Carbon sequestration from bamboo biochar on the productivity of ultisols and soybean [Glycine max L.] plants

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Abstract. Soil carbon is very important in food security, ecosystems, and environmental health, especially in the context of global climate change. This study was to determine the effect of carbon sequestration from bamboo biochar on increasing the productivity of marginal soils in the second planting season planted with soybean [Glycine max L.]. This study used a completely randomized design with 3 replications in 5 treatments: A = 0.0% [0g pot\(^{-1}\)]; B = 0.5% [173g pot\(^{-1}\)]; C = 1.0% [348g pot\(^{-1}\)]; D = 1.5% [520g pot\(^{-1}\)] and E = 2.0 [693g pot\(^{-1}\)] of bamboo biochar. The results showed that carbon sequestration from bamboo biochar had a significant effect on the chemical properties of Ultisols, such as increasing pH, available P, organic C, total N, CEC, and Ca-exch and could reduce Al-exch, by 0.90 units, 2.50 ppm P, 1.12% C, 0.13% N, 5.48; 1.79 and 0.88 cmol\(\cdot\)kg\(^{-1}\), compared to controls and increase in soybean growth and NPK nutrient uptake in stems and leaves [3.57g N, 2.61g P, 4.64g K], also in roots [0.93g N, 1.03g P, 0.94g K], compared to controls. Carbon sequestration from bamboo biochar with 2% application can increase the productivity of marginal soil [Ultisols] and soybean [Glycine max L.].

Keywords: Bamboo biochar, Carbon sequestration, Soybean, Ultisols.

1. Introduction
Agricultural land in Indonesia is mostly marginal land that has low soil fertility and acid reactions such as Ultisols, Oxisols, and Inceptisols [1]. In Indonesia, the land type for Ultisols is quite extensive, namely 45.794.000 hectares. [2] The value of organic C Ultisols is low because the organic matter content is very small, then the supply of nutrients will be also low. But then the organic matter can still supply nutrients to plants. One of the efforts made is the addition of organic materials such as biochar as carbon reserves.

Biochar application can permanently increase soil carbon content [3] and reduce CO\(_2\) emissions from semiarid farmland [4]. Biochar is a stable form of charcoal that is produced by combustion at high temperatures and low in oxygen [pyrolysis]. Biochar has the potential to store carbon for a very long time [100 years in soil] by balancing the rate at which organic matter is added and the rate at which it decomposes and returns to the atmosphere as CO\(_2\). A large imbalance between the release of carbon into the atmosphere and the uptake of carbon by other compartments causes a continuous
increase in CO₂ in the atmosphere which is equivalent to a rate of 4.1*10⁹ tons of carbon per year [5-6].

![Diagram of CO₂ cycle and biochar sequestration](image)

**Figure 1.** Biochar sequestration

Based on the potential of biochar as carbon sequestration, bamboo is an alternative raw material for improving the quality of biochar. Bamboo biochar in the first planting season has been applied to Ultisols and corn plants, then planted with soybean plants in the second planting season. Soybean is an important food after rice and maize [6]. The purpose of this study was to determine the effect of carbon sequestration from bamboo biochar on the increase in marginal soil productivity in the second planting season of soybean [*Glycine max* L.].

2. **Material and method**

The research was conducted at the Warehouse and Soil Fertility Chemistry Laboratory, Soil Department of Agriculture, Andalas University, Padang, starting from April to November 2020.

2.1 **Experimental design**

This research investigated the residual effect of bamboo biochar, with 5 treatments: A = 0.0% [0g pot⁻¹]; B = 0.5% [173g pot⁻¹]; C = 1.0% [348g pot⁻¹]; D = 1.5% [520g pot⁻¹] and E = 2.0% [693g pot⁻¹], of bamboo biochar and applying 3 replications using a Completely Randomized Experimental Design.
2.2 Feedsequestration, biochar, and soil sampling
Bamboo Betung [Dendrocalamus asper] is obtained from smallholder plantations in Limau Manis, Padang, cutting 30 cm long and drying. The process of making biochar uses the principle of pyrolysis in a conventional method [drum] at a temperature of 400–500°C at ±45 minutes. Ultisols used for the experiment were taken as composite samples at a depth of 0-20 cm from the soil surface in the Experimental Garden of the Faculty of Agriculture. Furthermore, the soil sample was dried, mashed, then passed through a 2 mm sieve and stirred until it was homogeneous and put in a polybag of 12kg of absolute dry equivalent soil. Then the soil samples were mixed evenly with biochar with a dose according to the treatment in each study and water was added to field capacity and incubated for 15 days. After the incubation period, soil samples were taken for analysis in the laboratory, where the first soil sample is the sample from the first growing season when corn was planted, and the second after the production in the first planting season to determine the carbon sequestration of biochar in the soil and aims to be used for the second planting season planted with soybean plants.

