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The Effect of Biochar From Plant Materials on Agricultural Acid Sulfate Soil: A Laboratory incubation

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Abstract

The scarcity of suitable arable land has led to the development of acid sulfate soil for cultivation. The major problems of acid sulfate soil are the inherent low pH and available phosphorus (P) as well as the mobilization of toxic elements such as aluminium (Al) and iron (Fe), rendering the soil unfavourable for crop production. The present work aimed to evaluate the effect of biochar from plant materials on the selected parameters of acid sulfate soil in a laboratory incubation, with unamended control and dolomite treatment soils for comparison. The application of biochar significantly increased (P < 0.05) soil pH by 0.4–0.6 units as well as the soil available P by 13.1 mg kg⁻¹ relative to the control. The soil exchangeable Al was significantly reduced (by 2.4 cmol kg⁻¹ when compared with the control treatment. The dolomite treatment was superior relative to biochar application in increasing soil pH and decreasing Al. The dolomite application, however, was inferior to biochar treatment in increasing soil available P. Moreover, no favourable change was observed in available Fe with the applications of either biochar or lime. These results indicated that biochar has the potential for the amelioration of acid sulfate soil, especially in increasing available P. Further studies should explore the effectiveness of biochar and lime co-application in altering a wider range of soil chemical parameters to inform management options of acid sulfate soil for cultivation.

Keywords: Acid sulfate soil, Biochar, Plant material

1. Introduction

Rice security has been one of the major emphases in the food security portfolio of Brunei Darussalam. However, efforts to attain rice self-sufficiency are under threat in Brunei Darussalam as the major rice production sites are dominated by acid sulfate soil (Grealish & Fitzpatrick, 2013; Zin et al., 2017). The limitations to crop production in acid sulfate soil are the inherent low pH and lack of nutrients, such as available P due to the complexation with high amounts of soil Al and Fe (Zin et al., 2015). Therefore, a suitable management option to remediate agricultural acid sulfate soil is imperative.
Numerous studies have been conducted to ameliorate acid soil and acid sulfate soil in particular. The conventional and widely used method is the application of lime with the aim of reducing soil acidity (Azam & Gazey, 2021; Santri et al., 2019). In addition, biochar application has been studied as a potential ameliorant of soil acidity to use as a substitute for lime in acid soil (Lauricella et al., 2021; Yuan et al., 2011) as well as acid sulfate soil (Manickam et al., 2015; Masulili et al., 2010). In addition to increasing soil pH due to their alkaline nature, biochar soil amendment also provides other benefits to the soil such as improved provision of essential plant nutrients, particularly P, which is often a limiting factor for crop growth in acid soils (Haynes & Mokolobate, 2001). Furthermore, toxic elements such as Al and Fe can be reduced upon biochar application as a result of the increase in soil pH (Nguyen et al., 2022).

The above findings suggest that biochar as a soil amendment could be used to reclaim acid sulfate soil. Nevertheless, there have been few studies conducted to examine the effects of biochar on acid sulfate soil. This suggests that more studies are needed to provide a better understanding of the influence of biochar on acid sulfate soil. Therefore, the current study was conducted to assess the effects of three different biochars from plant materials on the selected properties of acid sulfate soil with dolomite application as a comparison. It was hypothesized that adding biochar to acid sulfate soil would ameliorate the constraints through increasing soil pH which would lead to reductions in exchangeable Al and available Fe as well as improve soil P availability.

