

Effectivity of Soil Amelioration on Peat Soil and Rice Productivity

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ABSTRACT

Application of ameliorant on peat soil has an important role on improving fertility status of peat soil via increasing soil pH, reducing organic acids and toxic ions, and also increasing nutrients availability. Soil amelioration with polyvalent cations (Fe, Al, Cu, and Zn) using slag, lateritic soils, and river mud are effective to reduce harmful effects of phenolic acids. The objective of the study was to determine the effect of soil amelioration on peat soil chemical properties and rice productivity (both biomass and yield). The study was consisted of two sets of experiments, namely soil incubation experiment conducted in the laboratory and a pot experiment conducted in the greenhouse. The experiment was designed in a complete randomized design (CRD) with 14 treatments and 4 replications. The results showed that the application of slag and dolomite as ameliorant showed a significant effect on increasing pH, base saturation (BS), and the amount of exchangeable-Ca and -Mg. Moreover, slag application was better in improving chemical properties of peat soil as it increased pH, base saturation (BS), and nutrient content (Ca, silica, ash and Fe). Application of burnt trass + dolomite (TD) showed no significant effect on increasing silica content in the peat soil. The application of slag resulted in the highest dry weight of biomass and grains of rice plants. The application of slag on peat soil in general provides better effects on the soil chemical conditions compared to that of trass, dolomite or ameliorant combination [trass + dolomite (TD) with slag].

Keywords: Ameliorant, organic acids, paddy, peat soil

ABSTRAK

Amelioran berperan untuk memperbaiki kesuburan tanah gambut yaitu memperbaiki lingkungan akar bagi pertumbuhan tanaman melalui peningkatan pH, menurunkan asam-asam organik dan ion-ion toksik, dan meningkatkan ketersediaan hara. Amelioran yang mengandung kation polivalen (Fe, Al, Cu, dan Zn) seperti terak baja, tanah mineral laterit atau lumpur sungai sangat efektif mengurangi dampak buruk asam fenolat. Tujuan penelitian ini adalah mempelajari: 1) pengaruh aplikasi bahan amelioran dalam memperbaiki sifat kimia tanah gambut, 2) suhu pembakaran amelioran tras dan dolomit terhadap ketersediaan silika tanah gambut, 3) pengaruh aplikasi bahan amelioran terhadap pertumbuhan dan produksi (berat kering biomas dan berat kering gabah) tanaman padi. Penelitian terdiri atas dua percobaan, yaitu inkubasi sampel tanah dilakukan dilaboratorium dan percobaan rumah kaca dengan menggunakan rancangan acak lengkap (RAL) dengan 4 ulangan. Hasil penelitian yaitu 1) aplikasi amelioran *slag* dan dolomit berpengaruh nyata dalam meningkatkan pH, kejenuhan basa (KB), dan kadar hara (Ca dan Mg), namun aplikasi *slag* lebih baik dalam memperbaiki kondisi kimia pada tanah gambut, selain meningkatkan pH, KB, kadar hara Ca, juga meningkatkan kadar silika, kadar abu dan Fe sebagai kation polivalen. 2) Pembakaran amelioran tras+dolomit (TD) tidak berpengaruh nyata dalam meningkatkan ketersediaan kadar silika pada tanah gambut. 3) Aplikasi amelioran *slag* berpengaruh nyata dalam meningkatkan bobot kering biomas dan bobot kering gabah (BKG) pada tanaman padi. Amelioran terbaik yaitu *slag* dibandingkan tras, dolomit atau kombinasi [tras+dolomit (TD) dengan *slag*].

Kata kunci: Asam organik, bahan amelioran, silika, padi, tanah gambut

INTRODUCTION

Increasing population has led to an increase of food production. Therefore, it is important to support national food security. However, nowadays the food production is decreasing due to the decrease of the number of productive agricultural land. Therefore, utilization of suboptimal land such as peatland for agricultural land purposes is necessary. Indonesia has the largest peatland among tropical countries, comprises of about 14.9 million ha, spreading mainly in Sumatra, Kalimantan and Papua (BB R & D SDLP 2011).

