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Research Article
Effect of Oil Palm Boiler Ash on Growth and Yield of TR8 Rice Variety Planted on Acid Sulphate Soil

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Abstract
Background and Objective: Rice production in Kota Belud, Sabah (Sabah's rice bowl), is challenged by highly acidic soil (3.68 pH). The ideal rice growth requires a pH between 5.5 to 6.5. This study aims to determine the optimal oil palm boiler ash rates for improving soil pH and enhancing the growth and yield of TR8 rice. **Materials and Methods:** The study involved a soil incubation with 12 treatments and 3 replications, using different oil palm boiler ash rates (0 to 50 ton/ha). Soil pH was measured at 10 day intervals over 60 days. Based on the incubation results, 5 ash rates (20-50 ton/ha) were selected for a pot experiment with TR8 lowland rice, using 6 treatments and 5 replications. Data were analyzed with ANOVA, LSD ($p \leq 0.05$) and Pearson correlation to examine relationships between variables. **Results:** Application of 50 ton/ha oil palm boiler ash recorded the highest chlorophyll content (26.98), tiller number per hill (23.40) and yield per pot (795.15 g/m^2). On the other hand, the application of 40 ton/ha oil palm boiler ash recorded the highest percentage of filled grain (88.69%) and the panicle number (23). In addition, the control (without oil palm boiler ash application) recorded the highest flag leaf length (38.22 cm). There was a strong positive correlation between yield per pot and number of panicles. This study showed that oil palm boiler ash at 50 ton/ha increased the soil pH to 6.29 potentially improving vegetative growth and increasing the yield of TR8 lowland rice. **Conclusion:** While, this study shows promise for using oil palm boiler ash to improve rice production in acidic soils, particularly for the TR8 rice variety, further field research is crucial to explore the effects on different soil types and rice varieties under field conditions.

Key words: Acid sulphate soil, boiler ash, oil palm waste, TR8 lowland rice, positive correlation

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Rice is a staple food and a symbol of cultural identity in Malaysia. However, despite being known as the "golden grains", Malaysia struggles to meet its rice demands solely through domestic production, leading to a reliance on imports. This dependence creates a challenging situation, leaving the nation vulnerable to external factors and raising questions about long-term food security. Reliance on imports may cause price hikes that can unfairly affect low-income households. Additionally, global food supply chain disruptions can create food shortages, jeopardizing national stability. Furthermore, dependence on imports weakens the domestic agricultural sector, potentially impacting rural livelihoods and economic security. The growing population also leads to an increase in food demand. In 2021, Malaysia consumed 2.90 million metric tons of rice, feeding a population of approximately 32.6 million people. The country's population is growing at a rate of 0.2% annually[1].

Peninsular Malaysia is the heart of rice production in the country, contributing over 80% of the national paddy planting area (522,669 ha) out of a total of 637,955 ha. The remaining area is divided between Sabah (37,343 ha) and Sarawak (77,943 ha). Malaysia prioritizes rice production in designated granary areas, which encompass 416,848 ha. However, average yields have dipped in recent years. In 2019, Malaysia's main granaries contributed over 62% (2.18 million metric tons) of the nation's total rice production (3.51 million metric tons), with an average yield of 5.1 metric tons per ha. Malaysia's granary zones are divided into Northern, Western and Eastern zones. The Kota Belud granary area (IADA) is located in the Eastern zone. While Kota Belud is known as Malaysia's "rice bowl" and is expected to contribute significantly to food security[2], its rice production has dropped from 3,112 ton/ha in 2018 to 2,813 ton/ha in 2019, representing a decline of 9.6%[3]. Compared to other granary zones, Kota Belud has one of the lowest production rates.

The rice self-sufficiency level (SSL) in Sabah has witnessed a decrease, dropping from 26% SSL in 2012 and approximately 22.8% in 2021[3]. This decline is partly due to the acidic nature of the soil particularly in Kota Belud's paddy fields, where the soil pH is as low as 3.68. In Malaysia, some soils fall under the category of "acid sulfate soil", characterized by very low pH levels. Rice plant thrives in a more neutral environment, with optimal soil pH ranges of 5.5 to 6.5. Soil pH significantly influences plant growth by affecting the chemical forms and solubility of essential plant nutrients, thereby regulating their availability for plant uptake[4]. The availability of plant nutrients fluctuates with soil pH, with some nutrients becoming more accessible in acidic environments and others thriving in slightly alkaline conditions. To boost productivity, the agriculture sector relies heavily on chemical fertilizers. While chemical fertilizers can maximize agricultural output, they also cause acceleration of soil acidification and reduce soil fertility. However, liming material is costly for small farmers in rural areas and on top of that, it must be applied repeatedly[5]. Studies suggest that oil palm boiler ash can both increase soil acidity and enrich it with essential nutrients[6]. This makes oil palm waste a promising and potentially sustainable alternative for managing soil[7].

