The effects of Biochar and manure on some soil characteristics and growth of garlic \([\textit{Allium sativum} \, \text{L.}]\) on ultisols

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Abstract. Ultisol is a soil type having high clay content and low OM, therefore it has limited aeration and drainage. Generally, the soil is not conducive for plant growth, especially for tuber crops. Organic matter is known as a soil ameliorant because it can improve soil’s physical, chemical, and biological properties. Besides manure having widely used, another OM source is biochar which can stay for a long time in soil. This research was aimed to improve the soil properties of Ultisols and the growth of garlic \([\textit{Allium sativum}]\) by applying biochar and manure. The research was conducted using a pot trial with 9 treatments and 3 replications, the treatment units were allocated based on a completely randomized design \([\text{CRD}]\). The data have statistically analyzed the variance \([\text{F test}]\) and then continued using HSD at a 5\% level of significance. The results showed the highest soil moisture level was found on \(6:2:2\) and the highest level for OC was on \(7:2:1\) for soil:biochar: manure composition. The biochar and manure could improve soil moisture \([\text{by 37\%}]\) and organic carbon \([\text{by 564\%}]\) content of Ultisols compared to the control. However, crop height and leaf number of garlic were not yet affected by the ameliorants on the 6\textsuperscript{th} week after planting.

Keywords: biochar, garlic, manure, OM, Ultisols

1. Introduction

Garlic \([\textit{Allium sativum}]\) is a type of horticulture crop being used to grow at a higher altitude, but some varieties can grow well at a lower altitude. It is reported \([1]\) that some red onion \([\textit{Allium sativum} \, \text{L.}]\) could adapt well in the sandy soil next to the beach. A big problem found in cultivating garlic in West Sumatra is due to the high rainfall intensity and clay content of soils. The clayey soils have a high percentage of micro-pores and retain more water in the pores for a long time, therefore the soil becomes muddy which is not suitable for the growth of bulb crops, such as garlic. Garlic crops need fertile and porous soils for the bulb to develop well \([2]\).

One effort to change clayey soils such as Ultisol Limau Manis to be fertile and porous is by adding manure and biochar. Manure has been widely used to improve soil’s physical and chemical properties. Manure has been used by farmers to increase soil fertility since thousands of years ago. Manure is easy to get by farmers. However, the great amount of manure available at a time needed is hard to provide.
Therefore, besides manure, biochar has been intensively studied as a soil ameliorant lately. Biochar is an organic material that undergoes incomplete combustion and only uses limited oxygen [pyrolysis] to produce.

1.1. Role of Manure and Biochar

Manure as a soil ameliorant was able to create crumb and stable aggregates, maintain good soil aeration and drainage [3] of clayey texture like Ultisols. Ultisols Limau Manis was reported to have low pH [5.2] and organic matter [1.92%] content [4]. The physical properties of Ultisols can be improved by the application of organic matter, such as compost [5], manure [6], and green manure [3]. Besides improving soil physical properties, manure was also able to provide nutrients for plant growth and to increase the cation exchange capacity of the soil.

Biochar as a soil amendment is very beneficial for less fertile soils, it can increase available water capacity, fertilization efficiency, and production [7, 8]. Biochar can improve the physical, chemical, and biological properties of soil [9]. For soil physical properties, biochar can loosen the soil and increase water retention capacity, thus increasing water availability for plant growth. Furthermore, besides increasing the water holding capacity of the soil, biochar was also able to increase the amount of plant-available water [as much as 3.2% and 45% in the application of 22 and 44-to biochar ha\(^{-1}\) compared to control] and increased the leaf water potential [24 and 37% compared to control] for plant growth [10].

Besides, biochar derived from any raw materials [either from waste or wood] could increase soil pH [11]. As found by de Figueiredo et al. [12] that high soil pH with the addition of biochar was able to reduce the solubility of toxic elements, such as Al and heavy metals. They, for example, found that the application of 15 t biochar/ha could reduce the concentration of heavy metals in the soil. Besides, Crutchfield [8] reports that biochar was able to absorb nitrate, ammonium, and phosphate, thereby reducing the leaching of these elements from the rooting zone of plants.

