Jurnal Lahan Suboptimal : Journal of Suboptimal Lands
ISSN: 2252-6188 (Print), ISSN: 2302-3015 (Online, https://jlsuboptimal.unsri.ac.id/index.php/jlso)
Vol. 14, No.2: 210-215 October 2025
DOI: 10.36706/JLSO.14.2.2025.727

Utilization of coal burning waste fly ash as a soil improving material in red yellow podsolic soil

Asia Afriyani*), Ali Martinus, Inneke Fratiwi
Departement of Environment Science, Serasan University, Muara Enim 31312, South Sumatera, Indonesia
*)Email address: asiaafriayani@unsan.ac.id

(Received: 5 December 2024, Revision accepted: 16 September 2025)

Citation: Afriyani, A., Martinus, A., & Fratiwi, I. (2025). Utilization of coal burning waste fly ash as a soil improving material in red yellow podzolic soil. *Jurnal Lahan Suboptimal : Journal of Suboptimal Lands. 14* (2): 210-215. https://doi.org/10.36706/JLSO.14.2.2025.727.

ABSTRACT

This research aimed to characterize and test the chemical properties of red-yellow podzolic soil and fly ash. The experiment was conducted using polybags with various dosage levels of 2 types of red-yellow podzolic soil, as well as fly ash. Dolomite was used as a control. The experiment used 3 types of experiments with 3 repetitions on the soil (A1=10 g of fly ash /polybag, A2=15 g of fly ash/polybag, A3=20 g of fly ash/polybag, and A0=10 g of dolomite/polybag as a control). The results showed that the application of fly ash waste can increase the pH of podzolic soil. There was an increase in K-dd from 0.34 to 1.36. Al-dd analysis of the addition of fly ash ameliorant Al-dd levels decreased quite significantly with an average of 5.26–7.16. Al-dd levels were very low in treatment A3 with the addition of 20 g/polybag. H-dd analysis on Red and Yellow Podzolic soils resulted in an increase in the initial H-dd of the soil from 0.4 to 4.61–7.16. The highest H-dd was in A2 with the addition of 15 g of fly ash/polybag and the lowest H-dd iss in treatment A3 with the addition of 20 g/polybag.

Keywords: ameliorant, coal burning, fly ash, red yellow podzolic soil, waste

INTRODUCTION

Environmental issues were a hot topic of discussion throughout the world. Almost every sector includes environmental issues in its development plans, including the industrial sector. One of the environmental issues in the industrial sector was the use of solid fuel in the form of coal for PLTUs, where in the process the burned coal produces fly ash solid waste which will cause and cause air pollution.

The results of burning coal can produce waste in the Toxic and Hazardous Materials (B3) category in the form of 80% fly ash and 20% Bottom Ash. which will cause environmental pollution, and a large place or land was needed for its storage. This was very clear, resulting in the process of managing coal-burning ash waste mostly still being carried out by landfill (Aida et al., 2018).

Fly ash has the same properties and composition as coal. Chemically, fly ash was an aluminosilicate mineral containing many elements such as Ca, K, and Na. This mineral also contains some C and N elements in small amounts. Some nutrients needed by many plants and found in coal ash include Boron (B), phosphorus (P), and elements such as Cu, Zn, Mn, Mo, and Se. Most coal ash has alkaline properties, namely a pH ranging from 8-12 (Kinasti & Notodisurzo, 2017). Fly ash could also be used as a source of potassium, phosphorus, calcium, magnesium, sulfur, and several other micronutrients (Rhazista, 2013). Fly ash also has the potential to be utilized in the agricultural sector (Wong et al., 1997).

Red and yellow podzolic soil in soil classification was a type of soil that has different diagnostic properties, such as. Soil color, soil moisture regime and pH. The red type has a drier soil moisture regime and a higher pH (less acidic) than the yellow type (Notohadiprawiro, 1968). However, from the point of view of general agricultural importance, the two types of soil can be compared because of the similarity in characteristics which were the main obstacles to plant cultivation. In the soil classification (Subardja et al., 2016) Red and Yellow Podzolic are equivalent to the Ultisol soil type from soil taxonomy.