Several studies have found that oil palm byproducts are good sources of potassium (K). Ichriani *et al.*[8] reported that a 100 g empty fruit bunch (EFB) contains 36.75% potassium. Similarly, Damayanti *et al.*[9] reported that ash from palm rung contains 36.48% K_2O. Susanti and Harahap[10] also reported that oil palm ash contains 35 to 40% of K_2O. Apart from that, Omeje *et al.*[11] believe that empty oil palm bunch ash has the potential to improve microbial activity in soils. It helps to facilitate the supply of organic matter in nutrient-deficient soil and increases the availability of macronutrients and other beneficial nutrients. Furthermore, Omeje *et al.*[11] also reported enhancement when treated with empty oil palm bunch ash. Application of bunch ash improves the leaf area index, number of leaves and plant height of cocoyam. Moreover, Ahaiwe[12] revealed that the use of oil palm refuse bunch ash as a treatment for ginger cultivation can lead to enhanced growth and yield. Copper (Cu) is involved in carbohydrates and protein metabolism, whereas manganese (Mn) has a significant role in the process of photosynthesis.

Apart from the nutrient content, oil palm ashes also have alkaline chemical properties. Law-Ogbomo *et al.*[13] and Adjei-Nsiah[7] stated that the chemical composition of oil palm boiler ash from the laboratory analysis recorded a pH value of 10.90 and 10.80, respectively. In contrast, Law-Ogbomo and Ogedegbe *et al.*[14] and Kim *et al.*[15], however, reported a comparatively lower pH value of 8.80 and 8.78, respectively. While, Damayanti *et al.*[9] reported a higher pH value of oil palm ashes ranging from 11.9 to 12.0. Oil palm ash exhibits an alkaline nature, with reported pH values ranging from 8.78 to 12.0. However, the characteristics of the ashes are influenced by burning conditions and palm variety. Given its potential to improve soil conditions, this study explores the effects of OPBA (oil palm boiler ash) on the growth of TR8 lowland rice grown in acidic soil. The readily available nature of OPBA makes it an attractive option. Produced from the combustion of oil palm mesocarp, it's readily obtainable in large quantities from palm oil mills. The objective of this study was to evaluate the effect of oil palm boiler ash on the growth and yield of the TR8 rice variety planted on acid-sulfate soil.

MATERIALS AND METHODS

Study area: The study was carried out from March to August, 2023. The oil palm boiler ash was obtained from Maha Sawit Sdn. Bhd., Tawau, Malaysia. The soil sample was obtained from Kota Belud, Sabah, Malaysia. The soil is known as acid sulfate soil and is highly acidic (3.68 pH).

Research protocol: The research consists of two parts: Soil incubation and pot experiment. The soil incubation consisted of 12 treatments with 3 replications, including a control treatment. Where 150 g soil mixed different rates of oil palm boiler ash as follows: 0.0 g (0 ton/ha), 0.15 g (2 ton/ha), 0.30 g (4 ton/ha), 0.45 g (6 ton/ha), 0.6 g (8 ton/ha), 0.75 g (10 ton/ha), 1.13 g (15 ton/ha), 1.5 g (20 ton/ha), 1.88 g (25 ton/ha), 2.25 g (30 ton/ha), 3.0 g (40 ton/ha) and 3.75 g (50 ton/ha). The soil pH was measured in the water solution method at every 10 day interval for 60 days incubation period, in Final Year Project, Laboratory 2 at the Faculty of Sustainable Agriculture (FSA). For nutrient analysis, the samples were sent to Kulumpang Development Corporation (KDC) Laboratory, Tawau, Sabah, Malaysia. Following the incubation result, boiler ash treatments (20, 25, 30, 40 and 50 ton/ha) were selected and applied in the pot experiment.

