Journal of Metallurgical Engineering and Processing Technology, Vol. 4, No. 2
February, 2024
P-ISSN: 2723-6854, E-ISSN: 2798-1037, page 49-59
DOI: https://doi.org/10.31315/jmept

Analysis of Humic Acid Content of Reject Coal Used as an Organic Fertilizer in Coal Mining Reclamation Areas

Roy Nastigor Nasution[1], Edy Nursanto[1], Rika Ernawati[1] Shofa Rijalul Haq[1]
[1]Universitas Pembangunan Nasional "Veteran" Yogyakarta, Indonesia.
*Corresponding author : awn030310@gmail.com

Received 08/11/2023; Revised 13/12/2023; Published 28/02/2024

Abstract

An important effort to restore the productivity of degraded land is land reclamation, especially in areas where ecosystems have been destroyed. The use of organic materials that can improve soil quality is one of the methods used in the reclamation process. Humic acid, an organic component found in natural organic materials such as humus and compost, has attracted attention as an organic fertilizer material that can be used in reclamation, this research aims to analyze the use of humic acid as an organic fertilizer in the reclamation process in the Spice Land area, South Kalimantan. This research was carried out through field and laboratory studies, looking at how humic acid affects the properties of degraded soil, pH, height, and stem diameter. The results showed that the application of humic acid significantly improved the quality of reclaimed soil by increasing the soil's capacity to store water and increasing its fertility in addition to the physicochemical benefits, the use of humic acid helps the environment. By using it as an organic fertilizer in the reclamation process, we no longer need to rely on synthetic chemical fertilizers that can harm the environment. Instead, we should support sustainable agricultural practices. One such practice is using humic acid as an organic fertilizer to increase the success rate of restoring degraded land. This research encourages environmentally friendly approaches to restoring damaged ecosystems and promoting sustainable land management.
Keywords: Reject Coal, Humic Acid, Reclamation.

Introduction

In 2013, based on data from the Central Statistics Agency and the Ministry of Energy and Mineral Resources, Indonesia produced 70 million tons of coal. However, only 70% of the coal acquired from processing is usable, while the remaining 30% is waste such as mud coal or coal that cannot be marketed. This has led to a significant amount of coal waste in Indonesia. Fine coal, which is coal that is less than 2 millimeters in diameter, is a common type of waste produced during mining and processing (Kadir, AA, & Sulaiman, WRW. 2015). The waste coal is often thrown in disposal sites, which can cause environmental damage and form a congested, dark-colored substance resembling chocolate.

Coal is formed from plants and is considered a mineral energy source that can be burned to produce energy. It mainly consists of carbon (C), with small amounts of

Journal of Metallurgical Engineering and Processing Technology, Vol. 4, No. 2
February, 2024
P-ISSN: 2723-6854, E-ISSN: 2798-1037, page 49-59
DOI: https://doi.org/10.31315/jmept

oxygen (O), hydrogen (H), and nitrogen (N) (Rhazista Noviardi .2013). The process of coal formation can be influenced by factors such as bacteria decomposer, temperature, time, and pressure.

Humic acid, a complex organic compound found in soil, has been used in various agricultural applications due to its potential benefits. potential to improve soil quality and fertilizer efficiency (Sutedjo, MM. 1996). One important aspect in understanding the effect of humic acid is how this compound can influence the content of basic elements such as carbon (C), hydrogen (H), sulfur (S), and oxygen (O) in organic materials. This article will outline the influence of humic acid on these elements and their impact on agriculture and the environment. Change composition chemistry type coal started from type peat (peat) until with type the so-called anthracite degrees coal (coal rank). Rate or ranking coal can determined based on some very important parameters including analysis proximate analysis petrography.

