Water management and rice husk biochar application to solve acid sulfate soil problems to promote rice yield and reduce greenhouse gas emission

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Abstract. The use of biochar for soil fertility improvement is gaining popularity due to its potential to improve soil quality and increase crop yield in swampland. Water management plays a key role in controlling various dynamic processes such as acidity production. The water management system in acid sulfate soil should have a proper leaching and flushing capacity of the oxidation product. When these soils are used for rice, we 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). The experiment was carried out to investigate the effects of water management and rice husk biochar and compost applied in combination (0,1% of each w/w, thus 0,1% compost + 1% rice husk biochar) on growth, the yield of rice and methane emission on acid sulfate soil. The Provision of 50% compost + 50% Biochar rice husk with washing water management every two weeks (P2) in acid sulfate soil could reduce methane emissions by up to 53.16% with the highest dried unhusked rice yield of 3.86 t/ha.

1. Introduction
The problem of acid sulfate soil originates from the presence of pyrite (FeS₂) in the soil layer. If this pyrite layer undergoes oxidation, Fe will be released to become Fe³⁺ and S will be oxidized to sulfate which causes the soil pH to decrease to become unusually acidic (pH <3.5), so that plants cannot grow. The high acidity in the soil due to the oxidation of pyrite will have an impact on increasing the solubility of toxic elements such as Fe and Al accompanied by available P and low base saturation and other nutrient deficiencies. The utilization of acid sulfate soil for lowland rice with a minimum thickness slows the pyrite oxidation process. Pyrite oxidation can be suppressed by maintaining the soil environment in reductive conditions. Continuous inundation on the soil in tidal lands results in: (1) an increase in the concentration of ferrous iron (Fe²⁺), (2) a decrease in the value of soil redox potential (Eh) due to the reduction of NO³⁻ and Fe³⁺ which results in the accumulation of NH₄⁺ and Fe²⁺, so that the soil condition becomes very reductive and (3) increase in soil pH due to the release of OH⁻ and H⁺ consumption followed by a decrease in the activity of H⁺.

One of the efforts to overcome the fertility problems of acid sulfate soils is by adding ameliorants such as biochar [1]. Panhwar [2] reported that the soils need to be improved with some soil amendments like the application of basalt, ground magnesium limestone, and organic materials.
(biofertilizer) that can increase the soil pH, improve soil nutrients and reduce the Al and Fe toxicity. As a soil amendment agent, biochar has unique physical and chemical characteristics. Biochar can improve soil physical and chemical properties, reduce nutrient leaching, optimize soil microbial population structure and richness, and biochar can promote crop growth, yield, and quality [3]. Plants grown in biochar-amended soil has greater root mass and root length densities, as well as total and individual root lengths for secondary and tertiary roots, compared with plants grown in unamended soil[4]. Biochar in acid Sulfate soils has great potential to reduce the content of toxic elements and their mobility in the soil due to their high surface area and mostly negative charge for most types of biochar and increase soil pH. The results of a study by Zhang [5] showed that the combination of organic fertilizer and biochar had improved soil nutrient status and soil fertility. In addition, biochar has strong adsorption functions, which can effectively adsorb toxic elements [6]. The amendment of rice husk biochar to acid sulfate soils from Malaysia was found to improve soil physicochemical properties and increase the yield of corn and rice. The rice husk biochar produced via a gasification process in a local rice mill possesses physicochemical properties that are able to neutralize the acidic nature of the soils [7]. Qayyum [8] reported that the application of biochar combined compost reduced absorption of P and increased the bioavailability of P.

2. Materials and methods

2.1. Time and location

This experiment was carried out from July to October 2019 at the Balittra Experimental Garden (ISARI), Barito Kuala Regency, South Kalimantan Province, Indonesia (-5 ° 10'15 ″ S, 114 ° 36'12 ″ E), with an annual average temperature of 26-27°C. According to the "Schmit and Ferguson" classification, Barito Kuala is a Type B rainfall, which has 1-2 dry months a year. According to[9], the soil in the study location was included in the Typic Sulfaquent subgroup, seen from the soil pH value of 3.81, but after being oxidized the pH decreased to <3.5. The pyrite oxidation process produced Fe²⁺ and SO₄²⁻ and H₂ which resulted in a decrease in pH. According to Dent [10] that a pH value <2.5 or 3 after given H₂O₂ indicates strong acidity of sulfate. In addition, the decomposition of aluminum silicate minerals will free aluminum ions. These ions can be absorbed by soil colloids, and when hydrolyzed will donate H⁺ ions, so that the soil becomes acidic due to the increased contribution of H⁺ ions.

