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RESEARCH ARTICLE

THE POTENTIAL OF NICKEL SLAG WITH HUMIC SUBSTANCE ADDITION AS AMELIORATION MATERIALS ON GAJRUG RED-YELLOW PODZOLIC

Febrianti Rosalina*[1], Dyah Tjahyandari[2], and Darmawan[2]

Department of Soil Science and Land Resources, Faculty of Agriculture,
Bogor Agricultural University, Bogor, Indonesia
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ABSTRACT

Nickel slag and humic substance have a strong potential for use as soil ameliorant in land remediation, owing to their chemical properties that can improve acidic soils. This study aimed to determine the effect of nickel slag and humic substance on the red-yellow podzolic soil. This greenhouse incubation study used a 2-factorial completely randomized design. The first Factor was nickel slag about 0, 8, 12, and 16 ton ha^{-1} and the second Factor was humic substance about 0, 15, and 30 litre ha^{-1}, with 3 replications. Statistical analysis of the data used analysis of variance, and whenever a significant difference was detected, further verification was tested using Duncan's Multiple Range Test at a level of significance (α) of 5%. The results showed that the application of nickel slag and humic substance can increase the values of pH, total-N, available-P, and exchangeable-Mg of the red-yellow podzolic soil, but also decreased exchangeable-H. The interactive effects of nickel slag and humic substance raise soil K-exchangeable only. The levels of heavy metals (Pb, Cd, and As) in the soil after the application of nickel slag and humic substance remain within normal limits (The normal limits for Pb, Cd, and As in soil are 2-200 mg kg^{-1}, 0.1-7.0 mg kg^{-1}, and 0.1-40 mg kg^{-1}) that is, they are environmentally safe for use as a soil ameliorant.

Keywords: Heavy metal, humic substance, nickel slag, soil acidity

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INTRODUCTION

Nickel processing produces by-products and solid residues, including slag that is formed when nickel ore is smelted and later goes through cooling. The rapid accumulation of nickel slag in slag dumps over time poses a serious problem attendant to industrial waste disposal. The slag requires large landfill sites; pollutes the environment, particularly when there are water bodies near the dump; and is a waste of resources which can otherwise, be recovered and recycled. There are potential utilization values of nickel slag. For instance, some mining companies recover nickel slag and use it as a surfacing material for mining access roads. It is also being processed as an additive for abrasives for general industrial uses, and in ceramic and cement manufactures.

There has been a number of studies on the utilization potential of mining slag in agriculture however, these have been limited to steel slag. As an example, steel slag has been found to be a good material for liming acidic soils (Ali & Sedaghat Hoor, 2007; Ning, Liang, Liu, Xiao, & Duan, 2016); as silicon (Si) fertilizer for rice paddy and sugar field (Kato & Owa,

** Corresponding Author :*
Email: rosalina.febrianti@yahoo.com

1997); for improvement of the chemical properties of soil; and for boosting the growth and yield of rice in paddy field and in peatland (Ulfah, 2014).

Unfortunately, the utilization of nickel slag in agricultural production is constrained by the fact that it falls under category Hazardous and Toxic Substances (in *Bahasa Indonesia Limbah Bahaya dan Beracun = B3*) waste material, the handling of which must strictly follow existing government regulations. In particular, PP No. 101/2014 ir: Hazardous and Toxic Wastes, requires prior *Toxicity Characteristic Leaching Procedure* (TCLP) testing. Interestingly, previous TCLP tests for nickel slag have yielded results that fall below-set quality specifications. In other words, nickel slag is actually "not hazardous" and therefore, should not be classified as a *B3* waste. Hence, nickel slag should be re-classified and promoted to be utilized, instead of simply left lying idle and accumulating in slag dumps. For instance, nickel slag can be used in agricultural cultivation, as it contains useful chemical elements such as K, Ca, Mg, Na, and Si which are suitable as liming agents for soil amelioration.

It is interesting to note that the chemical composition of nickel slag is quite similar to that of steel slag. It thus, follows that nickel slag can be as suitable as steel slag for soil amelioration purposes. There is. however another major constraint in that the solubility of nickel slag elements is rather poor due to its inherently hard physical nature. To remedy this limitation, a suitable chemical compound must be added to the nickel slag in order to improve its element solubility. One feasible material that can fill this need is a humic substance, as it contains organic acids that can effectively dissolve minerals through the chemical reaction (e.g. hydrolysis, acidolysis, complexolysis). This is made possible by the high negative load of humic substances, which indirectly facilitates chelation of cations and increase cation exchange capacity in the soil. In addition, the humic substance can interact with metal ions, oxides, hydroxides, and other contaminant substances (Schnitzer & Khan, 1978). (Ahmad, 2011) also reported that humic substance serves as a good extractor for igneous rock, and in the release of nutrient elements. Furthermore, it renders an ameliorating influence on the physical, chemical, and biological aspects of soil quality.

