The utilization of agricultural waste as biochar for optimizing swampland: a review

A Susilawati*, E Maftuah and A Fahmi
Indonesian Swampland Agriculture Research Institute (ISARI), Indonesia
Jl. Kebun Karet- Lokatabat- Banjarbaru- South Kalimatan- Indonesia

Email: ani.nbl@gmail.com

Abstract. The utilization of agricultural waste as biochar is one way to manage agricultural waste to encourage swamps optimization. There is quite a lot of agricultural waste in Indonesia estimated to reach 10.7 t y⁻¹, including rice-husks, cocoa pods, coconut-shells, oil palm shells, and corncobs. One of the management of agricultural waste is to make biochar from various sources of raw materials. This paper is intended to provide information about agricultural waste as biochar in agriculture to optimize swampland in Indonesia. The quality of biochar depends on raw materials, incinerator, combustion temperature, and the length of combustion. The application of biochar on agricultural land serves as a soil enhancer that can improve its chemical properties and soil physical properties. Improvements in the quality of the soil chemical and physical properties impact the availability of nutrients and water through the ability of biochar to retain nutrients and water. In the end, the addition of biochar has implications for increasing the productivity of food crops. In the future, it is expected that with the application of biochar, swamplands can increase productivity.

1. Introduction
Swampland is one of Indonesia’s most extensive agroecology and has considerable potential for agricultural development now and in the future, but its utilization has not been carried out optimally. Tidal swampland consists of mineral soil (sulfuric acid) reaching 7.55 million ha and peat reaching 1.37 million ha, while lebak swampland consists of mineral land reaching 11.64 million ha and peat reaching 13.56 million ha [1]. However, swamps are generally marginal and infertile so proper management is needed. Swamp management requires specific technologies including improving soil conditions through amelioration. Farmers in swampland often use ameliorant materials such as lime, manure, and ash [2]. Proper management of swamps will make a real contribution to Indonesia’s food security. However, along with the declining quality of the soil and the environment, efforts are needed to manage swampland wisely (wise use) based on sustainability and safe for the environment.

When this has begun to develop globally, biochar/charcoal from agricultural waste as an alternative soil enhancer. Biochar is produced through a process of thermal decomposition of organic matter under conditions of limited oxygen. Similar to charcoal produced from natural combustion, but different because of its function as an amendment to the ground [3,4]. Biochar can be produced from various biomass sources such as plant residues, plant waste or animal waste. The characteristics of biochar depend on the raw material and pyrolysis conditions such as temperature, time duration and oxygen supply [4]. Biochar has demonstrated the ability to improve soil chemical properties such as pH [5,6,7,8], nutrient availability [9], nutrient and water retention [10,11,12] and cation exchange capacity [10,6,7,13], reducing N fertilizer loss [14] and reducing nutrient leaching [15,16]. Also, on
soil physical properties: increasing water holding capacity and available water [6], reducing soil density and strength [6] and can change the structure and abundance of soil biological communities [17]. Biochar can last a long time in the soil or has a relatively long effect, or is relatively resistant to microorganism attack, so the decomposition process is slow. Biochar is also able to reduce the washing of pesticides and nutrients and ultimately impact the quality of the environment. Biochar did not disturb the carbon-nitrogen balance, but it can hold and makes the water and nutrients more available to plants. Biochar structures with micropores can increase water holding capacity [18,19,20], and reduce nitrogen run off [21,22].

Biochar can be used to manufacture biological fertilizers because it is an effective carrier for microbes needed in the soil [18]. In the biochar micropore, the fungus can sporulate because the competition is relatively low with other saprophytes [23]. The diversity of microorganisms in the soil can be improved by the application of biochar [8]. The role of biochar in the soil can be a habitat for soil microbes, but it is not consumed by mycorrhizae in a short time so that the applied biochar can stay in the soil for a long time.

Biochar production is agricultural waste management that can be developed considering the abundant raw material sources. In the future, it is hoped that the optimization of swamps can be done by utilizing agricultural waste available in situ. This paper aims to provide information about the potential use of agricultural waste as biochar in agriculture, significantly to optimize swampland in Indonesia and describe the role of biochar in improving the quality of swamps, namely chemical properties, physical properties, soil biology, and land productivity.