2. Materials and methods

2.1. Soil and biochar

The soil (0–20 cm) was collected from a rice field in Limau Manis, Brunei Darussalam (4°46′06″N, 114°49′25″E). The soil was oven-dried at 40 °C for 48 h and sieved (<2 mm). The soil is classified as peat acid sulfate soil (Fitzpatrick et al., 2008) with a pH of 3.84 (1:5 soil/water), available P at 4.7 mg kg⁻¹, exchangeable Al at 8.2 cmol kg⁻¹, and exchangeable Fe at 795.7 mg kg⁻¹. Three abundantly available plant materials were used as feedstock for biochar production, namely Melastoma malabathricum (MM, kuduk-kuduk), Dicranopteris linearis (DL, forked fern), and Oryza sativa (RS; rice straw). These plant materials were selected because they are widely available either in the wild and on-farm. The plant materials were oven-dried at 60 °C for 24 h and sieved (<1 mm). The ground plant materials were packed in ceramic crucibles with covers and pyrolyzed at 300 °C for 2 h in a muffle furnace under oxygen limited condition. Selected initial properties of the resulting biochar (BC) are presented in Table 1. The biochar was designated with the feedstock abbreviation, namely, MMBC for biochar produced from Melastoma malabathricum, DLBC for biochar produced from Dicranopteris linearis, and RSBC for rice straw biochar.

2.2. Soil incubation

Oven-dried soil (30 g) was thoroughly mixed with 0.6 g biochar in a plastic pot, inundated with distilled water until the soil surface was covered by a 2 cm water layer, and allowed to incubate for 30 days. The application rate is equivalent to 40 t ha⁻¹ in the field, considering a soil depth of 0.20 m and soil bulk density of 1.0 g cm⁻³. Unamended soil was included as a control. Soil with dolomite was also included to provide a comparison with the conventional method of acid soil remediation. To minimize moisture loss but allow gas exchange, the pot was lightly covered with a plastic lid. The incubation was conducted at room temperature (c. 23 °C). There were three replicates per treatment. At the end of the incubation, soil samples were air-dried prior to the determination of pH, available P, exchangeable Al, and available Fe.

2.3. Analysis

Soil pH was determined in a 1:5 soil/water suspension using a pH meter. Soil available P was measured using a UV-spectrophotometer according to the Bray I method (Reeuwijk, 2002) after displacement with an extractant mixture (0.03 M NH₄F and 0.025 M HCl). Soil exchangeable Al was extracted with 1 M KCl (1:20) and titrated against 0.1 M HCl to phenolphthalein endpoint (Melean, 1965). Available Fe was determined using an atomic emission spectrometer after extraction with 0.005 M diethylene triamine penta-acetic acid (DTPA) solution at 1:3 soil/solution ratio (Lindsay & Norvell, 1978).

Data normality and heteroscedasticity were assessed with Shapiro-Wilk and Levene tests.

Table 1. Selected properties of biochar.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>MMBC</th>
<th>DLBC</th>
<th>RSBC</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH (1:10)</td>
<td>5.78</td>
<td>5.96</td>
<td>5.82</td>
</tr>
<tr>
<td>Total P (mg/g)</td>
<td>1.52</td>
<td>1.12</td>
<td>2.40</td>
</tr>
<tr>
<td>Base cation b (mg/g)</td>
<td>35.73</td>
<td>11.91</td>
<td>11.82</td>
</tr>
<tr>
<td>Fe (mg/g)</td>
<td>0.06</td>
<td>0.06</td>
<td>1.80</td>
</tr>
</tbody>
</table>

a MMBC: biochar of Melastoma malabathricum; DLBC: biochar of Dicranopteris linearis; RSBC: biochar of rice straw biochar.

b Base cation is the sum of total K, Ca, and Mg.
respectively. A one-way analysis of variance was conducted on the effects of treatments towards selected soil properties at the end of incubation, with treatment as the main effect at α-critical of 0.05. Pearson correlation was used to determine the relationships between changes in soil pH with changes in soil P, Al, and Fe following biochar treatment (RStudio version 4.0.3).

3. Results and discussion

Soil pH significantly increased \( (p < 0.05) \) by 0.40–0.60 units with the application of biochar from MM (MMBC), DL (DLBC) and RS (RSBC) relative to unamended control (Fig. 1). However, biochar application was inferior to dolomite in increasing soil pH by 1.3–1.4 units. Soil exchangeable Al only significantly decreased by 2.4 cmol kg\(^{-1}\) with the application of MMBC compared with unamended control, and inferior to dolomite application by 3.4 cmol kg\(^{-1}\). There is a strong negative correlation between changes in soil pH and exchangeable Al upon biochar application \( (r = -0.84; p = 0.004) \). Soil available P only significantly increased with the application of RSBC by 13.1 mg kg\(^{-1}\) compared with unamended control, and by 11.6 mg kg\(^{-1}\) relative to dolomite application. No significant correlation between changes in soil pH with soil available P upon biochar application \( (r = -0.35; p = 0.36) \). Finally, no significant change in soil available Fe with biochar application was inferior to dolomite.

