Utilization of the trash biochar and waste of sugarcane to improve the quality of sandy soil and growth of sugarcane

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Abstract. An abundance of sugarcane trash (ST) can be converted into soil amendment to improve soil quality. Pot research was carried out in Malang, East Java from October 2013 to October 2014. The research aimed to study changes in the properties of sand-textured soil due to the application of trash biochar and other sugarcane wastes, as well as its effect on sugarcane growth. The study was arranged in a randomized block design with six treatments and three replications. Treatment includes: 1) ST biochar 10 t ha⁻¹; 2) boiler ash 10 t ha⁻¹; 3) ST compost 10 t ha⁻¹; 4) ST biochar 5 t ha⁻¹ + ST compost 5 t ha⁻¹; 5) boiler ash 5 t ha⁻¹ + ST compost 5 t ha⁻¹; and 6) control (without soil amendment). The treatments improved the physical and chemical properties of sandy soil, namely bulk density, total porosity, available moisture content, aggregate stability, organic-C, total-N, available-P, exchangeable-K, and CEC. However, the improvement of this soil did not affect the growth and yield of sugarcane. Further research is needed to study the effect of residues from the application of biochar on ratoon sugarcane, and research on sugarcane development land.

Keywords: soil amendment, soil physical-chemical properties

1. Introduction
In sugarcane cultivation (*Saccharum officinarum* L.), at the time of harvest, there is an abundant amount of sugarcane trash (ST); which is about 6-8 t ha⁻¹ [1, 2], even reaching 10-20 t ha⁻¹ [3]. The trash of sugarcane after harvesting achieve 14% compare to stem production [4]. If sugarcane productivity in Indonesia reached 85 t ha⁻¹, then there are 11.9 t ha⁻¹ unused trash leaved on land.

In Indonesia, sugarcane trash is often seen as a waste that makes it difficult for farmers to manage ratoon, so that trash is burned and leaved ash. Not many use it as mulch or process it into compost [2, 5]. This abundant trash has the potential to be converted into biochar, which can be returned to the soil as soil amendment [6, 7]. In sugarcane industry, waste is produced by bagasse (28%) [8]. Usually,
bagasse is used for boiler fuel and leaved boiler ash 2-5% [9]. Boiler ash can be used to improve land quality.

Biochar which is a carbon solid material resulting from the process of biomass pyrolysis or combustion under limited oxygen conditions at temperatures of <700 °C, is known to be more efficient in improving soil quality compared to other organic soil amendments [10, 11]. Biochar is resistant to degradation by microorganisms so that the carbon will last longer (stable) in the soil. Therefore, biochar is very useful for maintaining soil carbon content [12].

Biochar is known to improve soil quality, both physical, chemical and biological characteristics of the soil [13, 14]. Biochar can increase water holding capacity thereby saving irrigation, supports fixation and retention of N thereby reducing the degradation of N and N2O emissions. The application of biochar can increase cation exchange capacity (CEC) and improve soil acidity so that fertility increased. The biochar application can increase the number of beneficial soil microbes. The application of biochar to the soil means storing C in the soil thereby reducing greenhouse gas emissions. Thus, the application of biochar can reduce farmers' dependence on fertilizer inputs, can increase plant growth and yield [15].

To increase sugarcane production as a raw material for support sugar factory in Indonesia, sugarcane development is also carried out on suboptimal land, including rain-fed dry land with sand-textured soil, which is usually of low soil quality. In terms of plants, in addition to the use of sugarcane seedlings in the form of cuttings, sugar cane cultivation is also developed using seeds from one bud (bud chip) which grown first in nursery before planted in the field. For the success of sugarcane cultivation with a planting system using bud chip seedlings in sandy soil, appropriate land management technology support is needed. This research aims to study changes in some properties of sand-textured soil due to the application of ST biochar, ST compost, boiler ash, and its combinations, also its effect on sugarcane growth using bud chip seedling.

2. Materials and Methods

2.1. Time and place
The study was carried out at the Experimental Station of Indonesian Sweetener and Fiber Crops Research Institute (ISFCRI) in Karangploso, Malang, East Java, Indonesia (7°54'26" S; 112°37'22" E; 522 m asl) in October 2013 to October 2014. Soil analysis was carried out at the Laboratory of Indonesian Legume and Tuber Crops Research Institute (ILETRI), and Soil Laboratory of Brawijaya University, Malang. The analysis of fourier transform infrared spectroscopy (FTIR) using Shimadzu FTIR-8400S was carried out in the Chemical Laboratory of Brawijaya University Malang, to identify the functional groups of chemical bonds contained in biochar. To find out the structure of biochar surface morphology, scanning electron microscopy (SEM) and Energy Dispersive X-Ray (EDX) analysis using Hitachi TM3000 were conducted at Bioscience Laboratory of Brawijaya University, Malang.