2. Potential of agricultural waste biochar raw materials
Organic materials derived from living bodies, both animals and plants, are widely used as raw materials for agriculture, animal husbandry, construction, and so on, eventually producing waste products. This biomass waste will become a problem if it is not appropriately utilized, and eventually it will become waste that is not useful and can pollute the environment. The direct utilization of biomass waste is considered inefficient and needs to be converted into biochar first [24].

Biochar is a new term used to describe porous charcoal (finely pulverized charcoal) made from various biomass. Charcoal result of incomplete combustion with limited oxygen or no oxygen-called biochar [25,26,27]. Basic ingredients can be sourced from agricultural, livestock, forestry and household waste [28] which is abundant agricultural waste such as rice husk, rice field 1 ha with an average yield of 7 t rice will yield about 1.54 tons of agricultural waste rice hulls for every harvest season [27].

The potential of biochar raw materials in Indonesia is relatively abundant in agricultural residual waste, especially those that are difficult to decompose or with high C/N ratios such as wood residues, coconut shells, rice husks, cocoa pods, corncobs, sufficiently available. Thahir [29] informed that the rice milling process could produce 16.3-28.0% of the husk every time. The coconut shell’s potential is also enormous considering the coconut plant area reaches 3.79 million hectares with copra equivalent production of 2.94 million t [30], where the proportion of shells from one coconut is around 15-19%. The area of coconut plants is around 1.85 million ha [30] with the production of dried fruit skins around 830 thousand tons/year [31] and the proportion of corn cobs 21% of the weight of dried cobs [32]. So far, agricultural waste has not been used optimally, only limited to being used as a renewable energy source [33] and animal feed.

Results analysis of Sarwani [34] informs that nationally, the potential of agricultural biomass that can be converted into biochar is estimated to be around 10. 7 million tons, producing 3.1 million tons of biochar. The highest potential comes from rice husk which reaches 6. 8 million t and will produce biochar 1. 77 million t or around 56. 48% of the total national biochar potential (table 1). The high potential of biomass to be used as biochar is highly dependent on availability and competition with other uses. Coconut shell biomass is widely used for other purposes, namely energy sources, whole corn cobs can be used for animal feed. Other sources that can be utilized are the rest of
the twigs, cassava stems, oil palm empty fruit bunches, mangrove stems. In principle, the source of biochar raw material is agricultural waste.

**Table 1.** Estimated agricultural waste and it is potential as a biochar raw material.

| Agricultural biomass         | Total (t y⁻¹) | Assuming the proportion of biomass that can be converted (%) | Potential of biomass that can be converted into biochar (t y⁻¹) | Biochar/biomass ratio | Biochar potential (t y⁻¹) |
|-----------------------------|---------------|-------------------------------------------------------------|---------------------------------------------------------------|-----------------------|--------------------------|
| Rice husk                   | 13 612 343    | 50                                                          | 6806172                                                       | 0.26                  | 1769605                  |
| Coconut shell               | 539.644       | 50                                                          | 269822                                                        | 0.25                  | 67456                    |
| Oil palm shell              | 6400 000      | 30                                                          | 1920000                                                       | 0.5                   | 960000                   |
| Cocoa pods                  | 1.208553      | 50                                                          | 604277                                                        | 0.33                  | 199411                   |
| Corn cobs                   | 3652372       | 30                                                          | 1095712                                                       | 0.13                  | 142443                   |
| Total                       | 25412912      |                                                             | 10695982                                                      |                       | 313891                   |

Source: Sarwani (34)

In swamps, the raw materials for making biochar with high levels of abundance include rice husks, corn straw, rice straw, kalakai, karamunting, galam, bamboo, palm oil cake, palm leaves, palm fronds, oil palm bunches, coconut shells and purun tikus. The characterization and analysis of cellulose content, hemicellulose, and C/N ratio of each biochar material are presented in table 2. The highest lignin levels are found in raw materials kalakai (35.76%) and the lowest in corn straw (17.03%). High lignin content makes it difficult for organic matter to decompose [35]. The highest cellulose content was found in organic matter from oil palm cake (34.45%) and the lowest was in organic matter from corn straw (17.03%), in contrast to hemicellulose content. Hemicellulose is an amorphous polymer associated with cellulose and lignin, easy to undergo depolymerization, hydrolysis by acids, are alkaline, and easily dissolve in water. Hemicellulose has a bond with lignin stronger than a bond with cellulose and easily binds to water. Hemicellulose levels differ in the type of needle-leaf wood and broad-leaf wood [36].