The pot experiment was carried out in insect-proof rain shelter No. 3 (RKS3) at the Faculty of Sustainable Agriculture (FSA). The experiment consisted of 6 treatments with 5 replications as follows: 6 kg of Kota Belud soils with oil palm boiler ash rates at 20 ton/ha (60 g), 25 ton/ha (75 g), 30 ton/ha (90), 40 ton/ha (120 g), 50 ton/ha (150 g) and a control treatment (0 ton/ha). The TR8 lowland rice seeds were planted directly into the pot. After a week, the water level was maintained at 2 cm from the soil surface[16]. All treatments get the same amount of NPK fertilizer rates (1.38 g Urea, 0.46 g TSP and 0.36 g MOP). The treated TR8 rice was observed for plant height (cm), number of tillers, productive tillers (%), number of leaves, panicle length (cm), flag leaf length (cm), relative chlorophyll, number of panicles, weight of 1000 grains (g), filled grains (%), unfilled grains (%) and yield per pot (g/m^2).

Statistical analysis: The data (mean values) were analyzed with a One-way Analysis of Variance (ANOVA) test. The Least Significance Difference (LSD) test was conducted to evaluate the significance of differences between treatments at $p \leq 0.05$. The Pearson correlation test was conducted to determine the strength and direction of a relationship between two variables. All tests were conducted with IBM SPSS Statistics software v27.0 (IBM Corp, Armonk, New York, USA) for all parameters.

Plant growth parameters: Throughout the study, the rice plant growth was monitored by recording growth parameter data every week. The plant height is measured from the distance between the plant base and the tip of the latest spikelet on the panicle, which does not include the awn of the spikelet[17]. The total number of tillers on each hill, including the main stem, was counted manually[18]. The length of the panicle was measured from the base of the rachis to the tip of the panicle. Three panicles from each hill were randomly selected and measured to get the mean value. The flag leaf length was measured from the uppermost leaf below the panicle was measured from each hill. To determine the number of leaves, present in a rice crop, the number of leaf blades in each plant was used as the basis for counting. The chlorophyll content was measured by using a chlorophyll meter (SPAD 502 plus chlorophyll meter). The chlorophyll content was taken starting from the flag leaf as the first leaves, the second and third leaves below the flag leaf. The percentage of productive tiller was calculated as follows[19] (Eq. 1):

$$\text{Productive tillers (\%)} = \frac{\text{Number of panicles}}{\text{Total number of tillers per hill}} \times 100 \quad (1)$$

Plant yield parameters: The rice yield was measured at harvest (99 DAP). Panicles from each hill were cut and kept in zip-lock bags and transported to the laboratory, to count the number of panicles, number of filled grains and the number of unfilled grains[19]. To determine the weight of 1000 grains (g), unfilled and filled grains were manually separated and 1,000 filled grains from each treatment were randomly selected. These grains were then weighed using an electronic balance (Mettler Toledo, Germany). The filled grains (%) was calculated by dividing the number of filled grains by the total number of grains, multiplied by 100% (Eq. 2). The unfilled grains (%) was determined by dividing the number of unfilled grains by the total number of grains and multiplied by 100% (Eq. 3). The yield per pot was determined by dividing the weight of the grains harvested by the surface area of the pot (Eq. 4):

$$\text{Filled grains (\%)} = \frac{\text{Number of filled grains}}{\text{Total number of grains}} \times 100 \quad (2)$$

$$\text{Unfilled grains (\%)} = \frac{\text{Number or unfilled grains}}{\text{Total number of grains}} \times 100 \quad (3)$$

$$\text{Yield per pot} = \frac{\text{Wright of grains (g)}}{\text{Area of pot (m}^2\text{)}} \quad (4)$$

RESULTS AND DISCUSSION

Effect of oil palm boiler ash on acid sulfate soil pH: The study recorded the soil pH at different rates of oil palm boiler ash treatments including control treatments. The soil pH increased with increasing oil palm boiler ash rates.

The initial pH of the soil was 3.68 and it remained relatively low throughout 60 days of incubation, the soil exhibited high acidity. The highest pH was observed in 50 ton/ha BA (6.29) followed by 40 ton/ha BA (6.18), whereas the lowest soil pH was observed in 0 ton/ha BA (3.76) (Table 1). Based on the result, all of the oil palm boiler ash treatments showed an increase in soil pH and reached their peak at day 50 before starting to decline thereafter. The oil palm boiler ash's high alkalinity (9.6 pH) neutralizes soil acidity. This was supported by Xu *et al.*[20], who found that alkalinity and excess cation release from the ash raises soil pH.

