Influence of Oil Palm Empty Fruit Bunch Biochar on Floodwater pH and Yield Components of Rice Cultivated on Acid Sulphate Soil under Rice Intensification Practices

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Abstract: Rice has a vital role in food security but the production is limited in infertile and degraded soils. Rice is cultivated on acid sulphate soil in the coastal area of Peninsular Malaysia. Soil amendment using biological charcoal (biochar) increases the soil fertility. Thus, empty fruit bunch biochar (EFBB) was applied in a pot experiment under a controlled environment using an organic system of rice intensification (SRI) practice and its effects on the floodwater pH, acid sulphate soil properties and growth performance of rice and yield of rice MR219 were preliminarily investigated. EFBB increased grain yield by 141 to 472%. Plant growth and yield parameters in EFBB amended soils were significantly higher than in soil without biochar. The number of tillers increased significantly with the increase in biochar applied; 28 tillers were produced in the control, while up to 80 tillers were produced in the plots applied 40 t ha⁻¹ EFBB. Moreover, the decline of Al³⁺ in flood water indicated that EFBB mitigated Al³⁺ toxicity. Soil water pH increased from 3.5 to 6 with increasing EFBB application rates. The grain yield was linearly correlated to the application rate of EFBB. This pot study demonstrates that the application of EFBB combined with organic fertilization and intermittent irrigation has the potential to improve rice yield on acid sulphate soil. Further study in the field is warranted to determine the effect of EFBB on large scale rice production.

Key words: Al³⁺ toxicity, Biochar, Floodwater pH, Organic fertilization, Rice, System of rice intensification.

Rice is the staple food for more than half of the world's population, particularly in Asia (Zeigler and Barclay, 2008). With the population of Asia currently growing at the rate of 2.9% per year (Brown, 2014), it will soon overtake the production capacity of rice cultivation. Hence, rice producing countries such as Malaysia has to increase its productivity in order to sustain the growing population and achieve food security for food security. To date, Malaysia has achieved rice self-sufficiency level of 72% (Rusli et al., 2013) and further improvement is needed to achieve full sufficiency. However, fertile land is scarce and is utilized to cultivate other crops, such as oil palm. Thus, to increase rice production, farmers have resorted to cultivate rice on poor soils such as the acid sulphate soils.

Acid sulphate soils form a significant group of soils in Malaysia, particularly along the coastal areas of Peninsular Malaysia (Paramananthan and Daud, 1986), such as in Kemasin-semerak area in Northern-East Coast of Peninsular Malaysia. This soil is a mixture of riverine and marine alluvium soils formed by the rise and fall of sea level. Major agronomic problems of these soils are low pH value (<3.5) (Moore, 1990) and presence of sulfidic materials such as pyrite (FeS₂) that produce jarosite and sulphuric acid upon oxidation resulting in Al³⁺ and Fe²⁺ toxicity which is detrimental to crops growth (Shamshuddin, 2006; Muhrizal et al., 2006). Floodwater pH of the paddy field located on acid sulphate soils is reported to be far below the critical level of pH 6 to be suitable for healthy rice growth (Shamshuddin et al., 2004). Therefore, rice yield on acid sulphate soil is < 2 t ha⁻¹ season⁻¹ (Elisa, 2012) which is well below the current national average yield of 4.3 t ha⁻¹ (Hegde and Hegde, 2013).

A common practice to mitigate Al³⁺ and Fe²⁺ toxicity on acid sulphate soil is liming. Liming increases soil pH and reduces the solubility of Al³⁺ and Fe²⁺ (Suswanto et al., 2007; Shamshuddin et al., 2014). Hence, rice farmers have applied lime at a high rate of 4 t ha⁻¹ ground magnesium limestone to alleviate the soil acidity problem (Elisa et al., 2014). However, since liming only remediates the symptoms
repeated application is needed (Fitzpatrick et al., 2003). This is a burden for small farmers on the long-term. Furthermore, liming leaves natural element C which is a non-renewable resource.

