or dust pollution (UNDP Laos, 2022). However, ash possesses high recycling potential because it is rich in essential plant nutrients, including Calcium (Ca), Magnesium (Mg), Potassium (K), and Phosphorus (P) (Li et al., 2019). Furthermore, its alkaline properties allow it to be used as a soil amendment to neutralize acidity. Therefore, utilizing ash as a raw material for bio-fertilizer production is a strategic approach to waste reduction and value addition within the agricultural sector (Wang et al., 2020).

In the Lao PDR, particularly in Luang Prabang Province, urban waste management faces ongoing challenges due to community expansion and tourism activities (Department of Environment, Lao PDR, 2021). The accumulation of large volumes of ash from waste incineration plants necessitates sustainable management practices (UNDP Laos, 2022). Integrating ash into bio-fertilizer production is a vital pathway that aligns with the government's organic agriculture development policy (Ministry of Agriculture and Forestry, Lao PDR, 2018) by promoting the use of local resources and reducing dependence on imported chemical fertilizers.

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Ash derived from Municipal Solid Waste Incineration (MSWI) has high agricultural potential due to its chemical properties and nutrient-enhancing capabilities. Specifically, MSWI ash is rich in primary macronutrients such as $K_2O$ and $P_2O_5$ (Li et al., 2019; Vassilev et al., 2013). Research by Magdziarz et al. (2018) confirms that biomass ash contains high concentrations of $K_2O$ and $P_2O_5$. Consequently, blending ash into bio-fertilizers can upgrade the quality of organic fertilizers regarding Phosphorus (P) and Potassium (K) supply (Wang et al., 2020).

Ash is highly alkaline, with pH levels reaching as high as 12.9 due to the presence of alkali metal oxides (Bridle & Pritchard, 2004; EMU DSpace, 2021). The application of this ash can raise the pH of the fertilizer, helping to reduce soil acidity and increasing the solubility and bioavailability of nutrients like phosphorus ($P_2O_5$). Nevertheless, MSWI ash carries risks regarding high concentrations of heavy metals, such as Cadmium (Cd), Lead (Pb), Zinc (Zn), and Chromium (Cr) (Satheesh et al., 2018). To mitigate these risks, incorporating ash into the bio-fertilizer composting process can help immobilize heavy metals through the action of organic matter and high pH levels (RSC Publishing, 2025; Qu et al., 2025).

Regardless, verifying the chemical composition and safety of the fertilizer before application is essential. Therefore, this study aims to investigate the optimal mixing ratios of incinerator ash for bio-fertilizer production and to analyze the chemical components (pH, OM, N, P, K) of bio-fertilizers produced from varying proportions of ash.

## 2. Materials and Methods

### 2.1. Materials

The equipment used in this experiment included fertilizer bags and black plastic sheeting. The raw materials used for bio-fertilizer production consisted of:

- Waste Incinerator Ash: Obtained from the waste-to-energy plant in Ban Chang Hai, Pak Ou District, Luang Prabang Province.
- Rice Husk Charcoal: Purchased from general agricultural supply stores.
- Sawdust: Sourced from a wood processing factory in Ban Chang Hai.
- Effective Microorganisms (EM): Ready-to-use EM solution purchased from agricultural stores.
- Cow Manure: Obtained from the livestock farm of the Northern Agriculture and Forestry College.

### 2.2. Chemicals

The chemicals used for analyzing the chemical composition of the fertilizer included:

- KCl and Standard Buffer Solutions (pH 4, 7, 14): Used for pH analysis.
- Potassium Dichromate ($K_2Cr_2O_7$) and Sulfuric Acid ($H_2SO_4$): Used for Organic Matter (OM) analysis.
- Sodium Hydroxide (NaOH) and Hydrochloric Acid (HCl): Used for analyzing Nitrogen (N), Phosphorus (P), and Potassium (K) content.

### 2.3. Experimental Design

The experiment utilized a Completely Randomized Design (CRD) with 8 treatments and 3 replications. The bio-fertilizer was produced by mixing incinerator ash with other components (cow manure, rice husk charcoal, sawdust, and EM solution) in varying proportions as detailed in Table 1.

### 2.4. Experimental Procedures

The ash and all other raw materials were sieved to remove impurities. The components were then mixed according to the specified ratios for each treatment. The mixture was hydrated with an EM solution (15 ml of EM per 20 L of clean water mixed with molasses), ensuring a final moisture content of 50–60%, verified using a moisture meter. The mixture was formed into rectangular piles (20 cm high and 1 meter wide) and covered with black plastic sheeting to maintain moisture and protect against rain. The fermentation process lasted 45 days, during which the piles were turned every 7 days to maintain temperatures between 45–60°C. After fermentation, the fertilizer was air-dried in the shade, packed into bags, and stored in a dry place for further chemical analysis.