The utilization potential of nickel slag mixed with humic substance as ameliorant material can be applied to red-yellow podzolic (RYP) soil, which is characteristically acidic. Covering a wide expanse in Indonesia (nearly 25% of the total land area of the country), RYP soil has tremendous utilization potential for dryland agricultural development. Nevertheless, there is a need to address the problem of very low nutrient content in RYP soil, as well as its high Aluminium saturation that can bring about Al^{3+} poisoning in plants (Havlin & Tisdale, 2005).

In view of the foregoing, this study intended to analyze the efficacy of nickel slag and humic substance in improving the chemical characteristics of Red Yellow Podzolic soil, particularly its pH, macronutrient element content, bases content, exchangeable acids, cation exchange capacity (CEC), as well as its concentration of heavy metals (Pb, Cd, As).

MATERIALS AND METHODS

Samples of red-yellow podzolic (RYP) soil was collected from Gajrug village, Cipanas sub-regency, Banten province in West Java, Indonesia. The chemical properties of the Gajrug RYP soil are shown in Table 1. The humic substance was received from the Department of Soil Science and Land Resources, Bogor Agricultural University. Table 2 summarizes the results of the chemical analysis of the humic substance. Nickel slag was obtained from a nickel mine in South Sulawesi, Indonesia. Data on the properties of the nickel slag are shown in Table 3.

This study involved an incubation experiment using a 2-factorial Completely Randomized Design (CRD). The first Factor was nickel slag (T) about T0, T1, T2, and T3 corresponding to 0, 8, 12, and 16 ton ha^{-1} and the second Factor was humic substance about H0, H1, and H2, corresponding to 0, 15, and 30 litre ha^{-1}, respectively, in the field, with 3 replications, or a total of 36 experimental units.

Incubation Media Trial

The RYP soil samples used as incubation media were obtained from several sampling points in the field at a depth of 0-20 cm and composited. Then, they were air-dried for 2 weeks sifted using a 5-mm sieve, and 36 air-dried samples, each weighing 0.5 kg, were prepared. The soil samples were placed inside plastic glasses for the incubation trial with the ameliorant material, at the specified dosage levels.

The nickel slag was ground using a grinding stone and sifted with a 65 mesh. The nickel slag that passed the sieve was weighed following the set dosage levels of each treatment, and placed inside the incubation media. Afterward, the incubation media were applied with basic fertilizer at dosages of 0.14 g pot^{-1} (corresponding to 300 kg ha^{-1} urea), 0,06 g pot^{-1} (corresponding to 100 kg ha^{-1} SP-36), and 0.04 g pot^{-1} (corresponding to 100 kg ha^{-1} KCl).

The humic substance was first diluted with 100 times distilled water. Then, the diluted humic substance was added into the plastic glasses that already contained the prepared levels of nickel slag. Afterward, the plastic glasses were put inside the greenhouse, with the experimental RYP soil being maintained at field capacity for the whole incubation period. After 6 weeks, the RYP soil samples were collected for laboratory analysis.

Table 1. Chemical Properties of the Gajrug RYP Soil before Treatment

Parameter	Unit	Determination Method/Measuring Device	Value
pH	-	pH meter	4.03
Organic-C	%	*Walkley & Black*	0.07
Total-N	%	*Kjeldahl*	0.08
Available-P	Ppm	*Bray 1*	7.92
exchangeable-K	cmol (+) $100g^{-1}$	NH_4OA_C pH 7	2.30
Exchangeable-Ca	cmol (+) $100g^{-1}$	NH_4OA_C pH 8	13.07
Exchangeable-Na	cmol (+) $100g^{-1}$	NH_4OA_C pH 9	0.84
Exchangeable-Mg	cmol (+) $100g^{-1}$	NH_4OA_C pH 10	0.54
CEC	cmol (+) $100g^{-1}$	NH_4OA_C pH 11	20.31
Exchangeable-Al	cmol (+) $100g^{-1}$	KCl 1 N	30.12
Exchangeable-H	cmol (+) $100g^{-1}$	KCl 1 N	4.18
Heavy metal:			
Pb	mg L^{-1}	AAS (Atomic Absorption Spectroscopy)	<0.038
Cd	mg L^{-1}	AAS (Atomic Absorption Spectroscopy)	0.025
AS	mg L^{-1}	AAS (Atomic Absorption Spectroscopy)	0.012