However, the peatland utilization for agricultural development faces many limiting factors such as acidity, low base saturation, organic acid toxicity, and nutrient deficiency. Tadano *et al.* (1990) and Prasetyo (1996) reported that the low productivity of peat soils is mainly due to the high content of organic acids, which are toxic to plants, especially the derivatives of phenolic acids. Peatland development for agriculture must consider water regulation and ameliorant application since in most cases peatlands are generally inundated and infertile. Ameliorant has an important role on improving peat soil fertility such as increasing soil pH, reducing the amount of organic acids and toxic ions, and increasing nutrients availability (Attiken *et al.* 1998). Soil amelioration with polyvalent cations (Fe, Al, Cu, and Zn) using slag, lateritic soils, and river mud effectively reduces harmful effects of phenolic acids (Sabiham and Ismangun 1997; Salampak 1999).

Rice plant requires very high amount of silica for its growth. According to Barker and Pilbeam (2007) silica is an essential nutrient for rice plant and rice plant absorbs silica approximately 150-300 kg Si ha⁻¹. Several studies have shown that application of trass and burned dolomite increased pH, silica, and base cation content of peat soil. The untreated trass contained the lowest amount of SiO₂, *i.e.* 0.043%, whereas the combustion of trass at 105°C for 24 hours increased SiO₂ content by 0.066%, and the trass added with dolomite and burned at 700°C contained 0.149% SiO₂ (Meliala 2015).

The objectives of the study were to determine the effect of soil amelioration on peat soil chemical properties, to determine the effect of temperature of combustion of ameliorant trass and dolomite on the availability of silica in peat soil, and to determine the effect of soil amelioration on increasing crop productivity (both biomass and yield).

MATERIALS AND METHODS

Experimental Setup

The experiment was consisted of two parts, namely peat soil incubation experiment conducted

in the laboratory and pot experiment using rice plants conducted in the greenhouse. The pot experiment was carried out at the Greenhouse Installation of the Soil Research Institute, the Center for Agricultural Land Resources, while the laboratory experiment was carried out at the Laboratory of the Department of Soil Science and Land Resources of Bogor Agricultural University (IPB). The research was conducted from December 2015 until November 2016.

Material Characteristics Used in the Study

Ameliorants used in this study were slag, dolomite, and trass. The type of slag used was iron furnace slag, which was rich in iron minerals with the Fe₂O₃ content of 42.6%. The slag was obtained from PT Krakatau Steel. The dolomite used in this study was derived from carbonate sedimentary rocks consisting of two carbonate minerals namely calcite (CaCO₃) and magnesite (MgCO₃). The dolomite was obtained from Indo Bumi Agung Gresik. Trass derived from volcanic eruptions is rich in feldspar and silica, with the SiO₂ content of 64.7%, but the silica in the trass is very insoluble/unavailable to plants. The trass was obtained from Cigombong Bogor Regency. The peat soil was taken from Dusun Karya Maju, Pematang Rahim Subdistrict, East Tanjung Jabung District, Jambi Province, Indonesia. The peat soil is classified as oligotrophic peat with the decomposition degree of sapric and peat thickness of 100 cm.

Experimental Design and Treatments

Both the soil incubation experiment and pot experiment were conducted using a complete randomized design (CRD). The dosages of ameliorants applied in the peat soil incubation experiment are presented in Table 1. The dosages of macronutrient and micronutrient fertilizers used in this study were 267 kg urea ha⁻¹, 100 kg SP-36 ha⁻¹, 100 kg KCl ha⁻¹, 10 kg CuSO₄ ha⁻¹, 20 kg ZnSO₄ ha⁻¹, and 20 kg FeSO₄ ha⁻¹. The treatment of trass-dolomite (TD) is a mixture of trass and dolomite with a ratio of 1:1.5, which is then burned at 700°C, 1000°C and 1200°C. The dosage of ameliorant applied in each treatment was 5% of absolute dry weight (ADW) of peat soil. The amounts of available silica and total silica in the ameliorant materials used in this study were analyzed using yellow silicomolybdic acid method and gravimetric method, respectively.

