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Utilization of *Fly Ash* and *Bottom Ash* from Steam Power Plants (PLTU) as Soil Amendments for Tomato Plants (*Solanum lycopersicum* L.)

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Abstract: Fly ash and bottom ash are waste produced from burning coal in the Steam Power Plant industry. The higher the coal consumption, the higher the FABA waste produced. However, despite the abundant production, this waste has not been optimally managed and utilized. This research aims to determine the effect of using FABA as an ameliorant in planting media for tomato plants. This research used the Completely Randomized Design (CRD) method which consisted of 3 treatments with repetition 4 times to obtain 12 experimental units (polybags). The results of the research indicate that the use of coal waste, namely fly ash and bottom ash as an ameliorant in planting media, has a significant influence on plant height, number of flowers, number of fruits, and fruit weight of tomato plants. Planting media with a composition of 50% soil plus 50% fly ash (treatment A) yielded the lowest results among the three treatments. Meanwhile, the planting medium composition of 50% soil plus 50% bottom ash (treatment B) yielded the best results, exceeding the use of 100% soil (treatment O/control). Bottom ash as an ameliorant has a positive influence on the growth and production of tomato plants.

Keywords: Ameliorant; Bottom Ash; Fly Ash; Tomato Plants.

Introduction

Steam power plant (PLTU) activities produce waste in the form of combustion ash known as *fly ash* and *bottom ash* (FABA). *Fly ash* is solid waste from coal combustion carried along with exhaust gases and captured by an air control device called *an electrostatic precipitator (*ESP), while *bottom ash* is solid waste from coal combustion that falls to the bottom of the combustion chamber (Asof et al., 2022). The higher the coal consumption, the higher the amount of FABA waste produced (Yunita et al., 2017). Ali et al (2020) stated that in a single production cycle, approximately 5% of FABA is generated from the total coal used, with a composition of approximately 80–90% *fly ash* and the remaining 10–20% being *bottom ash*. However, despite the abundant production, the management and utilization of this waste have not been optimized (Fu et al., 2020; Yawahar & Putri, 2023). The large amount of coal ash waste, if not managed and utilized properly, can cause serious environmental problems (Nurfitria & Febriyantiningrum, 2023) and require extensive storage facilities (Winarno et al., 2019).

The utilization of FABA has been widely practiced in the construction sector, such as in the production of *paving blocks*, cement mixtures, and others. Bhattacharya et al (2021) stated that FABA can also be applied in the agricultural sector, particularly in maintaining soil stability. According to Sobari et al (2019), FABA has potential as a soil amendment because it contains

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macronutrients such as Nitrogen (N), Phosphorus (P), Potassium (K), Calcium (Ca), Magnesium (Mg), and micronutrients such as Iron (Fe), Zinc (Zn), and Manganese (Mn), which can enhance soil fertility and plant growth. Asof et al (2022) stated that FABA can also be utilized as a soil conditioner (amendment). However, at the same time, the utilization of FABA in agriculture faces challenges due to the presence of heavy metals in it (Varshney et al., 2022).

This study uses tomato plants (*Solanum lycopersicum* L.) as an indicator for its utilization. One of the factors influencing tomato plant growth is the growing medium. According to (Safitry & Kartika, 2013), the growing medium is the place where plants stand, store water and nutrients, and support the entire plant. Tomato plants are known to be highly sensitive to contamination, so if the growing medium is contaminated, the plants will immediately show effects on their growth process (Wardani et al., 2012). Therefore, the use of FABA as an ameliorant to improve the quality of the growing medium for tomato plant growth and production is expected to become an innovation in the field of agriculture and a suitable strategy to address the issue of coal combustion waste accumulation.

The objective of this study was to determine the effect of *fly ash* and *bottom ash* utilization as soil conditioners on tomato (*Solanum lycopersicum* L.) growing media. This study is useful as input for coal-fired power plants as producers of FABA waste regarding its utilization in agriculture, in this case as a soil conditioner to reduce waste accumulation as an effort to prevent environmental pollution. Additionally, it is hoped that this study will contribute to the body of knowledge and technology in the field of Soil Fertility and Environmental Science.

