BIO Web of Conferences **80**, 03001 (2023) https://doi.org/10.1051/bioconf/20238003001
*ICoSIA 2023*

# Amelioration of dry land suboptimal using biochar and compost to improve soil physical properties and soybean yield

Endriani [1*] and *Diah* Listyarini [1]

[1] Agroecotechnology Department, Faculty of Agriculture, Jambi University

**Abstract.** The primary constraint of suboptimal soils under wet tropical regions, besides their low pH, is their low soil organic matter (SOM) content. This research aimed to improve the soil properties of dry land suboptimal and the yield of soybeans by applying biochar and compost. This research was carried out to investigate the effects of coconut shell biochar (B) and Leucaena compost (C) applied alone (at a rate of 10 ton.ha$^{-1}$) or in combination (5 B: 10 C; 10 B: 15 C each. thus 10 [1] B: 10 C) on soil physicochemical properties, growth, and yield of Soybean on Ultisols in Jambi Province. Biochar and compost applied alone or in combination significantly increased soil organic matter (SOM), total porosity (TP), and Aeration Pore (AP); decreased bulk density (BD) and low drainage pore (LDP). Also, combined application and single application biochar or compost to impact beneficially on soil water retention and available water (AW). Additionally, combined application and single application biochar or compost additions increased components of yield as a number of pods of soybean. The study showed that biochar applied alone or in combination with compost offers the potential to enhance soil quality and improve soybean yield.

## 1. Introduction

The dryland areas with less-than-ideal conditions in Jambi are primarily characterized by Ultisols, which originate from acidic sedimentary rock parent materials. As a result, the soil has an acidic pH, and the base saturation levels are below 35% [1]. Ultisols exhibit poor aeration and soil stability indexes, making the soil prone to compaction and erosion susceptibility. Consequently, the permeability of roots into the soil is hindered, leading to inhibited plant root growth [2]. This mineral soil has been used intensively for agriculture. However. the big problem found in the use of Ultisols for soybean farming is the high clay content in subsoil, low stability aggregate, and relatively low organic matter. High clay content and low soil organic matter cause soil micropores to dominate and cause an imbalance between micro and macro pores [3]. This condition is unfavourable for soybean growth which requires porous soil with sufficient available air and water in the soil.

An approach to enhance the fertility and porosity of clayey soils like Ultisols in Tangkit Jambi involves the incorporation of biochar and compost. Compost has a long history of being utilized by farmers to enhance both the physical and chemical characteristics of soil, making it an effective method for increasing soil fertility.

Right now, using biochar and compost together is seen as a highly effective and sustainable agricultural approach to reduce environmental risks and boost soil fertility and crop yields [4,5]. Recent research suggests that biochar is most beneficial in enhancing soil qualities when it is used alongside or processed together with other soil amendments like biosolids, paper mill sludge, manure, and compost [6-9].

Biochar is a carbon-rich, solid, porous substance created through pyrolysis in an oxygen-deprived setting, known for its extensive surface area and cation exchange capacity (CEC) [10,11]. Many studies have shown that using biochar in soil can have positive impacts on crops and soil properties, such as improved increased hydraulic conductivity, reduced bulk density, infiltration rate, porosity, water retention, and soil structure [12-14], which may lead to an increase in crop yield [15-19]. Mensah and Frimpong [20] found that using biochar could enhance soil health by raising pH, increasing water retention capacity, cation exchange capacity (CEC), and influencing microbial communities.

Incorporating compost can improve soil structure by reducing compaction and increasing water content [21]. Plants that have a high biomass that can be used as compost is leucaena Plants that have a high biomass that can be used as compost is leucaena. According to Agbede [22] Leucaena leaves have a chemical composition are 39% OC; 3.23 % N; 12.1 C: N; 0.23 % P; 1.68 % K; 1.24 % Ca; dan 0.35 % Mg.

Adding organic manures can enhance root growth by altering soil physical properties [23]. Biochar, while carbon-rich, lacks sufficient nutrients for demanding crops. Combining biochar with chemical fertilizers and compost enhances soil water retention [24], aggregate stability [25], more efficient use of nutrients [26,27], enhance in microbial biomass and activities which lead plant growth [11,28,29], over the sole application [30,31]. In addition, the application of biochar with

*Corresponding author: endriani@unja.ac.id

compost or lime to its impact on soil parameters and plant growth decreases the leaching of nutrients and improves the efficiency of compost [26,27].

Structure stability, bulk density, hydraulic conductivity, and water retention are common indicators for studying soil physical health and hydraulic properties [32,33]. Limited research has examined the impact of compost and biochar on soil hydraulic properties [34].

In Jambi Province's Ultisols dry land, poor soil properties hinder plant growth. This study aimed to improve soybean yield and soil properties using biochar and compost. The hypothesis was that combining biochar and compost would enhance soil physical properties better than using them separately in sub-tropical conditions.

