Utilization of cacao shell biochar and compost to improve cayenne pepper (*Capsicum frutescens L.*) in acid upland

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Abstract. Acid upland is considered a potential area for horticulture crop such as cayenne pepper (*Capsicum frutescens L*). This study aimed to evaluate the effects of the use of cacao shell biochar and compost to soil properties and the productivity of cayenne pepper in acid upland. This research was conducted in Taman Bogo research station, Lampung Province, Indonesia in 2017. This research used a randomized block design with seven treatments and three replications. The treatments consisted of P0: control (no soil ameliorant and mulch), P1: biochar 20 t ha⁻¹, P2: P1+ mulch, P3: compost 20 t ha⁻¹, P4: P3+mulch, P5: biochar+compost (1:1) 20 t ha⁻¹, and P6: P5+mulch. The raw material of biochar was cacao shell, while compost was manure. The result showed that soil bulk density of biochar, compost, and a combination of biochar and compost treatment lower than control. Biochar with and without compost have soil water content higher than other treatments. Moreover, biochar with and without compost were increase pH, reduce exchangeable Al level, increase C and N content also increase cation exchange capacity (CEC) and base saturation. The use of biochar and compost had positive effects on plant height, the diameter of canopies, and crop yields.

1. Introduction

Increasing the production of horticultural crops, especially shallot and pepper is a priority program of the Ministry of Agriculture. These two commodities have become the basic needs of the Indonesian people, so the stock of commodities must continue to be available. To satisfy demand increasing, a lot of horticulture planted on suboptimal land as acidic dryland, where in general horticulture crops require a good condition of growth media. Small chili pepper plants can grow better in good condition of soil fertility, soil porous, sufficient of water availability, and free from nematode and wilted bacteria. In addition to that, good condition of soil aeration and drainage could support the optimal growth of cayenne pepper and avoid plant disease. Soil pH must be considered in planting cayenne pepper, soil pH of 5.5 to 6.5 is very good for plant growth. Soil pH higher than 6.5 causes plant chlorosis or stunts, and yellowing leaves, whereas soil pH lower than 5.0 experiences the same symptoms of calcium (Ca) and magnesium (Mg) plant deficiency or experiencing aluminum poisoning and manganese (Mn) [1].

Therefore, improvement efforts are needed to soil to be an ideal growing medium for horticultural crops such as chili, especially if the soil suffered degradation process. In Indonesia, the area of acid upland (pH <5) is around 108.7 million ha, with 62.6 million ha already identified as potential land for development as agricultural land [2]. Improvement in the characteristics of acid upland is a determining factor so that this potential can be used to support national production. These soils have the characteristics of low pH, low CEC, low exchangeable bases, low organic matter, and a
predominance of Fe-Al oxide minerals [3].

Acid upland has a natural limiting factor of acidity, which characterized by high Al saturation, that hinder plant productivity. The impact of Al poisoning in roots is inhibition of root formation or elongation [4], thus inhibiting water and nutrients absorption. Root cells will become stunted and brittle, root hairs will not form, and the root apex (root tip) becomes swollen and damaged [5]. Apart from that, some other typical constraints are average pH <4.5, high Al saturation, low macronutrient content, especially P, K, Ca, and Mg, and low organic matter content [6]. Most of the cultivated acid upland has undergone a land degradation process characterized by a decrease in soil organic matter content. Soils in subtropical and tropical regions due to subsistence agriculture, about 60-80% of soil organic carbon has disappeared [7].

The use of high doses of organic matter in horticultural crops is a common practice for farmers, organic matter that can be used is manure compost. Biochar, which is made from hard-to-weather organic matter and is widely available in the field, has not been widely used by farmers. Some research results on acid upland have shown a positive impact on biochar use in improving soil quality and plant productivity. charcoal biochar which has a high total C-organic content (> 4%) can increase soil organic matter content and play a role in improving soil physical and biological properties [8]. Other research on Ultisol in East Lampung District showed that the use of biochar waste from rice husk agricultural waste at a dose of 2.5 to 7.5 t ha⁻¹ improved soil quality. Soil acidity, CEC, and available water pores increased after biochar application for one growing season, and biochar application was also able to increase maize production [9].