Addition of organic soil amendment, such as biochar can improve the condition of highly weathered or degraded tropical soils (Lehmann and Rondon, 2006). Biochar or biological charcoal is a recalcitrant C which is resistant to microbial degradation and functions as soil amendment in agricultural soil. However, the benefits offered by biochar is heavily influenced by two factors, type of feedstock and production condition such as heating rate, maximum temperature and residence time (Sukiran et al., 2011; Zhao et al., 2013). Thus, different types of biochar such as grass biochar are less resistant to degradation than wood biochar but it provides more nutrients to plants (Zimmerman et al., 2011; Crombie et al., 2014). In general, continuous application of biochar increases soil organic C and enhance soil properties. Biochar has been shown in several studies to improve the soil physico-chemical characteristics, soil structure and water retention, nutrient availability, soil pH, and reduced Al toxicity and increased crop productivity (Peter, 2007; Major et al., 2010; Zhang et al., 2011). Qian et al. (2013) reported that application of cattle manure biochar (0.2% w/v) in acidic soil able to reduce the inhibition of wheat growth by decreasing Al toxicity. A study on tsunami-affected paddy fields in Sri Lanka showed that application of 2 t ha\(^{-1}\) rice husk biochar was able to increase grain yield to more than 5 t ha\(^{-1}\) compared to 4 t ha\(^{-1}\) yields in the control, 0 t ha\(^{-1}\) biochar (Reichenauer et al., 2009).

About 75.5% of biomass waste in Malaysia is underutilized (Othman et al., 2000) and a major portion is produced from oil palm industries. Oil palm empty fruit bunches (EFB) are generated in substantial amount compared to other oil palm wastes like palm kernel shell and mesocarp fibre. Handling a large volume of EFB biomass with conventional methods like land filling and mesocarp fibre. Handling a large volume of EFB biomass with conventional methods like land filling and incineration in the mill will posed serious environmental problems. Thus, converting EFB into biochar can be an alternative waste management practice which produces a soil amendment with moderate liming capabilities. Moreover, the cost of liming could be reduced by biochar application especially in rice cultivation.

The system of rice intensification (SRI) has gained global attention with its agro-ecological practice with the aim of increasing productivity of irrigated rice with less external inputs and production costs (Noltze et al., 2012). It is a production system that involves the adaptation of certain changes in the management practices which will lead to better growing environment for the crop. The main principles of SRI are: (i) transplanting young seedlings between 8 – 12 days old (2 – 3 leaf stage) to preserve potential for tillering and rooting ability; (ii) careful planting of single seedlings; (iii) wider spacing; (iv) use of mechanical weeder to aerate the soil as well as controlling weeds; (v) alternate wetting and dry method; and (vi) use of organic manure or vermicompost. Larjani and Hoseini (2012) reported that SRI improved yield production compared to the conventional cultivation system on a strongly weathered soil with low fertility. As reviewed by Dobermann (2004), SRI has shown to be effective in cultivating rice on low fertility acidic soil due to Al\(^{3+}\) and Fe\(^{3+}\) toxicity in Madagascar. Moreover, this system is simple for smallholders to adapt (Stoop et al., 2002) and is environmental friendly (Chapagain et al., 2011). According to Krishna et al. (2008), transplanting 12-day-old seedlings produced more tillers and productive tillers per plant attributed to higher tillering and better root development. Furthermore, intermittent irrigation also contributes greater root growth, grain filling rate and remobilization of C reserved from vegetative tissues to grain (Tuong et al., 2005; Ceesay et al., 2006; Sinha and Talati, 2006; Yang et al., 2007; Zhang et al., 2008, 2009). McHugh et al. (2002) also reported that, intermittent irrigation reduced water used by 19 – 55% compared to conventional flooding method. In recent years, SRI and Korean Natural Farming practices has gained the attention of small rice farmer in Malaysia. One of the common practices adopted by the farmer is the use of seawater with the liquid organic fertilizer. Seawater is added during flowering and panicle initiation stages to supply essential minerals essential for healthy plant growth (Miller et al., 2013).

Thus, combining biochar application and organic practices based on the SRI system or intermittent irrigation can offer positive agronomy value to rice production as well as mitigate environmental issues. However, the influence of EFBB on rice yield has been studied mainly using the conventional flooding system. Under constant flooding or saturated flow, biochar with smaller particle size move along the soil profile and biochar-C is eluted from the soil (Zhang et al., 2010). Intermittent irrigation should reduce C leaching from the rice production system. Hence, in this pot study we conducted intermittent irrigation to investigate the effects of oil palm empty fruit bunch biochar (EFBB) when applied to the SRI system on the chemical properties of acid sulphate soil and the growth performance of rice.