**Table 2.** Cellulose content, hemicellulose, and C/N ratio of some organic biochar sources.

| Type of material             | Lignin | Cellulose | Hemicellulose | C    | N    | C/N  |
|-----------------------------|--------|-----------|---------------|------|------|------|
| Karamunting                 | 27.7   | 50.8      | 20.5          | 52.6 | 1.1  | 46.9 |
| Kalakai                     | 35.7   | 42.6      | 21.1          | 53.8 | 1.1  | 48.1 |
| Corn straw                  | 17.0   | 34.0      | 37.6          | 54.8 | 1.1  | 48.9 |
| Palm leaf                   | 30.0   | 42.9      | 26.3          | 50.4 | 0.9  | 51.5 |
| Rice husks                  | 32.6   | 43.4      | 23.1          | 49.0 | 0.8  | 58.4 |
| Purun tikus                 | 26.3   | 43.8      | 19.1          | 50.6 | 0.8  | 60.3 |
| Rice straw                  | 24.4   | 40.4      | 30.7          | 51.1 | 0.8  | 60.9 |
| Oil palm bunches            | 25.6   | 49.6      | 20.6          | 55.4 | 0.7  | 79.2 |
| Bamboo                      | 24.8   | 50.1      | 24.5          | 56.4 | 0.5  | 112.0|
| Palm midrib                 | 25.4   | 50.1      | 24.3          | 55.9 | 0.4  | 124.9|
| Coconut shell               | 31.8   | 46.3      | 19.6          | 55.5 | 0.4  | 132.1|
| Oil palm cake               | 34.4   | 51.5      | 14.0          | 50.5 | 0.3  | 138.9|
| Galam                       | 25.6   | 51.0      | 23.3          | 57.5 | 0.3  | 171.2|

Sources: Maftuah dan Nursyamsi [37]

One way to increase the effectiveness and efficiency of biomass waste is by carbonization using pyrolysis technology. A pyrolysis is a complex event, where organic compounds in biomass are
decomposed by heating without oxygen. Only the volatile matter is released, while the carbon remains in it, this process occurs at temperatures above 300 °C for 4 - 7 hours [38].

The chemical and physical properties of biochar determine the quality of biochar (table 3), and these properties are determined by the type of raw material (softwood, hardwood, rice husk, etc.) and carbonization method (The type of combustion tool, temperature), and the form of biochar (solid, powder, activated carbon) [39,40]. The characteristics of biochar are influenced by the base material itself and have different effects on soil and plants [27].

### Table 3. Characteristics of biochar physical-chemical properties.

| Type of biochar | Pyrolysis temperature (°C) | C (%) | pH | CEC Cmol/kg | SiO₂ | Ash content (%) | N (%) | P (%) | K (%) | Ca (%) | Mg (%) | Fe (%) |
|----------------|---------------------------|-------|----|-------------|------|-----------------|-------|-------|-------|--------|--------|--------|
| Rice husk 1)   | 300-400                    | 23.40 | 8.99| 37.38       | 34.8 | 44.35           | 0.73  | 0.48  | 0.54  | 0.21   | 0.18   | 0.26   |
| Palm bunches 2) | 350-450                    | 42.33 | 9.39| 9.93        | 4.90  | 27.09           | 0.99  | 0.49  | 8.65  | 0.43   | 0.67   | 0.53   |
| Bamboo 1)      | 350-450                    | 50.03 | 9.30| 9.30        | 3.21  | 11.26           | 1.04  | 0.45  | 3.18  | 0.16   | 0.13   | 0.16   |
| Palm midrih 3) | 300-400                    | 40.04 | 9.74| 9.74        | 6.30  | 31.17           | 1.01  | 0.39  | 5.33  | 0.53   | 0.96   | 0.15   |
| Coconut shell 3) | 250-350                    | 29.69 | 9.61| 9.61        | 4.04  | 48.96           | 1.28  | 0.52  | 2.96  | 0.29   | 4.43   | 0.29   |
| Palm cake 3)   | 350-500                    | 23.73 | 8.30| 8.30        | 3.90  | 59.32           | 0.87  | 0.44  | 0.72  | 0.09   | 0.30   | 0.04   |
| Galam stem 3)  | 45.06                      | 9.04  | 9.04| 2.13        | 23.15 | 0.54            | 0.42  | 1.14  | 0.43  | 0.05   | 0.14   |
| Cocoa pods 2)  | 250-350                    | 33.04 | 10.8| -           | -     | 0.83            | 0.33  | 11.25 | -     | -      | -      |
| Oil palm shells 2) | 250-350                   | 49.18 | 8.2 | -           | -     | 1.61            | 0.25  | 0.04  | -     | -      | -      |
| Branch legume  | -                          | 18.11 | 9.4 | 7.05        | -     | 0.58            | 0.1   | 1.11  | -     | -      | -      |
| Tree 3)        | 500                        | 25.62 | 4.58| -           | -     | 1.32            | 0.07  | 0.08  | -     | -      | -      |