Cacao shells which are agricultural waste can be processed into biochar with a high enough quality. cacao shells can produce biochar which is effective for agricultural land in increasing the productivity of maize and upland rice and overcoming soil acidity [10-12]. The yield of biochar application on plant productivity is highly dependent on the characteristics of the biochar properties, the dosage used and its ability to overcome the main problems of biochar being applied [13]. There are also many biochar ingredients from cacao shells in the field of the total area of 73,999 ha of cacao trees in Lampung, cacao shells production is 35,078 tons or has yield productivity of 860 kg ha⁻¹ [14]. This study aimed to evaluate the effects of the use of cacao shell biochar and compost to improve soil properties and increase the productivity of cayenne pepper (Capsicum frutescens L.) in acid upland.

2. Material and methods

The research was a plot-scale experiment, conducted on acid upland with a pH <5.0 at Taman Bogo research station, East Lampung District, Indonesia in 2017. The characteristics of the soil used for the experiment are presented in table 1.

The soil analysis results before treatment (table 1) showed that the acidic soil with 4.87 of pH H₂O extract and 4.04 of pH KCl extract, the low C-organic content of the soil was <1%, and the organic N content was also small only with average 0.13%. The C/N ratio of this soil has 14, (moderate) indicates that the soil organic matter is relatively stable.

Table 1 was also showed the indicator that the land in the research location lacks of soil chemical indicator, which is also indicated by the low cation exchange capacity, while Ca, Mg, and K, classified as very low. For base saturation is still classified as moderate, and the content of exchangeable Al and H on average <1% it is hoped that the Al problem can be solved by using organic materials (no need to use lime).

The soil analysis results before treatment showed soil density <1 g cm⁻³ indicates that the soil is not too dense, with soil porosity >50%. The pore proportion calculated based on the results of water content measurements at various pF levels showed that the proportion of fast drainage pores is 29.30% on average by volume. The proportion of slow drainage averages <5% by volume, while the water availability has 6.33% by volume.
Table 1. Soil chemical and physic properties before treatment.

| Soil chemical properties* | Analysis results | Soil physic properties* | Analysis results |
|---------------------------|------------------|------------------------|------------------|
| pH                        |                  | Bulk density (BD)      | 0.97             |
| H₂O                       | 4.87             | Particle density (PD)  | 2.32             |
| KCl                       | 4.04             | Total pore space       | 58.32            |
| Organic material          |                  |                        |                  |
| C (%)                     | 1.68             | pF1 (% volume)         | 45.10            |
| N (%)                     | 0.13             | pF 2 (% volume)        | 29.00            |
| C/N (%)                   | 14.46            | pF2.54 (% volume)      | 24.84            |

Exchangeable cation:

| Ca (cmol₉ kg⁻¹) | 3.66 | Pore drainage |
|-----------------|------|---------------|
| Mg (cmol₉ kg⁻¹) | 0.72 | Fast (% volume) |
| K (cmol₉ kg⁻¹)  | 0.16 | Slow (% volume) |
| Na (cmol₉ kg⁻¹) | 0.05 | Water availability (% volume) |

CEC (cmol₉ kg⁻¹) | 10.34
Base saturation (%) | 44.38
Exchangeable Al | 0.70
H⁺ | 0.32

*) Source: Dariah et al [23]

2.1. Research methods

The experiment was carried out using a completely randomized design with seven treatments and three replications in the plot area sized 5 x 4 meters, the treatments were: (1) P0: control (without soil amendment and mulch), (2) P1: cacao shell biochar dose of 20 t ha⁻¹, (3) P2: cacao shell biochar dose of 20 t ha⁻¹ + mulch, (4) P3: compost of manure at a dose of 20 t ha⁻¹, (5) P4: compost of manure at a dose of 20 t ha⁻¹ + mulch, (6) P5: mixed of cacao shell biochar and manure (1:1) dose of 20 t ha⁻¹, (7) P6: mixed of cacao shell biochar and manure (1:1) dose of 20 t ha⁻¹ + mulch. The indicator plant used was the Laskar variety of cayenne pepper.