Method

Location and Time

This study was conducted at the Sulut-3 Power Plant, Kema Satu Village, Kema District, Minahasa Utara Regency, over a period of 5 months. Analyses were carried out at the Soil and Environmental Science Laboratory, Department of Soil Science, Faculty of Agriculture, Sam Ratulangi University.

Equipment and Materials

The equipment used includes: polybags, shovels, scales, writing tools, measuring tapes, and plant pots. The materials used include: soil, FABA from the Sulut-3 Power Plant, and tomato plant seeds.

Research Method

The Complete Randomized Design (CRD) method was used. Three treatments were conducted with four replications, resulting in 12 experimental samples. The treatments used were:
O: 100% Soil (Control)
A: 50% soil, 50% *fly ash*
B: 50% soil, 50% *bottom ash*

Research Procedure

Laboratory analysis of chemical and physical properties

Laboratory analysis preparation includes: collection of initial soil samples, *fly ash*, and *bottom ash*. These are then dried, ground, and weighed for chemical analysis of nutrient content: N, P, K, and pH. Physical analysis includes texture and permeability.

Planting

1. Planting is first carried out in seedling trays. After 2 weeks or when the plants reach a height of 5 cm, they are transferred to polybags.
2. While waiting for germination, the growing medium is mixed according to the design for each treatment. The weight of the growing medium is 5 kg, which is a mixture of soil and FABA.
3. After all materials are thoroughly mixed, incubation is carried out for 14 days.
4. This is followed by planting, which takes approximately 5 months.
5. During the planting period, plant maintenance is carried out in the form of watering twice a day.
6. Observations are made once a week to measure plant height, number of flowers, number of fruits, and fruit weight.

Variables Observed

The parameters observed were chemical properties: nitrogen (N), phosphorus (P), potassium (K), organic carbon, and pH, as well as physical properties: soil texture and permeability, and FABA as the growing medium. In tomato plants, the variables observed were plant height, number of flowers, number of fruits, and fresh fruit weight.

Data

This study was analyzed using analysis of variance, and if there was a significant effect, it was followed by a 5% BNT test.

Result and Discussion

Results of Chemical Analysis of Soil and FABA

This study conducted chemical property analysis on soil, *fly ash*, and *bottom ash* samples as an initial test, as shown in Table 1. All three samples had a neutral pH (6.6–7.5). The organic carbon (C) and nitrogen (N) content in all three samples falls within the low criteria. The available phosphorus (P) content in the soil is moderate, while in *fly ash* and *bottom ash* it is very low. The available potassium (K) content in the soil shows higher values than in *fly ash* and *bottom ash.*

Table 1. Results of Chemical Property Analysis of Soil and FABA

Type of Analysis	Sample			Analysis Method
	Soil	*Fly Ash*	*Bottom Ash*	
pH H_2O	6.79 (Neutral)	7.5 (Neutral)	7.13 (Neutral)	pH Meter
C-Organic (%)	1.74 (Low)	1.81 (Low)	1.39 (Low)	Walkey and Black
N Soil (%)	0.15 (Low)	0.16 (Low)	0.12 (Low)	Kjeldahl
P (P_2O_5) Available (ppm)	17.2 (Medium)	2.8 (Very low)	3.15 (Very low)	Bray 1
K (K_2O) Available (ppm)	29.1	11.86	13.1	Bray 1

Soil pH

The pH test results for soil samples (6.79), *fly ash* (7.50), and *bottom ash* (7.13) used in this study indicate neutral criteria (6.6–7.5). According to Tambanung et al (2018), pH within this range is a requirement for tomato plants to achieve good yields. Gunawan et al (2019) stated that soil pH plays a crucial role in determining how easily nutrients are absorbed by plants. Nutrients are generally absorbed well by plants at neutral pH levels.

C-Organic

The results of organic carbon analysis in the soil, *fly ash*, and *bottom ash* used in this study showed values of 1.74, 1.81, and 1.39, respectively, which fall into the low category. The low C-Organic content in the three samples is assumed to be due to the sampling location being open land (low vegetation). In her study, Widyantari et al 2015) stated that the presence of vegetation increases organic matter content, meaning an increase in C-Organic content.