Sources: 1) Mafiuhah and Sosiawan [41]; 2) Nurida [42]; 3) Dariah [43]; 4) Santi dan Goenadi [44]

Interest in biochar as a soil reformer has recently overgrown. In biochar production biochar, pyrolysis slow to have multiple benefits that include waste management, renewable energy production, climate change mitigation and adaptation, as well as agricultural productivity [45].

### 3. The Role of Biochar in Optimizing Swampland

Swamplands are lands throughout the year or during a long time in a year, always saturated with water or flooded [46]. Swamp is included in suboptimal land because it has low productivity due to internal and external factors [47]. Utilization of sub-optimal land, including swamps, will be the foundation of future expectations, but requires technological innovation to overcome obstacles following the land’s characteristics and typology.

Tidal swamps are swamps that are affected by tides. Based on soil classification [48], tidal swamps are characterized by aquatic conditions (saturated with water) and have sulfidic material (iron sulfide) or pyrite, generally reacting with extreme acidity (pH <4) so it is often called acid sulphate soil [46]. This land generally has a low level of fertility and productivity so that agricultural development requires technological input.

The freshwater swamp is a swampland that is not influenced by tides but is inundated by river overflows for at least three months with a pool of at least 50 cm [46]. The chemical nature of the soil in the swamp swamplands is very dependent on the type of soil. Mineral soil (river sediment) has a clay texture and pH of 4.5 to 6.5. Every year the lebak land gets silt from the upper area (upstream area), so that the soil fertility is classified as moderate. Generally, N, P, and K values are low to moderate, but Ca and Mg content and CEC are generally moderate to high. The high or low nutrient content is influenced by the amount of nutrient contribution from the upstream area that enters through water run-off. This land is suitable for agricultural business. The problem only lies in the dynamics of water levels that are difficult to predict.

Peatlands consist of mostly organic matter which is weathered, with ash content equal to or less than 35%, peat depth equal to or more than 50 cm, and organic carbon content according to its weight of at least 12% [49]. Peatland development for agriculture faces biophysical land, socioeconomic and
environmental constraints. Biophysical land conditions that often arise are subsidence, dry back, acidification, nutrient deficiency, low load-carrying capacity, and high porosity.

The utilization of biochar in swamps as ameliorant has not been done much. Biochar is a carbon-rich solid material formed through the combustion process of organic or biomass materials without or with little oxygen (pyrolysis) at 250-500 °C. Unlike organic matter, biochar is stable for thousands of years when biochar is mixed into the soil and can absorb carbon [25,50,51].

Biochar is a pyrolysis residue in charcoal that contains high carbon and is useful for agriculture especially, for improving physical, chemical, and biological soil properties. The addition of biochar can improve soil fertility and restore degraded soil quality [52,10]. Biochar can improve the soil by increasing pH, retaining water, retaining nutrients, increasing biota activity, and reducing pollution [11]. The availability of P, soil pH, K, and Ca-dd increases with biochar application biochar [6].

Biochar can increase plant productivity directly or indirectly. The influence of biochar directly through the donation of nutrients released, while indirectly through the improvement of soil buffering capacity in holding nutrients [11,53,12], increasing soil pH [8,5,7], and the increase in CEC, improvement of soil physical properties and their effects on microbial function and population. Biochar can reduce nutrient loss through leaching, to improve fertilizer efficiency [15,16]. The provision of biochar can reduce N fertilizer losses [14,21,22,54]. This also applies to P nutrients that are not retained by ordinary organic matter. Biochar is more able to survive in the soil than other organic materials [25]. The biochar function works, absorbs and binds water, and supplies calcium and magnesium elements to plants.