2.2. Preparation of research materials
The materials used were sandy soil, ST which was processed into biochar and compost, boiler ash, sugarcane seedlings from the bud chip of Bululawang (BL) varieties, NPK (15-15-15) fertilizer, ZA fertilizer, chemicals for laboratory analysis. The soil was taken from Asembagus-Situbondo (7°45'35" S; 14°15' E; 46 m asl) with several physical properties: bulk density 1.23 g cm\(^{-3}\), particle density 2.09 g cm\(^{-3}\), total porosity 40.90%, water content at pF 0, 2.5 and 4.2 were 41%, 35% and 5% respectively, sand, silt and clay fractions were 92.40%, 3.10% and 4.50 % respectively. Some soil chemical properties: pH (H\(_2\)O) 6.7, organic-C 0.61%, total-N 0.1%, P\(_{2}\)O\(_5\) (Bray-1) 5.17 mg kg\(^{-1}\). Exchangeable cation (NH\(_4\)OAc 1N pH7 extract) which is exchangeable-K 0.09 cmol kg\(^{-1}\), exchangeable-Na 0.35 cmol kg\(^{-1}\), exchangeable-Ca 5.57 cmol kg\(^{-1}\), exchangeable-Mg 0.48 cmol kg\(^{-1}\), cation exchange capacity (CEC) 11.54 cmol kg\(^{-1}\).

ST biochar was made with biochar drum kilns. The chemical properties of biochar used were pH (H\(_2\)O) 9.1, organic-C 35.2%, total-N 0.92%, total-P, total-K, total-Na, total-Ca and total-Mg (HNO\(_3\) + HClO\(_4\) extract): 2.75%, 3.19%, 0.28%, 1.60% and 0.39% respectively; CEC (NH\(_4\)OAc 1N pH7) 15.08
Compost is processed from trash composted with EM4 decomposer. The ST compost chemical properties were pH (H$_2$O) 7.60, organic-C 12.9%, total-N 0.97%; total-P, total-K, total-Na, total-Ca and total-Mg (HNO$_3$ + HClO$_4$ extract): 2.31%, 1.23%, 0.45%, 1.21% and 0.33% respectively; CEC (NH$_4$OAc 1N pH7) 22.83 cmol kg$^{-1}$. Boiler ash was obtained from Kebon Agung Sugar Factory Malang, with chemical properties: pH (H$_2$O) 9.2, organic-C 2.80%, total-N 0.08%; total-P, total-K, total-Na, total-Ca and Mg (HNO$_3$ + HClO$_4$ extract): 4.05%, 2.83%, 0.12%, 11.81% and 0.37% respectively; CEC (NH$_4$OAc 1N pH7) 13.63 cmol kg$^{-1}$. All soil amendments were crushed and sifted using a 2 mm diameter sieve.

Equipment used is pots, soil ring samplers, scales, and laboratory analysis equipment. The pot is made from a half drum, with 58 cm in diameter and 42 cm in height. The bottom of the pot is given 49 drainage holes with 1 cm in diameter. The inside of the pot was coated with silver plastic. The outside of the pot was painted in silver.

2.3. Methods
The study was arranged in a randomized block design with six treatments and repeated three times. Treatment includes: 1) ST biochar 10 t ha$^{-1}$; 2) boiler ash 10 t ha$^{-1}$; 3) ST compost 10 t ha$^{-1}$; 4) ST biochar 5 t ha$^{-1}$ + ST compost 5 t ha$^{-1}$; 5) boiler ash 5 t ha$^{-1}$ + ST compost 5 t ha$^{-1}$; and 6) control (without soil amendment).

The pot was filled with soil 30 cm high, weighing 95 kg. The pot was arranged according to the spacing of sugarcane in the field, with a distance between blocks/replications of 200 cm and the distance between pots of 130 cm. Each unit consists of 3 pots, arranged in a row so that the distance between planting holes was 60 cm. Soil amendments were mixed evenly with soil in pots according to the treatment, then incubated for 2 weeks under field capacity conditions.

