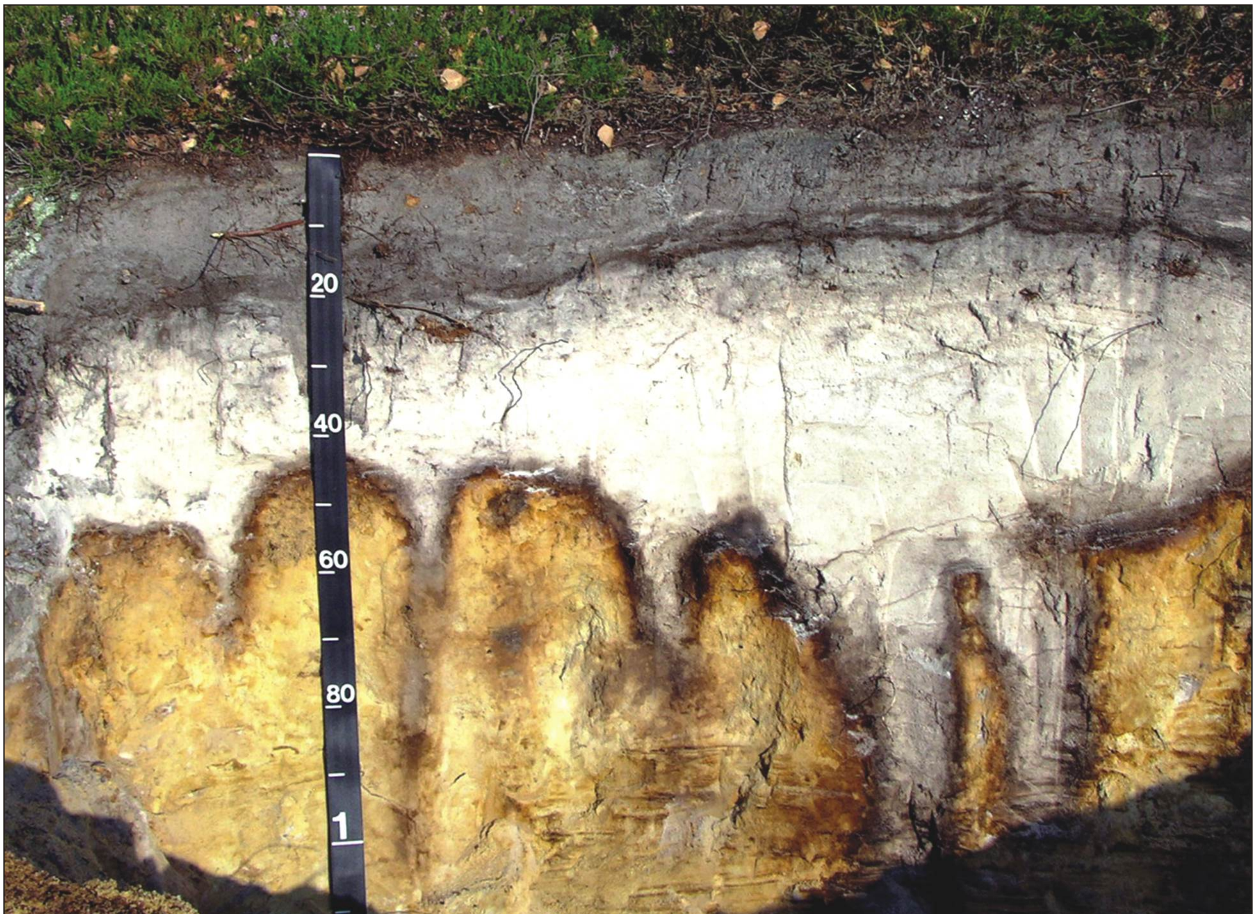

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Research Article
Biochar Derived from Sugarcane Industry Waste Increasing Productivity of Degraded Land

[1]Titiek Islami, [2]Erwin Ismu Wisnubroto and [3]Waego Hadi Nugroho

[1]Research Centre for Tuber Crop, Univerisity of Brawijaya, Malang, Indonesia
[2]Faculty of Agriculture, Tribhuwana Tunggadewi University, Malang, Indonesia
[3]Faculty of Mathematic and Natural Science, University of Brawijaya, Malang, Indonesia