A good combination of air and water for soil microbial growth is in biochar. Useful carrier material for the microbes also exists in biochar, which can make biological fertilizer [18], biochar micropores, fungi can sporulate because low competition occurs with other saprophytes [23]. Nugraheni [57] added that biochar could increase soil fertility and provide suitable habitat for soil microbes that can even hold water and nutrients to be more available to plants.

Masulli [6] applied biochar to acid sulphate soils. It reduced Al-dd, dissolved Fe, increase porosity, pH, P, CEC, Ca-dd, and K-dd. The combination treatment of biochar and chicken manure can increase the yield of Inpara-3 rice. Improvement of soil chemical properties through biochar and other ameliorant administration also impacts increasing rice yields in acid sulphate soils [6].

According to Ferizal [56] the provision of biochar as a soil enhancer derived from the combustion of agricultural waste with limited oxygen has excellent ability as a material change in soil because organic C still survives in carbon black. Biological charcoal produced from this combustion will produce activated carbon, which contains minerals such as calcium or magnesium and inorganic carbon, biochar is widely used as ameliorant material to improve soil quality, especially marginal soils [57]. So that biochar can be a substitute for growing media in plants. The biochar structure, which has a micropore can increase water’s holding capacity [18,19,20].

Soil chemical properties sub-optimal land can be improved by applying biochar, including acid sulphate tidal swamps and peatlands. Biochar can increase soil pH, total N, available P, and K-dd in an acid dry land, dry climate dry land, tidal swamps, and peatlands (table 4).

### Table 4. The influence of biochar on soil chemical properties in swampland.

| Treatment                  | pH H2O | N total % | P tsd ppm | K-dd me/100 g | Type of land | Reference  |
|---------------------------|--------|-----------|------------|---------------|--------------|------------|
| Control                   | 4.84   | 0.11      | 26.55      | 0.37          | 6.29         | Tidal      | Barus and  |
| Rice husk biochar, 5 t/ha | 5.13   | 0.13      | 27.87      | 0.43          | 7.60         | swampland  | Santri [58]|
| Rice husk biochar, 19 t/ha| 5.22   | 0.14      | 30.15      | 0.48          | 8.34         |            |            |
| Control                   | 4.18   | 0.93      | 120.19     | 0.53          | -            | peatlands  | Maftuah and|
| Galam stem biochar 8 t/ha | 4.20   | 0.95      | 156.58     | 0.59          | -            |            | Nursyamsi  |
| Rice husk biochar 8 t/ha  | 4.19   | 0.95      | 262.14     | 0.96          | -            |            | [59]       |
| Palm midrib biochar 8 t/ha| 4.20   | 0.95      | 263.09     | 0.95          | -            |            |            |
| Coconut shell biochar 8 t/ha| 4.29  | 1.26    | 175.59     | 0.94          | -            |            |            |

Note: -; data not available
The increase in crop production occurs due to the application of biochar in swamps (table 5). Application of rice husk biochar increases rice yield in tidal land reaching 4.35 - 5.36 t/ha [58]. On peatlands, there was an increase in corn yield due to the administration of rice husk biochar to 59% [60]. Biochar also provides increased soybean crop production in sub-optimal land. Giving rice husk biochar 10 t/ha increases the dry weight of soybean seeds to reach 2.5-2.9 t/ha [61].

Table 5. Effect of biochar on swampland productivity.

| Treatment                  | Corn dry pilip t/ha | Rice dry grain t/ha | Increased (%) | Type of land | Reference         |
|----------------------------|---------------------|---------------------|---------------|--------------|-------------------|
| Without biochar            | -                   | 5.25                |               | Tidal swampland|                  |
| Rice husk Biochar, 2 t/ha  | -                   | 5.36                | 2             | (acid sulphate soil) | Barus [62] |
| Without biochar            | 3.59                | -                   |               | Peatland     |                   |
| Rice husk Biochar, 7.5 t/ha| 5.71                | -                   | 59            |              | Simatupang [60]   |
| Coconut shell Biochar, 7.5 t/ha| 4.29          | -                   | 19.5          |              |                   |

4. Conclusion

One effort to manage agricultural waste is by making biochar. Biochar utilization opportunities for agricultural land are tremendous, both in terms of the availability of raw materials and their functions. Biochar application can be a solution in the use and optimization of swampland. Biochar in swampland plays a role in improving soil properties both, physical, chemical, and biological so that land productivity can increase. Plant productivity also increases in line with the improvement in land quality. The effectiveness of biochar in improving soil properties is influenced by biochar type, biochar manufacturing process, dosage, application method, biochar size, and soil type. The use of biochar is an alternative effort to improve soil fertility and improve the environment in a sustainable and easy and inexpensive way.