Proximate analysis of coal used for know characteristics and quality coal. Implementation with the use coal that is for no amount relatively air moisture (moisture content), volatile matter (VM), ash (ash), and carbon (FC). contained coal in it. Analysis proximate This is exam fundamental end in determining quality coal. In coal, water contains at least consists from One compound chemistry. The shape can flow air fast from the sample in coal, compound adsorbed, or as a bonded compound in a way chemistry. Several water vapor is a component coal mineral substances that are not bound. Coal ash is interpreted as something substance material remaining organic in the sample after coal is burned (incinerated) in condition standard until obtained heavily fixed.

At the moment burning coal, and mineral substances change, because That Lots generally gray more small compared to with amount of substance pollution iron, disposal will impact bad Good to rivers and land around it. In the study This review about characteristic chemistry and humates. element acid in coal, quality coal is determined by natural chemical influences potency of its use. From analysis tests coal fine content ash, iron, potassium, calcium, and magnesium indicated that coal smooth rich compound organic in one company in Tanah Bumbu place researcher take the data.

Every year, a significant amount of coal is rejected during the processing and normalization stages, resulting in a pool of sediment in the port area that amounts to 12,000 tons. As a consequence, the dumping area in the port area has become cramped and inconvenient for production activities. This has led to the stacking of rejected/fine coal, which amounts to 10-15 thousand tons and requires lots of space. The rejected/fine coal must be thrown away and returned to the disposal site, which is located 20-30 km away., and is influenced by factors the weather is not uncertain. To utilize it as fertilizer and reclaiming mine activity, reject/fine coal is studied.

Waste coal (sludge) is a carbon-derived material from precipitate rock that contains sediment and organic material (Arsyad, AR. 1997). Characteristics of waste

Journal of Metallurgical Engineering and Processing Technology, Vol. 4, No. 2
February, 2024
P-ISSN: 2723-6854, E-ISSN: 2798-1037, page 49-59
DOI: https://doi.org/10.31315/jmept

coal depend on the characteristics of the source coal and are generally low-rank coal. Humic acid is an organic compound found in soil and natural organic matter. This compound makes up most of the organic matter in the soil and is also present in various types of organic fertilizer. Humic acid is formed through the decomposition of organic matter, such as dead plants, and consists of various functional groups, including hydroxyl, carboxyl, and phenol groups (Restida M, Sarno & Ginting YC. 2014). This complex structure gives humic acid unique properties that can impact various aspects of the environment and agriculture (figure 1).

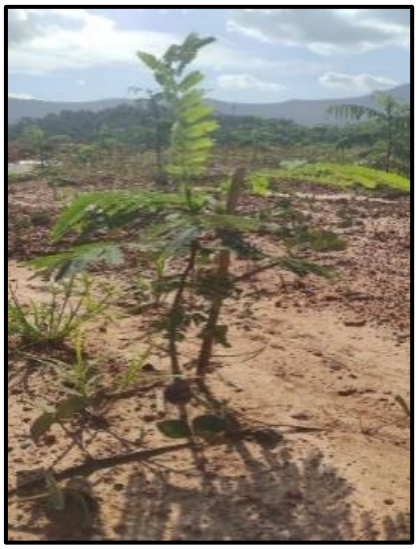

Figure 1. Sengon tree (Paraserianthes falcataria)

In this study, sour humate was used as an organic material fertilizer during the reclamation process. The research focused on the use of 3-month sengon plants that were 30 cm in height, with a trunk diameter of 0.3 cm. The research period was 2 weeks, during which the progress was monitored based on the analysis results of the land's spices in South Kalimantan. Study This was done through studies field and laboratory, to see how sour humate influences traits of degraded soil, pH, height, and stem diameter plant. Research results show that giving sour humate increases quality land reclamation in a way significant with increased capacity land for saving water and increasing fertility.