The oil palm boiler ash offers a long-term solution for acidic soil due to its high initial pH (9.6 pH). Law-Ogbomo and Ogedegbe[14] also confirm oil palm boiler ash's effectiveness as a liming material and nutrient source. The ability of liming material to alleviate soil acidity depends on the number of bases that can readily dissolve or react with water to release base cations. Therefore, boiler ash from oil palm waste can be a more effective way to raise soil pH and act as a soil amendment agent.

Effect of oil palm boiler ash on soil nutrients: The mean value of Exchangeable Nitrogen, Phosphorus, Calcium, Magnesium and Cation Exchange Capacity (CEC), Total P, Available P, Organic carbon and N (%) was presented in Table 2 and 3. Significant increase occurred on exchangeable K, exchangeable Ca, exchangeable Mg, total P, available P, Organic carbon (%) and N (%) except CEC and exchangeable Na. In addition to its liming effect, palm bunch ash benefits soil by enriching it with essential nutrients like nitrogen, phosphorus, magnesium and calcium.

The oil palm boiler ash treatments show no significant effect on soil exchangeable Na and soil CEC. Soil Na ranged between 0.18 and 0.37 (meq/100 g). Most plants do not require Sodium (Na^+). Excess Na^+ in the cytosol is detrimental[21,22]. This is because it competes for binding sites with other essential ions (K^+, Ca^{2+} and Mg^{2+}) potentially hindering nutrient intake and affecting plant growth development. Meanwhile, the soil exchangeable K was significantly different among the treatments, from 0.23 meq/100 g in control to 2.30 meq/100 g at 50 ton/ha BA. This result suggests that oil palm boiler ash is a good source of K and can effectively improvesoil K availability which is beneficial for plant growth. Mulyani *et al.*[23] and Suan *et al.*[24] also reported a significant increase in soil exchangeable K, from 0.51 meq/100 g (control) to 0.71 meq/100 g (27.3 g BA/plot). The mean soil CEC ranges from 14.14 to 17.91 meq/100 g. The oil palm boiler ash did not affect the soil CEC because the organic matter from the ash was burnt into gas during the incineration process. Both soils' exchangeable Ca and exchangeable Mg slightly increased with the oil palm boiler ash treatments. This was especially evident at the highest application rate (50 ton/ha BA) where the exchangeable Ca went from from 1.16 meq/100 g Ca (control) to 1.94 meq/100 g and exchangeable Mg increased from 0.72 meq/100 g (control) to 1.42 meq/100 g. This is supported by Law-Ogbomo *et al.*[13], who observed similar results. However, there are conflicting reports, Suan *et al.*[24] reported that boiler ash increased soil exchangeable Ca but not Mg. While, Yang *et al.*[25] observed increased soil exchangeable Mg but not Ca. Apart from that, the oil palm boiler shows no significant effect in the soil CEC, ranging from 14.14 to 17.91 meq/100 g. According to Siddiqui *et al.*[26], the amount of organic matter in soil directly impacts its cation exchange capacity. However, because oil palm boiler ash contains no organic matter, the treatments have no significant influence on soil CEC in this study. During the incineration process, the organic matter was thought to be burned into gas.

The soil total P and available P were significantly increased with oil palm boiler ash treatments (Table 3). The pot treated with 25 ton/ha BA produced the highest (484.67 ppm) and 2 ton/ha BA produced the lowest (307.00 ppm). Total P refers to the total amount of phosphorus present, both organic and inorganic. This result indicates a potential contribution of P from the ash but is not directly available for plant uptake. The pot treated with 40 ton/ha BA produced the highest available P (128.07 ppm) compared to the control (17.37 ppm). While the total P content reflects the overall P in the soil, it doesn't necessarily translate directly to the amount of P readily available for plants. The oil palm boiler

Table 1: Soil pH at different rates of oil palm boiler ash after 60 days of incubation

