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Growing Rice (*Oriza sativa* L.) in the Sulphate Acid Soils of West Kalimantan, Indonesia

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ABSTRACT

The use of organic matter has been proposed as one of the option as liming material for acid soils in West Kalimantan, Indonesia. Biochar is a carbon (C) rich material that has been used as soil amendment to improve the properties of acidic soils. An incubation study followed by a glasshouse trial was conducted to study the changes in soil properties following the application of biochar and investigate the effect of biochar application to the plant growth and production. The incubation trial was arranged by using biochar made from coconut waste as soil amendment to a West Kalimantan acid soil. The biochars used in this trial was specifically produced as liming material to overcome the soil-specific plant growth limitations. The biochar was made from (1) Coconut husk waste and (2) Coconut shell waste and were applied at different rate of application. The glasshouse study was conducted to test the biochar-amended acid soil on rice growth and production. The results from incubation study of this trial suggested that biochars significantly ($p<0.05$) increased the soil pH and subsequently reduce the soluble Fe and exchangeable Al in soil. The glasshouse study showed that the biochar-amended soil improved rice growth and production, although there was no significant difference ($p>0.05$) between the two types of biochar used in this study.

Key words: Acid soils, liming, biochar, rice

INTRODUCTION

The acid sulfate soil in Sungai Kakap, West Kalimantan, Indonesia has been utilized for intensive rice growing since 1980. These soils have a high iron sulfate mineral content of predominantly pyrite and when the soil is drained it will release sulfuric acid and soluble heavy metals (including aluminium/Al and iron/Fe) that dangerous for plants and other living organisms. When these soils are used for rice, Moore *et al*. (1990) found that the most important constraints were (1) Acidity (which includes the combined effects of pH, Al toxicity and P deficiency) and (2) Fe stress (which is due to the combined effects of Fe toxicity and deficiencies of other divalent cations such as calcium/Ca).

In addition to these problems, growing rice in these lands faces the problem of soil compaction due to intensive tillage with puddling and removal of biomass continuously. Measurement prior to the conduction of the experiment showed that soil organic matter in these soils was less than 0.9% (Masulili *et al*., 2010). In this soil, organic matter is very important because in addition to being a source of plant nutrition, organic matter is the major source of negative charge, which is important for helping the soil to adsorb cations in the soil solution (Ponamperuma, 1984).

A common treatment to reduce the solubility of Al, Fe and other heavy metals in soil is to increase the soil pH, which is mostly done by liming (Ahmad and Tan, 1986; Hakim *et al*., 1989; Haby, 2002). However, liming only treats the symptoms of acid sulfate soils rather than the cause (Thomas *et al*., 2003), therefore, the beneficial effects of liming are short lived and it has to be done repeatedly (Shamshuddin *et al*., 1998). This makes liming very expensive and it is often un-economic for small farmers to obtain lime materials.

The other treatment suggested for improving the properties of acid sulfate soil is the application of organic matter (Kaderi, 2004; Shamshuddin *et al*., 2004). With negative charge provided by carboxyl compounds, organic matter is able to minimize toxicity by decreasing the solubility of heavy metals in the soil solutions. Positive effects of organic matter application on the properties of acidic soils, such as increasing soil pH and CEC and decreasing heavy metal toxicity have been reported elsewhere (Hesse, 1982; El Sharkawi *et al*., 2006). Organic matter is easy to find locally and is relatively cheap, especially if the organic matter used is the un-harvested biomass of the crop itself.

In the recent years, many scientists interested in using black-carbon material (biochar) as a soil amendment in poor soil to improve its productivity (Glaser *et al*., 2002; Topoliantz *et al*., 2005; Woolf, 2008). Biochar is a carbonaceous material produced from incomplete combustion (in the absence or low amounts of oxygen) of various organic feedstocks and intended to be used as soil amendment to improve soil functions and sequester C (Lehmann and Joseph, 2009). In Indonesia, biochar has been proposed as one of the technique to improve soil properties under rice fields in acid soils (Masulili *et al*., 2010).