2.2. Field implementation

Before sowing, border plants was carried out two weeks before around the experimental area. Border plants are intended as a biological pest control effort. In the experimental area a planting hole was made as deep as 20 to 30 cm. The beds were 1 to 1.2 m wide, 5 m long, 30 cm high, and 25 to 30 cm spaced. Furthermore, grooves and planting holes were made at a distance of 40 x 75 cm. In each bed, there were two rows of plants. Each treatment plot contained three beds, the distance between the treatment plots was about 50 cm.

Soil amendment was applied to the planting path of cayenne plants, with dosages according to treatment. To facilitate soil improvement application, biochar has been mixed with the soil from plot areas. Application was carried out one week after planting, meaning that the incubation period was carried out for one week.

Basic fertilizer was given according to the recommended level of fertilizer recommendations for chili plants [15] with 117 kg N ha⁻¹ (260 kg ha⁻¹ urea), 40 kg P₂O₅ ha⁻¹ (112 kg SP-36), and 131 kg K₂O ha⁻¹ (218 kg ha⁻¹ KCl).

Composite and undisturbed soil samples have been taken before treatments and soil samples after treatment has been taken one month before the second harvest (December 2017). Undisturbed soil sample was collected using ring sample with diameter 7.5 cm and height 4 cm at 20 cm soil depth. A composite soil sample was carried out using a soil auger with diameter of one inch on six sampling
point with 20 cm soil depth. Soil laboratory analysis (1) soil physic analysis as BD (bulk density), water content on pF 1; 2; 2.54 dan 4.2, (2) soil chemical properties analysis as pH (H₂O and KCl), Exchangeable cation, dan cation exchange capacity (CEC), C-organic, N, P and K, exchangeable Al and Al saturation, (3) plant growth and yield. Canopy width was measured the outer end of the tree canopy.

2.3. Data analysis
Data analysis for soil physic, chemical properties and plant growth and yield were analyzed using statistically analysis of variance (ANOVA). To find the effect of significant differences from variables due to treatment and their interactions, an LSD test was performed with α 5%.

3. Results and discussion
3.1. Impact of treatment on improving soil chemical properties

3.1.1. Soil acidity level. One of the main limiting factors for acid upland is high soil acidity, followed by levels of aluminum which can poison plants, high soil acidity also affects the availability of some aspects because aluminum elements bound it. Figure 1 shows the effect of treatment on soil acidity and exchangeable aluminum content. The best average increase in pH was achieved by P2 and P6 treatment with average pH > 5. Several previous studies have also shown the effectiveness of biochar in increasing soil pH. Soil pH in soil with a sandy clay texture with 5 t ha⁻¹ cocoa shell biochar can increase soil pH 0.51, and in sandy texture it can increase soil pH with 0.8 unit [16]. In another study, it was reported that the biochar pH of cocoa shell could reach 11 so it effectively increases soil pH [8].

The addition of biochar with or without manure is also useful in reducing interchangeable aluminum, the data in figure 1 shows that aluminum levels decreased drastically in the treatment of cacao shell biochar, while in the same dose the manure compost was not able to reduce exchangeable Al levels, the average value is almost the same as control. Cacao shell biochar has the ability to reduce soil acidity and aluminum content is an option to overcome the main limiting factors for agricultural development on the acid upland. Another study using rice husk biochar showed that biochar could reduce exchangeable Al levels up to 40.7 to 61.5% compared to without biochar [17].

![Fig 1](https://example.com/fig1.png)

**Figure 1.** Treatments effect for soil pH and exchangeable Aluminium

3.1.2. Soil organic C and N content. The land used for the experiment has undergone a process of land degradation, the results of soil analysis before treatment showed that the C-organic content was less than 1. The results of Oldfield [18] showed that the range of soil organic C content was optimal for plant growth in the range of 2-5%. In fertilized soil, 2% C-organic content can support growth and production, while in un-fertilized soil up to 4% C-organic content is needed, while there is a problem with water retention to 5% organic matter content is needed.