In the incubation experiment, the weight of peat soil used was equivalent to 244 grams of absolute dry weight (ADW) or equivalent to 1.0 kg of peat soil per pot, with the moisture content of 313%. The

Table 1. Dosages of ameliorants applied in the peat soil incubation experiment.

Treatment	Trass	Dolomite	Slag	TD (700 °C)	TD (1000 °C)	TD (1200 °C)
.....(g pot ⁻¹).....						
Control	0	0	0	0	0	0
Trass	12.2	0	0	0	0	0
Slag	0	0	12.2	0	0	0
Dolomite	0	12.2	0	0	0	0
100TD 700 °C	4.9*	7.3*	0	12.2	0	0
100TD 1000 °C	4.9*	7.3*	0	0	12.2	0
100TD 1200 °C	4.9*	7.3*	0	0	0	12.2
75TD 700 °C + 25 Slag	3.7*	5.5*	3.1	9.2	0	0
75TD 1000 °C + 25 Slag	3.7*	5.5*	3.1	0	9.2	0
75TD 1200 °C + 25 Slag	3.7*	5.5*	3.1	0	0	9.2
50TD 700 °C + 50 Slag	2.4*	3.6*	6	6	0	0
50TD 1000 °C + 50 Slag	2.4*	3.6*	6	0	6	0
50TD 1200 °C + 50 Slag	2.4*	3.6*	6	0	0	6

Note: The weight ratio of trass and dolomite in the mixed TD (trass + dolomite) treatment is 1:1.5.

ameliorants were mixed evenly with the peat soil according to the treatments, then incubated for 3 months in a flooded condition at the water height of 2-3 cm above the peat surface. No fertilizers were applied in the peat soil incubation experiment because we would like to determine the increase of nutrient content in the peat soil after the application of each ameliorant treatment. The incubated soil samples were taken, dried and then stored in a plastic bag for further analysis. The soil chemical properties including pH (H₂O), ash content, total-

N (Kjehldal), available-P (Bray-1), exchangeable cations (Ca, Mg, K, Na), base saturation, cation exchange capacity (CEC) (NH₄OAc 1N pH 7), available micronutrients (Fe, Cu, Zn, Mn, and Pb) (DTPA pH 7.3), and SiO₂ content (gravimetric method) were analyzed.

The weight of peat soil used in the pot experiment using rice plants was 3 kg of absolute dry weight (ADW) or equal to 12.5 kg of peat soil per pot, with a moisture content of 313%. The ameliorants were mixed evenly with the peat soil

Table 2. Dosages of ameliorants applied in the pot experiment using rice plants.

Treatment	Trass	Dolomite	Slag	TD (700 °C)	TD (1000 °C)	TD (1200 °C)
.....(g pot ⁻¹).....						
control	0	0	0	0	0	0
NPK standard**	0	0	0	0	0	0
Trass	150	0	0	0	0	0
Slag	0	0	150	0	0	0
Dolomite	0	150	0	0	0	0
100TD 700 °C	60*	90*	0	150	0	0
100TD 1000 °C	60*	90*	0	0	150	0
100TD 1200 °C	60*	90*	0	0	0	150
75TD 700 °C + 25 Slag	45*	68*	38	113	0	0
75TD 1000 °C + 25 Slag	45*	68*	38	0	113	0
75TD 1200 °C + 25 Slag	45*	68*	38	0	0	113
50TD 700 °C + 50 Slag	30*	45*	75	75	0	0
50TD 1000 °C + 50 Slag	30*	45*	75	0	75	0
50TD 1200 °C + 50 Slag	30*	45*	75	0	0	75

Note: * = The weight ratio of trass and dolomite in the mixed TD (trass + dolomite) treatment is 1:1.5.

** = Standard NPK treatment (100% of recommended doses of macronutrient and micronutrient fertilizers)

Table 3. Dosages of fertilizers applied in the pot experiment using rice plants.

