# Application of biochar produces changes in some soil properties

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The purpose of this review is to explore and study the feasibility of amending the soil with biochar and to assess impact on its chemical, physical, and biological properties. Soil pH, organic carbon, total N, K, Ca, Mg, and cation exchange capacity increased by applying biochar at an increasing rate. Bulk density, porosity, and water-holding capacity of the soil amended by biochar significantly changed, with better quality for crop production. The effects of biochar addition on soil biota vary, depending on the kind of biota existing in the environment.

Keywords: biochar, soil physics, soil biology, soil chemistry

Biochar has gotten the attention of researchers because of its capacity to improve the soil (Lehmann and Joseph 2009). Most research is related to the rehabilitation of degraded land and carbon sequestration, which holds promise for the improvement of soil chemical, physical, and biological properties.

In wet tropical regions such as Indonesia (especially in Sumatra where there is a wide coverage of acidic tropical soils), relatively high rainfall and temperature result in rapid loss of soil organic carbon. The recalcitrant fraction of biochar, which persists in the soil over the long term, is expected to increase soil fertility or rehabilitate degraded/poor soils.

Lampung has several large estates where land management is intensive and soils become rapidly degraded. One of the large estates is PT Gunung Madu Plantation, which was opened in 1975 through the conversion of secondary forest into commercial plantations (PT GMP 2009). The soil productivity of these plantations should be maintained for sustainable production. Application of biochar is one of the technologies that can improve soil productivity in degraded land or poor soil. PT Great Giant Pineapple is another agricultural venture in Indonesia where acid soil is used for pineapple production, which enhances nutrient depletion in the land. Likewise, rice, maize, cassava, and oil palm are major commodities that need to be maintained and whose productivity need to be improved.

Residues from various agricultural products are available in Lampung Province—oil palm empty fruit bunches, cassava skin, cacao skin, rice husks, rice straw, maize cobs, bagasse, etc. Since there is no way to use these materials, they remain as waste. Utilizing these materials as feedstock for biochar production is one of the better ways to get rid of the waste problem while enhancing soil productivity at the same time. Appropriate technology should be disseminated to local farmers to enable them to produce biochar from agricultural wastes.

In terms of using biochar as a soil amendment, the most frequently asked questions have to do with its effect on plant growth, what type of biochar will perform better, what is the lifetime of biochar in the soil, what is the optimal amount and mode of application, etc. There is much scope for scientific research in this realm. When applied to the soil, biochar may improve the nutrient supply to the plants, as well as the physical and biological properties of the soil. In view of all these, this review aims to explore and study the feasibility of amending soil with biochar and to determine its impact on the soil's chemical, physical, and biological properties. It summarizes existing data pertaining to changes in soil properties in any region.

## Changes in soil properties

Biochar application to the soils is considered a soil amelioration technique, enhancing plant growth by supplying more nutrients and providing other functions such as improving the physical and biological properties of the soil.

### *Soil chemical properties*

A number of studies have shown that biochar can increase soil pH, cation exchange capacity (CEC), total N, available P, exchangeable Ca, magnesium, etc. and can reduce Al availability (Table 1). Widowati et al (2012) reported that biochar application decreased N fertilizer requirement. They also found that organic carbon was increased by biochar application. Similar results were seen with different types of biochar and soil in various regions (Rondon et al 2007, Novak et al 2009, Cui et al 2011, Masulili et al 2010, Laird et al 2010). The increase in soil carbon through biochar application is attributed to the stability of biochar in the soil, which persists despite microbial action. By using isotopes, Steinbeiss et al (2009) reported that the mean residence time of biochar in the soil varied between 4 and 29 years, depending on soil type and quality of biochar. In soils regularly managed by biochar amendments, the increasing aromatic carbon content is likely to affect soil properties (Knicker et al 2013). This phenomenon needs further investigation.

