Effects of residual biochar amendment on soil chemical properties, nutrient uptake, crop yield and N₂O emissions reduction in acidic upland rice of East Lampung

Jubaedah¹, Muhtar² and N L Nurida¹

¹ Indonesian Soil Research Institute, Bogor, Indonesia
² Central Sulawesi Assessment Institute for Agricultural Technology, Palu, Indonesia
E-mail: jhjubaedah@gmail.com

Abstract. Previous studies have been recognized that biochar addition to poor soil may lead to improve soil and crop productivity, also reduce greenhouse gas (GHG) emissions. However, the results were varied and the mechanisms were not clear. Two rates of rice husk (RH) and cacao shell (CS) biochar namely 0 and 15 t ha⁻¹ were applied to soil, to investigate the effect of RH and CS biochar on soil chemical properties, nutrient uptake, crop yield, and N₂O emissions reduction on upland rice at acidic soil of East Lampung. It was residual effect study; biochar was applied only in the first planting season of 2012. In addition, N₂O emissions from the soil were monitored with close chamber method. The result showed that 15 t ha⁻¹ CS biochar treatment was the best treatment, resulted 1.21 t ha⁻¹ yield. Meanwhile on 15 t ha⁻¹ RH biochar treatment was only 0.22 t ha⁻¹. However, no significance difference on both nutrient uptake and N₂O emissions among the treatments. N₂O emissions from RH and CS biochar treatment were reduced 26% and 21% compare to control. Our result proposed that CS biochar may use as soil amendment, to improve crop productivity and also to combat climate change.

1. Introduction
Acidic upland is one of the potential land resources in Indonesia. The total area of acidic upland is approximately 102.8 million ha across Indonesia (Kalimantan 39 million ha, Sumatera 29 million ha, Papua and Maluku 21 million ha, Bali and NTT 13.8 million ha) and about 56 million ha of land are suitable for agricultural practice. Due to its tropical condition, leaching and weathering occurs more rapidly in such soils. Common soil properties are: low pH, low CEC (dominance of Al and Fe oxides and exchangeable cations are lost due to leaching), and low SOC (more decomposition in tropical condition). In low pH soils (< 5), Mg²⁺ may still be abundant, but the high concentration of exchangeable Al³⁺ will suppress plants in accessing this Mg²⁺ [1]. Increasing Al³⁺ and H⁺ concentration in soil solution will inhibit plants in nutrients uptake. Al³⁺ is toxic for plants due to inhibition of root growth [2]. Therefore, acid soil possesses low nutrient availability and nutrients retention. This causes low crop production capability in acidic soils.

Biochar application to soil has been reported to reduce soil acidity, thus improve soil properties and plants nutrient uptake, also increase crop yield. Furthermore, biochar is renewable, simple technology produced, more recalcitrant than other soil amendments. Biochar properties are depending on its feedstock and charring condition, thus related to its beneficial effects when applied to soil. Biochar is
Carbon negative that produced in a pyrolysis process. Pyrolysis is chemical organic decomposition through heating; the process is without O2 or in limited access of O2. Biochar is from organic waste and can be one of the solutions in agricultural waste management problems. Biochar is high in C content (> 50%) and it is very stable organic material.

N2O is a potent GHG and potentially to decrease concentration of stratospheric ozone. Agriculture soils represent the main sources of N2O emissions. It’s about 84% of global anthropogenic N2O emissions [3, 4]. Nitrogen enters soil through fertilizer management (inorganic N fertilizer, organic fertilizer), livestock management (excreta), and also lowland rice management (saturated condition) are potential processes that involved in N2O production.

Biochar as a source of exchangeable cations seems to promote the growth activity and N2O reducing activity in denitrifying communities [5]. Other biochar characteristics that seem can alter the conditions for N2O productions are porosity, specific surface area, and redox properties (oxic and anoxic) that facilitate transfer electrons to denitrifying organisms [6]. Furthermore, liming effect of biochar in Tenosol and Acrisol explains suppressing of N2O production due to increase N2 reductase enzyme activity [6, 7].