Abstract

Background and Objectives: Organic amendments, such as manure and charred organic matter, are largely used to improve the properties of degraded land. An experiment was carried out to study the possibility for using biochar made from sugarcane (*Saccharum officinarum* L.) industry waste to increase the productivity of degraded land in East Java Indonesia. The main objective of this experiment was to study the changes in soil properties that favor sugarcane growth and productivity following the application of various organic amendments. **Materials and Methods:** The soil amendments were carried out on dry land in the village of Wringin Anom, Blitar District, East Java, Indonesia from September, 2011-June, 2014. This 3 year experiment was designed to study the immediate effects of organic amendment and the subsequent residue of organic amendments on plant production. The soil was planted with sugarcane, the BL variety and treated with organic amendment of (1) Farm Yard Manure (FYM), (2) Sugarcane filter mud (filter mud), (3) Biochar made from sugarcane filter mud (filter mud biochar), (4) Sugarcane processing boiler ash (boiler ash) and (5) Without organic amendment as the control. These treatments were arranged in a randomized block design with 4 replicates. The data was analyzed using one-way analysis of variance (ANOVA) with a 95% degree of significance. **Results:** The results showed that application of FYM, filter mud, biochar made from filter mud and boiler ash improved the soil fertility status of degraded land, as indicated by increasing soil organic C, Cation Exchange Capacity (CEC) and various plant nutrients. The improvements in soil fertility status were followed by increasing cane yield, as well as sugar content. **Conclusion:** It was concluded that by following three years of sugarcane planting, the filtered cake biochar and boiler ash consistently showed higher sugarcane production than other organic amendment treatments. Boiler ash showed the best potential for use as a soil organic amendment to improve soil physical properties and subsequently increase sugarcane production.

Key words: Degraded land, sugarcane, biochar, boiler ash, soil organic amendments

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Corresponding Author: Titiek Islami, Research Centre for Tuber Crop, Univerisity of Brawijaya, Malang, Indonesia Tel: +6281290084300

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

There are enormous areas of degraded land in Indonesia. In the Brantas watershed area of East Java, for example, from a total area of about 1.1 million hectares in the upper Brantas watershed, approximately 271 thousand hectares are in degraded or nearly degraded conditions[1]. The soils in these degraded lands have an effective depth of less than 30 cm, are stony and are very infertile. The soils have very low organic matter content (approximately 1% or less), low nitrogen (less than 0.1%), low phosphorus (available P less than 10 ppm) and few other plant nutrients[1]. The most common crop grown on these lands is cassava (*Manihot esculenta* Crantz) and also to some extent maize (*Zea mays* L.), which produce very low yields under these conditions. These plants are the only crops that can produce any yield on these degraded lands[2], so that the farmers stay afloat to plant these crops.

Lately, with increasing competition from agricultural crops on irrigated land, these lands are planted with sugarcane (*Saccharum officinarum* L.). This presented a good opportunity to increase the farmers' income from degraded land. However, due to a very low fertility status, the yield is very low (around 30-50 t ha^{-1})[3]. A common treatment to increase the land productivity of this soil is the use of soil organic amendments, such as compost or manure. The use of compost or manure is generally understood could improve soil fertility status and cane yield or sugar yield[3,4]. However, it has since been realized that these materials decompose rapidly, hence requiring application every year. Because of the rapid decomposition rate, the application of compost or manure requires significant capital input and, in some cases, farmers have difficulty to obtain the materials.

In the sugarcane industry, there are various byproducts that potentially could be used as a source of soil organic amendment. These include cane trash, sugarcane filter mud and boiler ash. Improvements to soil fertility status and the subsequent consequence of crop yield increase upon application of these materials have been extensively demonstrated[5-8]. In Indonesian, however, it seems that only sugarcane filter mud that has been used for improving soil fertility status as an organic soil amendment[7]. In fact, the availability of boiler ash in the sugarcane industry is no less than filter mud. It is estimated that milling of 1 t of cane will produce 20 kg of boiler ash, so that one sugarcane factory milling 700 t cane year^{-1} (with land area of 10,000 ha) will produce 14,000 t boiler[7] ash year^{-1}.

From the preliminary laboratory analysis, boiler ash has a property similar to charred materials. These char materials, which are known as "Biochar" have been widely known as a very promising possibility for improving soil fertility status as organic amendment[9]. Biochar has reported to have positive effects on soil chemical properties[10,11], soil physical properties[12,13] and soil biology activities[14]. Biochar also has additional advantages because it is resistant to decomposition, so yearly application is not necessary[9].

Based on these facts, this experimental study was aimed to explore the use of boiler ash from the sugarcane industry to increase the productivity of degraded land planted with sugarcane. The study was also used to explore the possibility of increasing the resistance of filter mud to decomposition by change this material to "Charred" materials.