Reference

[1] Nawangsih A A, Purwanto H, dan Agung W 1999 Budidaya Cabai Hot Beauty Cetakan kedelapan (Jakarta: Penebar Swadaya)
[2] Ritung S, et al 2015 Sumberdaya lahan pertanian Indonesia: Luas, Penyebaran, dan Potensi Ketersediaan (Jakarta: IAARD Press) p 97
[3] Maftu’ah E 2012 Ameliorasi Lahan Gambut Terdegradasi dan Pengaruhnya terhadap Produksi Tanaman Jagung Manis [Disertasi] Universitas Gadjah Mada Yogyakarta.
[4] Lehmann J and Joseph S 2009 Biochar for Environmental Management. 1st ed (London: Earthscan) p 416
[5] Sohi S, Lopez-Capel E, Krull E and Bol R 2009 Biochar, climate change and soil: a review to guide future research CSIRO Land and Water Science Report 05/09 February 2009
[6] Topoliantz S, Ponge J F and Ballof S 2007 Manioc peel and charcoal: a potential organic amendment for sustainable soil fertility in the tropics Biol Fert Soils 41 15–21
[7] Masulili A, Utomo W H and Syechfani M S 2010 Rice husk biochar for rice based cropping system in acid soil: The characteristics of rice husk biochar and its influence on the properties of acid sulphate soils and rice growth in West Kalimantan, Indonesia J. Agric. Sci. 2 (1) 39-47
[8] Yuan J H, Quan W R K and Wang R H 2011 Comparation of ameliorating effect on an acidic ultisol between four crop straw and their biochars J. soil and Sediment 11(5) 741-50
[9] Li-li He, Zhe-ke Z and Hui-min Y 2016 Effects on soil quality of biochar and straw amendment in conjunction with chemical fertilizers J. Integrative Agric. 15(0) 60345–7
[10] Chan K Y, Van Zwieten L, Meszaros I, Downie A and Joseph S 2008 Using poultry litter biochars as soil amendments Aust J Soil Res. 46 437–44
[11] Glaser B, Lehmann J and Zech W 2002 Ameliorating physical and chemical properties of highly weathered soils in the tropics with charcoal: A review Biol Fertil Soils 35 219-30
[12] Laird D A, Fleming P, Davis D D, Horton R, Wang B Q and Karlen D L 2010 Impact of biochar amendment on quality of typical Midwestern Agricultural Soil Geoderma 158 (3-4) 443-9
[13] Zhang T, Fang C, Li P, Jiang R and Nie H 2013 Application of biochar for phosphate adsorption and recovery from wastewater Adv. Materials Res. (750-752) p 1389–92
[14] Van Zwieten L, Kimber S, Morris S, Chan KY, Downie A, Rust J, Joseph S and Cowie A 2010 Effect of biochar from slow pyrolysis of papermill waste on agronomic performance and soil fertility Plant and Soil 327 235-46
[15] Steiner C, Teixeira WG, Lehmann J, Nehls T, de Macêdo J L V, Blum W E H and Zech W 2007 Long term effects of manure, charcoal and mineral fertilization on crop production and fertility on a highly weathered Central Amazonian upland soil Plant soil 291: 275-90
[16] Novak J M, Busscher W J, Laird D L, Ahmedna M, Watts D W and Niandou M A S 2009 Impact of biochar amendment on fertility of a southeastern coastal plain soil Soil Sci 174 105–12
[17] Yao Y, Gao B, Zhang M, Inyang M and Zimmerman A R 2012 Effect of biochar amendment on sorption and leaching of nitrate, ammonium, and phosphate in a sandy soil Chemosphere 89 1467–71
[18] Pietikainen J, Kiikkila O and Fritze H 2000 Charcoal as a habitat for microbes and its effect on the microbial community of the underlying humus Oikos 89 331–42
[19] Santi L P and Goenadi D H 2010 Pemanfaatan bio-char sebagai pembawa mikroba untuk pemantap agregat tanah Ultisol dari Taman Bogo-Lampung Menara Perkebunan 78(2) 11-22
[20] Sutono S, Nurida N L 2012 Kemampuan biochar memegang air pada tanah bentektur pasir Buana Sains 12 (1) 45–52
[21] Yu O K, Brian Y R and Sam S 2013 Impact of biochar on the water holding capacity of loamy sand soil. Int. J. Energy and Env. Eng. 4 44
[22] Clough T J, Condron L M, Kammann C, Müller C 2013 A Review of Biochar and Soil Nitrogen Dynamics. Agronomy 3 275–93
[23] Knowles O A, Robinson B H, Contangelo A, Clucas L 2011 Biochar for the mitigation of nitrate leaching from soil amended with biosolids Science of the Total Environment 409 3206-10
[24] Saito M, Marumoto T 2002 Inoculation with arbuscular mycorrhizal fungi: the status quo in Japan and the future prospects Plant and Soil 244 273-9
[25] Bridgwater A 2003 Renewable fuels and chemicals by thermal processing of biomass Chem. Eng. J. 91 87-102
[26] Lehmann J 2007 Bio-energy in the black Front. Ecol. Environ. 5(7) 381–7
[27] Liang B J, Lenham D, Solomon S, Sohi J E, Thies J O, Skjemstad F J, Luizao M H, Engelhard, E G, Neves and Wirick 2008 Stability of Biomass drived Black Carbon in Soil Geochimika et Cosmochimica A. 72 6069-6078.
[28] Gani A 2009 Arang Hayati Biochar Sebagai Komponen Perbaikan Produktivitas Lahan Iptek Tanaman Pangan 4(1) 33-48.
[29] Shenbagavalli S andMahimairaja S 2012 Production and characterization of biochar from different biological wastes Int. J. Plant Animal and Environ. Sci. 2 (1) 197-201
[30] Thahir R Rachmat R and Suismono 2008 Pengembangan Agroindustri Padi Dalam Suyamto dkk (Ed) Padi: Inovasi Teknologi dan Ketahanan Pangan (Subang: Balai Besar Penelitian Padi) p 34 -76
[31] Badan Pusat Statistik 2013 Statistik Indonesia (Jakarta: BPS) p 668
[32] Direktorat Jenderal Bina Produksi 2007 Statistik Perkebunan Indonesia (Jakarta: Dirjen Perkebunan Deptan)
[33] Nurida NL, A Rachman dan Sutono 2012 Potensi pemanen tanah biochar dalam pemulihan sifat tanah terdegradasi dan peningkatan hasil jagung pada Typic Karahapuludults lampung Jurnal Penelitian Ilmu-Ilmu Kelaman 12 (1) 69-74