In previous research by Fauziah et al. (2022), the analysis and discussion at this stage were carried out on 14 experimental units of factors that supported the pot experiment. The pot experiment was carried out at various dosage levels of a mixture of cow dung compost and FABA and previous research by Wardhani et al. (2012), Utilization of coal fly ash has a mixture of planting media for tomato plants (*Solanum lycopersicum*) with treatment mixed media and 25%, 50%, 75%, 100% coal fly ash.

This research was focused on discussing the use of fly ash as waste from the coal burning process as a planting medium using the polybag method using red and yellow podzolic soil and several obstacles that may arise during the research. This was done as a form of environmental awareness to reduce environmental pollution that could be caused. Bearing in mind that until now the use of coal ash waste has not been carried out on a massive scale, so the impact of its use has not been felt. The objective of this research was to characterize and test the chemical properties of red yellow podzolic soil and fly ash from PTBA with various doses and carried out in three replications.

MATERIALS AND METHODS

Location

This research was conducted from July 2023 to December 2023. The research was conducted at Serasan University by taking Red and Yellow Podzolic Soil at the Experimental Garden Location of the Faculty of Agriculture, Sriwijaya Indralaya University and collecting Ash waste at PT. Tanjung Enim Bukit Asam (PTBA).

Initial soil and Fly Ash characterization

Initial soil property parameters analyzed include texture, pH H_2O (1:2.5), C-organic, N-total, P-available, CEC, exchangeable potassium (K-dd), exchangeable calcium (Ca-dd), exchangeable magnesium (Mg-dd), and exchangeable sodium (Na-dd). FABA from PTBA analyzed includes pH, total element content, and water content and the parameters analyzed include pH, total macronutrient content, and ash content. The method used for the analysis of FABA and soil before and after treatment was based on the analysis method by the Soil Research Institute (Soil Research Institute, 2009), as well as compost analysis.

Polybag Experiment

The polybag experiment was carried out at three dosage levels for red-yellow podzolic soil and fly ash, namely. By using Dolomite as a control, the following were the treatments in this Table 1. Incubation of treatment applications with all various treatments on red-yellow podzolic soil and acid sulfate soil was carried out for 40 days. On the 41st day, soil samples were taken to be tested in the soil laboratory according to the observation parameters.

Table 1. Description of experimental treatment

Code	Treatment
A0	10 g D /polybag
A1	10 g FA/polybag
A2	15 g FA/polybag
A3	20 g FA/polybag

RESULTS

Chemical Properties of Red-Yellow Podzolic Soils

The initial test results for the chemical properties of the red and yellow podzolic were taken and analytical measurements were carried out at the Soil Laboratory of PT. Bumi Andalas Permai. Both soils were analyzed before receiving Table 2.

Table 2. Preliminary test results for red yellow podzolic soil

chemical properties	RYP	Information
pH (H_20)	4.13	
Al-dd	8.78	Me/100 g
H-dd	0.40	Me/100 g
Al_Saturation	77.95	Me/100 g
Na-dd	0.62	Me/100 g
K-dd	0.34	Me/100 g
Ca-dd	0.57	Me/100 g
Mg-dd	0.55	Me/100 g
KTK	11.27	(cmol(+)/kg)
KB	18.49	%

Effluent Treatment (PET)

The following were the results of PET analysis.

Table 3. Chemical properties Fly Ash

Chemical Properties	Fly Ash	Information
Exc. Al	UDT	Meq/100 g
Exc. Ca	9.22	Meq/100 g (Ca)
Exc. H	0.17	Meq/100 g
Exc. K	0.28	Meq/100 g (K)
Exc. Mg	5.49	Meq/100 g (Mg)
Exc. Na	4.37	Meq/100 g (Na)
pH H2O	6.42	(1:10)
Al_Saturation	0.00	0
Base Saturation	99	0
KTK	19.52	(cmol(+)/kg)

Effect of Treatment on the Degree of Acidity (pH)

Treatment of red yellow podsolic soil which initially had a pH of 4.13 tended to increase slightly with an average increase in pH 4.59. Providing 15 g of fly ash in each polybag significantly increased soil pH compared to other treatments. The following were the results of the pH analysis.