The application of paper mill waste biochar, combined with inorganic fertilizer, showed higher soybean and radish biomass compared with sole application of inorganic fertilizer (van Zwieten et al 2010). Application of chicken manure and city waste biochar increased maize biomass (Widowati et al 2012). This higher biomass production is attributed to biochar increasing the soil pH. According to Chu et al (2011), biochar amendment significantly increases soil pH by 0.18–0.36 unit. Novak et al (2009) stated that, after 67 days and two leaching events, biochar addition to the Ultisols of Norfolk soil increased soil pH. The findings of van Zwieten et al (2010) suggest that while biochar may not provide a significant source of plant nutrients, it can improve the nutrient assimilation capability of the crop by positively influencing the soil environment. Sukartono et al (2011) reported that application of biochar improved soil fertility status, especially soil organic C, CEC, available P, exchangeable K, Ca, and Mg of the sandy soils in Lombok, Indonesia. Since biochar is highly porous and has a large specific surface area, its impact on soil CEC and other nutrients that have correlation with CEC is very important.

Besides the direct/indirect effect of biochar on soil fertility characteristics, application of biochar contributes to the interaction of soil with microelements such as lead and cadmium. Jiang et al (2012) reported that incorporation of biochar increased Pb(II) adsorption by variably charged soils. Biochar amendment significantly decreased extracted Cd in the soil by 17-47%. Some types of biochar also appear to reduce the mobility of heavy metals such as Cu and Zn (Hua et al 2009). Novak et al (2009) reported that most soil micronutrient concentrations were not influenced by biochar addition; however, biochar application decreased exchangeable acidity, S, and Zn.

### *Soil physical properties*

Studies on the effect of biochar on soil physical properties are limited. However, some studies showed effects on parameters such as bulk density, porosity, water-holding capacity, and aggregate stability (Table 2). Most research findings point to the improvement of soil bulk density with biochar application (Karhu et al 2011, Haryani and Gunito 2012, Masulili et al 2010); water-holding capacity also increased (Karhu et al 2011). Biochar has high porosity, which allows high water-holding capacity. However, it is hydrophobic as it is dry due to its high porosity and light bulk density. Adding biochar to the soil also improves soil physical property, water permeability, and aggregate stability (Table 2). Peng et al (2011) reported that, compared with chemical fertilizer application, biochar amendment to a typical Ultisol resulted in better crop growth.

**Table 1. Changes in chemical properties of the soil as affected by application of biochar in several experiments.**[a]

| Treatment | Location/soil type | Biochar origin | Soil pH ($H_2O$) | Available Al (mg $kg^{-1}$) | Organic C (%) | Total N (%) | Available P Bray I (ppm) | Exchangeable K (cmol $kg^{-1}$) | Ca (mg $kg^{-1}$) | Mg (mg $kg^{-1}$) | CEC (cmol $kg^{-1}$) | Information source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Control | Malang, Indonesia | | | | 1.20 a | 0.09 a | 19.45 a | 0.69 a | | | 13.22 a | Widowati et al (2012) |
| N (145 kg $ha^{-1}$) | Malang, Indonesia | | | | 1.15 a | 0.17 ab | 23.54 ab | 0.47 ab | | | 14.18 a | |
| N (145 kg $ha^{-1}$) + biochar (30 t $ha^{-1}$) | Malang, Indonesia | Chicken manure | | | 3.14 c | 0.39 c | 29.45 b | 2.18 c | | | 19.27 b | |
| N (145 kg $ha^{-1}$) + biochar (30 t $ha^{-1}$) | Malang, Indonesia | City waste | | | 3.18 c | 0.31 c | 30.04 b | 2.14 b | | | 18.34 b | |
| Control | Fixing bean, Typic Haplustox, Columbia | Logs of *Eucalyptus deglupta* | 5.04 e | 173.3 | 1.23 a | 0.08 a | 5.17 a | 0.94 d | 1012 | 28 de | 10.82 | Rondon et al (2007) |
| Biochar (30 g $kg^{-1}$) | | | 5.08 de | 140.2 | 2.12 b | 0.09 b | 4.62 ab | 2.19 c | 370 | 44c | 11.85 | |
| Biochar (60 g $kg^{-1}$) | | | 5.24 c | 120.8 | 2.70 c | 0.10 c | 4.34 ab | 3.21 b | 453 | 54 bc | 13.17 | |
| Biochar (90 g $kg^{-1}$) | | | 5.41 b | 97.2 | 3.80 d | 0.11 c | 4.42 ab | 4.51 a | 667 | 86 a | 13.15 | |
| Control | Non-fixing bean, Typic Haplustox, Columbia | | 5.13 cde | 139.5 | 1.14 a | 0.07 a | 4.47 ab | 1.06 d | 714 | 25 e | 10.25 | |
| Biochar (30 g $kg^{-1}$) | | | 5.17 cd | 114.5 | 1.84 b | 0.0867 b | 4.39 ab | 2.16 c | 508 | 43 cd | 10.34 | |
| Biochar (60 g $kg^{-1}$) | | | 5.34 bc | 110.8 | 2.25 c | 0.0893 bc | 2.01 c | 3.11 b | 697 | 62 b | 11.70 | |
| Biochar (90 g $kg^{-1}$) | | | 5.62 a | 82.3 | 4.16 d | 0.0951 c | 3.58 b | 4.89 a | 653 | 83 a | 12.90 | |
| Control | Rice farm, Jiangsu, China | Wheat straw | 5.89 | | 2.16 | | | | | | | Cui et al (2011) |
| Biochar (10 g $kg^{-1}$) | | | 6.13 | | 2.37 | | | | | | | |
| Biochar (20 g $kg^{-1}$) | | | 6.24 | | 2.90 | | | | | | | |
| Biochar (40 g $kg^{-1}$) | | | 6.27 | | 3.38 | | | | | | | |

