Biochar enriched with inorganic fertilizer for increasing fertilizer efficiency and soil improvement in acidic upland in East Lampung

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Abstract. The main function of applying biochar on acid mineral soil is to overcome soil acidity for optimizing the soil utilization. The high ability of biochar to retain nutrients can increase the efficiency of inorganic fertilizers. In the field, it can be reached by enriching biochar with inorganic fertilizers. The objective of study was to improve soil properties and inorganic fertilizer efficiency in degraded acid mineral soil in East Lampung. The study was conducted in 2018 at Taman Bogo Research station, Purbolinggo sub district, East Lampung district. The study used a randomized block design with 4 replications. Treatments tested were: 1) Cocoa shell Biochar (BC CS) + 100% Ponska dose (mixed), 2) BC CS + 50% Ponska dose (mixed), 3) BC CS + 100% Ponska dose (digged), 4) BC corn cobs (CC) + 100% Ponska dose (mixed), 5) BC CC + 50% Ponska dose (mixed), 6) BC CC + 100% Ponska dose (digged), 7) No BC+100% ponska dose (control). The parameters observed were the soil properties and crop yield. The results showed that BC CS was more effective in reducing soil acidity and yielded higher N, K and P significantly than BC CC. The biochar application can increase the K content up to 209-471%. Application a 50% Ponska dose only affected the soil K content. BC CC was better in improving soil physical properties than BC CC. The Ponska enrichment was more effective for BC CC application compared to BC CS although the highest yield was obtained in the BC CS application. The reduction of 50% Ponska dose decreased maize yield by 8.1% and 17%, but needed to be evaluated economically to choose profitable treatment.

1. Introduction

The potential of acidic upland in Indonesia for food crops is around 22.22 million ha [1] that can be utilized only if rehabilitation efforts have been carried out. The main problems of acidic upland that must be overcome is a high of soil acidity, a low of organic matter availability and a relatively high soil bulk density and a limited availability of water [2, 3]. Rehabilitation efforts can be carried out by providing soil amendment, including biochar, which is carbon-rich solid agricultural waste produced through the pyrolysis process [4].

The benefits of biochar on agricultural land have been widely proven by various studies specifically in increasing crop productivity, decreasing soil acidity and increasing soil retention capacity [4-10]. However, the effectiveness of biochar in improving soil quality is determined by the type of biochar feedstock, the technical production of biochar and the soil type on which biochar is
The results of the study using a meta-analysis concluded that biochar is more effectively applied to acidic, degraded soil and sandy-texture soils [12-13].

Another function of biochar that is very important in agriculture is its ability to retain nutrients [14-16]. In addition, biochar will reduce the leaching of PO$_4$-P, NO$_3$-N and NH$_3$-N because it is bound in the biochar cavity [17-19]. Further, nutrients will be released slowly and then be utilized by plants optimally [20]. The leaching of NPK macro nutrients is very detrimental to plants. The nutrient needs are not fulfilled so therefore that plants lack of nutrients. As a result, the use of inorganic fertilizers becomes inefficient and excessive, resulting in an increase in the need for inorganic fertilizers.

Biochar itself contains nutrients with high carbon content including NPK [11, 14, 20]. The addition of biochar is not only for improving the soil quality, but also for streamlining the use of inorganic fertilizers by binding nutrients in the biochar cavity. Therefore, it is not washed away by surface runoff. This study aims to improve soil properties and the efficiency of inorganic fertilizers used in degraded acidic upland in East Lampung.

2. Research methods

The research was carried out at the Indonesia Soil Research Station located in Taman Bogo Village, Purbolinggo District, East Lampung, which is located at the coordinates 05°00.406 'S; 105°29.405 'E. The altitude is around 300 m above sea level and the average rainfall is between 2,000-2,500 mm/year with Typic Kanhapludult soil types.

The research was carried out in December 2017-April 2018. The crop used were BISI18 variety maize which was planted with a spacing of 25 cm x 75 cm. The use of inorganic fertilizers was 300 kg/ha Urea and 200 kg/ha Phonska, while pest control was carried out as needed. The study was arranged using a randomized block design of 7 treatments and 4 replications, with a plot size of 15 m$^2$.

Biochar used was 10 tons/ha of cocoa shell and corn cob. Enrichment with NPK (Phonska) compound inorganic fertilizer was done by dissolving Phonska (according to treatment) with enough water and then mixed with part of biochar or about 10% dose of biochar. The treatments were:

1. Cocoa shell Biochar (BC CS) + 100% Phonska dose (mixed)
2. BC CS + 50% Phonska dose (mixed)
3. BC CS + 100% Phonska dose (digged)
4. Corn cobs biochar (BC CC) + 100% Phonska dose (mixed)
5. BC CC + 50% Phonska dose (mixed)
6. BC CC + 100% Phonska dose (digged)
7. No BC+100% Phonska dose (control).