Fig. 1. Changes in soil pH, available P, exchangeable Al, and available Fe after incubation. Error bars indicate the standard error of the mean \( (n = 3) \). Significant difference \( (P < 0.05) \) between treatments is represented by the different letters. The dashed horizontal line is the initial soil properties. RSBC, MMBC and DLBC are biochar derived from rice straw, Melastoma malabathricum and Dicranopteris linearis.
application relative to unamended control and dolomite, apart from increased soil available Fe with RSBC application. No significant correlation was found between changes in soil pH with soil exchangeable Fe ($r = 0.14; p = 0.73$).

The observed liming effect of biochar application to acid sulfate soil, as depicted from the increased in soil pH, was related to the release of alkalinity from the biochar. Similar observations were also reported previously in the amelioration of acid soil (Lauricella et al., 2021; Mafu’Ah et al., 2021; Manickam et al., 2015; Masulili et al., 2010; Yuan et al., 2011). Biochar contains abundant alkaline functional groups such as carboxyl and carbonates which could react with soil H⁺, and increase the soil pH (Shi et al., 2019). The liming effect of biochar on acid soil pH was strongly associated with biochar alkalinity than biochar pH (Yuan et al., 2011). In this study, the increase in soil pH is unlikely due to the pH of biochar which was acidic (Table 1). Moreover, the base cation of biochar is positively correlated with biochar alkalinity (Fidel et al., 2017) and therefore base cation can be used as a proxy for liming capacity of biochar. The significantly greater increase in soil pH with MMBC relative to DLBC and RSBC might relate to the greater alkalinity content as depicted by the greater base cation concentration of MMBC. It has been reported that an increased in soil pH from biochar application could result in the reduction of exchangeable Al and Fe (Nguyen et al., 2022) as well as an increase in soil P availability (Hong & Lu, 2016). The strong correlation between changes in soil pH and exchangeable Al found in the present study ($r = -0.84; p = 0.004$) supports this mechanism, although the reduction in exchangeable Al was only significant with the application of MMBC which causes the greatest increase in soil pH. Although Fe concentration was reduced with all treatment relative to initial soil Fe value at 795.7 mg kg⁻¹, the low soil pH significantly increased Fe content with the application of RSBC which had the highest Fe content, suggesting the possibility of Fe dissolution at such low soil pH. Finally, the lack of correlation between soil pH and soil available P ($r = -0.35; p = 0.36$) implies that the increased in soil available P observed was not predominantly pH-driven, but rather direct dissolution from biochar especially with RSBC, a mechanism previously reported (Yang & Lu, 2021).

4. Conclusion

Soil pH changes after the addition of MMBC, DLBC, and RSBC were related to the release in alkalinity. The greatest increase in soil pH occurred with the application of MMBC which had the highest alkalinity as proxied by the highest base cation concentration. This increase in soil pH from MMBC application led to the greater reduction in soil exchangeable Al. The increase in soil available P was only achievable with RSBC, which had the greatest total P content. The application of biochar did not cause an ameliorative reduction in available Fe, with the possibility of Fe dissolution into soil, especially with the application of RSBC which had the greatest total Fe content. Further studies should explore the effectiveness of biochar co-application with dolomite onto acid sulfate soil to ameliorate both soil acidity and provide nutrients.

Authors’ contributions

S.S.; conceptualization, methodology, formal analysis, and investigation, writing – original draft. N.N.; supervision. G.H–R; writing – review and editing. Z.S.; supervision. K.L.; resources.

Declaration of AI technology usage

The authors declare that no Artificial Intelligence (AI) technologies or AI-assisted tools were utilized in any capacity during the writing and preparation of this article.

Conflicts of interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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