Treatment	Urea	SP-36	KCl	FeSO ₄	CuSO ₄	ZnSO ₄
.....(g pot ⁻¹).....						
Control	0	0	0	0	0	0
NPK standard	1.667	0.625	0.625	0.125	0.062	0.125
Trass	0.834	0.313	0.313	0	0	0
Slag	0.834	0.313	0.313	0	0	0
Dolomite	0.834	0.313	0.313	0	0	0
100TD 1000 ^o C	0.834	0.313	0.313	0	0	0
100TD 1000 ^o C	0.834	0.313	0.313	0	0	0
100TD 1200 ^o C	0.834	0.313	0.313	0	0	0
75TD 700 ^o C + 25 Slag	0.834	0.313	0.313	0	0	0
75TD1000 ^o C + 25Slag	0.834	0.313	0.313	0	0	0
75TD1200 ^o C + 25 Slag	0.834	0.313	0.313	0	0	0
50TD 700 ^o C + 50 Slag	0.834	0.313	0.313	0	0	0
50TD1000 ^o C + 50 Slag	0.834	0.313	0.313	0	0	0
50TD 1200 ^o C + 50 Slag	0.834	0.313	0.313	0	0	0

according to the treatments, then incubated for 1 month in a flooded condition with the water height of 2-3 cm above the peat surface. The rice seedlings with the age of 15 days were planted. At the time of planting, the starter fertilizers, *i.e.* urea, SP-36, and KCl were applied. Urea was applied twice (half dosage of urea was applied at 7 days after planting (DAP) and the rest was applied at 30 DAP), while KCl, SP-36, and micronutrient fertilizers were applied simultaneously at the planting time. The treatment of urea, KCl, SP-36 fertilizers is referred to as standard NPK treatment, which is considered as 100% of recommended doses of macronutrient and micronutrient fertilizers, while in the ameliorant treatments the dosage of fertilizers applied was 50 % of the recommended dose of macronutrient fertilizers. The control treatment was performed without ameliorant and fertilizer application. The dosages of ameliorants and fertilizers applied in the pot experiment are presented in Table 2 and 3. The rice plant variety IR-64 was used in the experiment. During the nurturing of rice plants, the water height was maintained at 2-3 cm above the surface of peat soil. The rice grains were harvested at 120-125 DAP or when 95% of rice grains turned to yellow. The plant parameters measured were the dry weight of rice plant biomass and dry weight of grains (DWG).

Statistical Analysis

The data were analyzed statistically using analysis of variance at 5% significance level using SAS 9.4 software in order to determine the significant effect of the treatments on the observed variables. The treatments with a significant effect

were further tested using Duncan Multiple Range Test (DMRT).

RESULTS AND DISCUSSION

The Initial Chemical Properties of Peat Soil

Table 4 showed that the pH of peat soil is very low/acidic; the macronutrient and micronutrient availability are low, except for the available-P and Fe (high) and the total-N content (medium); the cation exchange capacity (CEC) and base saturation (BS) are low. Based on the data in Table 4, the limiting factor of this peat soil is the low fertility level. The decomposition of woody materials rich in lignin in the peat soil occurs in an anaerobic state, producing aliphatic acids and phenolic acids in which most of these acids are toxic to plants (Kononova 1968; Tsutsuki dan Ponnampereuma 1987, Tsutsuki dan Kondo 1995). Several studies have shown that phenolic acids are phytotoxic to plants and able to inhibit plant growth (Driessen 1978; Steventson 1994, Tsutsuki 1984). Application of ameliorant, particularly the ameliorant that contains polyvalent cations such as Fe, Al, Cu, and Zn, on peat soil can be an option to improve the chemical properties of peat soil used as a planting medium.

The Effects of Ameliorant Application on the Chemical Properties of Peat Soil

The chemical properties of peat soil after ameliorant application in the soil incubation experiment are presented in Table 5. The soil pH was significantly affected by the ameliorant

Table 4. Initial chemical properties of peat soil.