2.2. Research design

The design used in this study was a split-plot design. The main plot was water management, namely: (1) inundation, (2) leaching every 1 week (P1), (3) leaching every 2 weeks (P2). Subplots were the use of ameliorants, namely: (1) Control (without ameliorant), (2) 50% compost + 50% Biochar rice husk.

2.3. Gas calculation

Gas was collected in the field using a syringe, then measured using Gas Chromatography (GC). Examples of gas in the field were taken from the closed chamber (Paralonfiber) using a syringe and then measured CH₄, also periodically at 30, 60, and 90 days afterward. The calculation of CH₄ flux in each treatment was done using equation 1.

\[
E = \frac{Bm}{Vm} \times \frac{\delta Csp}{\delta t} x \frac{V}{A} T + 273.2
\]  (1)
Where \( E \) is the emission of \( \text{CH}_4 \) (mg/m\(^2\)/day), \( V \) is the volume of the chamber (m\(^3\)), \( A \) is the area of the chamber (m\(^2\)), \( T \) is the temperature in chamber (°C), \( \delta \text{Csp}/\delta t \) is the rate of change in the concentration of \( \text{CH}_4 \) gas (ppm/minute), \( B_m \) is \( \text{CH}_4 \) gas molecular weight under standard conditions, and \( V_m \) is the gas volume at standard temperature and pressure is 22.41 liters at 23°K.

3. Results and discussion

3.1. Soil pH and Fe concentration

The characterization results showed that the study area had a high \( \text{Fe}^{2+} \) content of 319.58 mg.kg\(^{-1}\) and sulfate of 1097.97 mg.kg\(^{-1}\) and Aluminum of 15 cmol (+), kg\(^{-1}\). The high \( \text{Fe}^{2+} \) and \( \text{SO}_4^{2-} \) content was a result of the oxidation of pyrite which was released into the soil solution. This pattern of \( \text{Fe}^{2+} \) content is the same as that reported by Anda [11]. They reported that in acid sulfate soils in Kalimantan the total Fe content ranged between 0.5 and 1.3% in the oxidation layer which was lower than that in the reduction layer, namely 1.0-2.3% with the pyrite content in the oxidation layer ranging from 0.09 - 0.32% lower than in the layer, reduction which ranges from 0.17-1.91%. The high concentration of \( \text{Fe}^{2+} \) in the soil was accompanied by low exchangeable K[12]. This might be related to P and Zn deficiency and H\(\text{2S}\) toxicity [2].

The results of preliminary soil analysis showed that the initial soil pH ranged from 3.92 to 4.80 with ferrous iron solubility ranging from 119.43 to 809.53 ppm (figure 1). One of the high content of \( \text{Fe}^{2+} \) was the result of intensive oxidation of pyrite and was released into the soil solution.

![Figure 1. pH soil and Fe concentration in tidal swampland with water management and application of ameliorant.](image)

3.2. Methane emissions

Methane emissions in acid Sulfate soils are influenced by, among other things, the type of ameliorant material given as indicated by the research data. Provision of ameliorant 50% compost + 50% rice husk biochar could reduce methane emissions released from rice cultivation in acid sulfate soil by 53.16% compared to without ameliorant (figure 2). Agricultural practices such as water systems also affect the amount of methane emissions released from paddy fields because they are related to the dominant inundation process during the growth period, thus affecting the activity of roots and processes that take place such as photosynthetic and respiration processes. The results showed that the water system with two weeks of washing (P2) reduced \( \text{CH}_4 \) emissions by 48.03% and washing every one week (P1) reduced methane emissions by 42.10% compared to without washing (P0) (figure 3).
This was caused by continuous flooding in the process of rice cultivation making soil conditions anaerobic, so the rate of degradation of organic matter was low.