The application of biochar as soil amendment has been shown to improve in soil functions, such as soil hydraulic conductivity (Herath *et al*., 2013), soil pH (Novak *et al*., 2009; Van Zwieten *et al*., 2010a), soil cation exchange capacity and nutrient retention (Laird *et al*., 2009; Lehmann *et al*., 2003; Liang *et al*., 2006). Biochar also considered having additional nutrient value when it applied to the poor fertility soil (Hossain *et al*., 2011; Wang *et al*., 2012). While biochar is considerably low in nitrogen (Yao *et al*., 2010) a high-ash biochars are typically contain other nutrients (such as phosphorus and potassium) that was reported to be available for plant uptake (Wang *et al*., 2012; Yao *et al*., 2010).

Although, some studies have shown no effect of biochar application on crop yield (Gaskin *et al*., 2008; Slavich *et al*., 2013), others, especially those on poor quality soils have reported a significant increase in crop yield (Lehmann *et al*., 2003; Rondon *et al*., 2007; Van Zwieten *et al*., 2010a). Yamato *et al*. (2006) showed that the application of biochar made from *Acacia magnum* could increase soil pH, Ca base saturation and CEC and decrease Al saturation. Other study by Reichenauer *et al*. (2009) applied biochar in tsunami-affected paddy fields in Sri Lanka and the experimental results showed that the application of 2 t rice-husk-charcoal ha^{-1} increased the grain yield from less than 4 t ha^{-1} for the control treatment to more than 5 t ha^{-1} for the biochar treatment.

The difference in plant respond to biochar application is due to differences in properties among biochars (mainly dependent on production process and feedstocks type) and their ability to match the soil constrains that limit plants growth (Van Zwieten *et al*., 2010b). Therefore, it is important to clearly understand the properties of biochar that will be used as soil amendment if soil constrains are to be matched. The aim of this study was to investigate the effect of biochar made from coconut shell and coconut husk to improve the soil properties of west Kalimantan acidic soil and the possible improvement of rice productivity following the biochar application.

MATERIALS AND METHODS

Biochar production: Biochar in this experiment was made from (1) Coconut shell and (2) Coconut husk, which are collected from the coconut waste in the Sungai Kakap District, West Kalimantan Province, Indonesia. The pyrolysis process of these feedstocks into biochar was using a simple drum pyrolyzer with the final temperature of 350°C.

Biochar characterization: The Biochar was ground to pass through a 0.50 mm sieve. The Biochar moisture content was measured by oven drying a sub sample of 2 g at a temperature of 80°C for 24 h. Biochar characterization was done according to the method described by Ahmedna *et al.* (1997). The bulk density was determined by filling a 10 mL tube with dry ground biochar. The tubes were capped, tamped to a constant volume and weighed. Bulk density was calculated by dividing the weight of the dry sample with the volume of the packed materials. To measure the pH, 1% suspensions of biochar were prepared by diluting the biochar with de-ionized water. Then they were heated to about 90°C and stirred for 20 min to allow the dissolution of the soluble biochar components. The suspensions were then cooled to room temperature, after which the pH was measured with a pH-meter (Jenway 3305). Total C determination was done using the method described in ASTM D 3176 (ASTM., 2006). Total P was read with a spectrometer (Vitatron) and Ca, Mg, Na and Si were measured using AAS (Shimadzu).

Fourier-transformed infrared (FTIR) spectra of the carbonised materials were measured in triplicate with a Shimadzu 84005 FTIR. Spectra were obtained using KBr as a beam splitter with a resolution of 4 cm^{-1} and the spectral range was 4000-700 cm^{-1} with an aperture size of 34 cm. The obtained reflectance of each sample was then compared with the literature (Smith, 1999; Reig *et al.*, 2002; Smidt and Meissl, 2007) to correlate the relevant bands to possible functional groups.

Experimental set-up: The soil used in these experiments was collected from the experimental station of BPTP West Kalimantan in Sungai Kakap. Soil samples were collected from depths of up to 20 cm and then dried, ground and passed through a 2.0 mm sieve. Five kg of ground soil was then put in a plastic pot with an inside diameter of 30 cm.