MATERIALS AND METHODS

Study location: The experiments were carried out on farmers' field at the village of Wringin Anom, Blitar Regency, East Java, Indonesia from 2011-2014. The average soil depth of the field was less than 25 cm with approximately 10% gravel and/or stone on the soil surface. This soil is usually classified as *Entisols* and the properties of the soil are given in Table 1. The location has a distinct wet and dry season with an average annual rainfall of approximately 2000 mm. The rainy season begins around the middle of November and ends in the early of March of the following year. The average daily temperature is 30°C, which varies from 25°C at night to approximately 32°C in the afternoon.

Experimental treatments: The experimental treatments consisted of 4 organic amendments and 1 control without organic amendment. The organic amendments were (1) Farm Yard Manure (FYM), (2) Sugarcane filter mud (filter mud), (3) Biochar made from sugarcane filter mud

Table 1: Chemical characteristics of soil and organic amendments

Soil/organic amendments	pH	C (%)	N (%)	P*	K*	CEC (cmol kg^{-1})
Soil	6.92	1.08	0.09	7.59	1.22	11.75
Farm Yard Manure (FYM)	6.54	17.28	1.23	0.39	0.42	10.67
Sugarcane Filter Mud (SFM)	7.04	19.28	0.83	1.26	0.76	14.26
Sugarcane filter mud biochar	7.65	29.88	0.08	2.06	1.28	24.65
Sugarcane boiler ash	7.44	26.73	0.08	1.96	1.37	17.64

*P and K in the organic amendments are in %; while P and K in the soil is expressed in ppm and cmol kg^{-1}

(filter mud biochar) and (4) Sugarcane processing boiler ash (boiler ash). These treatments were arranged in a randomized block design with 4 replicates.

The FYM was collected from the farmers at the village of Wringin Anom; the sugarcane filter mud and sugarcane boiler ash were obtained from the Krebet sugarcane factory, Malang, Indonesia. Biocharwas made by the Sukartono *et al.*[15] method. Filter mud biochar and boiler ash were applied at an application rate of 10 t ha^{-1}, whereas, FYM and filter mud were applied at a rate of 20 t ha^{-1}. All organic amendments were mixed with the top soil at the same time as soil preparation.

Sugarcane cuttings (about 40 cm length) of BL variety (a high yielding Indonesian sugarcane variety) were planted with a distance of 1.25 m (between rows) in a plot of 10.0×10.0 m. The first cane (plant cane) was planted on 12 September, 2011 and harvested on 5 September, 2012. After the first harvest, the same cane was pruned (Known as "Ratoon cane") and harvested on 30 July, 2013. After harvesting the ratoon cane, the cane was again pruned (called the second ratoon cane) and harvested on 16 June, 2014. All of the sugarcane plants were fertilized with the recommended fertilizer application of 100 kg ha^{-1} ammonium sulphate, 300 kg ha^{-1} urea, 300 kg super phosphate (36% P_2O_5) and 200 kg ha^{-1} KCl.

The data collected in this experiment were plant height, plant diameter, number of plant m^{-1} of row, cane yield and sugar content. Twenty randomly selected plants were used to measure plant height and plant diameter. Plant diameter was measured at an average height of 50 cm. The soil was sampled before experiment and after every harvesting event. The sampling was done by a zig-zag system to a depth of approximately 20 cm, after which the samples were combined according to relevant treatment. The composite samples were then processed for laboratory analysis. Undisturbed soil samples were taken for soil bulk density measurements and penetrometer resistance measurements to assess the physical changes within the soil in terms of plant root growth.

Laboratory analysis: The biochar was analyzed for its pH, organic Carbon (C) content, Nitrogen (N) content, Phosphorus (P) content, potassium (K) content and Cation Exchange Capacity (CEC). The pH of biochar was measured in a 1% suspension in de-ionized water which had been heated at about 90°C for 20 min and then cooled to room temperature. The pH was measured with a pH meter (Jenway 3305). Total C amount was analyzed with an ASTM D 3176[16]. The available P was measured with a spectrometer (Vitatron).

The soil analysis include soil pH, organic carbon content, Nitrogen (N) content, Phosphorus (P) content, Cation Exchange Capacity (CEC), soil bulk density, soil aggregation and soil water available. Soil pH was measured in a 1:2.5 ratio of soil solutions with de-ionized water using a pH meter (Jenway 3305). The Walkley and Black wet oxidation method was used to determine organic content[17]. Total N content was measured by the Kjeldhal method[17]. To measure the soil CEC, the soil was extracted with 1 M NH_4 acelate (buffered at pH 7.0) and the total exchangeable base were measured using an AAS (Shimatzu).