Treatment (ton/ha BA)	pH value
0	3.76^{j}
2	4.16^{i}
4	4.30^{h}
6	4.40^{g}
8	4.40^{g}
10	4.60^{f}
15	4.81^{e}
20	5.41^{d}
25	5.59^{c}
30	5.67^{c}
40	6.18^{b}
50	6.29^{abc}

BA: Boiler ash, value with the same letter shows the mean is not significant at p<0.05 based on the least significant test (LSD)

Table 2: Effect of oil palm boiler ash on the mean of Na, K, Ca, Mg and CEC

Treatment (ton/ha)	Na (meq/100 g)	K (meq/100 g)	Ca (meq/100g)	Mg (meq/100 g)	CEC (meq/100 g)
0	0.18^{f}	0.23^{e}	1.16^{def}	0.72^{e}	16.52^{a}
2	0.18^{f}	0.23^{e}	1.04^{f}	0.72^{e}	16.17^{a}
4	0.27^{cde}	0.52^{de}	1.32^{cdef}	0.76^{e}	17.70^{a}
6	0.28^{bcd}	0.62^{de}	1.13^{ef}	0.80^{de}	15.44^{a}
8	0.25^{def}	0.78^{d}	1.26^{cdef}	0.83^{de}	15.40^{a}
10	0.20^{ef}	0.92^{d}	1.50^{bcde}	0.92^{de}	14.14^{a}
15	0.33^{abc}	0.92^{d}	1.50^{bcde}	0.95^{cde}	17.12^{a}
20	0.35^{ab}	1.70^{d}	1.58^{abc}	1.02^{bcd}	15.35^{a}
25	0.30^{bcd}	1.94^{bc}	1.56^{abcd}	1.19^{abc}	15.40^{a}
30	0.26^{de}	2.00^{bc}	1.78^{ab}	1.22^{ab}	15.56^{a}
40	0.37^{a}	2.31^{ab}	1.66^{abc}	1.39^{a}	17.56^{a}
50	0.30^{abcd}	2.70^{a}	1.94^{a}	1.42^{a}	15.38^{a}

Value with same letter shows the mean is not significant at $p<0.05$ based on the least significant test (LSD) and CEC: Cation exchange capacity

Table 3: Effect of oil palm boiler ash on the mean of total P, available P, Organic carbon and N of acid sulphate soil

Treatment (ton/ha)	Total P (ppm)	Available P (ppm)	Organic carbon (%)	N (%)
0	335.33^{bc}	17.37^{e}	1.85^{f}	0.19^{b}
2	307.00^{c}	24.23^{e}	1.89^{ef}	0.20^{b}
4	384.33^{abc}	28.67^{de}	2.55^{ab}	0.25^{a}
6	332.00^{bc}	32.77^{cde}	2.43^{abcd}	0.23^{ab}
8	423.33^{ab}	39.37^{cde}	2.69^{a}	0.28^{a}
10	380.33^{abc}	54.83^{cd}	2.18^{cde}	0.22^{b}
15	384.00^{abc}	54.27^{cd}	2.24^{cd}	0.22^{b}
20	249.00^{bc}	92.40^{c}	2.46^{abc}	0.23^{b}
25	484.67^{a}	92.40^{b}	2.37^{bcd}	0.22^{b}
30	417.67^{abc}	91.67^{b}	2.16^{de}	0.23^{b}
40	481.33^{a}	128.07^{a}	2.44^{abcd}	0.24^{ab}
50	410.33^{a}	122.70^{a}	2.18^{cde}	0.21^{b}

Value with the same letter shows the mean is not significant at $p<0.05$ based on the least significant test (LSD)

ash may contain both organic and inorganic P forms. While organic P needs to be decomposed by soil microbes to become available, inorganic P can be directly taken up by plants. Higher oil palm boiler application leads to more total P addition, but the proportion of inorganic P might not increase proportionally.

Although the changes were small, oil palm boiler ash did increase soil organic carbon (%) and soil N content (%) (Table 3). The highest soil organic carbon was observed in soil treated with 8 ton/ha oil palm boiler ash (2.69%) and the lowest was in control (1.85%). However, adding more OPBA may not increase the soil's organic carbon. This may be attributed to the high alkalinity of oil palm boiler ash which can saturate negatively charged exchange sites in the soil, reducing the adsorption of organic matter. Other research has shown mixed results, where Adjei-Nsiah and Obeng[21] reported increased oil organic carbon with palm bunch ash application while, Mulyani *et al.*[23] observed no changes. Meanwhile, the highest mean soil N content was observed in 8 ton/ha BA (0.28%) and the lowest mean was observed in the control (0.19%). Soil N content may not be further increased with the application of oil palm boiler ash. This is because N contained in the ash is lost as gaseous through the incineration process. Ash derived from oil palm waste alone may not be effective in compensating for N deficiency in soils. Therefore, oil palm boiler ash is not a reliable source of N for plants.