[34] Okimori Y, Ogawa M and Takahashi F 2003 Potential of CO₂ reduction by carbonizing biomass waste from industrial tree plantation in South Sumatra, Indonesia Mitigation and Adaption Strategies for Global Change 8 261-80

[35] Sarwani M, Nurida N and Agus F 2013 Greenhouse emissions and land use issues related to the use of bioenergy in Indonesia Jurnal Penelitian dan Pengembangan Pertanian 32(2) 56-66

[36] Pratikno H 2002 Studi Pemanfaatan Berbagai Biomasa Flora untuk Peningkatan Ketersediaan P dan Bahan Organik Tanah pada Tanah Berkapur di DAS Brantas Hulu Malang Selatan [Tesis] Universitas Brawijaya, Malang

[37] Achmadi S 1990 kimia Kayu (Bogor: Institut Pertanian Bogor)

[38] Maftuah E and Nursyamsi D 2015 Prosiding Sem. Nas. Maxy. Biodiversitas Indonesia (Yogyakarta: ISSN 2407-8050) I(4) 776-81

[39] Demirbas A 2005 Pyrolysis of Ground Wood In Irregular Heating Rate Conditions J. Analyt. and Appl. Pyrolysis 72 243-8

[40] Ogawa, M 2006 Carbon sequestration by carbonization of biomass and forestation: three case studies mitigation and adaptation strategies for global change Springer 11(2) p 421-36

[41] Amonette J and Joseph S 2009 Characteristics of Biochar: Micro-Chemical Properties In: Biochar for Environmental Management: Science and Technology, Lehmann, J. and S. Joseph (ed). (London: Earthscan-UK) p 33–52

[42] Maftuah E and Sosiawan H 2018 Biochar: ameliorant material that environmentally friendly for swampland Proc. Int. Workshop and Seminar Innov. Environ.-Friendly Agricultural Tech. Supp. Sustainable Food Self-Sufficiency (Surakarta: ISBN 978-602-344-252-2)