Soil bulk density was determined by the clod method,according to the soil survey manual[17]. To evaluate soil aggregation, 2.0 – 4.0 mm diameter of soil aggregates were put through a series of sieves (2.0, 1.5, 1.0, 0.5 and 0.25 mm) and then soil aggregate stability was measured by the wet sieving method, as described by Utomo and Dexter[18]. The result was expressed in the Mean Weight Diameter (MWD), which was calculated the following equation by Utomo and Dexter[18]:

$$\mathrm{MWD} = \sum\nolimits_{w=0}^{w=i} \mathrm{widi} \qquad (1)$$

In which MWD is the mean weight diameter of water stable aggregate and w and d denote the percentage (by weight) of the aggregate retained on the sieves with d diameter.

Available soil water was considered as the water held in the soil pores in between the matrix potential of -33 kPa (field capacity) with the matrix potential of -15 kPa (wilting point). The soil water content at these matrix potentials was determined using a pressure plate apparatus (Soil moisture equipment corp). Penetration resistance was measured on undisturbed soil samples at a matrix potential of -33 kPa with a laboratory penetrometer[18].

Statistical analysis: The data was analyzed with a one-way analysis of variance (ANOVA) at 95% degree of significance. If there was a significant difference the LSD test was performed[19] using the Minitab ver. 16 Software (Minitab Inc.).

RESULTS

Soil properties changes following organic amendments application: Changes in soil chemical properties, following the application of organic amendments, are presented in Table 2. The soil pH significantly increased ($p<0.05$) following

Table 2: Effect of organic amendments on soil chemical characteristics

	Soil chemical properties								
	After the 1st plant harvest			After the 2nd plant harvest			After the 3rd plant harvest		
Treatments	Soil pH	Total N (%)	Available P (ppm)	Soil pH	Total N (%)	Available P (ppm)	Soil pH	Total N (%)	Available P (ppm)
Farm yard manure	6.88[a]	0.11	7.90	6.92[a]	0.10	7.99	6.62[a]	0.10	7.99
Sugarcane filter mud	6.95[a]	0.09	8.50	7.02[a]	0.09	7.47	6.70[a]	0.11	7.47
Biochar from filter mud	7.29[b]	0.10	8.06	7.32[b]	0.12	7.65	7.42[b]	0.11	7.65
Boiler ash	7.26[b]	0.11	7.94	7.29[b]	0.12	7.86	7.29[b]	0.12	7.86
Control	6.94[a]	0.09	7.59	6.90[a]	0.09	7.59	6.70[a]	0.10	7.59
		NS	NS		NS	NS		NS	NS

Means followed by the same letter are not significantly different ($p>0.05$), NS: Not significant

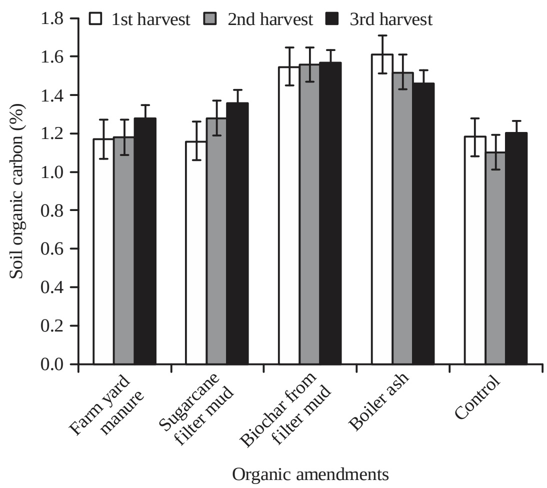

Fig. 1: Changes in soil organic carbon following the application of organic amendments
Standard bars represent Standard Deviation of relevant data