Research Methods

The study done with use material that is waste processing coal (Reject coal) taken in the port area as many as 2 bags of samples each weighing 2 kilograms, were then entered into pocket plastic given Name samples and sent to the laboratory . Study This use method experiment that is with carry out laboratory tests To obtain results analysis remainder processing coal (reject/fine coal) to obtain information related to properties

Journal of Metallurgical Engineering and Processing Technology, Vol. 4, No. 2
February, 2024
P-ISSN: 2723-6854, E-ISSN: 2798-1037, page 49-59
DOI: https://doi.org/10.31315/jmept

and characteristics of coal smooth that becomes reference material fertilizer. In the area reclamation, where testing use laboratory Geoservice and company survey and BALITTRA (Hall Soil and Swamp Research) in Banjarbaru, South Kalimantan for Ultimate and proximity analysis, methods of extraction sour humate from rejected coal has been developed and tested in the laboratory. Analysis of composition chemistry, as well as traits physicochemistry from sour extracted humate has been done.

Next, research also includes studies field in the reclamation area mining coal that has been using sour humate from rejected coal as material fertilizer organic. Parameters like growth plants, quality land, and impact the environment will too evaluated (figure 2).

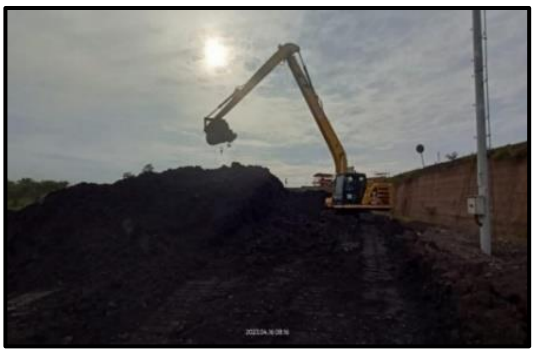

Figure 2. Reject Coal Stock

Result and Discussion

The results obtained based on the results of laboratory data for Ultimate analysis, namely in Table 1. Extraction Process Sour Humat: Method extraction of sour humate from rejected coal has been successfully developed and tested in a study this . Extraction process This involves steps of purification and isolation of sour humate from matrix reject coal.

Table 1. Ultimate Analysis Reject Coal

No	Sample name	Ph	Sour humate
1	Reject coal	7.2	39.2

Analysis Chemical Composition: Analysis composition chemistry from sour extracted humate shows content of adequate nutrition important for growth plants, including nutrients such as nitrogen, phosphorus, and potassium (NPK), as well as element microelements required by plants.

Physicochemical Properties Sour Humat: Research also includes analysis of characteristic physicochemistry from sour extracted humates, such as solubility, capacity swap cations, and stability. Analysis results This gives understanding more carry on about How sour humate can interact with plants and soil.

Use Sour Humat on Land Reclamation: Study field in the reclamation area mine coal that has been using sour humate from rejected coal as material fertilizer organic show

Journal of Metallurgical Engineering and Processing Technology, Vol. 4, No. 2
February, 2024
P-ISSN: 2723-6854, E-ISSN: 2798-1037, page 49-59
DOI: https://doi.org/10.31315/jmept

enhancement in growth plant, increase quality land, and decline level drought land. Obtained results laboratory show that the sample coal on site study shows moisture content (moisture air dry) of 11.88% adb and content ash (ash) 35.71% adb . Where as amount volatile matter amounted to 29.23% adb, total sulfur reached 0.14% adb and the value calorific value 3411 cal /g adb . Fine Coal analysis results for pH content shows fulfil requirements of Minister of Agriculture Decree No. 28/ Permentan /SR.130/B/2009 , namely 4 - 8%, while function PH value in land have very important role For determine is or whether or not nutrient ions are absorbed plant . By general nutrients will easy absorbed plants at pH 6-7, because at that pH part big nutrients will easy late in water.

Analysis results fine coal For organic C- content show exceed limit SNI 19-7030-2004 requirements are 9.8 - 32% for laboratory tests . Total C- organic influenced by quality material organic and activity of microorganisms that play a role in the decomposition material organic, if the organic C value exceed the SNI provisions are worrying can bother the activity of microorganisms inside the soil. Water Content: Analysis proximate possible measurement internal water content coal smooth. High water content can influence mark heat of coal and efficiency of burning . The more tall the water content the the more low mark calories coal that.