### Materials and Methods

#### 1. Collection of soil, EFBB and compost

The acid sulphate soil was collected from a rice field located in Kemasin-Semerak Integrated Agricultural Development Project in the Kelantan Coastal Plains of Peninsular Malaysia. The soil was classified as Typic Sulvosaprists and selected chemical characteristics are summarized in Table 1. EFBB was produced by Nasmeh
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Technology Sdn. Bhd., through slow pyrolysis process at 300 – 400°C. The compost was produced from green wastes in the University Agriculture Park, Universiti Putra Malaysia. Selected chemical properties of the EFBB and compost are given in Table 2.

2. Pot experiment

A glasshouse pot experiment was conducted in Universiti Putra Malaysia (2° 59’ 59”N, 101° 42’ 25”E) using four EFBB application rates, i.e., 0, 10, 20 and 40 t ha⁻¹. The study was laid out in a randomized complete block design (RCBD) with four replications. Each pot measuring 30 cm in diameter and 38 cm in height was filled with 9.0 kg of soil. The rice variety used in this study was MR219 which was developed by Malaysian Agricultural Research and Development Institute (MARDI), and widely used by the local farmer.

Furthermore, 10 t ha⁻¹ equivalent of green waste compost mainly produced from twigs and leaves (chemical characteristics are shown in Table 1), was incorporated as basal fertilizer in all treatments one week before transplanting following organic practices based on SRI. An 11-day-old rice seedling was transplanted to each pot. Water management was carried out following the SRI practices, where the soil was flooded and dried to soil level for an alternate period of 3 – 6 days (intermittent wetting and drying) during the vegetation growth period, i.e., 1 to 40 days after transplanting (DAT). During the flowering stage (45 to 75 DAT), a thin layer of water was maintained at 2 cm from soil surface. This is followed by alternate wetting and drying in the grain filling period (75 DAT onward), and kept dry for 2 weeks before harvest (118 DAT).

Weeding and soil aeration were done manually every 10 days. Foliar fertilizer was applied according to organic SRI practice and selected chemical properties of the fertilizers

### Table 1. Selected chemical characteristics of acid sulphate soil at Semerak, Kelantan, Malaysia and effect of EFBB application on soil properties (collected at 118 DAT).

| Parameters | EFBB application rate (t ha⁻¹) |
|------------|-------------------------------|
|            | Before | 0 | 10 | 20 | 40 |
| pH (H₂O)   | 3.40   | 4.05 a⁺ | 4.05 a | 4.10 a | 4.10 a |
| TC (%)     | 1.50   | 4.45 b | 4.75 ab | 4.84 ab | 5.21 a |
| TN (%)     | 0.18   | 0.28 a | 0.29 a | 0.28 a | 0.30 a |
| Av. P (mg kg⁻¹) | 10.70 | 71.09 ab | 67.36 b | 72.71 ab | 100.01 a |
| CEC (cmolc kg⁻¹) | 3.35 | 24.26 b | 24.70 ab | 25.13 ab | 26.10 a |
| Exch. K (cmolc kg⁻¹) | 0.03 | 0.09 c | 0.13 bc | 0.15 ab | 0.19 a |
| Exch. Ca (cmolc kg⁻¹) | 0.43 | 0.83 b | 0.90 b | 1.03 ab | 1.14 a |
| Exch. Mg (cmolc kg⁻¹) | 1.0 | 0.59 a | 0.67 a | 0.47 a | 0.63 a |
| Extr. Fe (mg kg⁻¹) | 134.0 | – | – | – | – |

⁺ Means within the row with different letter indicate significant difference at 0.05 levels by Tukey test; TC = total carbon; TN = total nitrogen; Av. P = available phosphorus; CEC = cation exchange capacity; Exch. = exchangeable; Extrac. = Extractable.