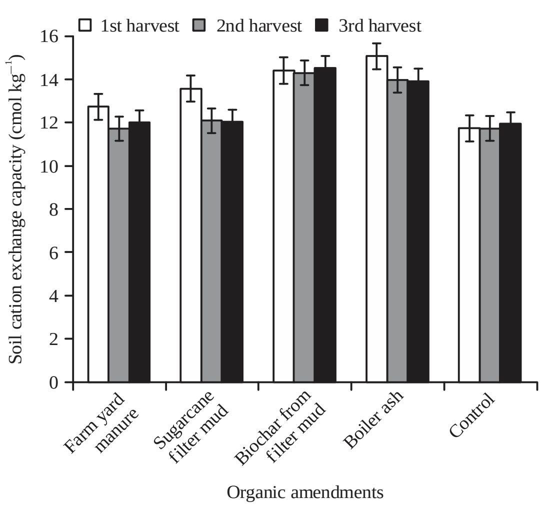

Fig. 2: Changes in soil exchange capacity following the application of organic amendments
Standard bars represent Standard Deviation of relevant data

the application of the organic amendments used in this experiment. Both the biochar from filter mud and boiler ash showed the highest increase in soil pH for three consecutive harvest periods. These increases were expected due to the liming ability of the biochar and the consequent boiler ash, which has the same properties as biochar (Table 1). The total soil N content did not increase throughout the experiment and this was expected given the low nitrogen content in the organic amendments used in this experiment (Table 1). The application of various organic amendments in this experiment also did not significantly ($p>0.05$) influence the soil available P (Table 2).

After the 3 harvest periods, soils that received organic amendments had a higher total soil Carbon (C) concentration (ranging from 1.17-1.61%) compared to the control (Fig. 1). However, it should be noted that the total soil C values were organic amendments type-dependent. At the end of the 1st harvest period, the addition of boiler ash and biochar from filter mud had significantly increased ($p<0.05$) the total soil C concentration, compared to the control treatment (Fig. 1). During the 2nd and 3rd harvests, the soil with boiler ash showed a slight decline in total soil C concentration, but not with the soil that received biochar from filter mud (Fig. 1).

The soil Cation Exchange Capacity (CEC) was found to increase following application of organic amendments (Fig. 2). The soil CEC was correlated to the soil pH and an increase in soil pH results in a higher soil CEC. The application of biochar from filter mud and boiler ash was showed higher soil CEC (14.5 and 15.06 cmol kg^{-1}, respectively), compared to the control (11.7 cmol kg^{-1}). It should be noted that the soil CEC in the boiler ash treatment showed a slight decline in soil CEC after the 3rd harvest period, while the soil CEC in the biochar treatment showed a relatively consistent value (Fig. 2).

Table 3: Effects of organics amendments on soil physical characteristics after harvesting plant cane (1st harvest) and ratoon cane (2nd and 3rd harvest)

	Soil physical properties					
	After the 1st plant harvest		After the 2nd plant harvest		After the 3rd plant harvest	
Treatments	Soil aggregation mean weight diameter (mm)	Available water (%)	Soil aggregation mean weight diameter (mm)	Available water (%)	Soil aggregation mean weight diameter (mm)	Available water (%)
Farm yard manure	1.25[ab]	15.75[b]	1.28[a]	13.64[a]	1.48[a]	15.69[a]
Sugarcane filter mud	1.36[ab]	14.96[ab]	1.30[a]	14.05[a]	1.36[a]	14.65[a]
Biochar from filter mud	1.58[b]	16.72[b]	1.78[b]	16.90[b]	1.72[b]	16.90[b]
Boiler ash	1.61[b]	16.44[b]	1.79[b]	16.95[b]	1.82[b]	16.90[b]
Control	1.15[a]	12.32[a]	1.20[a]	12.32[a]	1.36[a]	13.38[a]

Means followed by the same letter are not significantly different (p>0.05)

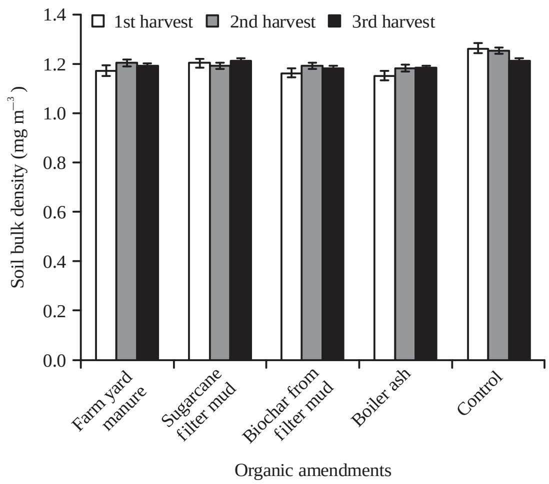

Fig. 3: Changes in soil bulk density following the application of organic amendments