Content Raw Materials (Volatile Matter): Measurement of content material gives description extent of coal that tends to evaporate when heated. This thing related to ability coal to burn and produce gas. Content material more standard tall usually shows the ability to more good. Fixed Carbon Content: Analysis This measures content remaining carbon after warmup early. Content carbon still important in evaluating potency combustion and generation of energy coal. Content: Ash content is the remaining minerals after burning. Ash content can influence quality burning, forming deposits, as well influence use and handling of coal.

Influence on Utilization: Analysis proximate can give information important in determining is coal fine suitable For use in various applications, incl generator electrical, industrial , or as material standard fertilizer. Content material standards and grade ash can influence the efficiency of burning and impact to the environment.Analysis proximate is an step important start_in identify characteristics and potential coal fine For various usability. Analysis results This helps in making decision about the utilization coal smooth in various industries and applications. Nitrogen content in coal finely researched varies between 0.57 to 0.74% based on laboratory tests. Based on the results mark fertilizer organic has fulfil The nitrogen content based on SNI is >0.4%, and the minimum limit for fertilizer N value based on: SNI 19-7030-2004 limits maximum fertilizer N value fertilizer based on: Minister of Agriculture Decree No. 28/ Minister of Agriculture /SR.130/B/2009. Below is a table of field experiments, All analyses refer to government regulations, which state that the results of the growth and development of the second plant determine whether a fertilizer is organic, biological, or a soil conditioner.

Journal of Metallurgical Engineering and Processing Technology, Vol. 4, No. 2
February, 2024
P-ISSN: 2723-6854, E-ISSN: 2798-1037, page 49-59
DOI: https://doi.org/10.31315/jmept

Table 2. Experiment 1 Reject coal fertilizer

Plant Plots	Height (cm)	Diameter (cm)	Healthy	Unhealthy _	Dead	Soil pH
						6.1
E1	51	0.6	◆			6.1
E2	58	0.7	◆			4.4
E3	56	0.7	◆			4
E4	53	0.6	◆			3,2
E5	52	0.6	◆			3
E6	45	0.5	◆			4
E7	36	0.4		◆		5
E8	59	0.6	◆			3
E9	43	0.6	◆			3.3
E10	55	0.6	◆			4
E11	40	0.5	◆			4.2
E12	40	0.6	◆			4
E13	44	0.5	◆			3.3
E14	49	0.6	◆			4
E15	40	0.6	◆			4.1

Table 3. Experiment Without Reject coal fertilizer

Plant Plots	Height (cm)	Diameter (cm)	Healthy	Unhealthy _	Dead	Soil pH
F1	49	0.4	◆			6.1
F2	50	0.3	◆			5
F3	48	0.5	◆			4
F4	49	0.2	◆			3,2
F5	46	0.3	◆			4
F6	35	0.3	◆			4
F7	35	0.3		◆		5
F8	38	0.3	◆			4
F9	45	0.3	◆			3.3
F10	46	0.3	◆			4
F11	44	0.3	◆			4.2
F12	50	0.3		◆		4
F13	43	0.3	◆			3.3
F14	42	0.3	◆			5
F15	44	0.3	◆			4.1

Journal of Metallurgical Engineering and Processing Technology, Vol. 4, No. 2
February, 2024
P-ISSN: 2723-6854, E-ISSN: 2798-1037, page 49-59
DOI: https://doi.org/10.31315/jmept

Content good potassium nutrient of 0.01% based on the values contained in SNI 19-7030-2004 must have minimum value of 0.2% and according to Minister of Agriculture Decree No. 28, it must be below 6%. Potassium is used by microorganisms at stages of composting as a catalyst (Sutedjo, 1996). Potassium has properties that can influence the speed of the decomposition process. The presence of bacteria with activities influence the enhancement of potassium content , potassium is bound and stored in cells by bacteria and fungi. If decomposition back, potassium will be available.