Effect of oil palm boiler ash on TR8 rice growth: The mean plant height, number of tillers per hill, percentage of productive tillers, panicle length, flag leaf length, number of leaves and relative chlorophyll were presented in Table 4. Statistical analysis showed a significant difference in the mean number of tillers per hill, flag leaf length and chlorophyll content whereas no significant difference in mean plant height, mean percentage of productive tillers and mean number of leaves.

The study suggested that the mean plant height of TR8 rice was not significantly influenced by the oil palm boiler ash treatments ($p = 0.940$). The plant height varied from 89.52 to 92.92 cm. The ash may be high in potassium, but it is not a reliable source of nitrogen (N). Nitrogen is crucial and its deficiency impacts grain yield[27]. Without a balanced nutrient profile, rice growth might be limited. The mean number of leaves was also not significantly affected by the ash treatments ($p = 0.481$). The mean number of leaves ranged from 52 to 42. The oil palm boiler ash is rich in minerals like potassium and calcium, which are beneficial for tillering, but lack other nutrients crucial for leaf development such as nitrogen and magnesium.

Table 4: Effect of oil palm-derived boiler ash rates on the different growth components of TR8 lowland rice

Boiler ash treatment (ton/ha)	Plant height (cm)	Number of tillers per hill	Productive tiller (%)	Panicle length (cm)	Flag leaf length (cm)	Number of leaves	Chlorophyll content (SPAD)
0	90.70[a]	17.50[b]	94.92[a]	24.42[a]	38.22[a]	41.60[a]	24.50[b]
20	89.52[a]	22.40[ab]	89.52[a]	24.72[a]	34.62[ab]	50.20[a]	25.54[ab]
25	89.82[a]	22.60[ab]	89.61[a]	24.88[a]	33.00[abc]	50.00[a]	25.10[b]
30	92.92[a]	22.20[ab]	96.92[a]	24.94[a]	27.20[b]	47.20[a]	24.26[b]
40	91.50[a]	22.60[ab]	91.43[a]	24.72[a]	30.36[ab]	48.00[a]	25.60[ab]
50	92.12[a]	23.40[a]	96.62[a]	24.32[a]	27.42[b]	52.40[a]	26.98[a]

Value with the same letter shows the mean is not significant at $p<0.05$ based on the least significant test (LSD)

Table 5: Effect of oil palm-derived boiler ash rates on the specific growth component of TR8 lowland rice

Boiler ash treatments (ton/ha)	Number of panicles	Weight of 1000 grains (g)	Filled grain (%)	Unfilled grain (%)	Yield per pot (g/m^2)
0	16.50[b]	23.29[a]	79.61[b]	20.43[a]	700.96[b]
20	20.00[ab]	22.80[a]	87.37[a]	12.63[b]	739.10[ab]
25	21.75[a]	23.91[a]	84.97[a]	15.03[b]	635.52[c]
30	21.40[ab]	23.98[a]	84.51[a]	15.49[b]	716.98[ab]
40	23.00[a]	22.94[a]	88.69[a]	11.31[b]	791.98[a]
50	22.60[a]	23.39[a]	87.54[a]	12.46[b]	795.15[a]

Value with the same letter shows the mean is not significant at $p<0.05$ based on the least significant test (LSD)

The number of tillers per hill did increase slightly with the oil palm boiler ash treatments ($p = 0.018$). The highest number of tillers per hill recorded was 23.0 in 50 ton/ha compared to 19.0 in the control, which is statistically similar to 22.40 (20 ton/ha), 22.60 (25 ton/ha), 22.20 (30 ton/ha) and 22.60 (40 ton/ha). All ash treatments produced slightly more tillers than the control group due to the higher potassium content in the ash. Potassium is a nutrient that promotes tillering in rice plants[28]. On the other hand, the mean percentage of productive tillers was not affected by the oil palm boiler ash treatments ($p = 0.801$), which ranges between 89.52 and 6.92%. The oil palm boiler ash might influence tiller development, but the ash's effect might be too subtle to be detected within the observed range.