## 2. Material and Methods

### 2.1 Biochar and Soil Preparation

Coconut shell biochar was produced through low-temperature pyrolysis at (300–400 ºC) using drum oil which on the bottom has been fitted with cavities. Coconut shells were burned separately for about 6-8 hours. According to some Authors, pyrolysis can be used in producing coconut shell biochar widely [35-43].

For composting, firstly Leucaena biomass was chopped and mixed with poultry manure with a balance of 3:1 and incubated with *Trichoderma sp* for one month. Chemical properties of coconut shell biochar and Leucaena compost were analyzed for pH (pH meter). Organic-C (Walkley and Black).

### 2.2. Experimental Design

The field experiment has been conducted at Tangkit Village. Sungai Gelam sub district. Muara Jambi Regency. Jambi Province in April – August 2023. The experiment used a randomized block design with four replicates to test various types of amendments, whereas treatments tested were some kind of amendment. that were A0: control; A1: Coconut shell biochar 10 kg ha$^{-1}$ ; A2: Leucaena compost 10 kg ha$^{-1}$; A3: Coconut shell biochar 10 ton ha$^{-1}$ + Leucaena compost 5 ton ha$^{-1}$; A4: Coconut shell biochar 5 ton ha$^{-1}$ + Leucaena compost 10 ton ha$^{-1}$; A5: Coconut shell biochar 10 ton ha$^{-1}$ +Leucaena compost 10 ton ha$^{-1}$. After one week of soil tillage, Soybean Variety Anjasmoro was planted with a spacing of 25 × 30 cm in plots measuring 2 × 3 m. Inorganic fertilizers (urea, SP-36, and KCl) were applied at planting time at rates of 50, 100, and 100 kg ha-$^{1}$, respectively. Plant parameter measurements, including pod count per plant, were taken at harvest after 93 days.

### 2.3. Soil Sampling Analyses.

Soil samples were collected before and after treatments, with undisturbed samples taken using a 5 cm diameter, 4 cm high ring at a 20 cm depth, and composite samples collected from six points at the same depth using a one-inch diameter soil auger. Soil analysis included bulk density (BD), water content at pF 1, 2, 2.54, and 4.2, as well as analysis of soil chemical properties such as organic carbon (C-organic). Yield components were also analyzed.

### 2.4. Data Analysis

Data were statistically analyzed using ANOVA or diversity tests at a 95% significance level. To identify significant differences among treatment variables, the Duncan Multiple Range Test (DMRT) was conducted at a 5% significance level.

## 3. Result and Discussion

### 3.1. Initial characteristics of soil.

According to Table 1, the soil had a sandy clay loam texture with low soil organic matter (SOM) content, poor hydraulic conductivity and infiltration rate, limited available water content, and high bulk and particle density. These characteristics rendered the soil unsuitable for soybean growth, as it lacked the necessary porosity and crumb structure essential for soybean root development. However, through soil amendment with organic matter, it has the potential to transform into a suitable medium for soybean cultivation.

According to Table 1, the soil had a sandy clay loam texture with low organic matter content, high bulk density, low total porosity, low permeability, low aggregate stability, and poor soil aggregation. Due to these characteristics, the soil was unsuitable for soybean growth as it requires a more porous and crumbly texture to support root development.

The soil had low pH, which made essential nutrients, particularly phosphorus, unavailable due to binding with aluminum and iron. To enhance its physical and chemical properties, soil amendment with organic matter is needed, potentially making it a suitable medium for soybean cultivation.

Table 1. Physicochemical attributes of initial soil

| Properties | Initial Soil | Criteria |
|---|---|---|
| C-organic (%) | 1.12 | Low * |
| pH (H2O) | 4.78 | Acid* |
| Organic Matter (%) | 1.93 | Low* |
| Bulk Density (g cm$^{-3}$) | 1.57 | High* |
| Total Porosity (%) | 41.88 | Low* |
| Particle Density (g cm$^{-3}$) | 2.84 | High* |
| Texture: Sand %) | 48.40 | Sandy clay loam |
| Silt (%) | 18.40 | |
| Clay (%) | 33.20 | |
| Water content (%) | 23.12 | Low* |
| Field Capacity (%) | 28.36 | |
| Available Water (%) | 8.88 | Low** |
| Wilting Point WC (%) | 19.48 | |
| Permeability (cm jam$^{-1}$) | 6.03 | Slow** |
| Infiltrasion Rate (cm jam$^{-1}$) | 14.2 | Medium** |
| % Aggregate (%) | 43.85 | Low* |
| Stability Agregat (%) | 52.41 | Low* |

* *Pusat Penelitian Tanah Bogor (1994);** Sarief (1989).*

## 3.2. Characteristics of coconut shell biochar and Leucaena compost

The characteristics of coconut shell biochar and Leucaena compost are shown in Table 2. Both biochar and compost have pH>7 and other chemical properties are quite different. Some of the previous studies are also showing the pH of coconut shell biochar > 7 [35, 44].