Nitrogen (N)

The results of total N analysis in soil, *fly ash*, and *bottom ash* used in this study showed values of 0.15, 0.16, and 0.12, respectively, which are classified as low. According to Lalenoh et al (2023), nitrogen deficiency in soil disrupts plant growth and development. This is related to nitrogen's function in plants, which includes promoting vegetative growth and forming proteins. However, excessive nitrogen levels can also have adverse effects on plants, such as delaying plant maturity, weakening plant structure, and reducing disease resistance (Hardjowigeno, 2007).

Available Phosphorus (P)

The results of available phosphorus analysis in the soil, *fly ash*, and *bottom ash* used in this study showed values of 17.2 (moderate), 2.80 (very low), and 3.15 (very low), respectively. The phosphorus content in FABA is lower than in the soil, likely due to the higher pH of FABA, which results in higher calcium levels that can fix phosphorus.

Potassium (K) Available

The results of K analysis in soil were higher than in FABA, with values of 29.11, while for FABA, the values were 11.86 and 13.11, respectively. According to Dotulong et al (2015), poor vegetative growth due to potassium deficiency results in poor generative growth, leading to reduced production. Leiwakabessy et al (2003); Trisnady et al (2017) stated that one of the factors influencing the availability of K in soil is cation exchange capacity, which is related to clay content, clay type, and organic matter.

Results of Physical Property Analysis in Soil Media Treatments

Texture

The results of laboratory analysis of texture in the growing medium are presented in Table 2.

Table 2. Results of Texture Analysis on Growing Media

Treatment	Texture (%)			Criteria
	Sand	Dust	Clay	
O	45.2	38.36	16.44	Clay
A	38.00	34.44	27.56	Clayey loam
B	51.70	26.34	21.96	Sandy clay

The results of soil texture analysis in Table 2 show that treatment O belongs to the clay texture class, treatment A belongs to the silty clay texture class, while treatment B has a sandy clay texture. Compared to the control treatment, the texture in treatment A experienced a decrease in the percentage of sand and silt but an increase in the percentage of clay. This occurs because the texture of *fly ash* is generally composed of silt and clay. Meanwhile, in treatment B, there was a decrease in the percentage of silt and an increase in the percentage of sand and clay. This also occurred due to the texture *of bottom ash,* which is generally sand because its particle size is larger than that of *fly ash.* Clay texture, which has a balanced percentage among the three soil fractions, is considered optimal for plant growth Foth (1994) in Idie et al (2017). Treatment B also showed a balanced ratio between dust and clay percentages but was more dominated by the sand fraction. Haridjaja et al (2013) stated that in sandy soils, despite having fewer pores, air and water movement is very rapid due to the dominance of macro pores.

Permeability

The results of laboratory analysis of permeability in the growing medium are presented in Table 3.

Table 3. Permeability Analysis Results in Growing Media

Treatment	K (cm/hour)	Criteria
O	1.8	Somewhat Slow
A	0.47	Slow
B	4.38	Moderate

The analysis results in Table 3 show that the slowest water permeability was found in treatment A, where the soil medium composition was 50% soil and 50% *fly ash*. This was followed by treatment O (100% soil) with a moderately slow criterion and treatment B (50% soil and 50% *bottom ash*) with a moderate criterion. Treatments O and A have similar textures, but treatment A is slightly more clayey, resulting in slower permeability compared to treatment O. Additionally, treatment A, which contains half of its growing medium as *fly ash, has* been previously reported to have polazoic properties (soil hardening) that strongly retain water. This is supported by Lalenoh et al (2023) in their study on FABA, which revealed that one of the characteristics *of fly ash* is its water-holding capacity ranging from moderate to high, resulting in low water permeability. According to Dariah et al (2015), soil amendments can enhance water retention capacity and available water quantity, increase macro and meso pore size, improve total porosity, enhance soil aeration, and increase soil permeability and infiltration.

Plant Growth and Production of Tomatoes

Plant Height

The results of plant height observations over several weeks are presented in Table 4.