Note: results of the pre-research analysis

Table 2. Properties of the Humic substance

Type of Analysis	Method/Instrument	Unit	Value		Remarks
pH	pH meter	-	8.71		In the concentrated liquid form
Electrical Conductivity	EC meter	mS cm^{-1}	13.89		In the concentrated liquid form
Carbon content	CNS (*C, N and S analyzer*)	%	41.77	*	In solid form
Nitrogen content	CNS (*C, N and S analyzer*)	%	1.17	*	In solid form
Ash content	Gravimetric	%	2.96	*	In solid form

* Calculated based on the level of density (7.74%)
Source: (Oklima, 2014)

Table 3. Properties of the Nickel Slag

Compound	Total (%)	Determination Method/Measuring Device
SiO_2	45.30	Gravimetric
Al_2O_3	2.53	AAS (Atomic Absorption Spectroscopy)
Fe_2O_3	21.30	AAS (Atomic Absorption Spectroscopy)
K_2O	0.17	AAS (Atomic Absorption Spectroscopy)
Na_2O	0.72	AAS (Atomic Absorption Spectroscopy)
CaO	1.00	AAS (Atomic Absorption Spectroscopy)
MgO	23.20	AAS (Atomic Absorption Spectroscopy)
MnO	0.63	AAS (Atomic Absorption Spectroscopy)
TiO_2	0.27	Spectrophotometer
P_2O_5	0.21	Spectrophotometer

Note: results of the pre-research analysis

The chemical parameters of the incubation media that were evaluated in this study included pH H_2O (using a pH meter); total-N (by means of *Kjeldahl method*); available-P (using *Bray I method*); exchangeable-K, exchangeable-Ca, exchangeable-Na, exchangeable-Mg, and CEC (with NH_4OA_C pH 7.0); exchangeable-Al and exchangeable-H (using KCl 1N); together with heavy metal content (Pb, Cd, and As) of the dissolved soil (using diethylene triamine penta acetic acid (DTPA) extraction). Statistical analysis of the data was done using *Analysis of Variance* (ANOVA) at (α =) 0.05 level of significance, and when a significant difference between treatments was observed, further statistical verification was carried out with *Duncan Multiple Range Test* (DMRT), also at α = 0.05 level.

Chemical Characteristics of the RYP Soil, Humic substance, and Nickel Slag

The chemical properties of the Gajrug RYP soil, humic substance, and nickel slag are presented in Table 1, Table 2, and Table 3, respectively.

RESULTS AND DISCUSSION

Soil Reaction

Table 4 showed the data on the Gajrug RYP soil after treatments. Nickel slag caused a significant increase in the RYP soil pH. As depicted in Table 4, the treatment of nickel slag at level 8 ton ha^{-1}, even without humic substance (T1H0), produced the greatest effect in raising soil pH (from 4.03 to 4.63). The increase of pH value was due to the presence of CaO and MgO (Table 3) which are released from nickel slag into the soil solution. Both CaO and MgO compounds found in the nickel slag reacted with H_2O forming $Ca(OH)_2$ and $Mg(OH)_2$ which disintegrated and became Ca^{2+} + $2OH^-$ and Mg^{2+} + $2OH^-$. The OH^- ions bonded with H^+ to become H_2O, therefore, H^+ ions that caused acidity decreases.

The nickel slag neutralizing capacity is not as high as the steel slag since the CaO in steel slag is higher (53.36%) (Gultom, 2012) than in nickel slag. In addition, based on the acid neutralization capacity (ANC) analysis of the nickel slag obtained value of 31.9%, which was far lower than that of steel slag (66.08%), according to (Utami, 2012), and dolomite (109%) when calculated based on $CaCO_3$ equivalence. This implies that in neutralizing soil acidity, the nickel slag can neutralize only 31.9% compared to $CaCO_3$ (100%). Although its acid neutralization capacity (ANC) is relatively low, nickel slag renders a liming effect on the Gajrug RYP soil.

Total Nitrogen

Table 4. Effect of the application of nickel slag and humic substance on soil pH

Nickel Slag	Humic substance		
	H0	H1	H2
T0	4.51 ab	4.55 a	4.58 a
T1	4.63 a	4.52 a	4.60 a
T2	4.53 b	4.47 a	4.47 a
T3	4.52 b	4.53 a	4.53 a

Numbers in the same column that are followed by similar letters denote not-significant difference at 5% significance level using Duncan's Multiple Range Test (DMRT).