Biochar as an ameliorant had very low mass and very high pores. so, it reduced soil BD and improved porosity. The biochar had 33.02% C and 4.68% ash. This amendment was very suitable to make soil porous and to provide a good medium for soybean growth.

This amendment was highly effective in improving soil porosity and creating an optimal environment for soybean root development.

Table 2. Characteristics of coconut shell biochar and Leucaena compost

| Parameters of Analyzed | Coconut shell Biochar | Leucaena Compost |
|---|---|---|
| Water content (%) | 9.40 | 34.28 |
| Organic Carbon | 33.02 | 26.97 |
| pH ($H_2O$) | 8.90 | 7.22 |
| Ash content (%) | 4.68 | - |
| Volatile matter (%) | 66.98 | - |
| N total (%) | - | 2.19 |
| C/N | - | 14.34 |

**Coconut shell biochar**

The coconut shell biochar exhibited a very high CEC (Cation Exchange Capacity) and a high specific surface area [45], indicating its strong reactivity in binding soil particles into aggregates. On the other hand, the Leucaena compost had a notably high organic carbon (OC) content, measuring at 26.97%, which was 3.3 times greater than that of the soil used. This suggests that using compost as an organic matter source can significantly increase soil organic matter, thereby improving both the physical and chemical properties of the soil.

## 3.3. Soil Physical Properties after application biochar and compost

**Effect of biochar and compost application on SOM**

The effect of biochar and compost on SOM was significant. However. addition of biochar and compost increased the SOM over the control (Figure 1). SOM was highest in A5 (5.83%), followed by A4 dan A2 (5.27% and 5.10 %) compared with control. The highest SOM content was found under treatment at 10:10. It was significantly different to treatment A0, A1, A2, A3, and A4.

A5 (BC 10: 10) has the highest percentage of soil organic matter, which could be attributed to the incorporation of biochar and compost. both of which are organic amendments high in organic matter. Because of its high stability towards degradation in the soil. the biochar application will make a lifelong increase in soil organic matter that will give benefit to all the main functions exhibited by the organic matter that is present in the soil [46].

Cox et al. [47], found that applying biochar to the soil surface increased soil organic matter (SOM) not only in the 0–10 cm depth but also in the 10–20 cm depth. They concluded that using biochar and compost boosted SOM in the 10–20 cm soil layer due to the movement and leaching of these amendments. Biochar, rich in carbon content, plays a role in humus production and enhances soil fertility [48,49].

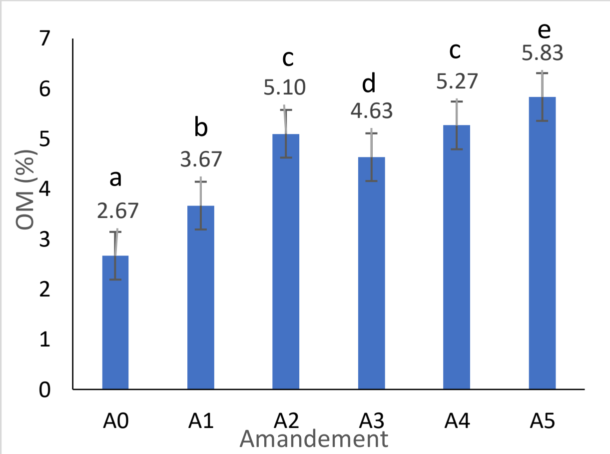


Fig 1. Effect of biochar and compost on SOM

**The effect of biochar and compost application on BD, TP, AP, and LDP**

Based on Table 3, the soil had a sandy clay loam texture, application of biochar and compost decreased the bulk density (BD) of the soil. This condition can occur because biochar is porous and compost-improved soil structure has a low BD from 0.08 to 0.17 g cm$^{-3}$. thus, contributable to the decrease of soil BD. Many studies reported that the application of biochar and organic fertilizer increased soil organic matter and decreased BD [46,47,50], found that using biochar, with or without compost, reduced bulk density and increased total porosity in the soil.

Table 3. Effect of biochar and compost on some soil physical properties

| Amd | BD (g cm$^{-3}$) | | TP (%vol) | | AP (%vol) | | LDP (%vol) | |
|---|---|---|---|---|---|---|---|---|
| A0 | 1.28 | a | 47.27 | b | 16.23 | a | 11.53 | a |
| A1 | 1.22 | b | 51.37 | b | 14.80 | ab | 9.47 | b |
| A2 | 1.17 | c | 55.91 | ab | 12.31 | b | 5.27 | d |
| A3 | 1.17 | c | 53.93 | b | 16.66 | a | 6.97 | c |
| A4 | 1.16 | c | 58.28 | ab | 16.58 | a | 6.53 | cd |
| A5 | 1.09 | d | 65.80 | a | 14.20 | ab | 5.70 | cd |

Notes: Amd=amandement; A0 = control; A1 = biochar 10; A2 = compost 10; A3 = biochar + compost 10:5; A4 = biochar + compost 5:10; A5 = biochar + compost 10:10

The results indicated that all treatments significantly boosted average total porosity from 11.43% to 39.20%, demonstrating increased water-holding capacity compared to the control. Biochar enhances porosity and pore spaces, leading to improved water retention and sandy soil stability. It also enhances soil structure, including bulk density (BD), porosity, water-holding capacity (WHC), available water for crops, and specific surface area [52].