Table 4. Results of pH Analysis in red-yellow podzolic

Code	Series			Amount	Average
	S1	S2	S3		
A0	4.77	4.95	4.44	14.16	4.72
A1	4.41	4.61	4.63	13.65	4.55
A2	4.57	4.54	4.71	13.82	4.61
A3	4.55	4.54	4.44	13.53	4.51

when seen in pH the graph was as followed (Figure 1):

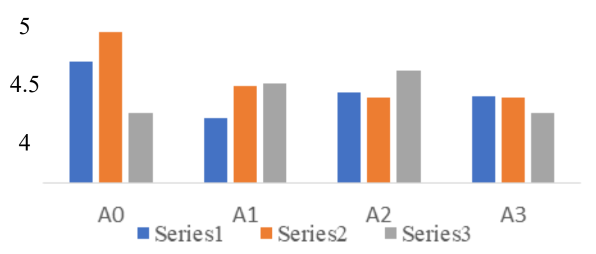

Figure 1. Results of pH analysis in red and yellow podzolic soil

K-dd levels

K-dd was a form of potassium in soil that electrostatically had an external complex bond to the surface of clay minerals and humus substances. This K element could also be exchanged and was included in the soil nutrient element which was ready to be absorbed by plants and could be exchanged for other cations. The release of exchangeable K in the soil solution was called desorption, while the reverse reaction was adsorption (Sparks, 1987).

Table 5. Result of K-dd Analysis in red yellow podsolic

Code	Series			Amount	Average
	S1	S2	S3		
A0	0.27	0.45	0.38	1.10	0.37
A1	0.31	0.25	0.46	1.02	0.34
A2	0.91	0.91	0.87	2.69	0.90
A3	1.45	0.71	1.93	4.09	1.36

The highest value of K ions that can be absorbed by plant roots in red and yellow podzolic soil was available in the treatment with the addition of 20 g of fly ash (A3). This was a very significant addition to the red and yellow podzolic soil which had an initial K-dd of 0.34 to an average of 1.36. This treatment was highly recommended if our goal was to increase the K-dd of the soil on red and yellow podzolic soil (Nursanti et al., 2021) (Figure 2).

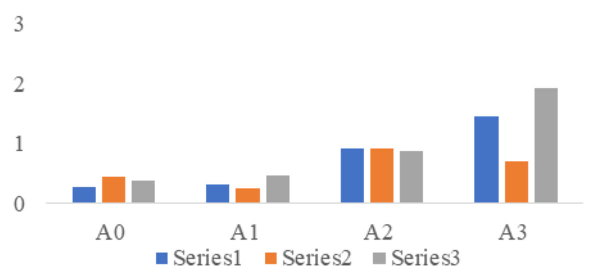

Figure 2. Results of K-dd analysis in red and yellow podzolic soil

Al-dd Levels

Al-dd was the aluminum content in the soil. Al in exchangeable form (Al-dd) was generally found in acidic soils with a pH<5.0. This aluminum was very active because it was in the form of Al3+, a monomer that was very detrimental by poisoning plants or binding phosphorus. Therefore, to measure the extent of Al's influence, it was necessary to determine its saturation.