The mean flag leaf length was significant among the oil palm boiler ash treatments ($p = 0.017$). However, the ash treatments showed a shorter flag leaf length compared to the control. The mean flag leaf length in the control was 38.22 cm while the pot treated with 40 ton/ha BA produced the shortest flag leaf, 27.20 cm. The result suggests that oil palm boiler ash may not benefit flag leaf growth and the resources might be directed towards panicle production over flag leaf growth. A moderate negative correlation between the panicle number and flag leaf length supports this idea (Table 4). However, the mean panicle length across treatments did not differ significantly ($p = 0.990$). The mean panicle length ranged between 24.94 and 24.88 cm. The rice plant might be prioritizing allocating resources toward grain filling rather than increasing the length of the panicle. Additionally, the chosen treatment rates might not have been sensitive enough to detect subtle differences in panicle length.

The study showed a statistically significant difference in the mean relative chlorophyll content of oil palm boiler ash treatments ($p = 0.037$). The pot treated with 50 ton/ha OPBA had the highest relative chlorophyll content (26.98 SPAD), which is statistically similar to 40 ton/ha (25.60 SPAD), while the pot treated with 30 ton/ha BA had the lowest relative chlorophyll content (24.26 SPAD), which is statistically similar to the control (24.50 SPAD) and 25 ton/ha BA (25.10 SPAD). When there's a sufficient supply of potassium nutrients, chlorophyll content in plants tends to increase[29]. Potassium acts as a catalyst that allows plants to effectively utilize nitrogen which translates to a higher chlorophyll content in leaves, which ultimately affects the plant's photosynthesis capacity[30].

The mean number of panicles was significant among the treatments ($p = 0.028$). The highest number of panicles was 23.0 in 40 ton/ha BA and the lowest was 16.5 in 0 ton/ha BA (Table 5). This can be attributed to the alkaline nature of boiler ash which raises the soil pH and enhances nutrient availability. Potassium plays a crucial role in plant metabolic process, photosynthesis, translocation of sugars and production of starch in grains. The number of panicles had a strong positive correlation with the number of tillers per hill, percentage of productive tillers, number of leaves, percentage of filled grain and yield per pot. A higher number of panicles indicates more tillers, which suggests good overall growth and the ability to produce panicle-bearing tillers. A greater number of tillers, especially productive ones, provide more opportunities for panicles to form. Additionally, more leaves likely indicate better plant health and potentially more resources available for panicle development.

Table 6: Pearson correlation coefficients for the growth and yield components of TR8 lowland rice

	Plant height (cm)	Number of tillers	Productive tiller (%)	Number of leaves	Flag leaf length (cm)	Panicle length (cm)	Chlorophyll Content	Number of panicles	1000 weight grain (g)	Filled grains (%)	Unfilled grains (%)	Yield per pot (g/m^2)
Plant height (cm)												
Number of tillers	-0.222											
Productive tillers (%)	0.136	0.109										
Number of leaves	-0.044	0.513**	0.517**									
Flag leaf length (cm)	-0.82	-0.314	-0.123	-0.266								
Panicle length (cm)	-0.037	-0.416*	-0.273	-0.314	0.341							
Chlorophyll content	0.304	0.027	-0.165	-0.067	-0.267	0.129						
Number of panicle	-0.142	0.864**	0.555**	0.608**	-0.470*	-0.383*	0.038					
1000 grain weight (g)	0.074	-0.015	0.135	-0.103	-0.161	0.158	0.065	0.238				
Filled grains (%)	-0.279	0.671**	0.087	0.418*	-0.250	-0.029	0.167	0.631**	-0.163			
Unfilled grains (%)	0.279	-0.671**	-0.087	-0.418*	0.250	0.028	-0.166	-0.631**	0.163	-1.000**		
Yield per pot (g/m^2)	0.199	0.455*	0.429*	0.378*	-0.122	0.087	0.245	0.558**	0.110	0.395*	-0.395*	

**Correlation is significant at the level 0.01 (2-tailed) and *Correlation is significant at the level 0.05 (2-tailed)

The weight of 1000 grains were not significantly affected by the oil palm boiler ash treatments (p = 0.433). The mean weight obtained was around 22.80 to 23.96 g. When there is a higher number of filled grains, a decrease in the weight of 1000 grains is observed. This is because the filled grains produced are smaller in size and less plump, resulting in a reduced grain weight. According to Wu *et al.*[31], the rice grain weight depends on a combination of factors of grain size and plumpness, which refers to the degree of grain filling. These factors rely on sufficient building blocks (assimilates) regulated by plant hormones[32].