The result also showed application of biochar and compost alone or combined significantly increased the average aeration pore (AP) and low drainage pore (LDP). Fast drainage and aeration pores (AP) were higher on average in biochar combined with compost compared to other treatments, although this trend wasn't consistent across all treatments.

The results showed that the treatments of sandy clay loam soil with compost 10-ton ha$^{-1}$. significantly decreased the average aeration pore (AP) from 31.84%, but non significantly with combined biochar and compost (10B:10C).

Aeration pores in all treatments remained relatively high (>10% by volume), falling within the moderate range (10 to 15% by volume). Conversely, the average low drainage pore content in all treatments remained very low.

The results indicated that the treatments of sandy clay loam soil with biochar and compost significantly reduced the average soil LDP from 21.75–111.79% with the following order A1 (9.47) < A3 (6.97) < A4(6.53) < A5 (5.70) <A2 (5.27). Decreasing the percentage of slow drainage pores will increase the arase pores. indicating more porous soil and reduced soil compaction.

### Effect of biochar and compost on soil retention

Based on Figure 2, combined application and single application biochar or compost additions increased water retention. The retention curve changes dynamically following the soil pore balance. Biochar consistently impacts water retention more predictably than other soil hydraulic properties.

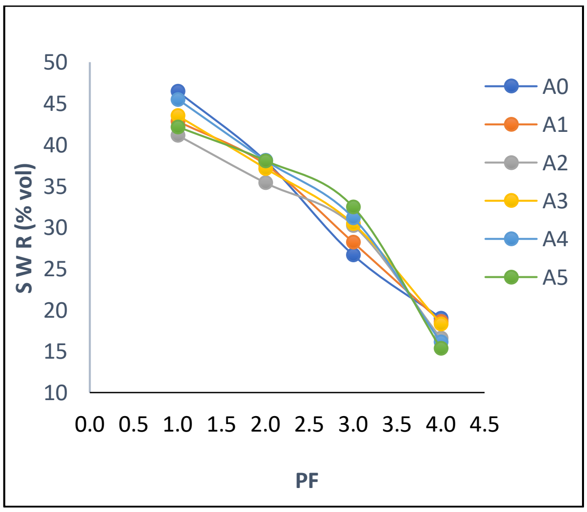


Fig 2. Effect of biochar and compost on Soil water retention

Blanco-Canqui [53] found that recent studies suggest biochar enhances water retention in 90% of cases, with 17 out of 19 soils showing improved retention. Biochar's water-absorbing capacity is highly effective. Notably, some studies reported increased water retention at low biochar application rates, while others observed improvements only at 15 tons per hectare [54,55]. Applying compost enhanced soil water retention properties [52,51].

Seyedsadr et al. [51] found that using biochar, with or without compost, can improve water retention in low-organic soils while maintaining or even enhancing nutrient retention.

### Effect of biochar and compost on available water

Based on, Figure 3. shows that the treatments of sandy clay loam soil with biochar and compost alone or combined significantly increased available water (AW). The results showed that the treatments of sandy clay loam soil with combined biochar and compost. and compos alone, or biochar alone significantly increased the average soil AW from 32.91.75–137.92 % with the following order A1 (9.57) < A3 (12.23) < A2(13.87) < A4 (15.07) <A5 (17.13). The greater combination of biochar and compost (10:10) contributed the most to available water.

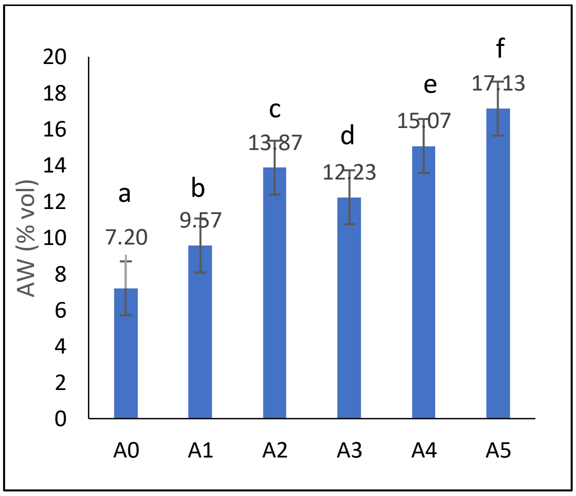


Fig 3. Effect of biochar and compost on available water

Biochar's enhanced water availability is likely due to its increased specific surface area and porosity, which can reach up to 3000 m² g$^{-1}$.