Several studies on acidic upland have been done in East Lampung to prove biochar effectiveness on soil quality and crop production improvement [8, 9]. However, biochar investigation on its effectiveness to reduce N2O emissions from upland soil, while also hoping to improve soil quality and crop production is rarely been doing in Indonesia. The objective of the study was to investigate the effect of cacao shell and rice husk biochar on soil chemical properties, nutrient uptake, crop yield, and N2O emissions reduction on upland rice at acidic soil of East Lampung.

2. Materials and methods
The study was conducted at Taman Bogo Research Station, Taman Bogo Village, Purbolinggo Subdistrict, East Lampung, in earth coordinate position: 05°00’26” S; 105°29’03” E, from November 2013 to March 2014. The soil type in Taman Bogo is Typic Kanhapludults, with low pH range 3 to 4 in the upland system, and 4 to 5 in the lowland rice system. Taman Bogo research station is one of the representatives of degraded acidic upland ecosystems in Indonesia. The study was arranged in Randomized Complete Block Design (RCBD) with 5 replications. The treatments were control (no biochar added), 15 t ha\(^{-1}\) RH biochar and 15 t ha\(^{-1}\) CS biochar. The plant indicator in the study was *Oryza sativa* L. (Inpari variety), the plot size was 4x4 m, and with plant spacing was 20x20 cm.

The study was residual effect experiment of biochar as biochar application was done in the first planting season (first season of 2012). Biochar application was broadcasted after soil tillage with hand tractor, then mixed it hoe for 10 cm depth. After a week, two rice seed planted in a small hole which dug using wood stick. Biochar properties were presented at table 1. Fertilization was done in every season and not part of the treatment, namely N fertilizer (urea) in 200 kg ha\(^{-1}\) and NPK fertilizer (15:15:15) in 300 kg ha\(^{-1}\). Fertilizer was applied three times, at 0 days after planting (DAP), 21 DAP, and 45 DAP. First application of NPK was 50%, meanwhile Urea was 20%. The remaining fertilizer is evenly distributed for subsequent fertilization. Weed, insects, and diseases controlled using herbicides and pesticides when it was necessary.

Organic C content of each biochar qualifies for soil amendment standard required by Agricultural Ministerial Decree Number 1 of 2019 (Permentan 1/2019) which stated 15% at minimum, also complies with Biochar International Initiatives (IBI) class 2 (organic C content 30% ≤ 60% [20, 21]. It is also confirmed than cacao shell biochar was better than rice husk biochar. Several parameters (pH, organic C, organic N, C/N ratio, P2O5, and K2O) of cacao shell biochar was higher than rice husk biochar. Cacao shell biochar has higher pH that is one of most important characteristics as its soil amendment function. Improvement of soil properties due to biochar addition must be connected to improvement of crop productivity.
Table 1. Biochar chemical properties.

| Biochar               | pH  | Org C | Org N | C/N ratio | P<sub>2</sub>O<sub>5</sub> | K<sub>2</sub>O | Mg<sup>2+</sup> | Ca<sup>2+</sup> |
|-----------------------|-----|-------|-------|-----------|-----------------|-----------|-------------|-------------|
| Cacao shell biochar    | 9.7 | 35.14 | 1.03  | 32        | 0.87            | 2.24      | 3.39        | 4.08        |
| Rice husk biochar      | 9.0 | 33.07 | 0.64  | 48        | 0.42            | 1.58      | 3.87        | 4.08        |

Inpari was harvested at 110 DAP; one row of plant was eliminated to avoid plot edges (to prevent interaction between plot). Dry grain yield measured to get crop yield number. Shoots sampling were done when harvesting, collecting from composited sample plants. Shoots was dried under the roof, and then carried to soil laboratory. Plants are washed with deionized water to remove all the dirt and contaminant that may affect plant tissue analysis. Nutrient (N, P, and K) plant tissue content were analyzed using N-Kjeldal H<sub>2</sub>SO<sub>4</sub> wet digestion and HNO<sub>3</sub>-HClO<sub>4</sub> wet digestion, respectively [22].

N<sub>2</sub>O emissions from soil were monitored with close chamber method during rice planting season, the measurement was parted in four phases (three phases at fertilization and one phase at harvest phase). The chamber dimension was (100x15x23) cm. Each observation point took 30 second in interval when sampling. Before N<sub>2</sub>O sampling started, the chamber must swing to synchronize with the ambient air. N<sub>2</sub>O gas sampling were taken using a syringe, covered by silver paper and sealed by silicon, to avoid gas leaking. N<sub>2</sub>O gas concentration readings were measured at Greenhouse gas (GHG) laboratory of Agricultural Environment Research Institute in Pati, using Shimadzu Gas Chromatograph.