Li et al. [13] reported that the application of biochar as much as 9 kg/m\(^2\) of land was able to provide soil temperature according to plant needs, increase water retention, and improve the growth of soybean plants. Yulnafatmawita et al. [14] reported that the application of biochar was able to increase growth and reduce the frequency of irrigation for corn plants on Ultisols.

Besides, to improve soil physical properties, biochar can reduce heavy metals available in the soil [15]. This is due to that biochar has a high CEC and surface area, so it has a high capacity to absorb toxic elements so that they are not available to plants.

Furthermore, Penido et al. [11] reported that the use of biochar can reduce the availability of Cd, Pb, and Zn metals for plants. As reported [12] that the solubility of heavy metals is reduced. The concentration of heavy metal Cd decreased to <1.2% by applying 15 t/ha of biochar, this was due to its high pH, pore-volume, as well as its specific surface area. Biochar modified with sulfur or sulfur and iron reduced more Cd solubility [29.71 and 18.53%] than biochar alone [which was only 12.54%]. Additionally, the use of biochar as a soil amendment is also one way of increasing organic matter sequestration in soil [16] because biochar can survive in the soil for quite a long time unless it is eroded [7].

1.2. Benefits of Manure for Soil Fertility

Organic material, especially manure, has been widely used as a soil ameliorant. This is because this material can improve the physical, chemical, and biological properties of the soil. Manure has been used for a long time by farmers, because besides it is cheap, it is also easy to obtain by farmers. Yulnafatmawita et al. [17] reported that the addition of green manure as a source of organic matter and a source of
nutrients in Ultisols was able to increase water retention and aggregate stability of Ultisols, as well as corn production in Limau Manis.

In terms of soil physics, OM can increase retention and amount of water available to plants [18], increase porosity and soil aggregate stability [3]. This is since OM can absorb water much heavier than its dry weight. Also, OM can increase the pore size distribution, so that the water holding capacity of the soil increases.

Then, the use of OM as an alternative fertilizer in addition to achieving sustainable environment as well as to obtain high agricultural production that is safe for consumption, loosening the soil, and increasing soil porosity. Also, OM can increase soil water retention, as reported [19] that the application of 15 tonnes of cow manure/ha can increase soil water content by 4.06% in addition to increasing the total pore space by 2.59%. Furthermore, OM is also able to increase soil aggregate stability [3, 20].

Based on the above facts, the ability of manure and biochar to improve soil physical and chemical properties, research was conducted to identify the effect of both ameliorants to provide a better medium for garlic growth. This research was aimed to improve the properties of Ultisols, clay-textured soil, as a growth medium for garlic [Allium sativum L] by application of biochar and manure.

2. Material and methods

This research was carried out as a pot trial in the glasshouse of Agriculture Faculty Universitas Andalas Padang in 2020. The soil used was Ultisols having high clay content from Limau Manis Padang. The soil was ameliorated using biochar and manure to facilitate the medium for garlic crops. The cow manure used was from the cage of cow belongs to Animal Husbandry Faculty Andalas University Limau Manis Padang. Rice husk for biochar was taken from a rice mill in Piai Padang city. It is produced using pyrolysis in drum methods. Garlic bulbs used were from the local variety, Bukik Sileh Solok Regency, West Sumatra Indonesia.

The soil as the medium for the garlic growth was air-dried, sieved with a 2 mm sieve, then mixed with manure and rice husk as the determined composition [Table 1]. The materials were incubated for 15 days before they are planted with the garlic seedlings. During incubation, a garlic bulb was planted in a mixed soil-manure-biochar [1:1:1] medium based on volume for 10 days.

Parameters analyzed were soil texture [using pipet method], bulk density [BD] and total soil porosity [TSP] [using the gravimetric method], %SOC [using wet oxidation method], permeability [using constant head]

| Table 1. The comparison of soil, biochar, and manure as the treatment for garlic growth media |
|-----------------------------------------------|
| Treatment | Soil : | Biochar : | Manure |
| A         | 100   | 0       | 0      |
| B         | 90    | 10      | 0      |
| C         | 90    | 0       | 10     |
| D         | 80    | 10      | 10     |
| E         | 80    | 20      | 0      |
| F         | 80    | 0       | 20     |
| G         | 70    | 20      | 10     |
| H         | 70    | 10      | 20     |
| I         | 60    | 20      | 20     |
permeameter method based on Darcy’s law], pH [using pH meter], cation exchange capacity [CEC] [using NH₄OAc leaching method], total N [using Kjeldahl method], available P [using Bray II method], K, and Al-exchangeable [initial soil analyses], and pH, CEC, N, P, K, %SOC [after incubation], and crop height as well as the number of the leaf. The data resulted as affected by treatment especially soil characteristics after incubation and crop growth parameter have statistically analyzed the variance, if the F-test > F-table, the analyses were continued using HSD at 5% level of significance [using Stats 8.0].