Chemical properties	Value	Category
pH H ₂ O	3.2	Very acid
Total-N(%)	1.7	Medium
Available-P (ppm)	85.2	High
Exchangeable-Ca (cmol (+)kg ⁻¹)	7.7	Low
Exchangeable-Mg(cmol (+) kg ⁻¹)	2.3	Low
Exchangeable-K(cmol (+) kg ⁻¹)	0.3	Low
Exchangeable-Na(cmol (+) kg ⁻¹)	0.5	Low
CEC(cmol (+) kg ⁻¹)	73.4	Low
Base saturation (%)	14.9	Low
Available-Fe(ppm)	328.8	High
Available-Cu (ppm)	0.5	Low
Available-Zn (ppm)	3.9	Low
Available-Mn (ppm)	5.0	Low
Available-Pb(ppm)	1.3	-
Ash (%)	7.4	Medium *
SiO ₂ (%)	6.3	-

Note: Parameter of peat soil chemical properties (Fleischer, Halim, Jones Jr 2001, Tim IPB 1976, Tim PPT 1983, In Fatmawati. 2013). * Classification of peat soil fertility level (Fleischer in Driessen & Soepraptohardjo 1974).

application. The soil pHs in the control and trass treatments were very low, while the highest soil pH was observed in the dolomite treatment. This is due to the Ca and Mg in the dolomite are quickly dissolved and available, as well as due to the higher neutralizing power of the dolomite. According to Hardjowigeno (1986), dolomite can increase soil pH and soil base saturation as well as can add Ca and Mg into the soil. Meanwhile, the increase of pH after application of slag is probably caused by the ligand formation reaction between organic acids, such as carboxylic acids and phenolics, and hydroxyl groups of Fe and Al contained in the slag, liberating OH⁻ that can increase the soil pH. According to Suwarno and Goto (1997), the electric furnace slag has a pH (H₂O) of 11.1 and neutralizing power of 66.3%. The result of this study is consistent with other findings that showed that electric furnace (EF) slag from Indonesia can be used as lime to enhance the pH of acid soils as well as can be utilized as peat soil conditioner (Suwarno and Goto 1997; Suwarno 2002).

The amount of exchangeable-Ca and -Mg in the peat soil increased significantly after ameliorant application (Table 5). The highest amount of exchangeable-Ca and -Mg was observed after application of dolomite, while the lowest amount of exchangeable-Ca and -Mg was observed in the control and trass treatments. The increase of exchangeable-Ca and -Mg in the peat soil after dolomite application was due to the high contribution of Ca and Mg from the dolomite materials (30% CaO and 18% MgO). The amount of exchangeable-

Ca in the peat soil applied with dolomite was not significantly different from that in the peat soil applied with slag. This is because the slag material also contains Ca (26% CaO) (Suwarno and Goto 1997). This result corresponds to the study of Huang *et al.* (2012), which stated that steel slag contains CaO, MgO, and SiO₂, and application of steel slag can increase the pH and Ca content of acid soils. On the other hand, the amount of exchangeable-Na and -K in the peat soil was not significantly different among the treatments. The base saturation (BS) of peat soil was increased significantly after ameliorant application. The highest base saturation (BS) was measured in the dolomite treatment, while the lowest base saturation was observed in the control and trass treatments. The increase of base saturation in the peat soil was caused by the contribution of Ca and Mg from dolomite/slag materials. The ameliorant application showed no significant effect on the cation exchange capacity of peat soil.

Application of ameliorant showed a significant effect on the amount of available-P in the peat soil. In general, the amount of available-P decreased with increasing dosage of slag. The decrease of P availability in the slag treatment was due to the present of an Fe polyvalent cation derived from slag material that led to an increase of bonding between P and organic acids via a cation bridge. According to Hartatik *et al.* (2004) the application of ameliorant is able to reduce P leaching in peat soils. This result is in line with the study of Rachim (1995) that suggested that Al and Fe cations in peat soil are

Table 5. The pH (H₂O), exchangeable cations (Ca, Mg, K, Na), base saturation, CEC, available-P, total-N, ash content and available-Si in the peat soil of incubation experiment.