Table 6. Result of Al-dd Analysis in red yellow podsolic

Code	Series			Amount	Average
	S1	S2	S3		
A0	4.96	5.18	4.54	14.68	4.89
A1	6.18	6.13	6.37	18.68	6.23
A2	7.53	7.08	6.87	21.49	7.16
A3	5.86	5.72	4.20	15.78	5.26

This could be seen in the graph as followed (Figure 3):

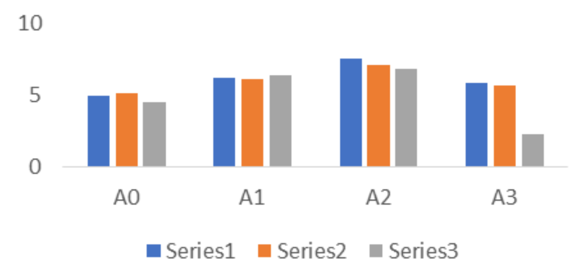

Figure 3. Results of Al-dd analysis in red and yellow podzolic soil

H-dd Levels

H-dd was the level of hydrogen found in the soil. Soil acidity had 2 components, namely (1) active H contained in the soil solution (potential), (2) H which could be exchanged or called reserve acidity. These two forms tend to form a balance so that changes in one result in changes in the other. When a base had been applied to acidic soil, the dissolved Hydrogen was neutralized and some of the exchangeable H was ionized to restore the state of balance. The amount of hydrogen that could be exchanged could slowly decrease (Table 7).

Table 7. Result of H-dd Analysis in red yellow podsolic

Code	Series			Amount	Average
	S1	S2	S3		
A0	4.96	5.18	4.54	14.68	4.89
A1	6.18	6.13	6.37	18.68	6.23
A2	7.53	7.08	6.87	21.49	7.16
A3	5.86	5.72	2.24	13.82	4.61

This could be seen in the graph as followed (Figure 4):

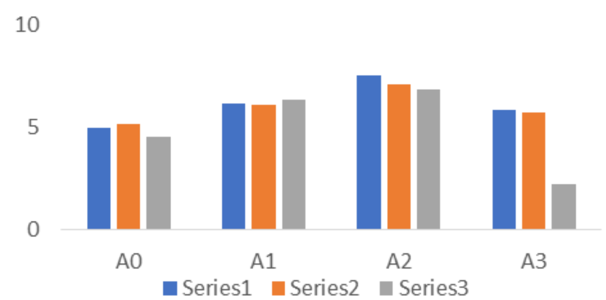

Figure 4. Results of H-dd analysis in red and yellow podzolic soil

Dissolved hydrogen could decrease and the pH will gradually increase. Soil acidity could be influenced by several factors, including lack of available P elements, lack of Ca and Mg elements as soil bases, lack of Mo elements, microorganism activity such as hampered N fixation of legume plants, excess Mn and Fe content which could be toxic. for soil and plants, and the solubility of Al and H ions was very high, so it was the main inhibiting factor for plant growth in acid soil (Sudaryono, 2016).

DISCUSSION

The analysis obtained was that the red and yellow podzolic soil was still in the acid soil category, namely 4.13. Aluminium was interchangeable at 8.78 Me/100 g. Hydrogen could be exchanged at even lower levels, namely 0.40 Me/100 g. Based on the following laboratory analysis, the chemical properties of coal waste fly ash were contained. The degree of acidity in fly ash was in the acid category at 6.42 (close to normal). For the ability to absorb and exchange or release cations back into the soil, it was classified as medium, namely 19.52. The highest compound content was Ca with a figure of 9.22 Meg/100 g and Mg compounds 5.49 Meg/100g.3.2.1 Primary. Fly ash mainly consists of silicate glass compounds containing silica (Si), alumina (Al), ferrum (Fe), and calcium (Ca). The small content of other compounds contained in fly ash was magnesium (Mg), sulfur (S), sodium (Na), potassium (P), and carbon (C) (Table 3). The dangerous ingredients contained in fly ash include: arsenic, beryllium, boron, cadmium, chromium, cobalt, lead, manganese, mercury, selenium, strontium, thallium, vanadium, it also contains dioxins and PAH (polycyclic aromatic hydrocarbon) compounds. Fly ash generally consists of solid spherical particles, and some were hollow spherical particles and spherical particles containing other smaller spherical particles (Nji, 2014).