Table 5. Effect of the application of nickel slag and humic substance on soil total-N (%)

Nickel Slag	Humic substance		
	H0	H1	H2
T0	0.11 b	0.10 a	0.11 a
T1	0.11 b	0.10 a	0.12 a
T2	0.12 a	0.14 a	0.14 a
T3	0.11 b	0.10 a	0.09 a

Numbers in the same column followed by similar letters denote not-significant difference at 5% level of significance, using Duncan's Multiple Range Test (DMRT).

The effects of adding nickel slag and humic substance on the total-N content of the Gajrug RYP soil are shown in Table 5. The results of the various statistical tests suggested that only the application of nickel slag produced a measurable effect on soil total-N.

Statistical analysis also established that the application of nickel slag at a level of 12 ton ha^{-1} (T2) produced the biggest effect in raising soil total-N (from 0.08% to 0.12%). According to (Munawar, 2011), when the soil is acidic, microbial activity is impeded, as nitrogen-fixing bacteria in the air are generally sensitive to a low pH level leading to a reduction in N intake. While humic substance, both at the level of H1 and H2 are not a significant reaction because the suspected dose is still too low to use. this is due to the humat substance are easily dissolve so that the rate of nitrogen release process in the soil is more quickly disappear before being bound by the soil material.

Table 6. Effect of the application of nickel slag and humic substance on soil available-P (ppm P_2O_5)

Nickel Slag	Humic substance		
	H0	H1	H2
T0	11.17 b	13.90 a	11.65 a
T1	11.29 ab	9.51 a	10.46 a
T2	19.25 a	14.62 a	12.60 a
T3	12.95 ab	11.88 a	12.84 a

Numbers in the same column that are followed by similar letters denote not-significant difference at 5% level of significance, using Duncan's Multiple Range Test (DMRT).

Table 7. Effect of the application of nickel slag and humic substance on soil exchangeable-H (cmol (+) $100g^{-1}$)

Nickel Slag	Humic substance		
	H0	H1	H2
T0	2.48 a	4.17 b	3.44 a
T1	3.49 a	3.28 a	2.86 a
T2	0.81 b	3.02 a	1.84 a
T3	2.76 ab	4.16 a	1.59 a

Numbers in the same column that are followed by similar letters denote not-significant difference at 5% level of significance, using Duncan's Multiple Range Test (DMRT).

Available Phosphor

Table 6 summarizes the effect of the application of nickel slag and humic substance on available-P in the Gajrug RYP soil. Statistical analysis revealed that only the application of nickel slag produced a significant effect on soil available-P.

When subjected to the statistical test, the data showed that the application of nickel slag significantly increased available-P of the Gajrug RYP soil (Table 6), with treatment T2 (12 ton ha^{-1}) producing the greatest increase (from 7.92 ppm to 19.25 ppm). This increase in the level of soil available-P could have been due to the P_2O_5 that was released from the nickel slag (Table 3) into the RYP soil solution. In addition, the SiO_2contained in the nickel slag was likewise released into soil solution hence, also contributed to the increase in the level of soil available-P (Myhr & Erstad, 1996). The Si content of the nickel slag (Tabel 3) also reduced P fixation by Al and Fe through ligand exchange, such that the SiO_2 in the nickel slag was hydrolyzed and formed SiO_4^{4-} anions that replaced PO_4^{3-}. This resulted in the release of P in the nickel slag into the soil solution.

Exchangeable-H

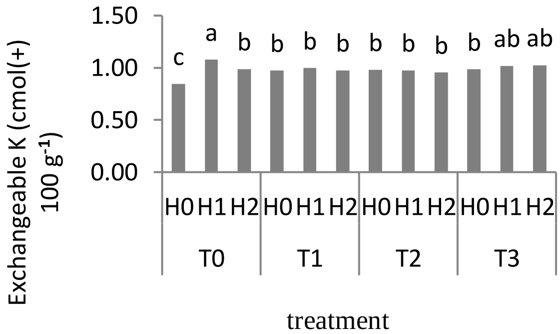
The effect of the application of nickel slag and humic substance on the level of exchangeable-H of the Gajrug RYP soil can be seen in Table 7. The application of nickel slag and humic substance generally lowered the level of exchangeable-H in the RYP soil.