Treatment	pH	Exch. Ca	Exch. Mg	Exch. K	Exch. Na	Base saturation	CEC	Available-P	Total-N	Ash content	Si
	H ₂ O(cmol(+) kg ⁻¹).....(cmol(+) kg ⁻¹).....(cmol(+) kg ⁻¹).....(%).....	(%)	(cmol(+) kg ⁻¹)	(ppm)(%).....(%).....(%).....
Control	3.24e	8.2d	2.6 e	0.378ab	0.799b	16.0 f	73.35 a	55.0a	1.73 a	7.5b	6.30ab
Trass	3.47d	15.0c	6.8de	0.357ab	0.743b	31.3ef	86.3 a	43.5ab	1.80 a	11.2a	5.24b
Slag	4.00bc	34.6ab	7.7cde	0.340ab	0.795b	56.8bcde	78.5 a	17.9c	1.72 a	12.6a	6.22ab
Dolomite	4.52a	41.0a	31.3a	0.329b	0.805b	90.8a	86.1 a	55.8a	1.52 a	11.5a	6.65ab
100TD700°C	3.88c	30.2b	11.9bcde	0.309b	0.649b	37.4def	114.0 a	51.8ab	1.63 a	11.6a	6.20ab
100TD1000°C	4.20b	32.9b	21.2b	0.300b	0.664b	84.1ab	65.5 a	55.2a	1.70 a	12.5a	7.65a
100TD1200°C	4.14b	34.7ab	19.9b	0.346ab	0.785b	61.2abcde	101.1 a	56.3a	1.85 a	12.4a	5.61ab
75TD700°C+25Slag	4.07bc	32.3b	12.3bcde	0.301b	0.710b	53.0bcde	95.5 a	46.3ab	1.74 a	11.9a	6.94ab
75TD1000°C+25Slag	4.13b	34.2ab	18.4bc	0.396ab	0.826b	67.4abcd	93.1 a	32.4abc	1.71 a	12.6a	7.89a
75TD 1200°C+25Slag	4.20b	33.0b	14.2bcd	0.521 a	0.871b	47.3cdef	109.7 a	33.6abc	1.54 a	12.0a	5.65ab
50TD 700°C+50Slag	4.09bc	30.0b	9.1cde	0.309b	0.791b	47.6cdef	91.3 a	35.9bc	1.75 a	12.2a	6.38ab
50TD 1000°C+50Slag	4.07bc	34.2ab	18.1bc	0.304b	0.869b	73.7abc	81.0 a	41.6abc	1.63 a	12.4a	6.59ab
50TD 1200°C+50Slag	4.01bc	36.4ab	14.4bcd	0.410ab	1.209a	53.2bcde	110.0 a	39.8abc	1.77 a	12.1a	7.24ab

Note: The values in the same column that are followed by the same letters indicate no significant difference at 5% significance level based on Duncan Multiple Range Test (DMRT).

able to increase P retention compared to that without the cations. The limiting factor of peat soil as a planting medium of rice plants is not only P availability, but also other peat soil problems, such as organic acid toxicity (which causes the nutrients in the soil are easily leached and not available to plants), high acidity, and low macronutrient (Ca and Mg) and micronutrient content. On the other hand, the total-N content in the peat soil applied with ameliorant was not significantly different from that in the control treatment (Table 5).

Application of ameliorant significantly increased the ash content of peat soil. In general, the ash content increased with increasing dosage of slag. This is due to the contribution of balanced macro and micro nutrients derived from the slag material (Ca, Mg, Si, and Fe). However, the ameliorant application did not affect the silica content in the peat soil. Yet in general, the silica content in the peat soil applied with ameliorant TD + slag increased with increasing dosage of the slag applied. This result is supported by the fact that the slag contains the highest total silica and available silica among other ameliorants (Table 6). According to Suwarno (2010), the electric furnace (EF) slag as a source of Si fertilizer for the rice plants is able to increase the growth and yield of rice plants grown on both low Si soil and peat soil.