Figure 2 shows the effect of the treatment on the organic C and N content. Treatment of biochar and manure at a dose of 20 t ha⁻¹ accompanied by mulch use significantly increased C-organic levels. If the use of mulch does not accompany by mulch, the average C-organic content will still increase.
The C-organic content in the combination treatment of biochar and compost was also higher on average than in control. Besides biochar is high in C. Moreover, C in biochar is more recalcitrant in soil. Biochar resistance in the soil can be up to more than 1,000 years and can sequester carbon in the soil [19], so that biochar has a very long residual effect. Indigenous people in the Amazon have proven that they feed charcoal into the soil and to date (100-1,000 years later) the physical and chemical qualities of the soil are much better than the surrounding soil [20].

Increasing C-organic levels in P2 and P4 treatments were also followed by an average organic N content that was higher than other treatments. The role of mulch in maintaining N loss is quite significant, this is shown that the N content in the treatment without mulch (P1 and P2) is still not different from the control.

**Figure 2.** Treatments effect for soil C and N organic content

3.1.3. *Cation exchange capacity and base saturation.* The effectiveness of P2 and P4 treatments on improving soil chemical properties was also shown by changes in the CEC value, the average CEC value in P2 and P4 treatments > 11 cmol, kg⁻¹ (figure 3). The CEC score in the P1, P5, and P6 treatments given biochar was higher than the control. Based on the results of a literature study [10], it shows the effectiveness of biochar in increasing soil CEC, so that biochar can reduce the level of nutrient loss caused by the washing process, which is likely to occur on wet gravel land such as in the research location.

The highest base saturation also achieved P2 treatment followed by P6 treatment, both of which are treatments using biochar accompanied by mulch use. The use of manure compost at a dose of 20 t ha⁻¹ is not effective in increasing base saturation.

**Figure 3.** Treatments effect CEC dan Base Saturation
3.2. Impact of treatment on improving soil physical properties

3.2.1. Bulk density and total pore. The average bulk density (BD) ranged from 1.11 to 0.93 g cm\(^{-3}\), the highest BD was achieved by control treatment while the lowest was achieved by treatment P2. Although the average BD in other treatments was lower than control, the value was still > 1 except for treatment P1 which was still <1. The same thing happened to the application of 15 t ha\(^{-1}\) of biochar for three growing seasons, which decreased soil BD from 4.5 to 8.3% compared to without biochar [13]. This condition can occur because biochar is porous and has a low BD from 0.08 to 0.17 g cm\(^{-3}\) thus contributable to the decrease of soil BD [21].

The total pore ranges from 49 to 52% by volume. The highest average total pore was also achieved with biochar treatment with or without mulch. This can occur because the porosity of biochar which can reach 80% by volume helps in increasing soil porosity [22]. Another study states that soil porosity given by biochar increased (2.0 to 7.6%) during the three growing seasons [13].

![Figure 4](image_url)

Figure 4. Treatments effect for bulk density and total pore space

3.2.2. Water Retention and pore distribution. Figure 5 shows the distribution of pores, especially pores which play a significant role in supporting a suitable environment for plant growth, namely fast drainage pores, slow drainage pores, and available water pores. The average percentage of fast drainage pores which also acted as aeration pores in biochar accompanied by mulch was higher than in other treatments. However, the aeration pore percent category in all treatments was still relatively high (> 15% by volume), except for the P4 treatment whose value was 15%, which was in the moderate limit (10 to 15% by volume). The average slow drainage pore in all treatments was still very low. The average pore water available in all treatments was low.