## 3. Sample Preparation and Chemical Analysis

1 kg sample from each treatment was labeled and sent to the Soil Analysis Center, Department of Land Management and Development, Ministry of Agriculture and Forestry in Vientiane. The analysis methods were as follows:

### 3.1. pH Analysis

The pH was analyzed following the *Handbook of Soil, Water, and Plant Practical Analysis (2010)* using a 1:2.5 (w/w) fertilizer-to-water ratio. 20g of fertilizer was mixed with 45 ml of distilled water, stirred for 30 minutes, and allowed to settle for another 30 minutes. The pH of the supernatant solution was measured using a pH meter in triplicate to obtain an average value.

### *3.2.* Organic Matter (OM) Analysis

OM content was determined using the Walkley & Black method (1947). 1g of fertilizer was reacted with 1.0 N $K_2Cr_2O_7$ and concentrated $H_2SO_4$. After cooling, the solution was diluted with distilled water and titrated with 0.5 N Ferrous Ammonium Sulfate (FAS) using ortho-phenanthroline as an indicator until the color changed from green to reddish-brown.

### *3.3.* N, $P_2O_5$, and $K_2O$ Analysis

The analysis of Nitrogen (N), Phosphorus ($P_2O_5$), and Potassium ($K_2O$) followed the Handbook of Soil, Water, and Plant Practical Analysis (2010) according to AOAC (1990) methods. The results were compared against standard nutrient values.

### 3.4. Statistical Analysis

Data obtained from the chemical analysis were subjected to statistical analysis to determine variance. Mean comparisons were performed using Duncan's Multiple Range Test (DMRT)

## 4. Results

### 4.1. Hydrogen Ion Concentration (pH)

The analysis of the pH values of the bio-fertilizer formulations revealed that each formula was slightly acidic, with average values ranging between 4.9 and 5.2. When comparing the experimental groups, it was observed that the pH values of the formulations containing incinerator ash showed statistically significant differences at a 95% ($p<0.05$) confidence level (Table 2). However, compared to the standard requirement of 5.5–7, the pH values remained relatively low, particularly in Treatment T1 (lowest ash content), which had a pH of only 4.9. Notably, the pH value increased sequentially as the proportion of ash was increased.

**Table 1** Composition of Bio-fertilizer Formulations (%)

| No. | Treatment | Cow Manure | Waste Ash | Rice Husk Charcoal | EM Solution | Sawdust |
|---|---|---|---|---|---|---|
| 1 | Treatment 1 (T1) | 60 | 0 | 15 | 15 | 10 |
| 2 | Treatment 2 (T2) | 55 | 5 | 15 | 15 | 10 |
| 3 | Treatment 3 (T3) | 50 | 10 | 15 | 15 | 10 |
| 4 | Treatment 4 (T4) | 45 | 15 | 15 | 15 | 10 |
| 5 | Treatment 5 (T5) | 40 | 20 | 15 | 15 | 10 |
| 6 | Treatment 6 (T6) | 35 | 25 | 15 | 15 | 10 |
| 7 | Treatment 7 (T7) | 30 | 30 | 15 | 15 | 10 |
| 8 | Treatment 8 (T8) | 0 | 100 | 0 | 0 | 0 |

Values with different superscripts in a column differ significantly )p<0.5(, as determined by Duncan's Multiple Range Test (DMRT).

**Table 2** pH Values of Bio-fertilizers

| No. | Treatment | pH Value ($H_2O$) | Standard pH Range |
|---|---|---|---|
| 1 | T1 | $4.90^{c}$ | 5.5 – 7.0 |
| 2 | T2 | $5.10^{ab}$ | |
| 3 | T3 | $5.10^{ab}$ | |
| 4 | T4 | $5.20^{a}$ | |
| 5 | T5 | $5.00^{bc}$ | |
| 6 | T6 | $5.00^{bc}$ | |
| 7 | T7 | 5.20a | |
| 8 | T8 | $5.20^{a}$ | |
| F-prob | | 0.0128 | |
| CV (%) | | 1.96 | |

Values with different superscripts in a column differ significantly )p<0.5(, as determined by Duncan's Multiple Range Test (DMRT).