Standard bars represent Standard Deviation of relevant data

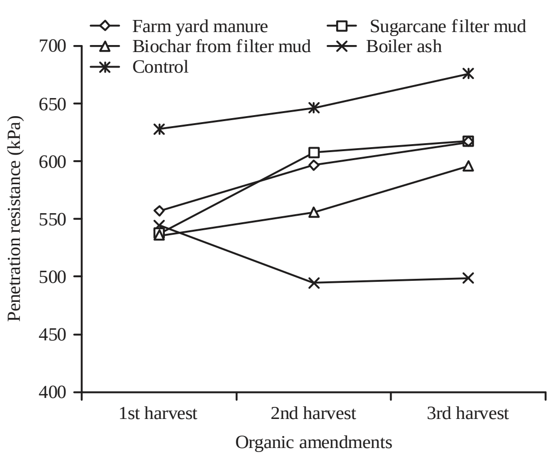

Fig. 4: Changes in soil penetration resistance

The effects of various organic amendments on soil physical changes are presented in Table 3. The application of organic amendments significantly increased ($p<0.05$) the soil aggregation and soil available water content (Table 3), subject to the different types of organic amendments used in the experiment. Both biochar from the filter mud and the boiler ash showed the highest soil available water content, compared to the other treatments.

The analysis of variance (ANOVA) showed that the type of organic amendments used in this experiment did not significantly influence the soil bulk density although soil that received organic amendments tended to have lower soil bulk density, compared to the control treatment (Fig. 3). Interestingly, the application of organic amendments significantly influenced the penetration resistance ($p<0.05$). The soil without organic amendments had the highest soil penetration resistance and the application of various organic amendments lowered the soil penetration resistance (Fig. 4). The application of boiler ash gave the lowest soil penetration resistance (498-544 kPa), compared to the other organic amendments (535-617 kPa).

Sugarcane growth and yield following organic amendment application: As expected, the application of organic amendments improved sugarcane growth (Table 4). The application of organic amendments did significantly increase ($p<0.05$) plant height in this experiment (2.25-2.30 cm), compared to the control treatment (1.85-1.95 cm). Similar to the effects of organic amendments on plant height, the stem diameter were also higher in plants receiving organic amendments (4.05-5.45 cm,) compared to the control treatment (3.50-4.35 cm) (Table 4). Throughout the three harvest periods, the organic amendments only significantly increased ($p<0.05$) the number of plants per row prior the second harvest period (Table 4).

The sugarcane yield following the three harvest periods were significantly influenced ($p<0.05$) by the application of organic amendments (Fig. 5a). In the first harvest period, the application of farm yard manure gave the highest yield

Table 4: Effects of organic amendments on the growth of the plant-cane and ratoon-cane

	Organic amendments								
	1st harvest			2nd harvest			3rd harvest		
Treatments	Plant height (cm)	Stem diameter (cm)	No. of plants per row	Plant height (cm)	Stem diameter (cm)	No. of plants per row	Plant height (cm)	Stem diameter (cm)	No. of plants per row
Farm yard manure	2.45^{c}	5.45^{b}	12.2	2.35^{b}	3.66^{ab}	11.2^{b}	2.17^{b}	4.76^{b}	11.3
Sugarcane filter mud	2.25^{b}	5.26^{b}	11.6	2.38^{b}	4.05^{b}	11.0^{b}	2.24^{b}	5.05^{bc}	11.0
Biochar from filter mud	2.36^{b}	5.05^{b}	10.8	2.56^{c}	5.15^{c}	11.2^{b}	2.36^{b}	5.20^{c}	11.1
Boiler ash	2.20^{b}	5.00^{b}	11.2	2.60^{c}	4.95^{c}	11.1^{b}	2.30^{b}	5.00b^{c}	11.2
Control	1.95^{a}	3.50^{a}	11.9	1.85^{a}	3.35^{a}	9.5^{a}	1.87^{a}	4.35^{a}	10.5
			NS						NS

Means followed by the same letter are not significantly different (p>0.05), NS: Not Significant

(84.7 t ha^{-1}), compared to the other organic amendment treatments (64.8-78.8 t ha^{-1}). This increase however, only occurred in the first harvest period. In the second and the third harvest periods, the farm yard manure application did not give the highest yield, compared to the other treatments (Fig. 5a). There was a decline in the sugarcane yield on the farm yard manure treatment, from 84.7 t ha^{-1} in the first harvest, to 58.7 and 68.8 t ha^{-1} in the second and third harvests, respectively. The highest total yield from all three harvest periods was achieve by the application of boiler ash (238 t ha^{-1}), while the biochar treatment had a total yield of 229 t ha^{-1}.