Content good Fe nutrition is maximum of 2%. Based on contained value _ in SNI 19-7030-2004, results analysis Fe content plays a big role important in the development of enzymes and proteins needed by microorganisms as well as in breathing in body organisms, however naturally No can more. Because it will harm plants later. The results of the laboratory analysis of PT Geoservis for proximate analysis of offline coal materials are in Table 4-5.

Table 4. Fine Coal Proximate Analysis Results

No	Lab Sample ID		AN23.01186
	Analysis results are as follows		
1	**Total Moisture**	%ar	33,6
2	**Proximate**		
	Moisture	%adb	11,88
	Ash	%adb	35,71
	Volatile Matter	%adb	29,23
	Fixed Carbon	%adb	23,18
3	**Total Sulfur**	%adb	0,14
4	**Calorific Value**		
	Air Dried Basis	Cal/g	3441
	As Received Basis	Cal/g	2593
	Dried Ash Free	Cal/g	6566

Table 5. Ultimate Analysis of Reject coal and soil Result

Type /Result of analysis	N	P	K	Mg	Na	Ca	Fe	S
Soil	0.11	11.73	19.81	0.3	0.22	-	-	-
Reject coal	0.41	-	0.18	0.05	0.07	0.07	0.28	Tu

Humic acid contains large amounts of organic carbon (Akimbekov N. S, Digel I, etc .2021), it is a basic element that forms the basic framework of all organic compounds.

Journal of Metallurgical Engineering and Processing Technology, Vol. 4, No. 2
February, 2024
P-ISSN: 2723-6854, E-ISSN: 2798-1037, page 49-59
DOI: https://doi.org/10.31315/jmept

The carbon content in humic acid varies depending on the source. Humic acids found in soil tend to have high carbon contents, while humic acids isolated from organic materials such as compost may have lower carbon contents. The influence of humic acid on soil carbon content and organic matter is complex. Humic acid can act as a "storage" for carbon in the soil, helping to reduce soil degradation and carbon loss. This can have a positive impact on soil quality and can help in climate change mitigation efforts.

Hydrogen is an important element in organic chemistry. In humic acid, the hydrogen content plays a role in the structure of this compound. The hydroxyl group (-OH) in humic acid is the main source of hydrogen. Hydrogen also plays a role in humic acid's ability to form hydrogen bonds with various other molecules. Humic acid can affect the hydrogen content in soil and organic matter in several ways. One way is to increase water retention in the soil. This can help prevent soil degradation and maintain the moisture necessary for plant growth. Humic acid can also interact with other organic materials and form complex compounds containing hydrogen.

Sulfur is another important element in organic compounds. In humic acid, sulfur can be present in the form of sulfonic or sulfhydryl groups. Humic acid from different sources can have varying sulfur content. The effect of humic acid on sulfur content in soil and organic matter is still the subject of intensive research. Several studies show that humic acid can increase the availability of sulfur to plants. This is important because sulfur is an essential nutrient that plants need for healthy growth.

Oxygen also plays an important role in organic compounds and therefore in humic acids. Oxygen can be found in various functional groups in humic acid, including the hydroxyl group and the carbonyl group. The effect of humic acid on oxygen content in organic materials is related to its ability to assist in the decomposition of organic materials. Humic acid can act as an oxidizing agent, helping to accelerate the decomposition of organic matter. This is important in improving nutrient cycling in the soil and making the nutrients contained in organic matter more easily available to plants. One of the positive effects of humic acid is increasing the cation exchange capacity of the soil, which can help increase the availability of nutrients for plants. This is especially important in soils that have nutrient deficiency problems. Humic acid can also help increase the water-holding capacity of soil, which helps maintain moisture which is critical for plant growth. This contributes to better soil quality and higher agricultural productivity.

Conclusions

Based on research that has been done, obtained conclusion as follows:

1. Potency Utilization Sour Humate in Reject Coal: Reject coal contains sour humat that can be used as material fertilizer. Sour humate This can give nutrition important for plants and repair quality land.