*Table 1 continued...*

| Treatment | Location/soil type | Biochar origin | Soil pH ($H_2O$) | Available Al (mg $kg^{-1}$) | Organic C (%) | Total N (%) | Available P Bray I (ppm) | Exchangeable K (cmol $kg^{-1}$) | Ca (mg $kg^{-1}$) | Mg (mg $kg^{-1}$) | CEC (cmol $kg^{-1}$) | Information source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Control | Ustipssam-ment Lombok, In-donesia, rainy season | | 6.29 | | 0.87 | 0.11 | 23.59 | 0.70 | | | 13.34 | Sukartono et al (2011) |
| Biochar (15 t $ha^{-1}$) | | Coconut shell | 6.49 | | 1.15 | 0.12 | 26.48 | 0.75 | | | 15.04 | |
| Biochar (15 t $ha^{-1}$) | | Cattle dung | 6.45 | | 1.14 | 0.16 | 26.24 | 0.89 | | | 15.10 | |
| Control | Acid sulfate soil of West Kalimantan, Indonesia | | 3.36 | | 0.54 | | | 0.20 | 0.24 | 3.55 | 6.64 | Masulili et al (2010) |
| Biochar (15 t $ha^{-1}$) | | Rice husk | 4.40 | | 4.09 | | | 0.51 | 0.44 | 3.57 | 8.03 | |
| Control | Ultisols, Norfolk soil, Florence, SC | | 5.2 | | 1.74 | | | | | | 5.2 | Novak et al (2009) |
| Biochar (0.5%) | | Pecan shells | 5.6 | | 1.83 | | | | | | 5.4 | |
| Biochar (1.0%) | | | 5.9 | | 2.19 | | | | | | 5.6 | |
| Biochar ( 2%) | | | 6.4 | | 2.92 | | | | | | 5.9 | |

[a]Means followed by the same letter in the same column are not significantly different ($p=0.05$).

## Soil biological properties

Many complex organisms live in soils, which are continually changing in response to varying soil characteristics, climate, and land management through application of organic matter (Thies and Rillig 2009). The addition of biochar to the soil is likely to have different effects on the soil biota. The soil biota is vital to the functioning of the soils, providing many essential ecosystem services. Little is known on the effect of biochar on soil biota, however. Some studies have mostly focused on bacteria, mycorrhiza, and earthworms. Quilliam et al (2012) reported the activity of soil microorganisms by soil respiration, saying that reapplication of biochar significantly increased the level of basal soil respiration with the highest rate in the 50 t $ha^{-1}$ soil application at the beginning and 50 t $ha^{-1}$ soil reapplication 13 days after sowing. In long-term plots, however, application rate of biochar had no significant influence on basal respiration rates compared with the control. It is hypothesized that the very porous biochar provides the surfaces on which soil microbes colonize and grow. Graber et al (2010) have found that, with increasing rate of biochar application, there were more culturable colonies of general bacteria, *Bacillus* spp., yeasts, and *Trichoderma* spp. but decreasing culturable filamentous fungi *Pseudomonas* spp. and *Actinomycetes* spp. Root-associated yeast and *Trichoderma* spp., which were non-measurable in the control treatment, increased by 3 and 2 log units in the biochar treatments, respectively. Significantly, a greater number of general bacteria, *Pseudomonas* spp., and fungi were also observed; bulk microbial abundance, diversity, and activity were strongly