Nurseries begin 3 months before planting, using bud chip which was sown in sand + soil media + manure (1:1:1), and continue in the nursery tray until ready to be planted. The sugarcane seedlings were chosen uniformly, then planted 1 seedling in the middle of each pot, with a depth of the stem base 10 cm from the ground.

Two weeks after planting, fertilization was carried out using NPK (15:15:15) 600 kg ha$^{-1}$, in holes 10 cm from the base of the plant as deep as 10 cm. The second fertilization was carried out at 3 months after planting, with 500 kg ha$^{-1}$ ZA fertilizer. After the second fertilization, the plants were piled up by adding 10 cm of soil. The pot was controlled from the interference of weeds and pests. The plants were harvested at the age of 11 months.

Soil samples for analysis took at the end of the incubation period (at planting), four months after planting (end of the growth phase), and at the time of the sugarcane harvest. The properties observed included the bulk density (cylinder method), total porosity (1 - (BD/PD) x 100%), available water content that is water content between field capacity (pF2.5 sandbox) and at permanent wilting point (pF4.2, pressure plate), aggregate stability (Vilensky method), organic-C (Walkey and Black), total-N (Kjehldahl), available-P (spectrophotometry), exchangeable-K (NH$_4$OAc 1N pH7, flame photometer), CEC (NH$_4$OAc 1N pH7, titration).

Observations of sugarcane included plant height, stem diameter (average of top, middle, and bottom), number and weight of harvested stems and potential sugar content. The data analyzed using Analysis of Variance (ANOVA) at the level of 5%, followed by Least Significance Difference (LSD) at the level of 5%.

3. Results and Discussion
The application of biochar and other wastes of sugarcane significantly affected the physical properties of sandy soil (Table 1). Compared to the control, application of soil amendments reduced the bulk density of sandy soil. The ST biochar combined with ST compost reduced soil bulk density more than other treatments. The porous characteristic and large specific surface of biochar caused low bulk density so that applied it into the soil caused lower soil bulk density [16, 17, 18, 19].
Porosity improvement is related to an increase in soil water holding capacity. The ST biochar and other sugarcane wastes application did not significantly increase the soil available water content at the end of the incubation period until the end of the growth phase, but they had a significant effect at the harvest. Increased availability of soil water content kept plants from water stress [20]. This increase in available water in the soil due to the presence of pores and biochar specific surface area as well as the presence of organic matter [17, 21, 22, 23], which improved aggregation and soil structure [24].

Table 1. The physical properties of sandy soil affected by trash biochar and waste of sugarcane.

| Treatment                           | Bulk density g cm⁻³ | Total porosity % | Available water content % volume | Aggregate stability Water droplet breaking point |
|-------------------------------------|---------------------|------------------|----------------------------------|-----------------------------------------------|
| **After incubation (at planting)**  |                     |                  |                                  |                                               |
| 1 ST biochar 10 t ha⁻¹              | 1.26 b              | 43.77 a          | 10.57                           | 11.50                                         |
| 2 Boiler ash 10 t ha⁻¹              | 1.33 a              | 40.45 b          | 10.09                           | 11.83                                         |
| 3 ST compost 10 t ha⁻¹              | 1.32 a              | 40.99 b          | 10.43                           | 12.50                                         |
| 4 ST biochar 5 t ha⁻¹ + ST compost 5 t ha⁻¹ | 1.30 ab | 41.94 b          | 11.06                           | 12.17                                         |
| 5 Boiler ash 5 t ha⁻¹ + ST compost 5 t ha⁻¹ | 1.29 ab | 42.21 ab         | 10.25                           | 10.50                                         |
| 6 Control (without soil amendment)  | 1.33 a              | 40.40 b          | 8.81                            | 10.00                                         |
| LSD 5%                              | 0.05                | 1.83             | ns                               | ns                                             |