There are two experiments in this study. The first experiment is the biochar incubation to the acid soils and the second experiment is growing rice on the biochar incubated soil. The first experiment was done on the Soil Laboratorium of Panca Bhakti University, West Kalimantanm Indonesia and lasted for 3 months. The experimental design was randomized block design with three replicates. The treatments were (1) Soil control (nil biochar/B0) (2) Soil+6 t ha^{-1} of coconut shell biochar (B1) (3) Soil+8 t ha^{-1} of coconut husk biochar (B2) (4) Soil+10 t ha^{-1} of coconut shell biochar (B3) (5) Soil+12 t ha^{-1} of coconut husk biochar (B4).

The second experiment was a glasshouse trial, using the incubated acid soil as the medium for growing rice (*Oryza sativa* L.). Twenty day old rice seedlings were transplanted to this incubated soil. The rice plants were grown as lowland rice and they were fertilized with 135 kg N ha^{-1}, 72 kg P_2O_5 ha^{-1} and 50 kg K_2O ha^{-1}.

Data collection: Soil pH was measured in 1:2.5 ratio soil solutions (with de ionized water) with a pH meter (Jenway 3305). The Walkley and Black wet oxidation method was used to determine organic C content (Soil Survey Laboratory Staff, 1992). Total N content was measured by the Kjeldhal method (Bremner and Mulyaeny, 1982), while the available P Total was read with a spectrometer (Vitatron). Exchange Al^{3+} and Fe^{2+} were extracted with 1M KCl (Barnhisel and Bertsch, 1982). The CEC was extracted with 1M NH4OAc (buffered at pH 7.0) and exchangeable base concentrations were measured using AAS (Shimadzu).

For the second experiment, the plants were harvested at 45 days after planting and measurements were done for plant height, number of tillers, productive tillers and total dry mass.

Statistical analysis: Analysis of variance was done to see the effects of different treatments to the soil variables measured in the two trials. A Least Significant Difference (LSD) posthoc tests were conducted to see the significant difference at ($p<0.05$) between variables measured.

RESULTS AND DISCUSSION

Feedstock and biochar chemical analysis: The coconut husk were characterized by a lower C content than the coconut shell (Table 1) but contained higher concentrations of N, P and Na. The coconut shell however, had a higher amount of Ca than the coconut husk. These chemical attributes were carried forward to properties of the respective biochars (Table 1). The bulk density (mass of produced biochar per volume of pyrolysis process) of the coconut husk biochar was higher than that of the coconut shell biochar (0.96 vs. 0.84 Mg m^{-3}) (Table 1). Conversely, the total C content was considerably smaller in the coconut husk biochar than in the coconut shell biochar (17.1 and 18.8%, respectively). Both biochar had a similar pH of 8.4-8.9, which may indicate its ability as liming material to acid soils. The CEC of both biochars were considerably higher (16.79-17.56 cmol kg^{-1}).

Biochar FT-IR analysis: The FT-IR spectra of the two biochars showed similar reflectance spectra but with different intensity (especially in the region of 1600-1000 cm^{-1}) (Fig. 1 and 2). The main bands in both spectra were at wave numbers ~1600 and 875 cm^{-1} for both biochar; while the coconut husk biochar showed a strong spectra at region of, 1420 cm^{-1}. The band at 1600 cm^{-1} was assigned to molecular vibration of ring stretching in C = C, 1420 cm^{-1} to C-H bending (Smith, 1999; Smidt and Meissl, 2007). Both of coconut shell and coconut husk biochar had a strong intensity of the reflectance in the 1500-1600 cm^{-1} (Fig. 1 and 2), associated with C = C bonds moieties (Chen *et al.*, 1996; Smith, 1999) and the aromatic C-H out-of-plane bending at 875 cm^{-1} (Reig *et al.*, 2002).