Biochar's porous nature retains water within its particles due to its high specific surface area. Micropores hold water more effectively than macropores and mesopores, thanks to capillary and adhesive forces. Adding biochar to soil can change total porosity, pore sizes, water transmission, and retention properties [53].

Ghorbani et al. [56] found that biochar and compost significantly increased available water capacity (AWC) in all conditions over two years. Biochar improved soil aggregation and porosity, enhancing water retention, particularly in low-water and polluted environments.

Panagea et al. [57] noted that the direct impact of soil organic carbon (SOC) on soil water retention (SWR) is minor. The indirect impact is more significant at higher matric potentials and varies with SOC composition. Different responses under various conditions suggest that combining practices, such as reducing soil disturbances and increasing organic matter inputs, is needed to enhance soil water-holding capacity.

**Effect of biochar and compost on component yield**

Based on, Figure 4. shows that the treatments of sandy clay loam soil with biochar and compost alone or combined significantly increased the number of pods. The results showed that the treatments of sandy clay loam soil with combined biochar and compost. and compos alone. or biochar alone significantly increased the average number of pods from 21.42–57.14% with the following order A2 (149) < A1 (153) < A3(171) < A4(176) < A5(197). The greater combination of biochar and compost (10:10) contributed the most to the number of pods.

Biochar and compost, alone or together, enhance hydro-physical properties of sandy clay loam soil. Improvement of soil properties (Table 3) also increased the effectiveness of soybean growth, as presented in Figure 4.

Currently, combining biochar and compost is a highly effective and sustainable agricultural practice for reducing environmental risks and enhancing soil fertility and crop yields (Izilan et al., 2022; Sharma et al., 2021; Ariani et al..2021; Sekaran et al., 2020). According to Nurida and Rahman [50], Soybeans gave better yield when the soil was treated with Biochar SP50 (50% biochar and 50% organic fertilizer). Improved soybean yields on acidic soil likely resulted from reduced soil acidity and increased availability of water pores.

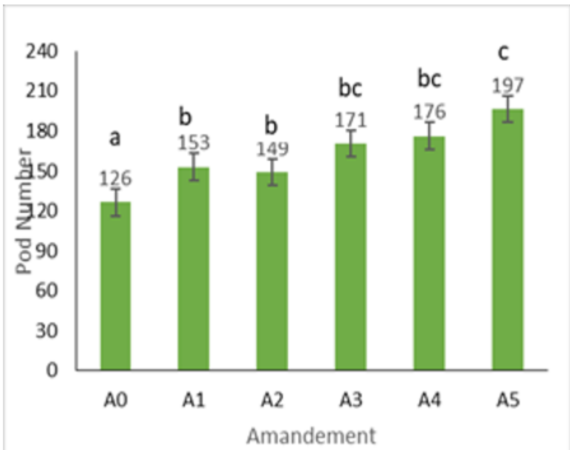


Fig 4. Effect of biochar and compost on the number of pods

## 4. Conclusion

The study showed that biochar applied alone or in combination with compost in combination significantly increased soil organic matter (SOM), total porosity (TP), and Aeration Pore (AP); decreased bulk density (BD) and low drainage pore (LDP). Both combined and individual applications of biochar or compost positively impacted soil water retention, available water (AW), and soybean yield components, such as pod numbers.

**Acknowledgments** This study was partially funded by Competitive Research Indonesia. The authors thank the Directorate General of Higher Education of Indonesia for superior university-applied research in 2023. Also, thanks to the Rector of Universitas Jambi who has supported this research.