The application of 12 ton ha^{-1} nickel slag without humic substance (T2H0), produced the highest reduction (from 2.48 cmol(+)100g^{-1} to 0.81 cmol(+)100g^{-1}. Allorerung (1988) found that the Si contained in the steel slag indirectly influenced the reduction in exchangeable-Al and exchangeable-H inRYP soil, as part of the silicates released (by the steel slag) into the soil solution reacted or settled with Al and Fe hydroxide. The same thing likely happened with the nickel slag considering its chemical composition (45.30%) is also SiO_2 (Table 3).

Exchangeable Cation (exchangeable-K, exchangeable-Mg)

The application of nickel slag and humic substance significantly increased exchangeable-K of the RYP soil and the single application of the humic substance (H1T0) resulted in the highest level of exchangeable-K (1.08 cmol(+) 100 g^{-1}.

As shown in Table 8, the addition of nickel slag into the Gajrug RYP soil significantly raised the level of soil exchangeable-Mg, notably rising with increasing dosage.



Numbers in the bar graph that are followed by similar letters denote not-significant difference at 5% level of significance, using Duncan's Multiple Range Test (DMRT).

Figure 1. Graph showing the effect of the application of nickel slag and humic substance on exchangeable-K of the RYP soil

Table 8. Effect of the application of nickel slag and humic substance on soil exchangeable-Mg (cmol(+)100g^{-1})

Nickel Slag	Humic substance		
	H0	H1	H2
T0	14.80 c	15.56 a	14.00 a
T1	18.14 b	17.66 a	19.04 a
T2	18.93 b	19.53 a	19.04 a
T3	21.33 a	21.64 a	21.77 a

Numbers in the same column that are followed by similar letters denote not-significant difference at 5% significance level, using Duncan's Multiple Range Test (DMRT).

Table 9. Effect of the application of nickel slag and humic substance on the rate of some heavy metals in the soil (ppm)

Treatment	Heavy Metal		
	Pb	Cd	As
T0H0	0.0126	0.0005	0.2169
T0H1	0.0075	0.0019	0.2467
T0H2	0.0187	0.0008	0.2030
T1H0	0.0190	0.0005	0.1925
T1H1	0.0081	0.0010	0.1577
T1H2	0.0090	nm	0.2104
T2H0	0.0215	0.0007	0.2055
T2H1	0.0081	0.0007	0.2064
T2H2	0.0191	0.0007	0.2745
T3H0	0.0140	0.0012	0.2424
T3H1	0.0256	0.0015	0.2497
T3H2	0.0199	0.0012	0.2190

note: nm – not measured

The highest nickel slag level of 16 ton ha^{-1} (T3) in Table 8 produced the greatest increase in exchangeable-Mg (21.33 cmol(+)100g^{-1}). This could be attributable to the fact that nickel slag possesses a high Mg level, as manifested by its high MgO content (Table 3).

Heavy Metals in the Soil

The results of the humic substance (Table 2) and the nickel slag (Table 3) showed the absence of Pb, Cd or As in humic substance and nickel slag. However, in the T0H0 (treatment soil without humic substance or nickel slag) it was found Pb, Cd and As. This indicates that the three heavy metals are already present in the soil (Table 1), but these are still in normal environmental standard. The critical limits for Pb, Cd, and As in soil are 100-400 mg kg^{-1}, 3-8 mg kg^{-1}, and 20-50 mg kg^{-1}, respectively (Alloway, 1995). While the normal limits for PB, Cd, and As in soil are 2-200 mg kg^{-1}, 0.1-7.0 mg kg^{-1}, and 0.1-40 mg kg^{-1} (Barchia, 2009).

The application of humic substance and nickel slag were tending to decrease the content of Pb and As in the soil. It can be seen in Table 9 that the levels of Pb, Cd, and As that were extracted using DTPA were lower than those obtained by Alloway (1995). The decrease in the heavy metal content of Pb and As is thought to be due to a reaction between heavy metals with a humic material forming a complex bond.

CONCLUSION

Based on the statistical analysis of the data obtained in this study, it is clear that the application of nickel slag into the Gajrug red-yellow podzolic soil can increase significantly the levels of soil pH, total-N, available-P, exchangeable-Mg. At the same time, the treatment can decrease exchangeable-H in the soil. The interaction effect of adding nickel slag and humic substance application into the RYP soil can increase exchangeable-K only. The application of nickel slag and humic substance into the Gajrug RYP soil tended to decrease heavy metals, notably Pb, Cd and As which implies they pose no environmental hazard, and can safely be used as a soil ameliorant. The concentration of the humic substance (both H1 and H2) should be increased so that the reaction in the soil is more optimal, especially in helping to dissolve the element of nickel slag so that the Gajrug red-yellow podzolic soil quality is better.