**Table 3** Organic Matter (OM) Content of Bio-fertilizers

| No. | Treatment | Analyzed OM Value (%) | Standard OM Levels |
|---|---|---|---|
| 1 | T1 | $3.50^{g}$ | 0.5–1.0 (Very Low)<br>1.6–2.0 (Medium)<br>2.6–3.5 (High)<br>> 3.5 (Very High) |
| 2 | T2 | $4.24^{b}$ | |
| 3 | T3 | $4.37^{a}$ | |
| 4 | T4 | $4.10^{cd}$ | |
| 5 | T5 | $3.70^{f}$ | |
| 6 | T6 | $3.83^{e}$ | |
| 7 | T7 | $4.17^{bc}$ | |
| 8 | T8 | $4.03^{d}$ | |
| F-prob | | 0.000 | |
| CV (%) | | 1.54 | |

Values with different superscripts in a column differ significantly )p<0.5(, as determined by Duncan's Multiple Range Test (DMRT).

**Table 4** Nitrogen (N) Content of Bio-fertilizers

| No. | Treatment | Analyzed N Value (%) | Standard N Levels |
|---|---|---|---|
| 1 | T1 | $0.50^{b}$ | ≤ 0.10 (Very Low)<br>0.11–0.15 (Low)<br>0.16–1.0 (Medium)<br>≥ 1.5 (High) |
| 2 | T2 | 0.56a$^{b}$ | |
| 3 | T3 | $0.62^{a}$ | |
| 4 | T4 | $0.45^{c}$ | |
| 5 | T5 | $0.39^{d}$ | |
| 6 | T6 | $0.50^{b}$ | |
| 7 | T7 | $0.34^{e}$ | |
| 8 | T8 | $0.28^{f}$ | |

| | | |
|---|---|---|
| F-prob | 0.0009 | |
| CV (%) | 2.12 | |

Values with different superscripts in a column differ significantly )p<0.5(, as determined by Duncan's Multiple Range Test (DMRT).

**Table 5** Phosphorus ($P_2O_5$) Content of Bio-fertilizers

| No. | Treatment | Analyzed $P_2O_5$ Value (%) | Standard $P_2O_5$ Levels |
|---|---|---|---|
| 1 | T1 | 0.79[d] | ≤ 0.05 (Very Low)<br>0.05–0.2 (Medium)<br>≥ 0.2 (High) |
| 2 | T2 | 0.96[c] | |
| 3 | T3 | 1.32[a] | |
| 4 | T4 | 1.20[ab] | |
| 5 | T5 | 0.97[c] | |
| 6 | T6 | 1.05b[c] | |
| 7 | T7 | 1.18[ab] | |
| 8 | T8 | 1.18[ab] | |
| F-prob | | 0.0002 | |
| CV (%) | | 8.65 | |

Values with different superscripts in a column differ significantly )p<0.5(, as determined by Duncan's Multiple Range Test (DMRT).

**Table 6** Potassium ($K_2O$) Content of Bio-fertilizers

| No. | Treatment | Analyzed $K_2O$ Value (%) | Standard $K_2O$ Levels |
|---|---|---|---|
| 1 | T1 | 1.06[d] | ≤ 0.2 (Very Low)<br>0.2–0.5 (Medium)<br>≥ 0.5 (High) |
| 2 | T2 | 1.12[cd] | |
| 3 | T3 | 1.17[cd] | |
| 4 | T4 | 1.20[cd] | |
| 5 | T5 | 1.29[bc] | |
| 6 | T6 | 1.29[bc] | |
| 7 | T7 | 1.38[b] | |
| 8 | T8 | 1.68[a] | |
| F-prob | | 0.0001 | |
| CV (%) | | 7.34 | |

Values with different superscripts in a column differ significantly )p<0.5(, as determined by Duncan's Multiple Range Test (DMRT).

### 4.2. Organic Matter (OM)

The results indicated that the Organic Matter (OM) content in all bio-fertilizer formulations was very high compared to the standard requirement for bio-fertilizers (≥ 3.5%). The highest OM content was recorded in Treatment T3 (4.37%), followed by T2 (4.24%). Furthermore, there were statistically significant differences between treatments ($p<0.05$), as shown in Table 3. This experiment demonstrates that varying the proportion of ash significantly affects OM levels, with some formulations showing a twofold increase compared to the control formula without ash.

### 4.3. Nitrogen (N)

The analysis showed that varying the ash content from 0% to 30% caused Nitrogen (N) levels to gradually increase from T2 to T3, while they tended to decrease from T4 to T6. Nevertheless, compared to T1 (control without ash), there were statistically significant differences ($p<0.05$). The N content across all treatments (T1–T8) fell within the medium range (0.16–1.00%) of the standard bio-fertilizer requirements. The highest N value was found in T3 (0.62%), followed by T2 (0.56%). In comparison, T1 had an N value of 0.50%. It can be concluded that different ash mixing ratios significantly impact N levels, leading to a 0.1-fold increase compared to the ash-free formula (Table 4).