## Reference

1. Prasetyo and Suriadikarta. *Characteristic, potential, and management of Ultisols for agricultural upland in Indonesia*. J Litbang Pertanian **25**: 39-46. (2006).
2. Subowo, G. *Empowerment of Soil Biological Resources for Rehabilitation of Degraded Ultisols.* Jurnal Sumberdaya Lahan. **6** ( 2): 79-88 (2012).
3. Endriani, Sunarti dan Ajidirman. 2013. *Pemanfaatan Biochar Cangkang Kelapa Sawit Sebagai Soil Amandement Ultisol Sungai Bahar Jamb*i. Jurnal Penelitian Universitas Jambi Seri Sains. **15** (1): 39-46 (2013).
4. N I S Izilan et al. *The effects of biochar-compost on soil properties and plant growth performance grown in sandy loam soil.* IOP Conf. Ser.: Earth Environ. Sci. **1059** 012021 (2022).
5. P Sharma, Vikas A, Vikas S, Shubham C, Ch. Srinivasa R, A.Q. Ganie, Daniel Ingo Hefft, Mohamed A. El-Sheikh, Sheikh M. *Effectiveness of biochar and compost on improving soil hydro-physical properties, crop yield and monetary returns in inceptisol subtropic*s. Saudi Journal of Biological Sciences. Vol **28**, (12): December 2021, 7539-7549 (2021).
6. Manirakiza. E., Ziadi. N., Luce. M.S.. Hamel. C.. Antoun. H.. and Karam. A. 2022. *Changes in soil pH and nutrient extractability after co-applying biochar and paper mill biosolids.* Can. J. Soil Sci.. **102**(1). (2022). doi:10.1139/cjss-2019-0138.
7. Ziadi, N., Zhang, X., Gagnon, B., and Manirakiza, E. *Soil phosphorus fractionation after co-applying biochar and paper mill biosolids.* Can. J. Soil Sci. **102**(1). doi:10.1139/cjss2020-0098.(2022).
8. Hangs. R.D., Schoenau. J.J... and Knight. J.D . *Impact of manure and biochar additions on annual crop growth. nutrient uptake. and the fate of 15 N-labelled fertilizers in two contrasting temperate prairie soils after four years*. Can. J. Soil Sci. **102**(1).
9. T T Doan. Thierry Henry-des-Tureaux. Cornelia Rumpel, Jean-Louis Juneau. Pascal Jouquet. 2015. *Impact of compost. vermicompost and biochar on soil fertility. Maize yield and soil erosion in Northern Vietnam: A three-year mesocosm experiment.* Science of the Total Environment **514** (2015) 147–154 (2015).
10. Hussain. M.. Farooq. M., Nawaz. A., Al-Sadi. A.M., Solaiman. Z.M., Alghamdi. S.S., Yong. U.A., Siddique. K.H.M. *Biochar for crop*

*production: potential benefits and risks.* J. Soils Sediments **17** (3). 685–716 (2017).