The enriched biochar Phonska was incubated for 7 days to allow fertilizer to be stored in the biochar cavity. Furthermore, Phonska-enriched biochar was placed in the planting hole, while most of the biochar (90%) was spread on the soil. The parameters measured were soil chemical-physical properties (after application) and crop productivity (growth and yield). Biochar was analyzed in the Soil Research Institute's soil laboratory to find out its quality. The parameters of the chemical properties of biochar measured were pH of H$_2$O, organic C (ignition), Total-N (Kjeldahl), levels of P$_2$O$_5$, K$_2$O, CaO and MgO (wet ashing with HNO$_3$ and HClO$_4$). The results of the analysis can be seen in Table 1.
Table 1. Chemical properties of biochar of cocoa shell and corn cobs as the research material in Taman Bogo KP, East Lampung.

| Parameter | Unit | Cacao shell biochar | Corn cob biochar |
|-----------|------|---------------------|------------------|
| pH H₂O    |      | 9.7                 | 8.6              |
| C         | %    | 35.14               | 19.30            |
| N         | %    | 1.09                | 0.45             |
| P₂O₅      | %    | 0.87                | 0.03             |
| K₂O       | %    | 2.24                | 0.55             |
| CaO       | %    | 4.08                | 0.02             |
| MgO       | %    | 3.39                | 0.01             |

The parameters observed were: 1) soil properties: composite soil samples were taken after harvesting of maize in each plot and the measured parameters were pH (H₂O), CEC, C organic, N total, P available, P potential, exchanged cations (K, Mg, Ca), soil acidity (Al³⁺ and H⁺); while undisturbed soil samples were taken after harvesting to measure Bulk Density (BD) and available water pores (AWP), 2) crop parameters measured were plant height at 2: 4: 6: 8 weeks after planting (WAP), biomass weight and maize yield.

The data were analyzed statistically on the observed variables, using analysis of variance (ANOVA) with a confidence interval of 95%. To see the effect of the real difference from the variables due to the treatment and their interactions, Duncan's multiple distance test (DNMRT, Duncan New Multiple Range Test) was used, at the 95%, significant level (α = 5%). In addition, quantitative descriptive analyses were carried out for crop variables.

3. Result and discussion

3.1. Soil chemical properties
In the first planting season, cocoa shell biochar (BC CS) 10 t/ha, BC CS enriched by Phonska 100% and 50% were able to increase soil pH to 5.83-6.01. The feedstock of cocoa shell had a good influence on increasing soil reactions, to close to neutral. The biochar was also able to increase the organic carbon content, nitrogen, total P₂O₅ and K₂O, and P₂O₅ available (Table 2 and Figure 1). Corn cob biochar was also able to increase nutrient content but its effectiveness was lower than that of cocoa shell biochar.
Table 2. Soil chemical properties after one season biochar application (after maize harvested).

| Treatments                        | pH<sub>H₂O</sub> | C<sub>organic</sub>-%(%) | Ca<sup>2+</sup> | Mg<sup>2+</sup> | K<sup>+</sup> | CEC cmol(+)/kg | Al<sup>3+</sup> |
|----------------------------------|------------------|--------------------------|----------------|---------------|-------------|----------------|--------------|
| BC CS + 100% Phonska doze (mixed)| 5.83 a            | 1.46 b                   | 3.15 ab        | 1.03 a        | 0.30 a      | 9.05 ab        | 0.12 d       |
| BC CS + 50% Phonska doze (mixed)| 5.93 a            | 1.50 b                   | 3.01 ab        | 0.85 a        | 0.26 ab     | 9.73 a         | 0.05 d       |
| BC CS + 100% Phonska doze (digged)| 6.10 a         | 1.73 a                   | 3.60 a         | 1.03 a        | 0.30 a      | 8.94 abc       | 0.00 d       |
| BC CC + 100% Phonska doze (mixed)| 5.40 b            | 1.35 cb                  | 2.48 bc        | 0.40 b        | 0.17 b      | 7.83 c         | 0.34 cd      |
| BC CC + 50% Phonska doze (mixed)| 5.13 b            | 1.28 c                   | 1.69 c         | 0.21 b        | 0.18 b      | 8.27 bc        | 0.82 ab      |
| BC CC + 100% Phonska doze (digged)| 5.33 b           | 1.30 bc                  | 2.24 bc        | 0.25 b        | 0.21 ab     | 8.44 bc        | 0.64 bc      |
| Control (100% Phonska, No BC)    | 5.08 b            | 1.23 c                   | 1.91 c         | 0.21 b        | 0.05 c      | 7.82 c         | 1.09 a       |

Different letters indicate significant difference within one column (P<5%; DMRT's test. BC CS: biochar of cocoa shell; BC CC: biochar of corn cob.