**Table 2. Physical properties of the soil as affected by application of biochar in several experiments.**[a]

| Treatment | Location/soil type | Biochar origin | Bulk density ($g\ cm^{-3}$) | Porosity (%) | Water-holding capacity ($g\ H_2O\ g^{-1}$ dry soil) | Aggregate stability index | Permeability ($cm\ h^{-1}$) | Information source |
|---|---|---|---|---|---|---|---|---|
| Control | Silt loam, southern Finland | | 1.30 | 50.9 | 0.485 ± 0.014 | | | Karhu et al (2011) |
| Biochar (9 t $ha^{-1}$) | | Charcoal | 1.25 | 52.8 | 0.540 ± 0.019 | | | |
| Control | Ultisols/Gunung Madu, Lampung | | 1.11 b | 43.19 a | | 0.67 a | 4.24 b | Haryani and Gunito (2012) |
| Biochar (10 t $ha^{-1}$) | | Bagasse | 1.07 a | 45.07 b | | 0.79 b | 2.83 a | |
| Control | Acid sulfate soil of West Kalimantan | | 1.24 | 44.43 | | | | Masulili et al (2010) |
| Biochar (15 t $ha^{-1}$) | | Rice husk | 1.17 | 53.16 | | | | |

[a]Means followed by the same letter in the same column are not significantly different (p=0.05).

influenced by soil pH. The buffering capacity imparted by the CEC of biochar may help maintain the appropriate pH conditions and minimize pH fluctuations in the microhabitats within the biochar particles.

Rondon et al (2007) stated that biochar application has the potential to improve N availability in agroecosystems by means of biological $N_2$ fixation (BNF). They reported that the proportion of fixed $N_2$ increased from 50% without biochar addition to 72% with 90 g $kg^{-1}$ biochar. Total N derived from the atmosphere significantly increased by 49 and 78% with 30 and 60 g $kg^{-1}$ biochar added to the soil, respectively. The higher BNF is perhaps caused by some nutrients such as Mo, P, Ca, and Mg, which were high in biochar-amended soils.

Warnock et al (2007) reviewed several research publications about the direct and indirect influence of biochar on arbuscular mycorrhizal fungi (AMF) colonization in plant roots and found that biochar increased the ability of AMF to assist their host in resisting infection by plant pathogens. Some studies have reported possible mechanisms: (1) biochar changes soil nutrient availability, (2) biochar alters the activity of other microorganisms that have effects on the mycorrhizae, (3) biochar alters the plant-mycorrhizal fungi signaling processes or detoxifies allelochemicals, leading to altered root colonization by mycorrhizal fungi, and (4) biochar serves as a refuge for the colonizing fungi and bacteria.

A limited number of studies have examined the impact of biochar addition to the soil on population density and biomass of earthworms. Weyers and Spokas (2011) reviewed some research on the addition of biochar and other black carbon substances, including slash-and-burn charcoal and wood ash, to earthworms. They identified a range, from short-term negative impacts to long-term null effects on earthworm population density and total biomass. They hypothesized that these are related to soil pH or to the fact that biochar is premoistened. Feeding behavior may be affected or there are unknown factors involved.

## Conclusions

The of literature showed that biochar has high potential in improving soil physical, chemical, and biological properties. However, it is not widely applied in Indonesia, partly due to the lack of awareness among the local producers. In an agroindusrial land where most of the people work as farmers, there are sufficient amounts and kinds of biomass materials for biochar production. The application of biochar to agricultural land seems suitable. This necessitates further studies to ensure the wide use of this important resource in Indonesia.

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## Notes


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