![Figure 5](image_url)

Figure 5. Treatments effect for pore distribution

In soil texture dominated by clay such as in experimental locations, soil amendment treatment using biochar and manure not at a dose of 20 t ha\(^{-1}\) has no significant effect on water retention, it is
shown that the water content at various pF levels, namely pF 1, 2, 2.54 and 4.2 in table 2. In clay-dominated soils, the possibility of water retention is dominated by clay particles.

| Treatments | Water content (% vol.) | pF1 | pF 2 | pF2.54 | pF 4.2 |
|------------|------------------------|-----|------|--------|--------|
| P0         | 42.15a*)               | 32.53a | 27.64a | 20.85a |
| P1         | 48.04a                 | 31.56a | 27.64a | 18.50a |
| P2         | 38.46a                 | 28.16a | 24.60a | 17.60a |
| P3         | 42.09a                 | 31.44a | 27.33a | 19.09a |
| P4         | 42.82a                 | 34.10a | 30.23a | 21.17a |
| P5         | 39.56a                 | 30.97a | 26.96a | 19.81a |
| P6         | 38.12a                 | 28.98a | 23.38a | 17.77a |

*) the numbers followed by the same letter in different columns are not significant at LSD 5%

3.3. Plant growth and yield

The treatment of soil amendment had a significant effect on plant growth, indicated by the plant height at the age of 6, 8 and 10 weeks after planting. The treatments treated with biochar with or without compost also resulted in significantly higher plant height than the control. The use of mulch did not significantly increase growth, it was shown that plant height was not significantly different between treatments with and without mulch (table 3). The application of manure did not significantly increase plant growth, and the plant height was not significantly different from the control.

| Treatments | Plant height (cm) ages (weeks after plant) |
|------------|-------------------------------------------|
|            | 2  | 4  | 6  | 8  | 10 |
| P0         | 14.1a | 27.3a | 52.1b | 68.3b | 78.7b |
| P1         | 14.3a | 30.7a | 59.3a | 80.2a | 92.6a |
| P2         | 14.8a | 38.9a | 54.8ab | 75.8ab | 86.8ab |
| P3         | 14.8a | 29.4a | 56.6ab | 76.9ab | 89.2ab |
| P4         | 18.9a | 28.4a | 53.3ab | 72.3ab | 86.6ab |
| P5         | 15.4a | 30.1a | 57.8ab | 77.9ab | 92.1a |
| P6         | 13.9a | 28.3a | 56.2ab | 79.8a | 89.9ab |

* the numbers followed by the same letter in different columns are not significant at LSD 5%

Other plant growth parameters, namely canopy width, also showed an almost identical trend as plant height. Treatment of biochar with or without manure compost resulted in a larger average canopy width. Based on canopy width data, mulch cannot increase plant growth and even tends to decrease there may be a relationship (figure 6). The main use of mulch is shown to reduce evaporation and pest attack. When water is not a limiting factor and disease attacks can be controlled, mulch cannot function optimally.
Figure 6. Effect of treatment on canopy width.

Figure 7 shows the effect of treatment on small chili pepper production. Soil ameliorant treatment had a significant effect on the number of chilies per tree. The average number of fruits in the treatment given biochar with or without compost and compost treatment was higher than the control. The use of mulch also cannot increase the number of fruits produced. The average fresh fruit weight in biochar treatment with and without manure and manure treatment was also higher than in control.

Figure 7. Treatment effect on the average number of fruit per plant and fresh fruits.

4. Conclusions
The use of cocoa shell biochar is effective in overcoming the main limiting factor of acid upland, shown by its ability to reduce soil acidity and reduce exchangeable Al levels. The use of cocoa shell biochar at a dose of 20 t ha\(^{-1}\) also had a positive effect on other chemical properties, namely organic C and N content, and CEC and base saturation. Biochar treatment was also effective in improving soil physical properties, indicated by the lower average BD and higher aeration pores than other treatments. In clay-dominated soils, the use of biochar and compost did not significantly affect water retention. The treatment of soil ameliorant significantly affected plant growth. The average plant height in biochar treatment was higher than the control. The use of mulch is not effective in increasing plant growth. The average number of fruit and fruit production in soil ameliorant treatment (both in the form of biochar with or without compost, and compost at a dose of 20 t ha\(^{-1}\)) was also higher than control.

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