11. Mansoor. S., Kour. N., Manhas. S.. Zahid. S., Wani. O.A., Sharma. V., Wijaya. L., Alyemeni. M.N., Alsahli. A.A. El-Serehy. H.A. Paray. B.A. *Biochar as a tool for effective management of drought and heavy metal toxicity*. Chemosphere. 129458. (2020).
12. Laird. D.A., Fleming. P., Davis. D.D., Horton. R., Vang. B., Karlen. D.L., 2010. *Impact of biochar amendments on the quality of a typical midwestern agricultural soil.* Geoderma **158** (3&4). 443–449 (2010).
13. Herath. H.M.S.K., Camps Arbestain. M., Hedley. M., 2013. *Effect of biochar on soil physical properties in two contrasting soils: an Alfisol and an Andisol*. Geoderma **209–210**. 188–197 (2013).
14. Abrol. V., Ben-Hur. M., Verheijen. F.G., Keizer. J.J., Martins. M.A., Tenaw. H., Tchehansky. L., Graber. E.R., 2016. *Biochar effects on soil water infiltration and erosion under seal formation conditions: rainfall simulation experiment*. J. Soils Sediments **16** (12). 2709–2719 (2016).
15. Basso. A.S., Ferrando. E.M., Laird. D.A., Horton. R., Westgate. M. *Assessing the potential of biochar for increasing the water-holding capacity of sandy soils.* Bioenergy **5** (2). 132–143 (2012).
16. Carlsson. M.. Andren. O.. Stenstrom. J.. Kirchmann. H.. Katterer. T.. 2012. *Charcoal application to arable soil: effects on CO2 emissions Commun.* Soil Sci. Plant Anal. **43**. 2262–2273 (2012).
17. H.M.S.K. Herath, Marta Camps-Arbestain, Mike H. *Effect of biochar on soil physical properties in two contrasting soils: An Alfisol and an Andisol.* Geoderma **209-210** (2013) 188–197.
18. Mukherjee, A., & Lal, R. *The biochar dilemma*. Soil research, **52**(3), 217-230 (2014).
19. Martinsen. V., Alling. V., Nurida. N.L., Mulder. J., Hale. S.E., Ritz. C., Rutherford. D.W., Heikens. A., Breedveld. G.D. Cornelissen. G. *pH effects of the addition of three biochars to acidic Indonesian mineral soils*. Soil Sci. Plant Nutrition. **61** (5). 821–834 (2015).
20. Hansen. V., Nielsen. H.H., Petersen. C.T., Mikkelsen. T.N., Stöver. D.M., *Effects of gasification biochar on plant-available water capacity and plant growth in two contrasting soil types.* Soil Tillage Res. **161**. 1–9 (2016).
21. Blanco-Canqui. H., Lal. R. *Crop residue removal impacts on soil productivity and environmental quality*. Crit. Rev. Plant Sci. **28.** 139–163 (2017).
22. Mensah. A.K., Frimpong. K.A. *Biochar and/or compost applications improve soil properties. growth. and yield of maize grown in acidic rainforest and coastal savannah soils in Ghana.* Int. J. Agron Vol **2018** (2018).
23. Evanylo. G.. Sherony. C.. Spargo. J.. Starner. D.. Brosius. M.. Hearing. K.. 2008. *Soil and water environmental effects of fertilizer. manure. and compost-based fertility practices in an organic vegetable cropping system.* Agric. Eco. Environ. **127**. 50–58. (2008).
24. Agbede. T. M. *Effect of Green Manure Application on Cassava (Manihot esculenta Crantz) Growth. Yield Quantity and Quality in Degraded Alfisols.* Pertanika J. Trop. Agric. Sc. **41** (4): 1757-1777 (2018).
25. Zhang P, Wei T, Jia Z, Han Q, Ren X, et al. (2014) *Effects of Straw Incorporation on Soil Organic Matter and Soil Water-Stable Aggregates Content in Semiarid Regions of Northwest China.* PLoS ONE **9**(3): e92839 (2014).
26. Abel. S., Peters. A., Trinks. S., Schonsky. H.. Facklam. M., Wessolek. G. *Impact of biochar and hydro-char addition on water retention and water repellency of sandy soil. Geoderma* 202–203. 83–191 (2013).
27. Sun. F., Lu. S.. 2014. Biochar improves aggregate stability. water retention. and porespace properties of clayey soil. J. Pl. Nutri. Soil Sci. **177** (1). 26–33 (2014).
28. Major. J. *A guide to conducting biochar trials*. Version 1.1. Int. Biochar Initiative. (2009)
29. Novak. J.M., Busscher. W.J., Laird. D.L., Ahmedna. M., Watts. D.W., Niandou. M.A.S. 2009. *Impact of biochar amendment on fertility of a southeastern coastal plain soil*. Soil Sci. **174** (2). 105–112 (2009)
30. Adekiya. A.O., Agbede. T.M., Aboyeji. C.M., Dunsin. O., Simevon. V.T.. 2018. Effects of biochar and poultry manure on soil characteristics and the yield of radish. Sci. Horti. **243** (3). 457–463.(2018)
31. Sadegh-Zadeh. F.. Tolekolai. S.F. Bahmanyar. M.A.. Emadi. M.. 2018. *Application of biochar and compost for enhancement of rice (OryzaSativa L.) grain yield in calcareous sandy soi*l. Commun. Soil Sci. Plant Anal. **49** (5). 552–566. (2018)
32. Ippolito. J.A., Stromberger. M.E., Lentz. R.D., Dungan. R.S., 2016. *Hardwood biochar and manure co-application to a calcareous soi*l. Chemosphere **142**: 84–91 (2016).
33. Hagemann. N., Harter. J., Kaldamukova. R.. Guzman-Bustamante. I., Ruser. R., Graeff. S. 2017. *Does soil aging affect the N2O mitigation potential of biochar? A combined microcosm and field study*. GCB Bioenergy. (2017).
34. Reynolds. W.D., Drury. C.F., Tan. C.S., Fox. C.A., Yang. X.M. 2009. *Use of indicators and pore volume-function characteristics to quantify soil physical quality*. Geoderma **152** : 252–263.
35. Castellini. M., Stellacci. A.M., Tomaiuolo. M. 2019. *Spatial variability of soil physical and hydraulic properties in a durum wheat field*: an assessment by BESTproducer. Water **11**: 1434–1437 (2019).
36. Kammann. C.,Glaser. B., Schmidt. H.P., 2016. *Combining biochar and organic amendments.* In: Shackley. S. Ruysschaert. G., Zwart. K., Glaser. B. (Eds.). Biochar in European Soils and Agriculture: Science and Practice. Routledge. New York. pp. 136–164 (2016).
37. A Ajien, Juferi I, Nurzawani Md S, Rafidah H and Hazman S. 2023. *Coconut shell and husk biochar:*

*A review of production and activation technology. economic. financial aspect and application*. Waste Management & Research **41**(1). 37-51 (2023).