[43] Nurida N L, Dariah A and Rachman A 2009 Kualitas limbah pertanian sebagai bahan baku pemanen berupa biochar untuk rehabilitasi lahan Pros. Sem. Nas. dan Dialog Sumberdaya Lahan Pertanian (Bogor: BPPP_Deptan) 209-15

[44] Dariah A, Nurida N L and Sutono 2013 The effect of biochar on soil quality and maize production in upland in dry climate region Proc. 11th Int. Conf. The East and Southeast Asia Federation of Soil Sci. Societies (Bogor: Society of Soil Science)

[45] Santi L P and Goenadi D H 2012 Pemanfaatan biochar cangkang sawit sebagai pembawa mikroba pemantap agregat J. Penelitian Ilmu-Ilmu Kelaman 12 (1) 7-14

[46] Chan K Y, Van Zwieten L, Meszaros I, Downie A and Joseph S 2007 Agronomic value of greenwaste biochar as a soil amendment Australian J. Soil Res. 45 629-34.

[47] Subagyo H 2006 Lahan Rawa Lebak in Karakteristik dan Pengelolaan Lahan Rawa, (Bogor: Balai Besar Litbang Sumberdaya Lahan Pertanian) p 99–116

[48] Mulyani A and Sarwani M 2013 Karakteristik dan potensi lahan suboptimal untuk pengembangan pertanian di Indonesia Jurnal Sumberdaya Lahan 2 47–56

[49] Soil Survey Staff 1999 Soil Taxonomy A Basic System for Making and Interpreting Soil Surveys 2nd Ed. (USA: USDA-NRCS Agric Handb.) 436

[50] Soil Survey Staff 2011 Soil Taxonomy a Basic System of Soil Classification for Making and Interpreting Soil Surveys 11th Ed. (United States: Depart.Agriculture Washington DC) p 754

[51] Renner R 2007 Rethinking biochar environ Sci. Technol. 41 5932–33

[52] Fraser B 2010 High-tech charcoal fights climate change Environ. Sci. Technol. 548.

[53] Atkinson C J, Fitzgerald J D and Hipps N A 2010 Potential mechanisms for achieving agricultural benefits from biochar application to temperate soils: A review Plant Soil 337 1–18

[54] Schulz H and Glaser B 2012 Effects of biochar compared to organic and inorganic fertilizers on soil quality and plant growth in a greenhouse experiment J Plant Nutr Soil Sci 175 410–22

[55] Gao S and DeLuca T H 2016 Influence of biochar on soil nutrient transformations, nutrient leaching, and crop yield Adv Plants Agric Res 4(5) 1–16
[56] Nugraheni S R, Prasetya A, and Sihana 2013 Processing Biochar from Solid Waste of Arenga Pinnata Flour Industry J. Tek. Kim. 11(1) 31-6
[57] Ferizal M and Basri A B 2011 Arang Hayati (Biochar) Sebagai Pembenah Tanah (Aceh: BPTP) p 2
[58] Rondon M J, Renner, Lehmann R, Ramirez J, and Hurtado M 2007 Biological nitrogen fixation by common beans (Phaseolus vulgaris L.) increases with biochar additions Bio. and Fert. in Soils 63(6) 699-708
[59] Barus J and Santri N 2016 Pros. Sem. Nas. Asosiasi Biochar Indonesia (Pontianak: ISBN) 978-602-72935-2-6
[60] Maftuah E, Nursyamsi D 2019 Effect of Biochar on Peat Soil Fertility and NPK Uptake by Corn AGRIVITA J. Agricult. Sci. 41(1) 64–73
[61] Simatupang R S, Maftu’ah E and Subagio H 2017 Pengaruh pemberian formula bahan amelioran terhadap pertumbuhan dan hasil jagung di lahan gambut In Fahmuddin A.(Eds) Pros. Kongr. Nas. Perkumpulan Masy. Gambut Indonesia (HGI) VII ed. (Bogor: BBSDLF ISBN) 978-602-459-049-9
[62] Endriani and Kurniawan A 2018 Konservasi tanah dan karbon melalui pemanfaatan biochar pada pertanaman kedelai J. Ilmiah Ilmu Terapan Univ. Jambi 2 (2) 93–106
[63] Barus J 2016 Utilization of crops residues as compost and biochar for improving soil physical properties and upland rice productivity J. Degraded Min Lands Manag 3(4) 631–7