This red-yellow podzolic soil has a low pH, namely 2.48 and 4.13, which was acidic and was difficult to increase above 4.9 because it was dominated by weathering of the parent material which contains Fe and Al metals. The application of lime/dolomite could increase soil pH but does not last long enough, while the application of organic materials to mineral soil has been proven to be able to maintain soil pH values for a longer time than the use of agricultural lime or dolomite. Apart from that, the use of organic materials could also function as a provider of nutrients (Figure 1). The availability of nutrients was very much influenced by the dynamics of soil pH, where acidic soil was very difficult to provide nutrients, because nutrients were strongly bound to the adsorption of H+ cations and other metals. The highest value of K ions that can be absorbed by plant roots in red and yellow podzolic soil was available in the treatment with the addition of 20 g of fly ash (A3). This was a very significant addition to the red and yellow podzolic soil which had an initial K-dd of 0.34 to an average of 1.36. This was more clearly the case in the following graphic image. Potassium in the soil can be divided into two categories, namely potential potassium and actual potassium. Potential potassium was the total amount in the soil micelles, while actual potassium was in the form of dissolution (K+) and exchangeable K (K-dd). Usually, the amount of soil K-dd was no more than 2% or between 10 and 400 ppm (Schroeder, 1984).

Fertilizer was applied in the hope that it will increase the availability of potassium in the soil. However, potassium was a type of substance that could and was easily lost and this was difficult to realize because it was often fixed by type 2:1 clay mineral in the smectite and vermiculite groups. Potassium loss often occurs due to leaching or transport when we harvest plants (Grimme & Mutsher, 1985). The application of fertilizer carried out together with the provision of organic material in the form of fly ash waste was expected to easily reduce K losses in leached conditions. Apart from that, the K levels in the waste were also expected to contribute to an increase in K levels in the soil.

The Al-dd content was still quite high, where the Al-dd in red and yellow podzolic soil before adding the fly ash composition was 8.78. After the addition of fly ash ameliorant, the Al-dd content decreased quite significantly with an average of 5.88. The Aldd content was very low in the A3 treatment by giving fly ash to the red and yellow podzolic soil as much as 20 g/polybag. If there was aluminum saturation of > 60%, this red and yellow podzolic soil was often said to be unfit for agricultural land until reclamation or amelioration was carried out first. Because aluminum saturation was influenced by cation exchange capacity and could also be influenced by texture, the rougher the texture, the higher the aluminum hazard level (Karo et al., 2017; He et al., 2017). Stated that aluminum poisoning inhibits the elongation and growth of primary roots, as well as preventing the formation of lateral roots and root hairs (Hakim et al., 1986). If root growth was disrupted, nutrient uptake and the formation of organic compounds will be disrupted. A root system that has been disturbed will result in the roots being inefficient at absorbing nutrients in Figure 3.

From the results of the analysis, it was found that the highest H-dd content was in treatment A1 with an average of 4,89 and the lowest H-dd content was in treatments A3. The H-dd levels here increase significantly when amiliorane was added. This was in accordance with the presence of soil buffer materials, which could prevent a drastic decrease in pH as a result of increasing hydrogen ions by a biological process or fertilization. The activities of microorganisms or the addition of acidic fertilizer will contribute a number of H ions (Ahmed et al., 2023). Exchangeable hydrogen ions were the main source of H+ until the soil pH becomes below 6, when the Al content in the Octahedral Al clay plate becomes unstable and was absorbed as exchangeable Al. This was a source of H+.H which was free from hydrolysis by Al. What can be exchanged was the increasing concentration of H+ in the soil solution which results from the dosing of H (micelles) which can be exchanged and what results from this was H adsorbed in H solution. In very acidic conditions, Al becomes very soluble which was found in the form of Al3+ cations and Al hydroxide. Both Al ions were more easily adsorbed on clay colloids than ionsH. Because Al in the soil solution was easily hydrolyzed, Al was the cause of acidity or a contributor to H ions. The H ions released in this way will provide a low pH value for the soil solution and may be the main source of H ions in most acid soils.