Concentrations of Micronutrients and Heavy Metals (Fe, Mn, Cu, Zn and Pb) in the Peat Soil

The amounts of micronutrients and heavy metals (Fe, Mn, Cu, Zn and Pb) in the peat soil after ameliorant applications are presented in Table 7. The highest amount of Fe in the peat soil was obtained after slag application, which was increased with increasing dosage of slag. This is due to the high Fe content (43.2% Fe₂O₃) in the slag material. The higher Fe content in the ameliorant in the form of a polyvalent cation, the more significant its function to reduce the adverse effects of phenolic acids. The formation of complexes between organic molecules and metal ions of more than one bond will usually

increase the stability of the complexes. Thus, Fe is a cation that has high reactivity in interacting with organic acids, so the slag application can suppress the concentration of some phenolic acid derivatives contained in the peat soil. Meanwhile, the amount of Mn in the peat soil in general increased significantly after ameliorant application, particularly in the treatment of TD + slag. It may be due to the contribution of Mn from trass/slag material applied.

Ameliorant application showed no significant effect on the Cu content in the peat soil, and the lowest Cu content in the peat soil was observed in the slag treatment. In general, Cu content decreased with increasing dosage of slag. It might occur because of 3 factors: 1) Cu reacts with carbonate so that its activity decreases in the soil. According to Hao *et al.* (2012), application of steel slag is able to increase the dissolved carbonate in the soil, which further reacts with Cu to form CuCO₃ and leads to the decrease of Cu activity; 2) A reaction occurs between organic acids with Cu so as to form a strong coordination bond (chelate). The formation of complex or chelate compounds between Cu and peat soil organic acids can suppress the adverse effects of phenolic and carboxylic acids (Zahrah 2010); 3) The Cu activity decreases along with the increase of pH of peat soil. According to Haihong *et al.* (2013), steel slag application can reduce soil acidity so as to reduce heavy metal activity and excessive micronutrients in the soil. Similarly, application of slag on peat soil resulted in lower availability of Zn compared to other treatments. The Pb content in the peat soil was quite low in all ameliorant treatments, and tended to decrease with increasing dosage of slag. Based on the criteria of heavy metal content in soil and plant proposed by the Soil Research Institute (2009), the Pb content in the peat soil used in this study is in the the normal range (2-300 mg kg⁻¹), while the critical limit of Pb content in soil is about 100-400 mg kg⁻¹. According to Soepardi (1983), the concentration of Pb in soil decreases along with the application of ameliorant slag and dolomite. In addition, the application of ameliorant

Table 6. The amounts of available silica and total silica in the ameliorants.

Ameliorant	Available Si	Total SiO ₂
	(%)	
Tras	0.328	84.05
Dolomite	0.135	13.92
Slag	2.468	31.86
Trass+Dolomit (TD) 700 °C	0.276	14.30
Trass+Dolomit (TD) 1000 °C	0.044	17.78
Trass+Dolomit (TD) 1200 °C	0.035	40.62

Table 7. The concentrations of micronutrients (Fe, Mn, Cu dan Zn) and Pb in the peat soil of incubation experiment.

Treatment	Fe	Mn	Cu	Zn	Pb
(ppm).....				
Control	379 cd	4.7 h	0.275 ab	3.74 a	1.43 a
Trass	507 c	23.5 fgh	0.227 abc	4.17 a	1.37 ab
Slag	966 a	19.6 gh	0.020 c	0.10 b	0.35 d
Dolomite	228 d	21.7 fgh	0.213 abc	3.00 a	1.46 a
100TD 700 °C	324 cd	26.4 efgh	0.289 ab	3.00 a	1.35 ab
100TD 1000 °C	325 cd	42.9 defg	0.123 abc	3.53 a	1.44 a
100TD 1200 °C	352 cd	40.7 defg	0.324 a	3.93 a	1.45 a
75TD 700 °C +25 Slag	707 b	85.6 ab	0.158 abc	3.97 a	1.34 ab
75TD 1000 °C +25 Slag	745 b	102.2 a	0.233 abc	5.01 a	1.48 a
75TD 1200 °C +25 Slag	695 b	66.3 bcd	0.116 abc	4.08 a	1.13 abc
50TD700 °C +50 Slag	791 ab	56.2 bcde	0.100 bc	3.95 a	0.98 bc
50TD 1000 °C +50 Slag	872 ab	77.7 abc	0.137 abc	3.94 a	1.10 abc
50TD 1200 °C +50 Slag	778 b	53.0 cdef	0.214 abc	4.31 a	0.87 c

Note: The values in the same colum that are followed by the same letters indicate no significant difference at 5% significance level based on DMRT.