### Table 2. Selected chemical properties of oil palm empty fruit bunch biochar, green waste compost and organic liquid fertilizer used in this study.

| Parameters      | Biochar | Green waste compost | SRI Anak* | SRI Bunga* | SRI Buah* |
|-----------------|---------|---------------------|-----------|------------|-----------|
| pH (H₂O)        | 8.0     | 7.4                | –         | –          | –         |
| CEC             | 17.40   | –                   | –         | –          | –         |
| Total C         | 61.24   | 15.96              | –         | –          | –         |
| Total N         | 0.13    | 0.156              | 66.23     | 63.26      | 63.26     |
| Total P         | 0.216   | 0.614              | 0.51      | 0.51       | 0.54      |
| Total K         | 3.504   | 0.563              | 0.40      | 0.28       | 0.35      |
| Total Ca        | 0.136   | 0.074              | 0.96      | 0.70       | 1.09      |
| Total Mg        | 0.817   | 0.197              | 0.011     | 0.908      | 0.010     |

CEC = cation exchange capacity; *Organic liquid fertilizer produced from NS Nature Rice Sdn. Bhd.
used are summarized in Table 2. Application timing and the amount applied per pot are shown in Table 3. The liquid organic fertilizer used in this study was purchased from NS Nature Rice Sdn. Bhd. and it consisted of three different formulations for the various rice growth stages. The liquid fertilizer was available as concentrate and was diluted to the required dosage for application (230ml for 25 L water). *SRI Anak* was used for tillering, *SRI Bunga* for panicle initiation and differentiation, and *SRI Buah* for the grain filling stage. Sea water, which is rich in sodium and micronutrients, was added to the *SRI Bunga* and *SRI Buah* mixture to stimulate plant metabolism.

### 3. Measurements of plant growth and yield parameter

Plant growth parameters such as plant height and number of tillers were recorded at 20, 40, 60, 80, 100 and 118 DAT. The rice plants were harvested at 118 DAT and yield parameters (number of panicles per hill, percentage of filled grains, weight of thousand filled grains and weight of dry biomass) were recorded. Plant tissue samples were collected and oven-dried at 70°C until constant weight was achieved to determine moisture content and dry matter weight. The samples were then grounded for analysis and stored in sealed plastic vial before further analysis.

### 4. Soil and plant tissue analysis

Before treatments and after harvesting, soil samples were collected from each experimental unit, air-dried and sieved through 2.0 mm mesh sieve. The analysis includes soil pH (1:2.5 ratio of soil:water), total carbon (LECO CR-412 Carbon Analyzer), total nitrogen (N) using Kjeldahl method (Bremner and Mulvaney, 1982), available phosphorus (P) according to Bray II Method (Bray and Kurtz, 1945), cation exchange capacity (CEC) and total exchangeable bases using ammonium acetate method (Banah and Barthakur, 1997). Concentration of N and P were determined using Auto Analyzer (LACHAT Instrument, QuikChem FIA+ 8000 series). An atomic absorption spectrophotometer (AAS; PerkinElmer AAAnalyst 400) was used to determine concentrations of K, Ca and Mg in the digested solution.

Floodwater was collected from 48 DAT at 10-day intervals (48, 58, 68, 78 and 88 DAT) to determine the effectiveness of biochar in reducing soil acidity and Al³⁺ and Fe²⁺ toxicity that was produced from the acid sulphate soil after flooding. Samples were filtered with Whatman No. 2 filter paper and Al³⁺ and Fe²⁺ concentrations were determined using Inductively Coupled Plasma (ICP; PerkinElmer Optima 8300).

### 5. Statistical Analysis

All experimental data were analyzed statistically with analysis of variance (ANOVA) using SAS version 9.2 (SAS Institute, Inc., Cary, N.C., USA.). Tukey test was used for comparison of treatment means when F values were significant at \(p < 0.05\) for all parameters except for Al³⁺ and Fe²⁺ in flooded water, soil water pH over time, plant height and number of tillers over time where least significant difference (LSD) was used.