Table 4. Average Plant Height at Several Weeks of Observation

Treatment	2MST	4MST	6 MST	8 MST
O	8.375a	13.25b	27.00b	47.75b
A	7.875a	10.00a	13.25a	19.25a
B	9.750b	23.00c	44.25c	57.00c
BNT 5%	1.269	2.756	3.59	2.69

Note: Numbers followed by the same letter are not significantly different at the 5% level

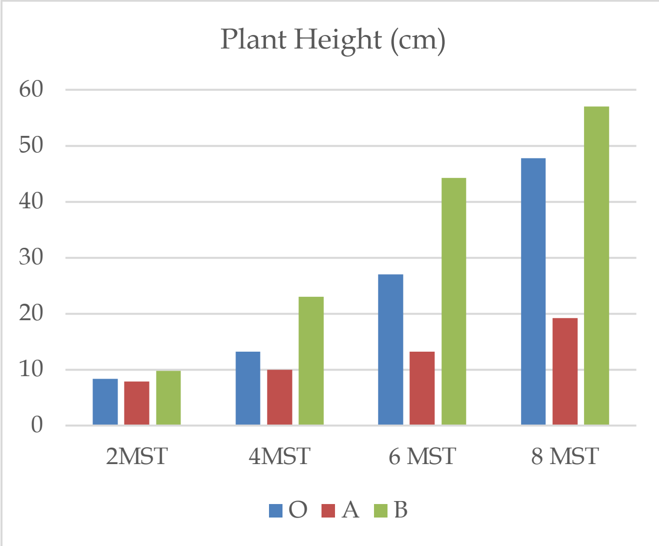

Figure 1. Average Plant Height at Several Weeks

The results of the analysis of variance (ANOVA) test on the utilization of *fly ash* and *bottom ash* as plant media with tomato plants as the indicator showed a significant effect on tomato plant height at weeks 2, 4, 6, and 8. Further analysis using the BNT test at 5% showed that at 2 MST, treatment A was not significantly different from treatment O (control), but both were significantly different from treatment B. At 4, 6, and 8 MST, significant differences were observed in all treatments. The results obtained indicate that the medium using 50% soil and 50% *fly ash* (Treatment A) produced the lowest plant height values at all four observation times.

Plant growth increased in all treatments, although nutrient deficiency symptoms were observed in the treatment using a 50% *fly ash* mixture of the total growing medium weight (5 kg). Growth was slower compared to the control and treatments using *bottom ash* at 50% of the same planting medium weight. Wardani et al (2012) stated that nitrogen deficiency makes plants highly sensitive during their growth stage.

According to Holilullah et al (2015), soil physical properties influence plant growth and production because they determine root penetration into the soil, soil water-holding capacity, drainage, soil aeration, and nutrient availability. Plants cannot develop optimally if aeration is poor, resulting in water applied to the soil failing to perform its functions effectively in water movement and nutrient transport. Additionally, Chen et al (2022) also noted that root penetration ability influences plants' ability to absorb air and nutrients, thereby determining plant productivity in adverse environments.

Treatment B has a clay-loam texture with moderate permeability, which is favorable for root penetration to absorb nutrients in the soil for plant growth. In contrast, root penetration is impaired in Treatment A due to the polazoic properties (soil hardening) of *fly ash*. The results of this study indicate that increased plant height in treatments with a soil medium composition of 50% soil plus 50% *bottom ash* (B) suggest that *bottom ash*, a byproduct of coal, can improve soil physical properties.

Number of Tomato Flowers

The results of flower count observations on tomato plants during the growth period are presented in Table 5.

Table 5. Average Number of Flowers

Treatment	Number of Flowers
O	9b
A	5a
B	15c
BNT5%	1.508

Note: Numbers followed by the same letter are not significantly different at the 5% level.

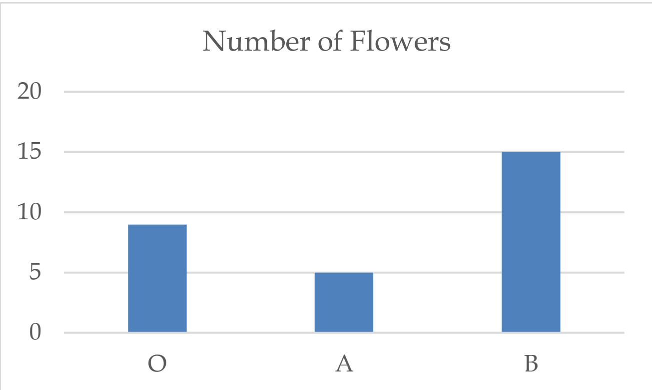

Figure 2. Average Number of Flowers

The results of the analysis of variance test on the utilization of *fly ash* and *bottom ash* as plant media with tomato plants as an indicator showed a significant effect on the number of tomato flowers. Further testing using BNT 5% indicated significant differences among all treatments. The treatment with 50% soil and 50% *fly ash* (A) had the lowest flower count, while the treatment with 50% soil and 50% *bottom ash* showed the highest flower count. However, not all flowers produced fruit; some wilted and died. This is suspected to be due to high temperatures at the research site. As stated by Wasonowati (2011), high temperatures can cause wilting and fruit drop in tomatoes.