The main limitation of management of acidic upland was the soil acidity reflected in the low pH and high Al<sup>3+</sup> content. Table 2 shows that in improving the chemical properties of the Taman Bogo field, cocoa shell biochar (BC CS) were more effective in reducing soil acidity compared to corn cob biochar (BC CC). It was reflected by the decrease of Al<sup>3+</sup> levels and the increase of Ca<sup>2+</sup> and Mg<sup>2+</sup> levels so that it had an impact on increasing pH. The research study in the same location found that the effect of cocoa shell biochar in overcoming soil acidity could last up to 5 planting seasons [16]. Mixing biochar with Phonska decreased the content of Al<sup>3+</sup> especially on corn cob biochar (dose of 100%). However, the mechanism cannot be explained yet.

The addition of cacao shell biochar significantly increased organic carbon content compared to the corn cob biochar and control. While organic carbon content in corn cob biochar addition was not significantly different from control. The difference of C-organic content was related to the total organic carbon content of biochar where the total C-content of biochar cacao shell reached 35.14% whereas the total C-content of corn cob biochar was only 19.30%. The mixing treatment of BC with Phonska had no effect on the organic carbon content, although it was suspected that mixing would stimulate root growth which would be an additional contributor to C-organic besides biochar.

The exchangeable cations such as Ca<sup>2+</sup>, Mg<sup>2+</sup> and K<sup>+</sup> in the soil added with cocoa shell biochar were much higher than those on the soil added with corn cob biochar. This was understandable considering that the content of these elements in cocoa shell biochar was much higher (Table 1). The application of cocoa shell biochar and Phonska biochar applied in digged provides the highest soil chemical properties. In the reduction of Al<sup>3+</sup>, it was proven that without biochar (control), the levels of Al<sup>3+</sup> were still more than 1 and other soil chemical properties were also at the lowest. This proves that the addition of cacao shell biochar was effective for rehabilitating acidic upland at KP Taman Bogo. The results of this study supported the results of previous studies on acidic upland [4, 16].
Figure 1. Total N and total K after one season biochar application.

Figure 2. Total K after one season biochar application.

Figure 3. Total P after one season biochar application.
Figures 1, 2, 3 and 4 show the responses of N, K and P to the addition of biochar and enrichment with Phonska. In general, the addition of cocoa shell biochar yielded significantly higher N, K and P levels than corn cob biochar. This was in line with the responses of cation-cation exchangeable (Table 2). The effect of the application of biochar was most evident in the total K-content, increasing from 361 to 471% and 209-308% respectively in the application of cocoa shell biochar and corn cob biochar compared to control. Several previous studies showed that the effectiveness of biochar on increasing K content was very significant [4, 11,14].

The enrichment of biochar with Phonska had no effect on the content of N and K in the soil after one planting season. Reduction of Phonska dose to 50% can be seen as an effect on the soil K content in the addition of cocoa shell biochar, but has no effect on the N content in the addition of both cocoa shell and corn cob biochar. The application of cocoa shell biochar had a significant effect on total P and available P. The application of corn cob biochar was less effective against total P-content but it is actually effective for P availability. The availability of P was in line with the increasing of soil pH where the ability of corn cob biochar in increasing pH was relatively low. Phonska’s biochar enrichment significantly increased P availability even though the 50% reduction of the Phonska dose had no effect on P-available.