P-ISSN: 2723-6854, E-ISSN: 2798-1037, page 49-59
DOI: https://doi.org/10.31315/jmept

2. Extraction Process Sour Humate: Extraction process of sour humate from rejected coal has been successfully developed in a study this. This process possibly separation sour humate from matrix-reject coal with efficient
3. Composition and Physicochemical Properties Sour Humat: Analysis of composition chemistry and properties of physicochemistry sour extracted humate shows content of adequate nutrition important for plants as well as supportive traits of its use as fertilizer organic.
4. Impact Positive on Land Reclamation: Use sour humate from rejected coal on the land reclamation mine coal has give impact positive in matter enhancement growth plants, repair quality land, and reduction problem drought land.
5. Potency For Agriculture Sustainable: Research results This show that the utilization sour humate from rejected coal as material fertilizer organic own potency support practice of agriculture sustainable with reduced dependence on fertilizer chemistry synthetic.

References

Adams, M. S., & Hower, J. C. (2016). Characterization of coal combustion residuals from coal-fired power plants with implications for the environment: Examples from the United States. International Journal of Coal Geology, 165, 40-52

Akimbekov N. S, Digel I, Tastambek K .T, Sherelkhan D. K, Jussupova D. J and Altynbay N. P .2021, Low-Rank Coal as a Source of Humic Substances for Soil Amendment and Fertility Management. Agriculture. 2021(11), 1261

Chakraborty, D., et al. (2017). Fly ash-based geopolymer for improving the mechanical and durability properties of concrete: A review. Construction and Building Materials, 131, 797-809.

Chen, S., & Zhang, W. (2017). Utilization of coal fly ash as a soil conditioner. Journal of Soils and Sediments, 17(4), 1121-1130.J. DOI: 10.1016/j.fuel.2006.10.040

Dass , S., et al. (2016). Utilization of fly ash as low-cost adsorbent for the removal of methylene blue, crystal violet, and rhodamine B dyes from textile effluent: A review. Environmental Chemistry Letters, 14(3), 237-265.

Dragovich, D., & Patterson, J. (1995). Condition of rehabilitated coal mines in the Hunter Valley, Australia. Land Degradation & Development, 6(1), 29-39

Fecko , P., Tora, B., & Tod, M. (2013). Coal waste: handling, pollution impacts, and utilization. In The coal handbook: towards cleaner production (pp. 63-84). Woodhead Publishing.

Ghasemi , M., & Raman, AAA (2015). Utilization of coal combustion by-products in sustainable construction materials. Procedia Engineering, 118, 788-797.

Ghosh, R. K., & Gupta, S. S. (2003). Evaluation of the use of fly ash for soil improvement. Journal of Geotechnical and Geoenvironmental Engineering, 129(5), 451-460.

P-ISSN: 2723-6854, E-ISSN: 2798-1037, page 49-59
DOI: https://doi.org/10.31315/jmept

Heydarizadeh, M., Naghavii, H., & Moghadam, M. (2014). Study of the chemical, and physical characteristics and reject coal fertility for use in agricultural activities (Case study: Coal washing plant Zarand -Kerman). Irrigation and Water Engineering, 4(2), 58-70.

Hower, AK Richardson, JB Venteris (2007). "Characteristics of Coal Combustion Residues from Power Plants and Their Geochemical and Environmental Behavior". Fuel journal

Huang, H., et al. (2017). Fly ash as a soil conditioner for improving the water retention capacity of sandy soil: A review. Environmental Engineering Research, 22(4), 327-334.

Kadir, AA, & Sulaiman , WRW (2015). The potential of coal bottom ash and coal fly ash for replacing fine aggregate in concrete. Procedia Engineering, 125, 253-257.

Kumar, M., & Goel, A. (2016). Utilization of fly ash as soil conditioner for sustainable agricultural practices: A review. International Journal of Engineering and Innovative Technology, 6(10), 16-20.