| **At the end of the growth phase**  |                     |                  |                                  |                                               |
| 1 ST biochar 10 t ha⁻¹              | 1.25 ab             | 44.97 ab         | 15.55                           | 19.11 a                                       |
| 2 Boiler ash 10 t ha⁻¹              | 1.29 a              | 43.10 c          | 15.50                           | 15.67 b                                       |
| 3 ST compost 10 t ha⁻¹              | 1.26 ab             | 43.30 c          | 14.90                           | 13.33 c                                       |
| 4 ST biochar 5 t ha⁻¹ + ST compost 5 t ha⁻¹ | 1.24 bc | 44.65 b          | 15.93                           | 15.22 b                                       |
| 5 Boiler ash 5 t ha⁻¹ + ST compost 5 t ha⁻¹ | 1.20 c  | 46.12 a          | 14.96                           | 15.67 b                                       |
| 6 Control (without soil amendment)  | 1.29 a              | 42.22 c          | 12.71                           | 8.11 d                                        |
| LSD 5%                              | 0.05                | 1.25             | ns                               | 1.59                                          |

| **At harvest**                      |                     |                  |                                  |                                               |
| 1 ST biochar 10 t ha⁻¹              | 1.23 b              | 46.20 a          | 9.60 a                           | 19.22 a                                       |
| 2 Boiler ash 10 t ha⁻¹              | 1.22 bc             | 46.49 a          | 8.43 bc                          | 18.33 ab                                      |
| 3 ST compost 10 t ha⁻¹              | 1.18 bc             | 48.17 a          | 9.14 ab                          | 14.67 d                                       |
| 4 ST biochar 5 t ha⁻¹ + ST compost 5 t ha⁻¹ | 1.15 c  | 48.96 a          | 8.24 c                           | 15.89 c                                       |
| 5 Boiler ash 5 t ha⁻¹ + ST compost 5 t ha⁻¹ | 1.22 bc | 46.65 a          | 8.44 bc                          | 17.56 b                                       |
| 6 Control (without soil amendment)  | 1.32 a              | 41.29 b          | 7.35 d                           | 10.11 e                                       |
| LSD 5%                              | 0.07                | 3.04             | 0.88                            | 1.18                                          |

Notes: Numbers followed by the same letters in the same column are not significantly different from the LSD 5% test; ns: not significantly different; water droplet breaking point: the number of water droplets needed to destroy the soil aggregate φ1 cm.

The application of ST biochar, boiler ash, ST compost, and its combination significantly increased aggregate stability at the end of the germination phase and at harvest time (Table 1). The treatment of ST biochar showed better than other treatments. Physical factors (soil minerals), chemical factors (metal/soil bases and biochar functional groups) and biological factors (organic matter and soil microbes) interacted with each other to make aggregates increasingly stable [25, 26].

The application of ST biochar, boiler ash, ST compost and its combination significantly affected sandy soil chemical properties as shown in Table 2. The soil amendment's treatment increased soil organic-C levels at the end of the incubation period until harvest. The organic-C level was maintained higher than the control until harvest. The ST biochar, ST compost, and combination treatments had the best effect. The soil amendments treatment increased the soil total-N at the end of the incubation period.
until harvest time. In sandy soil, the ST biochar application increased N retention so it is not easily degraded out due to biochar anion exchange capacity [21, 27, 28, 29]. The application of soil amendments affected soil available-P at the end of the incubation period and growth phase, but not significantly affected at harvest time. Changes in soil available-P occurred due to changes in soil reactions, as well as the release of P from biochar [13, 30].

ST biochar and other amendments application increased the soil exchangeable-K level at the end of the germination phase until at harvest time as shown in Table 2. An increased in soil exchangeable-K can occur due to the direct influence of biochar application [28, 30]. Compared to the control, the tested soil amendments treatment maintained the soil exchangeable-K so that it was still higher at harvest time. The treatment only significantly increased sandy soil CEC at the end of the incubation period/at planting and growth phase. The biochar nature which has pores, high surface area, functional groups, and surface charge causes an increase in soil CEC [28, 31, 32].

The improvement of sandy soil physical and chemical properties was due to ST biochar character as shown in Figure 1. The FTIR spectrum shows the main functional groups contained in ST biochar: OH, NH (with wavenumber 3443.66 cm\(^{-1}\)), C=C aromatic, Carboxylic CO, C=O ketone (1627.81 cm\(^{-1}\)), aliphatic CH (1416.62 cm\(^{-1}\)), esters, phenol COC, C-OH (1087.78 cm\(^{-1}\)), and CH aromatic (875.62-793.65 cm\(^{-1}\)) [33, 34]. The surface of biochar containing O, H, OH if oxidized or hydrolyzed caused a negative or positive charge, so biochar has a cation exchange capacity and anion exchange capacity [29, 35]. The potential for negative charges from biochar also has the opportunity to bind to other materials in the soil such as soil particles, soil organic matter, and soil microbes. These interactions will boost soil aggregation improvement [36].