The oil palm boiler ash treatments increased the mean percentage of filled grains and reduced the percentage of unfiled grains. The highest percentage of filled grains produced in pot treated with 40 ton/ha BA (88.69%) which is statistically similar to 50 ton/ha BA (87.54%), 20 ton/ha BA (87.37%), 25 ton/ha BA (84.97%) and 30 ton/ha BA (84.51%). The lowest percentage of filled grains was at control (79.61%). Meanwhile, the highest percentage of unfilled grains was produced at 0 ton/ha BA (20.43%) and the lowest was at 40 ton/ha BA (11.31%). The percentage of filled grains and unfilled grains exhibits a strong positive correlation with the number of tillers per hill and number of panicles which suggests that rice plants with more tillers and panicles tend to have a higher percentage of filled grains, which is a desirable outcome for yield.

Apart from that, the addition of oil palm boiler ash rates also showed a significant effect on the yield per pot of TR8 rice (p = 0.026). Oil palm boiler ash at 50 ton/ha produced the highest yield per pot, which is 795.15 g/m^2 while 25 ton/ha produced 635.52 g/m^2, the lowest yield per pot. The study shows a moderate positive correlation between yield per pot and several factors influencing yield (Table 5). These factors include the number of tillers per hill, percentage of productive tillers, number of leaves, number of panicles and percentage of filled grain. This study supports previous research. For instance, Oad *et al.*[32] also found a positive effect of the number of tillers on the grain yield. Similarly, Sreedhar *et al.*[33] and Osman *et al.*[34] highlighted that the number of tillers per plant, the number of filled grains per panicle and the 1000 grain weight are all significant factors influencing the grain yield of rice.

Pearson correlation test: The correlation coefficient was computed to assess the relationship between the rice traits (Table 6). The result indicated that there is a strong positive correlation between the number of tillers per hill and number of panicles (r = 0.864, p<0.001) and the percentage of filled grains (r = 0.671, p<0.001). The number of leaves had a strong positive correlation with the number of panicles (r = 0.608, p<0.001) and a moderate positive correlation with the number of tillers per hill (r = 0.513, p = 0.004), percentage of productive tiller (r = 0.517, p = 0.003), percentage of filled grain (r = 0.418, p = 0.022). The number of panicles had a strong positive correlation with the number of tillers per hill (r = 0.864, p<0.001), percentage of productive tillers (r = 0.555, p = 0.003), number of leaves (r = 0.608, p<0.001), filled grain (r = 0.631, p<0.001) and yield per pot (r = 0.558, p = 0.002). These findings suggest that traits like the number of tillers, panicles and filled grains are strongly interconnected. More tillers tend to lead to more panicles and potentially more filled grains, which can contribute to higher yield. Similarly, a greater number of leaves is associated with increased tillers, productive tillers and filled grains.

CONCLUSION

This study demonstrated that the application of 50 ton/ha oil palm boiler ash significantly improved vegetative growth and yield of TR8 lowland rice, with the highest chlorophyll content, tiller number and yield per pot recorded. The application of 40 ton/ha resulted in the highest percentage of filled grains and panicle number. Additionally, oil palm boiler ash increased soil pH to 6.29, enhancing growth conditions. However, to obtain more comprehensive data, it is necessary to conduct field experiments on a larger scale. Therefore, its use as a soil ameliorant requires further research to monitor its long-term impact on soil properties and crop performance.

SIGNIFICANCE STATEMENT

Rice yield in Sabah, Malaysia, is affected by highly acidic soil. Applying 50 ton/ha oil palm boiler ash significantly increases the soil pH on rice plantings compared to soil without amendment of oil palm boiler ash. Replacing costly liming materials with oil palm boiler ash can increase soil pH and enrich it with essential nutrients. This can utilize oil palm waste as a potentially sustainable alternative for managing soil acidity.

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