Table 1: Feedstock and biochar characteristic

Characteristics	Coconut husk	Coconut shell	Coconut husk biochar	Coconut shell biochar
Moisture content (%)	14.2	11.26	6.74	4.96
BD (Mg m^{-3})	-	-	0.96	0.84
pH	-	-	8.40	8.60
C (%)	36.4	43.77	17.09	18.72
N (%)	0.45	0.32	0.00	0.00
P (%)	0.09	0.07	0.08	0.17
CEC (cmol kg^{-1})	-	-	16.79	17.56
K (%)	0.12	0.12	0.16	0.21
Ca (%)	0.14	0.27	0.23	0.46
Mg (%)	0.17	0.16	0.22	0.48
Na (%)	0.22	0.60	1.25	1.41

BD: Bulk density, C: Carbon, N: Nitrogen, P: Phosphorus, CEC: Cations exchange capacity, K: Potassium , Ca: Calcium, Mg: Magnesium, Na: Sodium

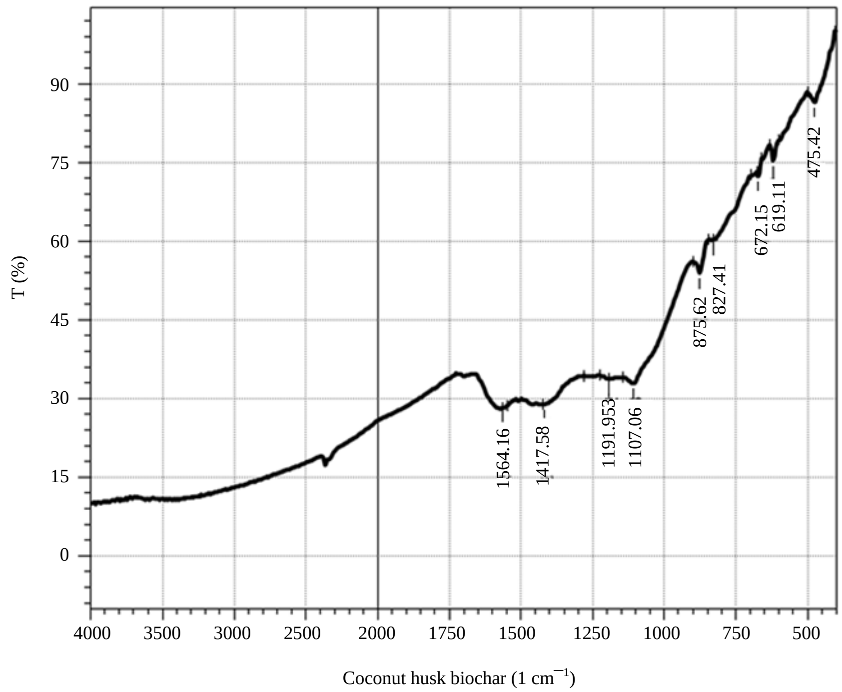

Fig. 1: Fourier transformed infrared spectra of coconut husk biochar

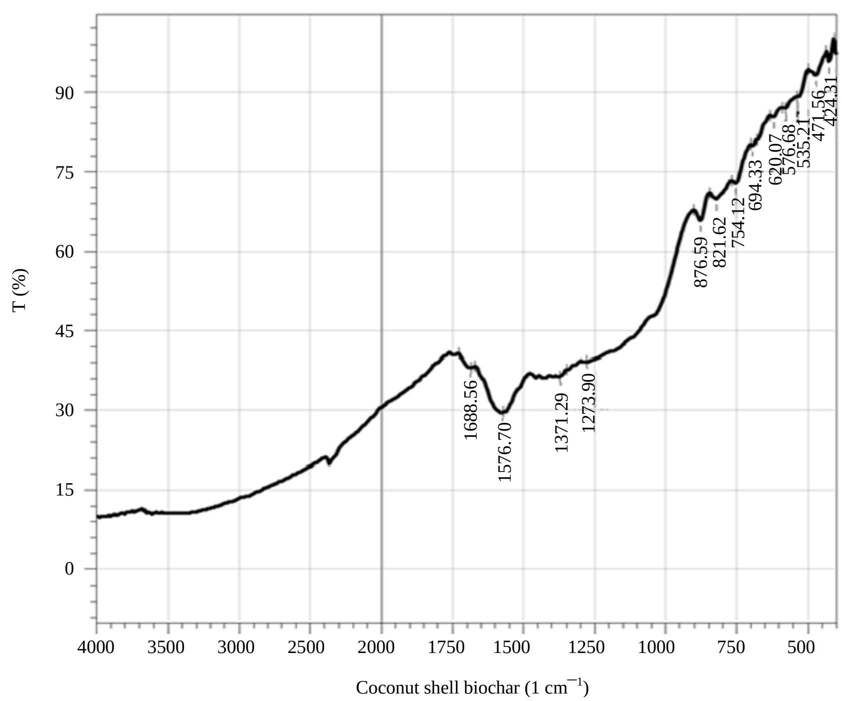

Fig. 2: Fourier transformed infrared spectra of coconut shell biochar

Incubation experiment: Changes in soil chemical properties following biochar incubation to West Kalimantan acid soil is presented in Table 2. The soil pH was significantly increased ($p<0.05$)

Table 2: Soil Chemical properties after 1 month of biochar-soil incubation

Treatments	pH H_2O*	Organic C (%)*	Available P (%)*	Exchangeable Al (%)*	Soluble Fe (%)*	CEC (cmol kg^{-1})*
Control	3.93^{a}	1.98^{a}	0.60^{a}	3.41^{b}	3.51^{b}	8.94^{a}
6 t ha^{-1} coconut shell biochar	4.22^{b}	2.23^{b}	0.64^{a}	3.41^{b}	3.34^{ab}	9.61^{b}
8 t ha^{-1} coconut husk biochar	4.23^{b}	3.91^{c}	0.65^{b}	3.29^{ab}	3.26^{a}	9.67^{a}
10 t ha^{-1} coconut shell biochar	4.46^{bc}	4.16^{cd}	0.68^{bc}	3.21^{a}	3.24^{a}	9.89^{cd}
12 t ha^{-1} coconut husk biochar	4.65^{c}	4.47^{d}	0.71^{c}	3.11^{a}	3.14^{a}	11.41^{d}

*Value followed by different letter showed a significant difference $p<0.05$

following the application of biochar from coconut waste to the acid soil. Increasing biochar application rate to the acid soil was found to increase the soil pH as expected. The highest increase in soil pH was observed in the application of 12 t ha^{-1} coconut husk biochar. The increase of soil pH following biochar application to acid soils also reported elsewhere (Novak *et al.*, 2009) and this was attributed to the liming ability of biochar.