![Figure 1](image.png)

**Figure 1.** FTIR spectrum of ST biochar (left) and micrographic Scanning Electron Microscopy (SEM) with 500x magnification (right).

The scanning electron microscopy (SEM) results on ST biochar with 500x magnification showed the number of micropores with irregular surface shape [37]. Elements detected by energy-dispersive X-ray (EDX) analysis of the area blocked in SEM showed high carbon content of 68.81% by weight. Other elements detected were N, O, Si, P, S, K of 7.35, 14.28, 3.74, 0.10, 1.13, 4.61% by weight respectively.

The application of soil amendments had not significantly increased plant height, stem diameter, sugarcane weight and potential sugar content (Table 3). The analysis of variance indicated that the treatment of soil amendments only affected the harvested stems number. The highest increase in stem number by 26% was achieved in 10 t ha\(^{-1}\) ST compost treatment, did not significantly different from ST biochar 5 t ha\(^{-1}\) + ST compost 5 t ha\(^{-1}\) and ST biochar 10 t ha\(^{-1}\) treatments.
that the application of organic soil amendments to sandy soil has a significant effect on sugarcane [38].

weight did not increase significantly compared to controls; not following previous research which states sugarcane wastes application have not been able to significantly improve crop yields [17, 24]. Sugarcane

diameter*) average diameter of the upper, middle and lower stems.

Notes: Numbers followed by the same letters in the same column are not significantly different from the LSD 5% test; ns: not significantly different.

Table 3. Biochar and other sugarcane wastes effect on sugarcane growth in sandy soil.

| Treatment                     | Plant height | Stem diameter*) | Number of stems harvested | Harvested sugarcane weight kg pot⁻¹ | Potential sugar content % |
|-------------------------------|--------------|------------------|----------------------------|-------------------------------------|---------------------------|
|                               | cm           | mm               |                            |                                     |                           |
| 1 ST biochar 10 t ha⁻¹        | 234.17       | 25.69            | 10.67 ab                   | 9.50                                | 10.23                     |
| 2 Boiler ash 10 t ha⁻¹        | 235.39       | 24.68            | 10.00 bc                   | 8.81                                | 9.92                      |
| 3 ST compost 10 t ha⁻¹        | 228.67       | 24.87            | 11.33 a                    | 9.52                                | 9.73                      |
| 4 ST biochar 5 t ha⁻¹ + ST compost 5 t ha⁻¹ | 227.50     | 25.34            | 11.00 ab                   | 9.20                                | 9.94                      |
| 5 Boiler ash 5 t ha⁻¹ + ST compost 5 t ha⁻¹ | 236.61     | 25.60            | 10.00 bc                   | 9.36                                | 9.71                      |
| 6 Control                     | 228.89       | 23.94            | 9.00 c                     | 8.48                                | 9.32                      |
| LSD 5%                        | ns           | ns               | 1.15                       | ns                                  | ns                        |

Notes: Numbers followed by the same letters in the same column are not significantly different from the LSD 5% test; ns: not significantly different; *) average diameter of the upper, middle and lower stems.

Improvements in some physical and chemical properties of sandy soil due to ST biochar and other sugarcane wastes application have not been able to significantly improve crop yields [17, 24]. Sugarcane weight did not increase significantly compared to controls; not following previous research which states that the application of organic soil amendments to sandy soil has a significant effect on sugarcane [38].
Harvested sugarcane weight increased 12% compared to control in ST compost 10 t ha\(^{-1}\) and ST biochar 10 t ha\(^{-1}\) treatment. Previous research also reported that biochar from sugarcane bagasse applied to the soil increased yield and sugar content \[39\]. In this study, although there was an increase of 10% yield potential in ST biochar 10 t ha\(^{-1}\) treatment, it was not significantly different from the other treatments.

4. Conclusions
The application of ST biochar and other sugarcane wastes improved sandy soil physical properties, namely the bulk density, total porosity, available water content, and aggregate stability. The sandy soil chemical properties can also be improved, namely organic-C, total-N, available-P, exchangeable-K, and CEC. However, the improvement of soil physical and chemical properties did not significantly increase sugarcane growth and yield. Further research is needed to study the effect of residue from biochar application on ratoon sugarcane. Similarly, research needs to be done on the sugarcane development area.

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