3. Results and discussion

3.1 Initial characteristics of soil, biochar, and manure
Based on Table 2, the soil had clay texture, low SOM content, and very low soil hydraulic conductivity. This soil was unsuitable for garlic growth since it needs porous and crumb soil to develop the bulb. Therefore, if the soil is amended with organic matter it may be a good medium for garlic.

Additionally, the soil had low pH, medium total-N, and extremely low P-availability. At low pH, some essential nutrients were unavailable, especially phosphorous was bound by aluminum and iron. Therefore, the soil needed ameliorant to improve the soil's physical and chemical properties.

Biochar as an ameliorant contained very low OC. However, it had very low mass and very high pores, so it reduced soil BD and improved porosity. The biochar had 18.32% C and 0.2%N [21]. This amendment was very suitable to make soil porous and to provide a good medium for bulb development. Rice husk biochar had very high CEC [112.5 cmol [+] kg⁻¹] and high specific surface area [SSA] [118.2 m² g⁻¹] [22]. High SSA means that the biochar was quite reactive to bind soil particles into aggregates. Rice husk biochar has a big potential for adsorbent [21], as it has high pH [8.7] [23]. Therefore, it could increase pH, OM percentage, water holding capacity, CEC, and cation-exchangeable, as well as decreased BD and Fe availability of marginal soil [24].

| Parameter                          | Soil | Biochar | Manure |
|------------------------------------|------|---------|--------|
| Particle Size Distribution         |      |         |        |
| Sand [%]                           | 9.34 |         |        |
| Silt [%]                           | 27.15|         |        |
| Clay [%]                           | 63.52|         |        |
| Texture Class                      | Clay |         |        |
| Bulk Density [g/cm³]               | 1.04 |         |        |
| Total Porosity [%]                 | 60.69|         |        |
| Hydraulic Conductivity [cm/h]     | 0.17 |         |        |
| pH value                           | 5.50 | 7.10    | 5.70   |
| Organic Carbon [%]                 | 1.64 | 0.28    | 5.40   |
| Total-N [%]                        | 0.22 | 0.51    | 2.61   |
| P-availability [ppm]               | 0.28 | 15.45   | 43.01  |
| Moisture [%]                       | 43.13| 7.22    | 184.36 |

While the OC content of manure was quite high [5.40%]. Its value reached 3.3 times that in soil used. It means that the application of manure as a source of organic matter could increase soil OM which can
improve soil physical and chemical properties. As reported that soil aggregate stability increased by application of some sources of organic matter, the best one was from tithonia (Thitonia difesifolia) [25] with a smaller size of organic matter application [3] in Ultisol Limau Manis.

3.2 Soil characteristics after 15 days of incubation

3.2.1 Soil moisture content

Based on Table 3 the soil moisture content increased by amendment application. The soil moisture content increased by increasing the amount of ameliorant added or by less soil proportion in the growth media. Comparison between the ameliorants, manure was able to increase soil moisture content much higher than that of biochar as indicated from the treatment of B, C, E, and F [Table 3]. This was due to the ability of manure in retaining water which could be much higher than the dry weight itself [18]. Among the treatments, the composition of 20% manure combined either with 20 or 10% biochar gave a higher water content percentage of Ultisol.

According to the initial analyses [Table 2], the water content of manure was quite high [184.36%] while the biochar had only 7.22%. Therefore, as manure was added to the soil, the soil water content increased more than that of biochar application.