![Figure 2. Performance of rice in tidal swampland with water management and application ameliorant](image)

3.3. The yield of rice (ton/ha)

The ameliorant treatment tested in the field was able to approach the yield potential of the swamp rice used (Inpara 3) (figure 4). The highest yield of dry unhulled rice was seen in the treatment of 50% compost + 50% Biochar rice husk combined with washing every two weeks (P2), namely 3.86 t/ha, while the treatment with the lowest GKP yield was 2.42 t/ha, seen in treatment A0 (without ameliorant) with water management treatment without washing (P0). This is related to the higher availability of N, P, K nutrients. Increased availability of N, P, K nutrients in both types of acid Sulfate soils, both natural and intensive, was related to the provision of compost and N, P, K fertilization[1].

Washing every two weeks was the best treatment in water management as well as giving ameliorant 50% compost + 50% Biochar of rice husk in acid Sulfate land because P2 treatment (two weeks of washing) had the highest plant with a height reaching 110.4 cm and increased GKP yield by 20%. This was related to the quality of water used in the washing process because P2 treatment (washing every two weeks) used better quality water (large tide) than P1 treatment (washing every one week) using water at large and small tide. Water quality at high tide is shown in figure 5. The
The correlation between pH and DHL values in large and small tide showed a very significant negative correlation with r values, respectively, \( r = -0.846 \) ** (\( p = 0.004 \)) and \( r = -0.521 \) * (\( p = 0.027 \)). It appears that there was an insignificant positive relationship between growth and methane emissions as indicated by the value of \( R^2 = 0.429 \) (figure 6).

**Figure 4.** The yield of rice with water management and application of ameliorant in tidal swampland.

**Figure 5.** Tidal water quality in tertiary channels.
4. Conclusion
The Provision of 50% compost + 50% Biochar rice husk with washing water management every two weeks (P2) in acid sulfate soil could reduce methane emissions by up to 53.16% with the highest dried unhusked rice yield of 3.86 t/ha.

Reference
[1] Annisa W and Nursyamsi D 2016 Pengaruh amelioran, pupuk dan sistem pengelolaan tanah sulfat masam terhadap hasil padi dan emisi metana Jurnal Tanah dan Iklim 40(2) 135–45
[2] Panhwar Q A, Naher U A, Radziah O, Shamshuddin J and Razi I M O H D 2014 Bio-Fertilizer, ground magnesium limestone and basalt applications may improve chemical properties of Malaysian acid sulfate soils and rice growth Pedosphere 24(6) 827-35
[3] Lehmann J, Rillig M C, Thies J, Masiello C A, Hockaday W C and Crowley D 2011 Soil biology & biochemistry biochar effects on soil biota: A review. Soil Biology and Biochem. 43(9) 1812-36
[4] Mitchell K, French E, Beckerman J, Iyer-Pascuzzi A, Volenc J and Gibson K 2018 Biochar alters the root systems of large crabgrass Hort. Science 53(3) 354–9
[5] Zhang J, He Z, Tian H, Zhu G and Peng X 2007 Identification of aluminium-responsive genes in rice cultivars with different aluminium sensitivities J. Experimental Botany 58(8) 2269–78
[6] Gu Y et al 2017 Application of biochar reduces Ralstonia solanacearum infection via effects on pathogen chemotaxis, swarming motility, and root exudate adsorption. Plant and Soil 415 p 269–81
[7] Ajwa H A and Tabatabai M A 1993. Comparison of some methods for determination of sulfate in soils Comm. in Soil Sci. and Plant Analysis, 24:15-16 1817-32
[8] Qayyum M F, Ashraf I, Abid, M and Steffens D 2015 Effect of biochar, lime, and compost application on phosphorus adsorption in a Ferralsol J. Plant Nutrition and Soil Sci. 178(4)
[9] Soil Survey Staff 2014 Keys to Soil Taxonomy, 12th ed. (Washington-DC: USDA-Natural Resources Conservation Service)
[10] Dent D L and Pons L J 1995 A world perspective on acid Sulfate soils Geoderma 67 263-76
[11] Anda M, Siswanto A B and Subandiono R E 2009 Properties of organic and acid sulfate soils and water of a “reclaimed” tidal backswamp in Central Kalimantan, Indonesia. Geoderma 149 (2009) 54–65
[12] Ottow J C G, Benckiser G, Watanabe I 1982 Iron toxicity of rice as a multiple nutritional soil stress *Proc. Int. symposium on distribution, characteristics and utilization of problem soils* (Ibaraki: Tropical Agriculture Research Center) p 167–79