2.3 Analysis of soil and plant
Soil analysis pH H₂O [1:1] by the Electrometric method, Al-exch by the Volumetric method, CEC, and K; Ca; and Mg-exch by the leaching of NH₄OAc pH 7 method and measured using AAS, available P by the Bray II Method, Organic C by the Walkley and Black method, total N by the Kjeldahl method. Whereas plant analysis plant height [cm], and plant nutrient content [N, P, and K] using the destruction method [7].

2.4 Statistical analysis
The statistical analysis has carried the software Statistix 8 and Microsoft Exel 2016 to analyze soil and plant samples. It submitted to an analysis of variance [ANOVA] and If the F test> F table, then the treatment results show a significant effect at the 5% level [*] and a very significant effect at the 1% level [**] of Duncan’s Test.

3. Results and discussion
The results of the analysis of soil chemical properties after incubation with bamboo biochar in the first and second planting season can be seen in Table 1. Based on the results of the variety of results, the effect of bamboo biochar was very significantly different on pH, Al-exch, available P, organic C, and CEC, and Ca-exch Ultisols, while not significantly different to total N, K, and Mg-exch Ultisols [Table 1A]. In Table 1B, it can be seen that the carbon sequestration of bamboo biochar has a significant effect on pH, available P, organic C, total N, CEC, and K-exch, and a decrease in Al-exch Ultisols, while it does not affect the K and Mg-exch Ultisols.

The increase in pH and organic C content due to the effect of carbon sequestration from bamboo biochar was 0.85 units and 1.61%, respectively compared to the first planting season of 2%. The visible effect of the effect of carbon sequestration from biochar is the decrease in Al-exch Ultisol from 0.91 cmol,kg⁻¹ until it is not measured, compared to the first planting season of 2%. Increasing pH and decreasing levels of Ultisol Al-exch caused an increase in available P levels of 1.36 ppm compared to the first planting season of 2%. This is because the biochar in the soil can function as a soil ameliorant for a long time. [8] Biochar in soil has a half-life of more than 1000 years. Biochar is also recalcitrant which is difficult to oxidize and is also a very stable compound, difficult to decompose by microbial oxidation in the soil [5].

The increase in pH causes a decrease in the Al-exch of the biochar residue from 2.74 cmol,kg⁻¹ to immeasurable [tu]. This is because the biochar structure can absorb Al. Provision of biochar can reduce the acidity [H⁺ and Al³⁺ ions] and increase soil pH and P. It can be seen that the effect of the residue of bamboo biochar causes an increase in available P of 2.50 ppm at 2% when compared to the control. The association between the surface of biochar and Al can take place during the first decade after the addition of biochar to the soil [9]. Biochar also has P which can survive in the soil [10]. Organic C content increased by 1.12% from the effect residue of 2% bamboo biochar, compared to the control, while the increase in total N from the residue of 2% bamboo biochar was 0.13%, compared to
the control. This is due to the carbon stability of biochar [Table 1B] and the influence of microorganism activity and carbon residue from the roots left in the soil [Table 1A], while biochar can also improve and increase the N of soil by supplying and holding nutrients in the soil [10]. Biochar has a high content of carbon with an aromatic carbon structure that is recalcitrant and potentially reduces greenhouse gas emissions [11]. In the second planting season, it can be seen that total N has decreased when compared to the first planting season. This is because N is mobile in the soil so it dissolves easily. Biochar can reduce this [8]. One of the properties of fertilizers containing N which is less useful is hygroscopic, volatile, and biodegradable [5]. Biochar can absorb NO$_3^-$ and NH$_4^+$ ions and reduce the rate of mineral and cation leaching in the soil.