3. Results and discussion

3.1. Soil chemical properties before and after biochar addition

Soil type in Taman Bogo research station is classified as Typic Kanhapludult. In the tropics, Ultisols leached heavily [23]. Because of that condition, Ultisols possessed high acidity and relatively low of exchangeable cations (Ca<sup>2+</sup>, Mg<sup>2+</sup>, K<sup>+</sup>) and make them inadequate for agricultural land. However, Ultisols can be so productive and support agricultural with appropriate land management with fertilization and liming. The soil properties of Ultisols at Taman Bogo research station before biochar application described in table 2.

Table 2. Soil chemical properties before biochar treatment.

| Soil Characteristic | Unit       | Content of the parameters | Criteria      |
|--------------------|------------|---------------------------|---------------|
| pH H<sub>2</sub>O  |            | 4.39±0.21                 | highly acid   |
| pH KCl             |            | 3.85±0.07                 |               |
| Organic C          | %          | 1.03±0.12                 | low           |
| Ca<sup>2+</sup>    | cmol.kg<sup>-1</sup> | 1.56±0.09       | very low      |
| Mg<sup>2+</sup>    | cmol.kg<sup>-1</sup> | 0.36±0.02       | very low      |
| K<sup>+</sup>      | cmol.kg<sup>-1</sup> | 0.02±0.02       | very low      |
| Na<sup>+</sup>     | cmol.kg<sup>-1</sup> | 0.14±0.01       | low           |
| CEC                | cmol.kg<sup>-1</sup> | 5.72±0.52       | low           |
| Base saturation    | %          | 36.66±3.02               | low           |
| Al<sup>3+</sup>    | cmol.kg<sup>-1</sup> | 0.75±0.22       |               |
| H<sup>+</sup>      | cmol.kg<sup>-1</sup> | 0.19±0.02       |               |

Before biochar application, the soil reaction at the site showed very acidic. It was also connected with other properties such as organic C, exchangeable cations, CEC and base saturation that described as low in criteria. Thus, was high in soil acidity content. Low CEC, exchangeable cations, and base
saturation imply that nutrient retention is a problem in the soil. Humid tropical conditions have led to rapid weathering of soil parent material and soil organic decomposition [10]. It is why, generally, SOC content (without biomass management) in the tropics is low. These data of table 2, showed that Ultisol in Taman Bogo station require a big number of fertilizers, liming, and or organic matter.

Biochar application would be a scientific and justified solution for its kind of problem in humid tropic agriculture. Biochar proved to be recalcitrant, so that rapid decomposition in the tropics will not affected biochar quality. Furthermore, biochar ability to retain nutrients has also confirmed. In the study, after biochar application some of soil properties were showing improvement (table 3).

| Parameters          | Control       | RH biochar (15 t ha⁻¹) | CS biochar (15 t ha⁻¹) |
|---------------------|---------------|------------------------|------------------------|
| pH H₂O              | *3.85±0.23    | *3.93±0.18             | *4.32±0.09             |
| C                   | 0.72±0.17     | 0.85±0.24              | 0.67±0.11              |
| N                   | 0.06±0.01     | 0.07±0.022             | 0.06±0.009             |
| C/N                 | 11.93±0.65    | 12.2±0.79              | 10.86±0.39             |
| Total P₂O₅           | cmol kg⁻¹     | 26.33±2.9              | 27.6±3.42              |
| Total K₂O            | cmol kg⁻¹     | 5.16±0.53              | 4.93±1.25              |
| Available P₂O₅       | cmol kg⁻¹     | 26.25±7.5              | 31.43±8.17             |
| Ca²⁺                 | cmol kg⁻¹     | 0.37±0.29              | 0.43±0.24              |
| Mg²⁺                 | cmol kg⁻¹     | 0.12±0.09              | 0.12±0.06              |
| K⁺                   | cmol kg⁻¹     | 0.08±0.02              | 0.07±0.03              |
| Na⁺                  | cmol kg⁻¹     | 0.05±0.02              | 0.03±0.004             |
| CEC                  | cmol kg⁻¹     | 4.95±0.94              | 4.57±0.8               |
| Base saturation      | %             | 12.94±7.03             | 15.25±8.8              |
| Al³⁺                 | cmol kg⁻¹     | 1.85±0.44              | 1.55±0.39              |
| H⁺                   | cmol kg⁻¹     | 0.29±0.08              | 0.34±0.05              |