3.2.2 Soil Chemical Properties

Table 4. Soil organic matter content of Ultisols as affected by biochar and manure after incubation

| Treatment [Soil:Biochar: Manure] | Soil pH | SOC [%] | Total-N [%] | Available-P [ppm] | C/N Ratio |
|---------------------------------|---------|---------|-------------|-------------------|-----------|
| A [100:0:0]                     | 5.57 a  | 1.14 e  | 0.25 d      | 0.15 d            | 4.51 b    |
| B [90:10:0]                     | 5.63 a  | 2.41 de | 0.29 d      | 0.08 d            | 8.13 ab   |
| C [90:0:10]                     | 5.90 a  | 3.25 cde| 0.57 ab     | 3.21 ab           | 5.75 b    |
| D [80:10:10]                    | 5.53 a  | 3.79 bcde| 0.50 bc     | 2.71 bc           | 7.47 ab   |
| E [80:20:0]                     | 5.73 a  | 5.68 abcd| 0.32 cd     | 1.74 cd           | 17.56 ab  |
| F [80:0:20]                     | 6.17 a  | 8.13 a  | 0.40 bcd    | 5.13 bcd          | 16.17 ab  |
| G [70:20:10]                    | 5.77 a  | 7.55 ab | 0.38 bcd    | 1.36 bcd          | 22.56 a   |
| H [70:10:20]                    | 6.07 a  | 6.99 abc| 0.70 a      | 5.96 a            | 10.24 ab  |
| I [60:20:20]                    | 5.97 a  | 7.53 ab | 0.42 bcd    | 5.60 bcd          | 18.15 ab  |

Soil OC content increased by increasing biochar and manure application. This was due to that both ameliorants contain OM. The highest SOC content was found under treatment 80:0:20, it was not significantly different to treatment G, H, dan I. Compared to control, the OC content at F [80:0:20] increased by 6.99% or 7.15 times.

Application of biochar and manure was not able to significantly change the soil pH of Ultisol. This could be due to the amount of the ameliorants added was not enough. As reported by Yunilasari et al [26] that biochar and manure application up to 20 T/ha on Entisols did not significantly affect soil pH, either before or 45 days after corn growth. However, there was a tendency of increasing soil pH either by manure or by biochar application, since the pH values of both ameliorants were higher than that of Ultisols.
The relationship between SOC and pH on some soil chemical properties were presented in Figure 1. It was showed that soil OC positively correlated to soil pH \([R^2=0.55]\), C/N ratio\([R^2=0.70]\), as well as to P-availability\([R^2=0.50]\). Soil pH itself, even though it was not significantly affected by biochar and manure application, positively correlated to P availability in the soil.

![Figure 1. The correlation between soil OC as well as soil pH and some soil chemical properties](image)

### 3.3 Crop growth

Table 5. Crop height and leaf number at 6 weeks after transplantation

| Treatment \ [Soil:Biochar: Manure] | Crop Height [cm] | Leaf Number |
|-----------------------------------|------------------|-------------|
| A [100:0:0]                       | 38.83 a          | 5.00 a      |
| B [90:10:0]                       | 38.17 a          | 4.67 a      |
| C [90:0:10]                       | 55.17 a          | 6.00 a      |
| D [80:10:10]                      | 54.17 a          | 5.67 a      |
| E [80:20:0]                       | 45.33 a          | 5.00 a      |
| F [80:0:20]                       | 59.17 a          | 6.33 a      |
| G [70:20:10]                      | 52.67 a          | 5.67 a      |
| H [70:10:20]                      | 48.17 a          | 5.00 a      |
| I [60:20:20]                      | 52.50 a          | 5.67 a      |

Based on Table 5, the crop height was not significantly different due to biochar and manure application after 6 weeks of transplantation. However, there was a tendency of increasing crop height by
application of ameliorant. The highest crop height was found on F [80:0:20] treatment. This was in line with the soil OC content and pH value of the soil [Table 4]. In this treatment, the crop height and leaf number increased by 52% and 27% respectively, compared to control.

4. Conclusion
Based on research conducted it could be concluded that the best properties of Ultisols after 2 weeks of incubation with manure and biochar were found on the application of 25% manure without biochar or treatment F [80:0:20]. It was indicated by the highest OC content [8.13%] and pH value [6.17]. This treatment F also gave the best performance of crop growth indicated by the highest crop height [59.17 cm] and the most number of the leaf [6.33].

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