### 4.4. Phosphorus ($P_2O_5$)

The phosphorus ($P_2O_5$) analysis revealed a significant increase in values with a 95% confidence level. The values rose from 0.79% to 1.32% (nearly a twofold increase), categorized as a high level compared to the standard of ≥ 0.2% (Table 5). The highest $P_2O_5$ content was observed in the formula with 10% ash (T3 = 1.32%), followed by 15% ash (T4 = 1.20%). These values were significantly higher ($p<0.05$) than the control (T1 = 0.79%). All formulations containing ash maintained high levels of $P_2O_5$, indicating that incinerator ash is an effective additive for increasing phosphorus in organic fertilizers.

### 4.5. Potassium ($K_2O$)

The experiment showed that the potassium ($K_2O$) content in the bio-fertilizers was very high compared to the standard (≥ 0.5%). The trend for $K_2O$ was consistent with the findings for OM, N, and P. The highest $K_2O$ value was recorded in T8 (100% ash = 1.68%), followed by T7 (30% ash = 1.38%). There were statistically significant differences ($p<0.05$) between treatments, particularly when compared to the control (T1 = 1.06%) as shown in Table 6. This study demonstrates that varying the ash content significantly increases $K_2O$ levels, with an increase of up to 0.6 times compared to the formula without ash.

## 5. Discussion

The nutrient analysis of the bio-fertilizers revealed that the pH values ranged between 4.9 and 5.2. Increasing the ash content (as seen in treatments T4, T7, and T8) elevated the pH compared to the control group (T1). This phenomenon aligns with the principle that biomass or waste ash is highly alkaline, with pH levels often reaching 10 to 13 due to high concentrations of Calcium (Ca) and other alkali metals (Rolka et al., 2025; Stankowski et al., 2021). Despite the addition of ash, the maximum pH reached was only 5.2, which remains slightly acidic compared to the ideal bio-fertilizer standard of 5.5–7. This is likely because, although ash can reach a pH of 12.9 due to alkali metal oxides (Bridle & Pritchard, 2004; EMU DSpace, 2021), the other raw materials in the mixture were highly acidic. Consequently, the final bio-fertilizers exhibited a neutralized or slightly acidic state resulting from the natural fermentation process.

Furthermore, increasing the ash ratio led to a dilution of Nitrogen (N) concentration derived from the animal manure, resulting in a peak N value of 0.62% in formula T3. This is consistent with the findings of Wang et al. (2020), who noted that while mixing ash into bio-fertilizers enhances the quality of organic fertilizers by increasing $P_2O5$ and $K_2O$, it conversely tends to decrease the N content.

However, the inclusion of ash significantly boosted the Organic Matter (OM) content, reaching levels up to 1.4 times higher than the standard requirement (≥ 3.5%) compared to ash-free formulas. This increase is attributed to the high carbon (C) content in ash, which ranges from 26.8% to 70% (Tchobanoglous et al., 1993), thus raising the OM value relative to the amount of ash added. Similarly, $P_2O_5$ and $K_2O$ levels increased sequentially and exceeded bio-fertilizer standards, particularly in treatments T3 and T8, which recorded $P_2O_5$ at 1.32% and $K_2O$ at 1.68%, respectively.

These results demonstrate that ash-based formulations promote higher levels of available $P_2O_5$ and $K_2O$ for plants, supporting the research by Li et al. (2019) and Vassilev et al. (2013), which identifies ash as an abundant source of these primary nutrients. Magdziarz et al. (2018) also confirmed high concentrations of $K_2O$ and $P_2O_5$ in biomass ash. Therefore, blending ash into bio-fertilizers effectively upgrades organic fertilizer quality in terms of P and K supply. Additionally, as noted by Ghosh et al. (2010), organic fertilizers decomposed by microorganisms release organic ligands, which further enhance the bioavailability of phosphorus for plant uptake.

## 6. Conclusion

The experiment on utilizing waste incinerator ash for bio-fertilizer production demonstrates that the chemical composition of the fertilizer changes according to the proportion of ash used in each formula. The treatment that showed the most significant improvement in chemical composition was T3 (10% ash content), which resulted in a 1-fold increase in Organic Matter (OM), a Nitrogen (N) content of 0.62%, Phosphorus ($P_2O_5$) at 1.32%, and Potassium ($K_2O$) at 1.68%. The study reveals that using ash in bio-fertilizer production significantly impacts nutrient levels with statistical significance. When compared to standard bio-fertilizer requirements, the nutrient levels in these formulations range from medium to high. In conclusion, varying ash quantities directly influence the nutrient profile of the fertilizers, and the most effective formulation identified in this study is the one containing 10% ash (T3).

## Compliance with ethical standards

### *Disclosure of conflict of interest*

No conflict of interest to be disclosed.

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