Table 1. Effect of carbon sequestration from bamboo biochar on the chemical properties of Ultisols

| Treatments                  | Parameters                      | Controls | 0.5% Bamboo Biochar | 1.0% Bamboo Biochar | 1.5% Bamboo Biochar | 2.0% Bamboo Biochar |
|-----------------------------|---------------------------------|----------|---------------------|---------------------|---------------------|---------------------|
|                             | pH H$_2$O                        |          |                     |                     |                     |                     |
|                             | unit ppm % cmol.kg$^{-1}$         | A. Season I: Corn [Zea mays L.] |                     |                     |                     |                     |
| A. Season I: Corn [Zea mays L.] |                                | 4.17 c   | 4.19 c              | 4.25 b              | 4.27 b              | 4.40 a              |
|                             | Cation Acid                      | 2.97 a   | 1.60 b              | 1.37 bc             | 1.14 c              | 0.91 c              |
|                             | Available P                      | 5.22 c   | 5.26 c              | 5.37 c              | 5.71 b              | 6.17 a              |
|                             | Organic C                        | 0.68 b   | 0.90 b              | 1.31 ab             | 1.45 a              | 1.66 a              |
|                             | N total                           | 0.37     | 0.37                | 0.38                | 0.38                | 0.40                |
|                             | CEC                              | 10.95 b  | 11.75 a             | 11.75 a             | 11.86 a             | 11.97 a             |
|                             | Cation Base                      | 0.66     | 0.84                | 0.89                | 0.95                | 1.05                |
|                             | K-exch                           | 1.62 b   | 2.46 a              | 2.48 a              | 2.72 a              | 2.93 a              |
|                             | Ca-exch                          | 1.96     | 2.23                | 2.61                | 2.74                | 2.96                |
|                             | Mg-exch                          |          |                     |                     |                     |                     |
|                             | Duncan’s Test                     | **       | **                  | **                  | **                  | **                  |
|                             | CV [%]                           | 3.3      | 15.56               | 1.37                | 13.69               | 4.36                |

Note: The numbers in the same column followed by the same lowercase letters are not significantly different according to Duncan’s test at the 5% level. ns = non-significant; * = significantly different; ** = very different and tu = immeasurable.

Plant observations were carried out during the maximum vegetative period [8 weeks after planting] and the generative period [Figure 2]. Based on the various results, the effect of carbon sequestration from bamboo biochar was not significantly different on plant height [2A] and very significant on nutrient uptake stem + leaves and roots [2B] for soybean [Glycine max L.]. The effect residue of bamboo biochar could increase the height from 65.5 to 85.5 cm by 2% bamboo biochar application, compared to the control. This is strongly influenced by the biochar as a soil amendment [Table 1B] and the types of varieties used in the cultivation process. Variety plays an important role in the development of soybean on plant height which is determined by the yield potential of the cultivated variety. Plant genotypes play a bigger role in responding to environmental factors in the process of growth and development of soybean plants [12].
Application residue of 2% bamboo biochar is the best way to increase N, P, and K nutrient uptake, compared to control. Nutrient uptake of the soybean plant is in line with the increased availability of N, P, and K in the soil [Table 1B]. This is because these nutrients play an important role in supporting the growth and production of soybean plants and the role of biochar in nutrient retention needed by plants. [14]. The vegetative phase requires nutrients [N, P, and K] for vegetative growth such as roots, stems, and leaves while in the generative phase, nutrients are used as constituents for the fruit [15].

4. Conclusions
Carbon sequestration from bamboo biochar has a significant effect on the chemical properties of Ultisols such as increasing pH, available P, organic C, total N, CEC, and Ca-exch such as 0.90 units, 2.50 ppm P, 1.12% C, 0.13% N, 5.48; 1.79 and 0.88 cmol.kg$^{-1}$, compared to controls. Additionally, it can also reduce Al-exch and increase soybean productivity. Biochar has a very significant effect on the nutrient uptake on stems + leaves and roots.
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