3.2. Bulk Density and water available pores
The results of the soil physical properties (Bulk Density, BD and Water available pore, AWP) showed that corn cob biochar was better in reducing soil BD and increase the AWP (Table 3) compared to cocoa shell biochar. Soil BD reduced to less than 1 gr/cm² during the first plating season on soil with corn cob biochar. The results of the study regarding to the ability of biochar to reduce BD were still vary depending on the soil type and the feedstock of biochar applied. The previous study showed a significant effect of the application of biochar towards BD on sandy soil [21-22]. Some research found that application of biochar on sandy soil more effectively decreased BD rather than on soils with high clay content whereas a decrease of BD occurred after 500 days of application [10,20].
Table 3. Soil physical properties after one season biochar application (after maize harvested).

| Treatments                          | Bulk Density (g/cm³) | Water available pore (%vol.) |
|-------------------------------------|----------------------|------------------------------|
| BC CS + 100% Phonska doze (mixed)  | 1.12 ab              | 10.48 b                      |
| BC CS + 50% Phonska doze (mixed)   | 1.05 ab              | 10.58 b                      |
| BC CS + 100% Phonska doze (digged) | 1.04 ab              | 10.03 b                      |
| BC CC + 100% Phonska doze (mixed)  | 0.96 b               | 15.95 a                      |
| BC CC + 50% Phonska doze (mixed)   | 1.00 ab              | 13.80 ab                     |
| BC CC + 100% Phonska doze (digged) | 0.97 b               | 13.85 ab                     |
| Control (100% Phonska, No BC)      | 1.15 a               | 12.55 ab                     |

Different letters indicate significant difference within one column (P<5%; DMRT's test. BC CS: biochar of cocoa shell; BC CC: biochar of corn cob)

3.3. Maize height and yield

Eight weeks after planting (WAP), the maize height reached more than 200 cm, except the control (Figure 5). In general, at the age of 8 WAP, the growth of maize with biochar and 100% dose of NPK was better than other plants with other treatments. Direct application of Phonska (in digged) had a markedly better growth in the application of cocoa shell biochar. However, the application of Phonska affected a worse growth in adding of corn cob biochar. Phonska given as an enrichment of corn cob biochar supported better maize growth than no enrichment. Biochar with a Phonska dose of 50% was still able to support maize growth.

![Figure 5. Maize height at 2-8 weeks after planting (WAP) after applying biochar enriched Phonska.](image)

The maize biomass in the one planting season can be seen in Figure 6. The addition of cocoa shell biochar, with or without phonska enrichment, provided an opportunity to increase the dry biomass compared to corn cob biochar. The highest yield was obtained from cocoa shell biochar with Phonska 100% (given mixed or digged) which was 6.91 t/ha and 7.09 t/ha, respectively. The dry grain obtained from application of corn cob biochar with 100% Phonska doses were around 6.66 t/ha and 5.71 t/ha respectively for mixing with and without Phonska. It showed that the application of 100% Phonska can be applied by mixing or separating if cocoa shell biochar added. However, if corn cob biochar applied, the enrichment of 100% Phonska by mixed method was more profitable than the separated method.
Figure 6. Dry biomass after applying biochar enriched Phonska.

Figure 7. Dry grain after applying biochar enriched Phonska.

Different letters indicate significant difference (P<5%; DMRT's test).

Reduction of Phonska dose by 50% produced dry grain of 6.39 t/ha when mixed with cocoa shell biochar. It decreased by around 8.1% when corn cob biochar was added which only produced 5.39 t/ha or 17% lower. The cost efficiency should be considered in the case of yield reduction (around 50% of the cost of purchasing Phonska). Although the dry grain were 8.1% and 17% lower, but if economically it was more profitable, the enrichment biochar with Phonska can be a good alternative.

The dry biomass of corn cob biochar enriched with 50% Phonska was not different with control. The cocoa shell biochar application produced the highest of dry cobs and dried grain (Figure 7). Overall, cocoa shell biochar consistently improve the soil properties and maize yields. The corn cob biochar enriched by 100% Phonska was able to provide sufficiently high maize yields but it had not been able to improve the soil chemical conditions.

4. Conclusion
In the acidic upland at the Taman Bogo, the application of cocoa shell biochar was more effective in reducing soil acidity and increasing N, K and P levels on the soil compared to that of corn cob biochar. The cocoa shell and corn cob biochar was rich in potassium nutrients therefore the addition of these biochar was able to increase the soil K content to 209-471%. The reduction of Phonska (NPK) inorganic fertilizer dose by 50% only affected in increasing the K content but did not affect the soil N and P content. The application of corn cob biochar was better to reduce the soil bulk density and
increase available water pore compared to cocoa shell biochar. The enrichment of 100% dose Phonska (NPK) and inorganic fertilizer (NPK) was more effective when it was added to corn cob biochar compared to cocoa shell biochar although the highest yields were obtained in the cocoa shell biochar. The efficiency of 50% Phonska inorganic fertilizer was recommended as a dose which might reduce maize yield by 8.1% and 17%. Furthermore, a study on economic aspect should be considered in determining the best technology that provides more profit to the farmers.

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