#### Results

1. **Soil properties**

The chemical properties of soil prior to treatment showed that the soil was highly acidic, pH 3.4 (Table 1). According to Shamshuddin et al. (2014), this is one of the obvious characteristic of acid sulphate soil, pH<3.5. After completion of the growth cycle and harvesting of the rice plant, soil chemical properties as a result of different rates of EFBB application are as presented in Table 1. Total carbon, available P, CEC, exchangeable K and Ca of the soil significantly increased \((p < 0.05)\) with the rates of...
biochar applied (Table 1). The level of changes was roughly proportional to the rate of biochar. Increase in soil CEC value is probably due to the negative charge arising from the carboxyl groups of the organic matter (compost); however, application of biochar further increases the soil CEC. The characterization of EFBB indicates that it could be a source of nitrogen (0.13%) but the study showed no significant increase in soil total N with increasing EFBB application rates. Available P, and exchangeable base Ca were increased about 41 and 37%, respectively, with 40 t ha\(^{-1}\) EFBB in comparison to the control. The increase in soil nutrient status (TC, Av. P, CEC, Exch K and Exch Ca) is in accordance with the amount of EFBB applied. Soil pH showed no significant difference among treatments due to the pyrite in the acid sulphate soil (FeS\(_2\)). However, pH of floodwater in the pot study increased with time, up to pH 6 (Fig. 1). Biochar was slightly alkaline (pH 8.0), and can reduce soil acidity. However, a similar trend was observed with 20 and 40 t ha\(^{-1}\) of EFBB, which may partly be due to the saturation effect of the high pH of EFBB added. Therefore, soil pH fluctuations showed a similar trend irrespective of the biochar addition rate. Hence, biochar has the potential to substitute lime materials as to increase the pH of acidic soil. Besides, at applications rates of 20 and 40 t ha\(^{-1}\), the Al\(^{3+}\) concentration was reduced to the tolerable level (>15 μM) for rice growth (Fig. 2). EFBB had no inhibitory effect on Fe\(^{2+}\) activity as the Fe\(^{2+}\) concentration in floodwater was low, >1.5 mg L\(^{-1}\) (Fig. 3). Hence, addition of EFBB might reduce the Al\(^{3+}\) and Fe\(^{2+}\) contents in the acidic soil, the decrease in Al\(^{3+}\) content was related to the increasing soil water pH.

### 2. Plant growth and yield parameters

The growth profile of the rice plant under various treatments was assessed based on visual observation and measuring plant height, total biomass, tiller number, panicle number, percentage of productive tillers, percentage of filled grain (Table 4) and grain yield (Fig. 4).

#### Table 4. Effect of EFBB application on rice plant growth and yield parameters.

| EFBB application rate (t ha\(^{-1}\)) | Plant height (cm) | Root biomass (g hill\(^{-1}\))\(^a\) | Total biomass (g hill\(^{-1}\))\(^a\) | % of productive tillers | No. of panicles/hill | No. of tillers/hill | Grain wt/panicle | % filled grain | Wt of 1000 grains (g) |
|---------------------------------------|-------------------|-----------------------------------|-----------------------------------|------------------------|---------------------|------------------|------------------|-----------------|---------------------|
| 0                                     | 87.0 b\(^1\)      | 29.67 c                           | 88.9 d                           | 95 a                   | 27.0 c              | 28.0 b           | 88.48 c         | 42.5 b          | 16.41 b             |
| 10                                    | 92.8 b            | 35.37 c                           | 168.6 c                          | 98 a                   | 39.0 bc             | 39.0 b           | 110.30 bc       | 52.2 ab         | 23.35 a             |
| 20                                    | 101.5 a           | 66.65 b                           | 256.7 b                          | 97 a                   | 59.0 ab             | 60.0 a           | 123.60 b        | 59.0 a          | 24.76 a             |
| 40                                    | 106.3 a           | 92.28 a                           | 372.1 a                          | 91 a                   | 71.0 a              | 79.0 a           | 165.78 a        | 57.1 ab         | 25.03 a             |

\(^a\)Means with different letter indicate significant difference at 0.05 levels by Tukey test; \(\alpha\) weight of tiller, panicle and root; Wt = weight.
t ha\(^{-1}\) EFBB, even though no single N-fertilizer was applied. The number of panicles and tillers per hill increased by 43, 118 and 186\% respectively, in 10, 20 and 40 t ha\(^{-1}\) EFBB, respectively as compared to the control. According to Tao et al. (2006), the number of tillers per hill is an important morpho-physiological trait of grain yield in rice since the number of tillers per hill is closely related to the number of panicles per hill. Although plant biomass dry weight significantly increased with increasing biochar application rate up to 40 t ha\(^{-1}\), the increase in tiller stopped at 20 t ha\(^{-1}\). Hence, 20 t ha\(^{-1}\) biochar is sufficient for maximum tillering. There was no significant difference in the percentage of productive tiller between the treatments, with values ranging from 91 to 98\%.