The soil CEC was found to be increased in the biochar incubated soil (Table 2). In acid soils, the soil CEC was correlated to the soil pH and an increase in soil pH will results in higher soil CEC. The application of 10 t ha^{-1} of coconut shell biochar and 12 t ha^{-1} of coconut husk biochar showed the higher soil CEC (9.89 cmol kg^{-1} and 11.41 cmol kg^{-1}, respectively) compared to the control (8.94 cmol kg^{-1}).

The application of biochar from coconut waste in this study results in the lower rate of soil exchangeable Al and soluble Fe following the incubation experiment (Table 2). Prior the biochar incubation experiment, the control soil had a high exchangeable Al (3.41%) and soluble Fe (3.51%). The lower rate of biochar application (6 t ha^{-1} of coconut shell biochar) showed a lower exchangeable Al and soluble Fe compare to the control, however the statistical analysis indicates that the treatment was not significantly different to the control ($p>0.05$). Only the higher doses of biochar application (10 t ha^{-1} of coconut shell biochar and 12 t ha^{-1} of coconut husk biochar) had a significantly ($p<0.05$) lower soil exchangeable Al and soluble Fe compare to the control (Table 2).

Given the high organic C content from the biochar, the total soil organic C content was significantly increase ($p<0.05$) following the incubation of biochar to the acid soils (Table 2). The addition of 12 t ha^{-1} coconut husk biochar to the West Kalimantan acid soil increase the total soil organic content from 1.98-4.47%. The application of 12 t ha^{-1} biochar equals to adding 2.04 t ha^{-1} stable C to the acid soils. The addition of biochar alone is responsible to the increase of soil total C in this experiment, similar to the reports by Novak *et al.* (2009) and Pereira *et al.* (2015).