38. Adorna J. Borines M. Dang VD. et al. *Coconut shell-derived activated biochar – manganese dioxide nanocomposites for high-performance capacitive deionization*. Desalination **492**: 114602 (2020)
39. Baharum NA. Nasir HM. Ishak MY. et al. (2020) *Highly efficient removal of diazinon pesticide from aqueous solutions by using coconut shell modified biochar*. Arabian Journal of Chemistry **13**: 6106–6121 (2020).
40. Behera B. Selvam MS. Dey B. et al. (2020) *Algal biodiesel production with engineered biochar as a heterogeneous solid acid catalyst.* Bioresource Technology **310**: 123392 (2020).
41. Khuenkaeo N and Tippayawong N. (2020) *Production and characterization of bio-oil and biochar from ablative pyrolysis of lignocellulosic biomass residues*. Chemical Engineering Communications **207**: 153–160 (2020).
42. Nuryana D. Alima MFR. Yahayu M. et al. (2020) *Methylene blue removal using coconut shell biochar synthesized through microwave-assisted pyrolysis.* Jurnal Teknologi **82**: 31–41 (2020).
43. Pituya P. Sriburi T and Wijitkosum S. (2016) *Properties of biochar prepared from acacia wood and coconut shell for soil amendment*. Engineering Journal **21**: 63–76 (2016).
44. Sari RM. Gea S. Wirjosentono B. et al. (2020). *Improving quality and yield production of coconut shell charcoal through a modified pyrolysis reactor with tar scrubber to reduce smoke pollution*. Journal of Environmental Study **29**: 1815–1824 (2020).
45. Windeatt JH. Ross AB. Williams PT. et al. (2014) *Characteristics of biochars from crop residues: Potential for carbon sequestration and soil amendment.* Journal of Environmental Management **146**: 189–197 (2014).
46. S. Abrishamkesh, M. Gorji, H. Asadi, G.H. Bagheri-Marandi, A.A. Pourbabaee. *Effects of rice husk biochar application on the properties of alkaline soil and lentil growth*. Plant, Soil and Environment · Vol. 61, 2015, No. **11**: 475–482 (2015).
47. Severo FF. da Silva LS. Moscôso JSC. Sarfaraz Q. Júnior LFR. Lopes AF. Marzari LB. and Molin GD. 2020. *Chemical and physical characterization of rice husk biochar and ashes and their iron adsorption capacity*. SN Appl. Sci. **2**. 1286 (2020).
48. Sánchez-Monedero. M. A.. Cayuela. M. L., Sánchez-García. M, Vandecasteele. B, D'Hose. T, López. G, Mondini. C. *Agronomic evaluation of biochar. compost and biochar-blended compost across different cropping systems: Perspective from the European project FERTIPLUS*. Agronomy. **9**(5). 225. (2019).
49. J. Cox. N. V. Hue. A. Ahmad. and K. D. Kobayashi. *Surface-applied or incorporated biochar and compost combination improves soil fertility. Chinese cabbage and papaya biomass*. Biochar. **3**(2): 213–227 (2021).
50. S. Yang. X. Chen. Z. Jiang. J. Ding. X. Sun. and J. Xu. *Effects of biochar application on soil organic carbon composition and enzyme activity in paddy soil under water-saving irrigation*. International Journal of Environmental Research and Public Health. vol. **17** (1): 333 (2020).
51. M. Ayaz. D. Feizien˙e. V. Tilvikien˙e. K. Akhtar. U. Stulpinait˙e and R. Iqbal. *Biochar's role in the sustainability of agriculture and environment*. Sustainability. vol. **13** (3): 1330 (2021).
52. Nurida, N.L., & Rachman, A. (2020). *Amelioration of acid upland to increase soil productivity and soybean yield.* AGRIVITA Journal of Agricultural Science, **42**(2), 350–359.
53. Seyedsadr S, Václav Š. Lukáš J, Michal S, Luke B, Michael P, Martin K, Lukáš T. 2022. *Biochar considerably increases the easily available water and nutrient content in low-organic soils amended with compost and manure*. J Chemosphere. Volume **293**. April 2022. 133586. (2022).
54. Głąb Andrzej Ż. Urszula S. Krzysztof G. Michał. M Mierzwa-Hersztek. Sylwester T. J Stanek-Tarkowska. *Fertilization effects of compost produced from maize. sewage sludge and biochar on soil water retention and chemical properties*. Soil and Tillage Research. Vol **197**. March 2020. 104493.
55. Blanco-Canqui H. *Biochar and Soil Physical Properties.* Soil Sci. Soc. Am. J. **81**:687–711 (2017).
56. Paneque. M., J.M. Rosa. J.D. Franco-Navarro. J.M. Colmenero-Flores. and H. Knicker. 2016. *Effect of biochar amendment on morphology. productivity and water relations of sunflower plants under non-irrigation conditions.* Catena **147** : 280–287 (2016).
57. Xiao. Q.. L. Zhu. H. Zhang. X. Li. Y. Shen. and S. Li. 2016. *Soil amendment with biochar increases maize yields in a semi-arid region by improving soil quality and root growth.* Crop Pasture Sci. **67**: 495–507 (2016).
58. M Ghorbani, Reinhard W. Neugschwandtner, Petr K, Hossein A, Marek K., Elnaz A. (2023) *Comparative effects of biochar and compost applications on water holding capacity and crop yield of rice under evaporation stress*: a two-year field study. Paddy and Water Environment. 23 January 2023. (2023).
59. Panagea. I.S., Berti. A., Cermak. P., Diels. J., Elsen. A., Kusá.ˇ H., Piccoli. I., Poesen. J., Stoate. C., Tits. M. et al. 2021. *Soil Water Retention as Affected by Management Induced Changes of Soil Organic Carbon*: Analysis of Long-Term Experiments in Europe. Land 2021. **10.** 1362. (2021)