*mean±standard deviation

After biochar addition, soil pH was increased compare to control in both biochar treatments. This was a 4th season measurement (biochar application was in first season), approved that biochar effect on soil pH still appear after four planting seasons. Improvement on soil pH has also related to soil acidity (Al³⁺ and H⁺), soil CEC, exchangeable cations (Ca²⁺, Mg²⁺, K⁺) and base saturation. All those stated soil properties were also improved after cacao shell biochar applications in 15 t ha⁻¹ of rate. Meanwhile, response of rice husk biochar on K⁺ and CEC was not appeared.

Previous studies stated that response of biochar addition on soil chemical properties were varied based on the type of biochar feedstock, soil characteristic, type of application, and also plant indicator [11 - 13]. It has claimed that biochar has strong response on low fertility soil [14, 15]. Response of both biochar treatments on soil properties improvement were corroborated with the previous study. Cacao shell biochar and rice husk biochar were differed in acid neutralizing capacity (ANC). Cacao shell biochar was higher pH, CEC and ANC than rice husk biochar [9]. So that, cacao shell biochar has stronger response than rice husk biochar.

In the fourth season, response of biochar application on Al³⁺ was still clear, that both biochar affected Al³⁺ concentration. Previous study has proven that Al³⁺ concentration will peak at pH 4.2, and then reduced when pH increased [15]. In the study, both biochar applications at rate 15 t ha⁻¹ after four planting seasons still was able to reduce Al³⁺. Cacao shell biochar also appeared with stronger response on soil CEC than rice husk biochar. The same response as soil CEC also happened in base saturation.
However, base saturation on cacao shell biochar had improved also due to biochar application, 204% higher than control. Meanwhile, effect of rice husk biochar on base saturation was increased 18% compare to control.

3.2. Rice yield and nutrient uptake
Dry grain of upland rice with cacao shell biochar was higher than rice husk biochar treatment (figure 1). Over all, yield generated in rice husk treatment showed that has no effect on improvement rice yield. Among biochar treatments, rice yield on 15 t ha\(^{-1}\) rice husk biochar is the lowest yield. Even though, negative standard deviation showed that in control treatment some crops may not produce any yield. Totally, rice yield improvement due to cacao shell biochar application were 134% higher than control, despite of 131% lower of rice yield in rice husk biochar treatment.

![Figure 1](image)

**Figure 1.** Upland rice yield obtained after biochar treatments.

Apparent, soil properties improvement of rice husk biochar application cannot support crop growth, due to of low pH of the biochar. Al toxicity and low nutrient retention were factors involved in low productivity of acid soil. In the study, rice husk biochar application only slightly improved Al\(^{3+}\) and nutrient retention. Al\(^{3+}\) concentration at 15 t ha\(^{-1}\) rice husk biochar was reduced 16% and 46% at 15 t ha\(^{-1}\) cacao shell biochar application. Meanwhile, Mg\(^{2+}\) concentration was not improved in rice husk biochar treatment, Ca\(^{2+}\) was increased 16 %. On the other hand, exchangeable cations (Ca\(^{2+}\), Mg\(^{2+}\), K\(^{+}\)) concentration were improved due to 15 t ha\(^{-1}\) cacao shell biochar addition. These were increased by 224%, 250%, and 225% respectively. Different response on Al\(^{3+}\) concentration and exchangeable cations in both biochar treatments may attribute to rice yield. It is consistent with previous study; soil pH and Ca/Al ratio were significantly correlated to crop yield [9].