The soil available P was increase following the increase of soil pH as a result of liming by biochar (Table 2). The highest biochar application (12 t ha^{-1} of coconut husk biochar) resulted in the highest soil available P content (Table 2), however, it slightly different than the 10 t ha^{-1} of coconut shell biochar treatment. The increase on soil P following biochar application also reported Wang *et al.* (2012) who found that biochar made from a mixture of manure and eucalyptus wood contained 70-80% of total P in an extractable form, which indicates the high availability of P in this particular biochar. This was further confirmed by the greater P recovery in the plant (39-93%) grown in soils amended with corresponding biochar (Wang *et al.*, 2012). These authors also reported that the maximum dry matter yield from biochar-treated soils was similar to those from P fertilized treatments, indicating the potential of manure derived biochar as an alternative to P source in the soil.

The application of biochar from coconut waste in this study showed the ability of biochar to improve soil properties of West Kalimantan acid soil. The distinctive results were the increase on soil pH and the lower rate of exchangeable Al and soluble Fe following the introduction of biochar to the acid soil. These decreases were undoubtedly due to the increase of CEC in the soil. The

Table 3: Plant (*Oryza sativa* L.) growth following the application of biochar from coconut waste

	Parameters			
Treatments	Plant height (cm)	No. of tillers	Dry weight of 100 grains (gram)	Root volume (cm^3)
Control	$63,20^a$	$10,47^a$	$1,14^a$	$30,30^a$
6 t ha^{-1} Coconut shell biochar	$79,40^b$	$15,78^b$	$1,49^b$	$49,60^b$
8 t ha^{-1} Coconut husk biochar	$79,00^b$	$15,79^b$	$1,49^b$	$49,70^b$
10 t ha^{-1} Coconut shell biochar	$78,93^b$	$15,80^b$	$1,50^b$	$49,70^b$
12 t ha^{-1} Coconut husk biochar	$78,87^b$	$15,80^b$	$1,51^b$	$50,90^b$

*Value followed by different letter showed a significant difference $p<0.05$

results in Table 2 show that exchangeable Al and soluble Fe decreases as CEC increases. The improvement of the soil's physical properties, especially soil aggregation might also contribute to the lowering of Fe in acid soil (Masulili *et al.*, 2010; Yuan and Xu, 2011). This soil structure improvement will make the soil condition more oxidative so the solubility of the Fe decreases.

Glasshouse experiment: Biochar has been reported to be an effective soil amendment to overcome the problem of acid soils in West Kalimantan (Masulili *et al.*, 2010). The application of rice husk biochar to these acid soils increase the rice growth and production as described by Masulili *et al.* (2010). In this study, the same acid soils were treated with coconut waste biochar (coconut husk biochar and coconut shell biochar). The glasshouse experiment showed that the application of coconut waste biochar to the acid soils improve plants growth and rice production compared to the control treatment (Table 3). There different rates of biochar application, however, did not resulted in a significant difference ($p<0.05$) on plant growth and yield (Table 3).

There were many factors contributing to the improvement of this rice growth and these factors can work either individually or simultaneously. Indeed, the decrease in exchangeable Al and soluble Fe would have been important factors for this growth improvement. The contribution of elemental plant nutrients from the organic soil amendments, especially P would have also had an important effect. As shown by the results given in Table 2, application of organic soil amendments increased the available P and soil CEC in the acid soil; however, the influence of the soil's physical improvement, especially the increase in soil macro pores and the decrease in soil strength cannot be neglected (Masulili *et al.*, 2010).

CONCLUSION

The application of coconut waste biochar (coconut shell and coconut husk biochar) improved the soil pH of an acid soils, thus indicates the liming ability of these biochar as soil amendment to overcome the problems in West Kalimantan acid soils. The coconut husk and coconut shell biochar were characterized by the strong aromatic C following the pyrolysis process of the corresponding feed stock. The application of coconut waste biochar increase the soil pH of West Kalimantan acid soils, subsequently lowering the soil exchangeable Al and soluble Fe, while improving the available P and soil CEC. The application of coconut waste biochar to the West Kalimantan acid soils increase rice growth and yields. However, the highest application of biochar (12 t ha^{-1} of coconut shell biochar) did not significantly improve plant yields compared to the lower application rate of biochar.

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