The application of organic amendments in this experiment significantly increased ($p<0.05$) the sugar content (Fig. 5b) and consequently the total sugar yield (Fig. 5c), compared to the sugarcane without any organic amendments. The highest sugar content measured in every harvest period was recorded in the biochar and the boiler ash treatments (average sugar content of 7%), compared to the other organic amendments (average sugar content of 6%). The total sugar yield in this experiment was significantly improved ($p<0.05$) by the application of organic amendments, with the biochar treatment giving the highest total sugar yield (within three harvest period) of 16.3 t ha^{-1}.

DISCUSSION

Improvements in soil properties following the application of organic amendments: The application of various organic amendments in this experiment did not directly increase the soil nutrient content, notably N and P. These findings contradict the results of organic amendment applications reported by Singh *et al.*[20] and Shukla *et al.*[21]. Both reports found an increase in soil N and P content following farm yard manure application to a sugar cane plantation. The lack of increase in soil N and P content in this experiment may be attributed to the low content of N and P in the organic amendments used in this study. Biochar from filter mud and boiler ash typically had low available N and P. Nitrogen in charred material has been reported to mostly be locked into a heterocyclic form[22], although some recent publications suggest it may be bioavailable to some extent[23,24]; this fraction increases as the temperature of pyrolysis increases[25,26], thus explaining the low N availability of biochar from both filter mud and boiler ash.

Unlike soil N and P content, there was an increase in both soil pH and soil organic matter content following the application of the organic amendments used in this experiment. The application of biochar from filter mud and boiler ash increased the soil pH, as expected. This phenomenon suggests that boiler ash a liming capacity that increases soil pH in an acid soil and was similar to the finding of Masulili *et al.*[27] and Pagiu *et al.*[28]. Both biochar from filter mud and boiler ash gave the highest increase in soil organic matter content throughout the three harvest periods. This increase was due to the higher content of recalcitrant carbon in both organic amendments. This finding showed the potential of boiler ash to be characterized as biochar. The increase in soil organic matter content could influence the soil physical properties and improve sugarcane growth.

The application of various organic amendments in this trial increased the soil available water content and soil aggregation (Table 3). The increase in soil available water content was expected, since the organic matters added this experiment increase soil water holding capacity and soil moisture. The results in Table 3 show that biochar from filter mud and boiler ash have the highest soil available water content. Similar results on increase water content following biochar application in sugar cane plantation were also reported by Chen *et al.*[29]. Biochar is characterized as a porous material and thus would increase water absorption and water storage in the soil[28,29].