The number of panicles was significantly increased and 164\% by application of biochar at 20 and 40 t ha\(^{-1}\), respectively, compared to the control. A high number of panicles per hill is a desirable trait for high rice yield. The percentage of filled grain increased from 43\% to 57\% with the biochar rate. However, this reading is lower than the percentage of filled grain in MR219 previously reported by MARDI (2000) which was 62\% to 64\%. This was due to infestation of *Leptocorisa acuta*, a serious pest of rice that sucks the sap from individual grains at the milking stage. This caused a decline in filled grains and made grains chaffy. Root biomass gradually increase with the increasing EFBB rates (Table 4). This signified the positive effect of EFBB reducing the Al\(^{3+}\) toxicity in acid sulphate soil.

Weight of 1000 grains was 42, 50 and 52\% higher after application of EFBB at 10, 20 and 40 t ha\(^{-1}\) respectively, compared to the control. The weight of 1000 grains of the control was 16.4 g. Application of 40 t ha\(^{-1}\) biochar increased the weight of 1000 grains to 25.0 g. According to MARDI (2000), the average weight of 1000 grains in MR219 is 27.11 g.

### 3. Plant nutrient uptake

Plant tissue analysis of rice straw revealed that biochar application significantly improved the nutrient uptake (Table 5). Biochar application also increased P, K, Ca and Mg concentration in the rice plant, but the difference was significant only at the highest EFBB application rate (40 t ha\(^{-1}\)). The increase in P, K and Mg content in rice plant was related to the high concentration of total P, K and Mg in the EFBB (Table 2).

**Discussion**

Biochar application to soil improves crop productivity by improving soil quality (Asai et al., 2009; Major et al., 2010; David and Gaunt, 2013). Biochar plays an important role in crop growth and yield by influencing the soil nutrient availability (Steiner et al., 2010; Taghizadeh-Toosi et al., 2012). This corresponded to the increase in yield of upland rice in Laos when wood residue biochar was applied (Asai et al., 2009). Biochar improves plant growth by direct nutrient additions, improving nutrient availability and retention by alleviating cation exchange capacity (CEC), increasing soil pH, improving soil physical
characteristics, and promoting positive interactions with soil microorganisms (Iswaran et al., 1980; Glaser et al., 2002; Lehmann and Rondon, 2006; Liang et al., 2006). Similar trends were observed for EFBB on acid sulphate soil in this study. The soil CEC applied with 40 t ha\(^{-1}\) EFBB was significantly higher than the control, highlighting the evident benefits brought by biochar. Furthermore, biochar applied to field was subjected to various abiotic reactions evolving from initial positive functionalities to negative charged surface groups like carboxylic, phenolic and hydroxyl (Cheng et al., 2008). This phenomenon increased the CEC of biochar over time and also indirectly raised the CEC of soil.

The positive modifications contributed by biochar were mainly attributed to the physico-chemical properties of biochar (Masulli et al., 2010) since addition of negatively charged biochar (carboxylic and phenolic functional groups) with a high surface area increases the soil CEC (Chan et al., 2007; Nigussie et al., 2012). Furthermore, Al was found adsorbed to the organic hydroxyl and carboxyl groups on the surface of biochar via complexation; proven by the increase of zeta potential when the biochar was loaded with Al (Qian et al., 2013). Qian et al. (2013) showed that rice straw biochar able to adsorbed Al\(^{3+}\) and increased soil water pH due to various chemical interactions. Furthermore, biochar addition also indirectly mitigated Al\(^{3+}\) toxicity in the soil by precipitating as inert Al-hydroxides (Shamshuddin, 2011). This indicated that EFBB addition was able to increase the soil pH and improve the condition of acid sulphate soil while expanding SRI rice production than normal liming practice. Apart from increase in soil pH, the biochar can release their base cations into the acidic soil where it can participate in exchange reactions and replace the exchangeable Al\(^{3+}\) and H\(^+\) on the soil surface and hence decrease the soil exchangeable H\(^+\) and Al\(^{3+}\) (Chan et al., 2008; Yuan et al., 2011). In this study, floodwater pH was measured as it provide better indication than soil pH in terms of measuring the effect of EFBB in alleviating soil acidity. This was primary caused by disintegration and dissolution of pyrite in acid sulphate soil when it was dried for further soil analysis hence releasing the acidity and causing the pH to decrease (Shamshuddin et al., 2004).