| Parameters | Unit | Control | RH biochar (15 t ha\(^{-1}\)) | CS biochar (15 t ha\(^{-1}\)) |
|------------|------|---------|-----------------------------|-----------------------------|
| N          | %    | 0.15±0.03* | 0.16±0.02*                  | 0.24±0.05*                  |
| P          | %    | 0.04±0.001  | 0.01±0.001                   | 0.012±0.004                 |
| K          | %    | 0.02±0.005  | 0.1±0.01                     | 0.15±0.05                   |
| Ca         | %    | 0.01±0.002  | 0.02±0.003                   | 0.05±0.008                  |
| Mg         | %    | 0.01±0.003  | 0.01±0.004                   | 0.03±0.004                  |

*mean±standard deviation
Total nutrient uptake due to biochar application had stated in table 4. Overall, the effect of nutrient uptake due to biochar application were low, excluding on total N and K of cacao shell biochar addition. Total N and K were increase 60% and 650% respectively in cacao shell biochar treatment. Thus, cacao shell biochar had better response on total nutrient uptake by crops than rice husk biochar addition.

3.3. Total N\textsubscript{2}O emissions and its variability

\textit{N}2\textsubscript{O} emissions measurement during upland rice planting can be seen in figure 2. Generally, biochar application caused lower total \textit{N}2\textsubscript{O} emissions in rice husk and cacao shell biochar application, 26 and 21% lower than control. It is consistent with the previous study that biochar reduced \textit{N}2\textsubscript{O} emissions from rice field with N fertilization [16]. However, clear mechanism of how-to biochar inhibited \textit{N}2\textsubscript{O} emissions are limited available. Previous research stated that \textit{N}2\textsubscript{O} inhibition could be attributed to effects of chemicals (ethylene) in the biochar on the activity of nitrification and denitrification [17].

However, effect of biochar to increase soil pH also important factor to reduce \textit{N}2\textsubscript{O} production in anoxic condition (saturated condition) [18]. Moreover, it causes a conversion of denitrification stoichiometry (product ratio \textit{N}2\textsubscript{O}/\textit{N}2) against \textit{N}2 after acid neutralization by alkaline biochar, increasing inhibition of \textit{N}2\textsubscript{O} reductase (the enzyme reducing \textit{N}2\textsubscript{O} to \textit{N}2) in acid soils. The study was in upland soil and with low to medium water content (figure 3), so that biochar effects on \textit{N}2\textsubscript{O} reduction may not really working because its environmental condition. Anaerobic condition is needed when denitrification occurred to produce \textit{N}2\textsubscript{O}. Moreover, soil pH increased due to biochar application was slightly improved, may less contributed to \textit{N}2\textsubscript{O} production process.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure2.png}
\caption{Total \textit{N}2\textsubscript{O} emissions among biochar treatment.}
\end{figure}

\textit{N}2\textsubscript{O} emissions were highly temporally and spatially variable. In daily measurement, number of \textit{N}2\textsubscript{O} emissions peak were four during crop cycle (figure 3). Those peak \textit{N}2\textsubscript{O} emissions correlated with N fertilizer application, meanwhile the fourth peak was end season measurement that may connected to soil temperature and water content. Soil temperature and water content at end \textit{N}2\textsubscript{O} measurement were relatively high. Also, the highest number of end measurement was at control treatment, indicated that environmental aspects (soil water and temperature) were more favorable than biochar to produce \textit{N}2\textsubscript{O} at after harvest measurement.
The result showed that CS biochar had stronger effect to improve soil chemical properties and crop yield productivity. CS biochar exhibited better properties than rice husk properties (mainly higher pH). Previous study showed that CS biochar bear acid neutralizing capacity also higher than RH biochar [9]. Apparently, CS biochar capacity to increase soil pH, thus to reduce Al$^{3+}$ is the main property that highlighted better result than RH biochar.

**Figure 3.** (a) N$_2$O emissions, (b) water content, and (c) soil temperature during upland rice crop cycle.
4. Conclusions
Cacao shell biochar quality was better than rice husk biochar quality. It is concluded that due to 15 t ha\(^{-1}\) cacao shell biochar application, soil chemical properties improvement was still available compare to 15 t ha\(^{-1}\) rice husk biochar treatment after four planting seasons of upland rice. Meanwhile, rice husk and cacao shell biochar application induced total N\(_2\)O emissions reduction during upland rice planting, 26% and 21% lower than control, respectively.

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