REFERENCES

Ahmad, A. (2011). *Increasing of Nutrient Elements Release from Igneous Rocks with Humic Substances*. IPB (Bogor Agricultural University). Retrieved from http://repository.ipb.ac.id/handle/123456789/46488

Ali, M. T., & Sedaghat Hoor, S. (2007). Converter Slag as a Liming Agent in the Amelioration of Acidic Soils. *INTERNATIONAL JOURNAL OF AGRICULTURE & BIOLOGY*, *9*(5), 715–720. https://doi.org/10.1017/CBO9781107415324.004

Allorerung, D. 1988. *Influence of Steel Slag on Red Yellow Podzolic Against Soil Chemical Characteristics, Nutrient Content, Uptake* *and Cane Production* [dissertation]. Bogor (id): Bogor Agricultural University.

Alloway, B. J. (1995). *Heavy Metals in Soils*. *Heavy metals in soils*. New York: Blackie Academic and Professional-Chapman and Hall. https://doi.org/10.1007/978-94-011-1344-1

Barchia, M. F. (2009). *Agroecosystem of Acid Minerals (Agroekosistem Tanah Mineral Masam)* (1st ed.). Yogyakarta: UGM Press. Retrieved from http://ugmpress.ugm.ac.id/id/product/pertanian/agroekosistem-tanah-mineral-masam

Gultom, P. R. (2012). *Effects of Steel Slag on Chemical Properties of Acid Sulphate Soil and Production of Rice (Oryza sativa L).* Bogor Agriculture University (IPB). Retrieved from http://repository.ipb.ac.id/jspui/handle/123456789/54909

Havlin, J., & Tisdale, S. L. (2005). *Soil fertility and fertilizers : an introduction to nutrient management*. (John Havlin, Ed.) (7th ed.). New Jersey: Pearson Prentice Hall. Retrieved from https://books.google.co.id/books/about/Soil_Fertility_and_Fertilizers.html?id=uVeuQgAACAAJ&redir_esc=y

Kato, N., & Owa, N. (1997). Dissolution of slag fertilizers in a paddy soil and Si uptake by rice plant. *Soil Science and Plant Nutrition*, *43*(2), 329–341. https://doi.org/10.1080/00380768.1997.10414757

Munawar, A. (2011). *Kesuburan Tanah dan Nutrisi Tanaman (Soil Fertility and Plant Nutrition*. (A. Munawar, Ed.). Bogor: IPB Press.

Myhr, K., & Erstad, K. J. n. (1996). Converter slag as a liming material on organic soils. *Norwegian Journal of Agricultural Sciences*, *10*(1), 82–93. Retrieved from https://geoscience.net/research/002/789/002789315.php#close

Ning, D., Liang, Y., Liu, Z., Xiao, J., & Duan, A. (2016). Impacts of steel-slag-based silicate fertilizer on soil acidity and silicon availability and metals-immobilization in a paddy soil. *PLoS ONE*, *11*(12). https://doi.org/10.1371/journal.pone.0168163

Oklima, A. M. (2014). *The Utilization of Coal Ash and Humic Substance as a Soil Ameliorant in the Reclamation of Ex-mining Land*. IPB (Bogor Agricultural University). Retrieved from http://repository.ipb.ac.id/handle/123456789/70546

Schnitzer, M., & Khan, S. U. (1978). *Soil organic matter* (8th ed.). Amsterdam: Elsevier Scientific Pub. Co. Retrieved from https://www.sciencedirect.com/bookseries/developments-in-soil-science/vol/8

Ulfah, P. (2014). *Residual Effect of Electric Furnace Slag, Dolomite, and Micro Nutrients on Chemical Soil Properties and Growth and Yield of Rice of Second Plant on Peat Soil*. Bogor Agriculture University (IPB). Retrieved from http://repository.ipb.ac.id/handle/123456789/68979

Utami, H. (2012). *Effect of Electric Furnace Slag, Dolomite, and Micro Nutrient on Chemical Soil Properties, Growth and Yield Rice on Peat Soil from Kumpeh, Jambi*. Bogor Agriculture University (IPB). Retrieved from http://repository.ipb.ac.id/bitstream/handle/123456789/60043/A12hut.pdf;jsessionid=535598003A7E40349271ED137CBEB3E6?sequence=1