Masto, R. E., & Chhonkar , P. K. (2006). Characterization of fly ash for their effective management and utilization in agriculture. African Journal of Agricultural Research, 1(3), 055-062.

Meena, H., & Talyan , V. (2013). Utilization of fly ash as a low-cost adsorbent for the removal of methylene blue, crystal violet, and rhodamine B dyes from textile effluent. Journal of Environmental Management, 130, 156-166.

N. Maniezzaman , DF Susanto, TMI Mahlia and SS Kim (2018). "Characterization of Fine Coal Waste Produced During Beneficiation Process of Low-rank Coal". Waste Management & Research journal, DOI: 10.1177/0734242X18756335

Narkiewicz , U., & Brzdekiewicz , A. (2019). Application of coal combustion products in soil improvement. Archives of Civil Engineering, 65(4), 1-15.

Pathak, A., & Awasthi, M. K. (2015). Potential utilization of coal fly ash with suitable waste catalyst to produce eco-friendly and cost-effective biodiesel: A review. Renewable and Sustainable Energy Reviews, 50, 1156-1167.

Pathak, A., & Awasthi, M. K. (2016). A comprehensive review on the utilization of wastewater from the pulp and paper industry for sustainable development. Journal of Environmental Management, 183, 229-245.

Permana, AP (2016). Coal rank study based on proximate analysis (studies case coal in the district shove). Journal of Engineering Volumes, 14(2).

Ramani, M.P., et al. (2014). A comprehensive review on fly ash. International Journal of Advanced Research, 2(4), 583-596.

Rajput, VD, et al. (2015). Fly ash a potential soil amendment and a component of growing media for horticultural crops: A review. Waste Management & Research, 33(8), 655-660

Restida M, Sarno & Ginting YC. (2014). Pengaruh Pemberian Asam Humat (berasal dari Batubara Muda) dan Pupuk N Terhadap Pertumbuhan dan Produksi Tanaman Tomat (Lycopersicum esculentum Mill). Jurnal Agrotek Tropika. 2(3) hal 482-486

Rhazista Noviardi (2013). Limbah Batubara Sebagai Pembenah Tanah dan Sumber Nutrisi : Studi Kasus Tanaman Bunga Matahari (Helianthus Annus). Jurnal Riset Geologi dan Pertamba. 2(1), Hal 61-72. ISSN 0125-9849

Smith, J., & Johnson, R. (2015). Coal combustion by-products in sustainable construction materials. Woodhead Publishing

Srivastava, R. K., & Mukherjee, S. (2018). Utilization of fly ash in agriculture: A review. Journal of Applied and Natural Science, 10(3), 1052-1061.

Sun, Y., et al. (2017). Influence of rejected coal on the performance of soil improvement. Journal of Soils and Sediments, 17(6), 1736-1745

Arsyad, AR (1997). Improvements in fertility marginal land and production agriculture through utilization material organic: Newsletter Jambi University Agronomy 1(4-5): 259-263

Sutedjo, MM (1996). Fertilizer and Fertilization Methods. Jakarta

Tan, KH 2010. Principles of Soil Chemistry Fourth Edition. CRC Press Tailor and Francis Group. Boca Raton. London. New York. 362 p. N, and AB, Harto . 2017.

Tiwari, AK, et al. (2016). Effect of fly ash on soil properties and crop productivity: A review. International Journal of Current Microbiology and Applied Sciences, 5(12), 254-265.

Ukwattage , N.L., et al. (2018). Characterization and utilization of fly ash as a construction material—A review. Sustainable Materials and Technologies, 15, 17-31.

Wang, Y., et al. (2018). A review on coal bottom ash and its utilization in concrete. Journal of Materials Science, 53(6), 3663-3685

Xu, Z., et al. (2018). The potential of coal combustion products in soil improvement: A review. Journal of Materials in Civil Engineering, 30(2), 04017362.