CONCLUSION

Based on the results of this research, it can be concluded as application of fly ash waste can increase soil pH in red and yellow podzolic soil. Treatment of PMK soil which initially had a pH of 4.13 tended to increase slightly with an average increase in pH of 4.51–4.61 compared to not using the waste. Analysis of the exchangeable potassium element (K-dd) shows that there is an increase in K-dd levels contained in the soil after being treated with the addition of fly ash, namely that there is a very significant increase in K-dd levels in PMK soil which has an initial K-dd of 0 .34 to 1.36. Analysis of interchangeable aluminum (Al-dd) where the Al-dd content is still quite high in red and yellow podzolic soil before adding fly ash composition is 8.78. After the addition of fly ash ameliorant, the Al-dd content decreased quite significantly with an average of 5.26–7.16. The Al-dd content was very low in the A3 treatment with the addition of 20 g/polybag. H-dd analysis on red and yellow Podzolic soil resulted in an increase in the initial H-dd of the soil from 0.4 to 4.61–7.16. In the graph, it can be seen that the highest H-dd was in treatment A2 with the addition of 15 g of fly ash/polybag and the lowest H-dd was in treatment A3 with a treatment of 20 g/polybag.

ACKNOWLEDGEMENTS

Thanks are conveyed to the Universitas Serasan Research Center and parties who have helped the author to complete useful tasks in conducting research or writing article manuscripts.

REFERENCES

Aida, E. R., Lisha, S. Y., & Puty, Y. (2018). Utilization of coal ash waste (Fly Ash) at PLTU ombilin as a coagulant. *Jurnal Pendidikan Teknologi Kejuruan, 1*(3), 125–131. https://doi.org/10.24036/jptk.v1i3.2223

Ahmed, T., Noman, M., Qi, Y., Shahid, Hussain, Ayesha, M., Xu, Hasan, Negm, S., El-Kott , Yao, Y., Qi, X., & Li, B (2023). Fertilization of microbial composts: a technology for improving stress resilience in Plants. *Plant Journal, 12*(20), 35–50. https://doi.org/10.3390/plants12203550

Fauziah, N., Iskandar, & Djajakirana, G. (2022). The effect of cow manure compost and fly ash-bottom ash (FABA) addition on the chemical properties of sandy soil and tomato growth.. *Journal of Soil And Environmental Science*. *24* (1), 1–5. https://doi.org/10.29244/jitl.24.1.1-5

LGrimme, H., & Mutsher, H. (1985). Potassium in the agricultural systems humid tropics. *In Proceedings of the 19th Colloquium of the International Potash Institute Held in Bangkok, Thailand.* Quoted by Helmi Abdillah and Muhammad Aldi. 2020. Application of rubber solid waste in red-yellow podzolic soil to macronutrien availability and improvement of soil physical properties. *EnviroScienteae, 16* (2), 264–275. https://doi.org/10.20527/es.v16i2.9658

He, H., Dong, Z., Peng, Q., & Wang, X. (2017). Impacts of coal fly ash on plant growth and accumulation of essential nutrients and trace elements by alfalfa (*Medicago sativa*) grown in a loessial soil. *Journal of Environmental Management, 197,* 428–439. https://doi.org/10.1016/j.jenvman.2017.04.028

Hakim, N., Nyakpa, M. Y., lubis, A. M., Nugraha, S. G., Saul, M. R., Diha, M. A., Hong, G. B., & Bailey, H. H. (1986). Basics of soil science. Universitas Lampung, Quoted by Susance Isir, Zetly E. Tamod, Joice M.J. Supit. (2022). Identification of soils chemical properties on land of shallots plantation (*Allium Ascalonicum*, L.) In Talikuran Village Remboken District Minahasa Regency. *Soil environmental Journal*, 22(1), 6–11. https://doi.org/10.35791/se.22.1.2022.38911