Table 8. Dry weight of biomass and grains of rice plants obtained in the greenhouse experiment.

Treatment	Dry biomass weight	Dry weight of grain
	Mg ha ⁻¹	
Control	0.06 g	0.06 f
Standard (NPK)	0.52 g	0.37 ef
Trass	0.14 g	0.07 f
Slag	4.66 a	4.11 a
Dolomite	2.64 def	1.53 cd
100TD 700 °C	1.88 f	1.00 def
100TD 1000 °C	2.14 ef	1.22 de
100TD 1200 °C	2.92 cde	1.96 bcd
75TD 700 °C +25 Slag	2.23 ef	1.50 cd
75TD 1000 °C +25 Slag	2.86 cde	1.86 cd
75TD 1200 °C +25 Slag	3.27 bcd	1.47 cd
50TD700 °C +50 Slag	3.94 ab	2.98 b
50TD 1000 °C +50 Slag	3.62 bc	2.48 bc
50TD 1200 °C +50 Slag	3.68 bc	3.03 b

Note: The values in the same column that are followed by the same letters indicate no significant difference at 5% significance level based on DMRT.

slag and dolomite increases the soil pH and affects the low solubility of heavy metals (less mobile in soil and less available to plant).

Effect of Ameliorant Application on the Dry Weight of Plant Biomass and Grains

The application of ameliorant on the peat soil significantly increased the dry weight of rice plant biomass and dry weight of grains, except for that in the NPK standard and trass treatments. In the

control, NPK standard and trass treatments, the rice plants suffered stunting and some were died, resulting in low plant biomass and yield. This phenomenon is influenced by the phenolic acids in the peat soil that is phytotoxic (toxic to the plant), thus inhibit the growth of plant. Phenolic acids can damage the root cells of plant so that the amino acids and other materials flow out of the cells thereby inhibiting root growth and nutrient uptake, as a result, the growth of the plant is stunted, the leaves suffered chlorosis

then eventually the plant will die (Driessen 1978). The highest dry weight of rice plant biomass and grains was obtained in the peat soil applied with slag. Moreover, the increased dosage of slag applied on the peat soil resulted in an increase of plant biomass and grains. The yields of rice plants are presented in Table 8.

The slag application on peat soil has advantages over other ameliorants in increasing rice plant biomass and grain production. This is due to the balanced macro and micro nutrients content in the slag material, besides the presence of Fe (43.20% Fe₂O₃) in the form of a polyvalent cation, in which the function of the polyvalent cation is to reduce the adverse effects of toxic organic acids. Polyvalent cations can form a coordination bond with organic ligands to form complex/chelate compounds, so that the nutrients present in the soil solution are not easily leached and can be absorbed optimally by plant. The application of slag as an ameliorant on peat soil also increased pH, base saturation (BS), exchangeable-Ca, Fe content, silica and soil ash content, however, it decreased Cu, Zn, and Pb content in the peat soil. Electric furnace (EF) slag is able to provide balanced macro and micro nutrients to the peat soil. Therefore, slag application on peat soil can improve soil chemical conditions to support the growth and production of rice plants optimally.

CONCLUSIONS

The application of slag and dolomite as ameliorant on peat soil shows a significant effect on increasing pH, base saturation (BS), and exchangeable-Ca and -Mg content. Moreover, slag application is better in improving the chemical properties of peat soil, *i.e.* the increase of pH, base saturation (BS), and nutrient content (Ca, silica, ash and Fe). Application of burnt trass + dolomite (TD) shows no significant effect on increasing silica content in the peat soil. The application of slag results in the highest dry weight of biomass and grains of rice plants. The application of slag on peat soil in general provides better effects on the soil chemical conditions compared to that of trass, dolomite or ameliorant combination [trass + dolomite (TD) with slag].

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