Thus, the dried soil pH showed no difference among treatments.

A soil pH of about 6, is favorable to root growth thereby increasing the ability of the plants to utilise the applied and available soil nutrients, resulting in the increase in dry matter. Meanwhile, at a low soil pH, rice root will grow abnormally, especially when planted in the acid sulphate soil without the process of amelioration by soil amendment. The presence of Al\(^{3+}\) in the soil water is stressful to rice growth, eventually damaging root cells and affecting the nutrient uptake of the plants (Elisa et al., 2011). However, the application of EFBB as soil amendment, provides a more favorable root growth environment and therefore increases the nutrient uptake, resulting in the increase in dry matter. Furthermore, the increased dry matter of rice plant at higher biochar application rates could partly be attributed to the increased supply of P and K in the biochar-amended soils.

| EFBB application rate (t ha\(^{-1}\)) | Total N (g hill\(^{-1}\)) | Total K (g hill\(^{-1}\)) | Total P (mg hill\(^{-1}\)) | Total Ca (mg hill\(^{-1}\)) | Total Mg (mg hill\(^{-1}\)) |
|--------------------------------------|------------------------|------------------------|------------------------|------------------------|------------------------|
| 0                                    | 0.81 b\(^{1}\)         | 0.79 c                 | 47.73 c                | 70.58 b                | 61.92 c                |
| 10                                   | 0.92 ab                | 1.52 c                 | 72.99 b                | 90.79 b                | 106.85 bc              |
| 20                                   | 1.25 ab                | 2.60 b                 | 133.47 a               | 180.84 ab              | 156.16 b               |
| 40                                   | 2.01 a                 | 5.54 a                 | 153.28 a               | 308.12 a               | 243.72 a               |

\(^1\)Means with different letter indicate significant difference at 0.05 levels by Tukey test.
the N availability but instead restricted by the decrease in C availability due to the recalcitrant nature of biochar. Moreover, in some studies, the addition of biochar increased the nitrogen fertilizer use efficiency (Chan et al., 2007; Steiner et al., 2008; Van Zwieten et al., 2010; Huang et al., 2014). This could potentially increase the crop yield and is believed to be incorporated into the effects of biochar on crop performance. Therefore, the amount of nitrogen fertilizer applied to the soil could be reduced with the improved effectiveness of nitrogen uptake. Hence, by the application of foliar fertilizer with high N content plus the ability of biochar to increase nitrogen fertilizer use in the plant, the grain yield was linearly correlated \((r^2 = 0.998)\) with the increase in biochar application rate (Fig. 4).

However, the optimal or threshold has not been achieved in this study, and higher application rates of EFBB may still increase the grain yield. The crop yield data are short term results (one rice crop cycle) but the effect of EFBB on rice yield could be more evident if longer period of study is conducted. This study showed that rice cultivated in acidic soil with biochar amendment produced a preferable growth profile and significantly higher yield compared to the control treatment. Although this study was based on pot experiment, a field experiment is necessary to further examine the effect of EFBB on the yield and soil acid soil properties under the SRI system. Furthermore, a long-term field experiment can provide more information regarding the interaction between biochar and rice production.

### Conclusions

The crop performance and yield of rice were improved by the increase in EFBB rates. Apart from improving soil chemical properties, the biochar reduced Al\(^{3+}\) concentration and increased floodwater pH. This preliminary study demonstrated that biochar has the potential to increase yield and growth of rice cultivated based on SRI system. A long term field experiment is recommended to better assess the effect of EFBB on rice yield and acid soil chemical properties.

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