Karo, H. Y. K., Pramono, N., Wahyuni, S., Mashoedi, I. D., & Latifah, L. (2017). Lavender (*Lavandula angustifolia*) aromatherapy as an alternative treatment in reducing pain in primiparous mothers in the active first stage of labor. *Belitung Nursing Journal, 3*(4), 420–425. https://doi.org/10.33546/bnj.159

Kinasti, R. M. A., & Notodisurzo, D. N. (2017). Utilization of coal burning waste (*bottom ash*) at the suralaya power plant as a planting media in an effort to reduce environmental pollution. *Jurnal Kajian Ilmu dan Teknologi*. *69*(02), 129–138. https://doi.org/10.33322/kilat.v6i2.129

Nji, L. T. (2014). Fly ash: Overview. http://lauwtjunnji.weebly.com/fly-ash-overview.

Nursanti, D. F., Defrian, & Novriani (2021). Growth and yield of okra applied with a bio-stimulant from golden apple snails extracts and fertilizer on ultisol. *Jurnal Lahan Suboptimal : Journal of Suboptimal Lands*, *10*(1), 37–45. https://doi.org/10.36706/JLSO.10.1.2021.515

Sudaryono. **(**2016**)**. Fertility Level Of Ultisol Soil In Sangatta Coal Mining Land, East Kalimantan. *Jurnal Telnologi Lingkungan, 10* (3), 337–346. https://doi.org/10.29122/jtl.v10i3.1480

Wong, J. W. C., & Su, D. C. (1997). Reutilization of coal ash and sewage sludge as an artificial soil mix: Effect of preincubation on soil physico-chemical properties. *145* (2014) https://doi.org/10.1016/S0960-8524(96)00174-5. In Shaheen, S. M. Hooda, P. S., Tsadilas, C. D (2014). Opportunities and challenges in the use of coal fly ash for soil improvements e A review. *Elsevier,* 249–267. https://doi.org/10.1016/j.jenvman.2014.07.005

Notohadiprawiro, T. (1968). A contribution to the identification of red-yellow. podzolic soils found in the tropics. *Jurnal Penelitian Tanah, 6*(1), 32–45.

Rhazista, N. (2013). Coal combustion waste as soil amelioratnat and source of nutrients: case study for sunflower (*Helianthus Annus*). *Jurnal Riset Geologi dan Pertambangan*, *23*(1), 61–72. https://doi.org/10.14203/risetgeotam2013.v23.70

Subardja, D., Ritung, S., Anda, M., Sukarman., Suryani, E., & Subandiono, R. E. (2016). Technical guidelines for national soil classification. 2nd edition. center for agricultural land resources research and development, agency for agricultural research and development. Bogor. 60 pp.

Sparks, D. L. (1987). Potassium dynamics in soils. springer-verlag new York, Inc. Advances in Soil Science, 6: 5–8 in Astria. In P. & R. Suntari. (2017). Application of urea and cocoa husk compost to increase availability and absorption of N,P,K and mustard greens production on Inceptisol Tulungrejo, Batu. *Journal of Soil and Land Resources, 4*(1), 82–87. https://doi.org/10.21776/ub.jtsl.2017.004.01.15

Schroeder, D. (1984). Soil fact and concepts (translate from German). PA. Gething International Potash Institute, Bern. Quoted by Suatika & Kasno (2021). Nutrition management on irrigated rice fied to increase maize productivity. 1st international conference on sustainable tropical land management. *Earth and Environmental Science* 648 (2021) 012076. https://doi.org/10.1088/1755-1315/648/1/012076

Soil Research Institute. (2009). *Chemical analysis of soil, plants, water, and fertilizers.* Bogor: Agricultural Research and Development Center, Department of Agriculture..

Wardhani, E., Sutina, M., Herlina, A., D. (2012). Evaluation of the utilization of fly ash as a planting stock for tomato plants (*Solanum Lycopersicum*). *ITN Bandung Technology Journal*, *16* (1), 44–56.