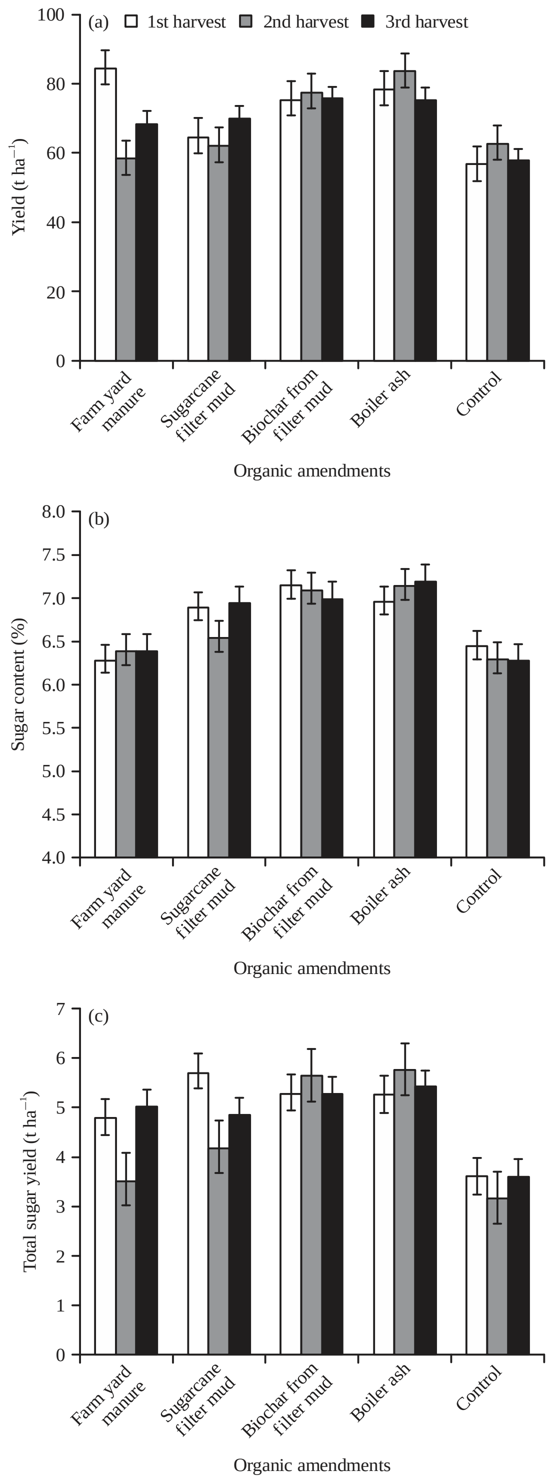

Fig. 5(a-c): (a) Sugarcane yield, (b) Sugar content and (c) Total sugar yield following the application of organic amendments

Standard bars represent Standard Deviation of relevant data

Unlike the results reported by Pagiu *et al.*[28], who found that the application boiler ash reduced the soil bulk density in a podzolic soil, the application of boiler ash and biochar from filter mud in this experiment resulted in a lower soil bulk density (Fig. 4). Interestingly, the soil penetration resistance was reduced following biochar and boiler ash application (Fig. 5). The soil used in this experiment was classified as *Entisol*, which consists of loose soil particles, resulting in a low soil bulk density. Although, the soil bulk density was low, the lack of soil aggregation in the control treatment (without organic amendments) could result in a higher soil penetration resistance. The application of organic amendments, especially biochar from filter mud and boiler ash did increase soil aggregation (Table 3). Soil aggregation is important in increasing soil porosity[30]. Therefore, application of organic amendments could lower soil penetration resistance and promote root proliferation to improve sugar cane growth.

Sugarcane growth and yield: The application of organic amendments (including biochar and boiler ash) to the *Entisol* soil alone increased the sugarcane growth, compared to control treatment (Table 4). Given that the organic amendments did not significantly increase the soil nutrient content (Table 2), the increase in plant growth may be associated with better nutrient retention from the amended soil. The sugarcane filtered mud biochar application has been reported to improve nutrient retention and availability in highly weathered soil[31,32]. In these experiments, boiler ash treatment showed the same growth rate to biochar treatment. Following, it can be inferred that boiler ash might have similar surface retention capacity as sugarcane filtered mud biochar. Further soil chemical analysis on the post-harvest soil is needed to confirm this suggestion.

Different responses regarding sugarcane yield were achieved when comparing the sugarcane yield of the three harvest period. The farm yard manure treatment only showed higher yield for the first harvest period and showed a decline in sugarcane yield in the first ratoon (2nd harvest) and second ratoon (3rd harvest). Unlike the farm yard manure treatment, the biochar and boiler ash treatment were able to maintain a relatively stable yield (Fig. 5a). Biochar has been acknowledge to be recalcitrant, thus exhibiting a positive effect on the soil nutrient retention[10,32] would make more nutrient available to plants during the first and second ratoon period, giving a stable sugarcane production.

Similar to the sugarcane yield, the sugar content of biochar and boiler ash treatments also showed higher total sugar yield, compared to other treatments (Fig. 5c). Paigu *et al.*[28] also reported a higher total sugar yield of sugarcane following the application of boiler ash. The increase of total sugar yield could be explained by the ability of biochar and boiler ash to maintain soil water content to produce higher sugar content[29]. The results from this experiment also confirm the possibility of using boiler ash as an organic amendment to improved sugarcane production in tropical soils.

CONCLUSION

Biochars produced from filtered mud, as well as boiler ash, were able to improved soil properties and sugarcane yield. The low nutrient content in biochar and boiler ash did not directly contribute to the increased plant yield. However, the application of these amendments improved the soil physical properties and created conditions favorable to sugarcane growth. When added to nutrient poor *Entisol* soil, biochar and boiler ash increased the soil water and nutrient retention and subsequently, lowered the soil nutrient losses. Therefore, by maintaining the soil water content available to plants, these amendments increase the total sugarcane yield. The results in this experiment showed the potential of boiler ash to be used as a soil amendment to improve sugarcane yield.

SIGNIFICANCE STATEMENTS

This study discovers the possible uses of sugarcane industrial waste, in particular boiler ash, as soil amendments. This study will assist farmers and the sugarcane industry to maximize the use of organic waste products for sustainable agricultural production.

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