Number of Fruits

The results of the observation of the number of tomato fruits until the end of the harvest period are presented in Table 6.

Table 6. Average Number of Fruits

Treatment	Number of Fruits
O	7b
A	3a
B	12c
BNT5%	2.048

Note: Numbers followed by the same letter are not significantly different at the 5% level.

Further testing using BNT 5% showed significant differences in all treatments. The treatment with 50% soil and 50% *fly ash* (Treatment A) had the lowest fruit yield, while the treatment with 50% soil and 50% *bottom ash* (Treatment B) showed the highest fruit yield. Tomatoes could be harvested for the first time after 90 days after sowing (DAS). Based on field observations, Treatment B produced more fruit. However, the fruit produced at harvest time was relatively small in quantity because many fruits were slow to set and some were still unripe when harvested. This is likely due to the low phosphorus (P) content in the growing medium, which plays a crucial role in flower formation, fruit development, and seed maturation, as well as accelerating ripening.

Fresh Fruit Weight

The results of fruit weight observations for tomato plants are presented in Table 7.

Table 7. Average Fresh Fruit Weight

Treatment	Fresh Fruit Weight (g)
O	107.75b
A	27a
B	284c
BNT5%	14.97

Note: Numbers followed by the same letter are not significantly different at the 5% level

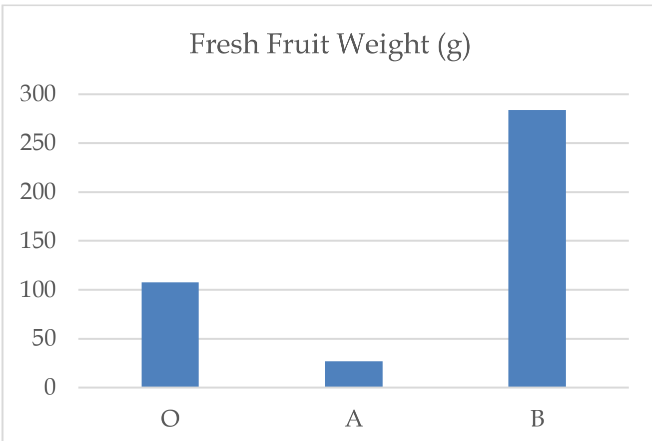

Figure 3. Average Fresh Fruit Weight

The results of the analysis of variance test on the utilization of *fly ash* and *bottom ash* as plant media with tomato plants as indicators showed a significant effect on the fruit weight of tomato plants. Further testing using BNT 5% showed significant differences in each treatment. The treatment with 50% soil and 50% *fly ash* (Treatment A) had the lowest fruit weight, while the treatment with 50% soil and 50% *bottom ash (*Treatment B) showed the highest fruit weight. Tomato fruit size varies, ranging from the smallest at 8 grams to the largest at 180 grams (Cahyono, 2008; Novitasari et al., 2019). The highest fresh weight was observed in treatment B.

Conclusion

The growing medium with a composition of 50% soil plus 50% *bottom ash* (treatment A) yielded the lowest results among the three treatments. Meanwhile, the soil mixture with a composition of 50% soil plus 50% *bottom ash* (treatment B) yielded the best results, surpassing the use of 100% soil (treatment O/control) through improvements in the physical properties of the soil mixture. This indicates that the utilization of coal ash waste, particularly *bottom ash,* as an ameliorant has a positive effect on the growth and production of tomato plants.

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Author Contributions
W.J.NK.: Developing ideas, analyzing, writing, reviewing, responding to reviewers' comments; M.T.M.S., R.I.K., Y.K., W.P.: analyzing data, overseeing data collection, reviewing scripts, and writing.

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Conflicts of Interest
The authors declare no conflict of interest.

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