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BIOCHAR, CHARACTERISTICS AND ITS EFFECTS ON SOIL PROPERTIES AND ENVIRONMENTAL MITIGATION

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Abstract: Biochar (biological charcoal) is a charcoal product produced by heating biomass at temperatures ranging from 400oC-500oC in conditions without oxygen or minimal oxygen (pyrolysis). Biochar has the characteristic of having a high amount of aromatic carbon that is difficult to decompose by microorganisms. The use of biochar in the tropics is very beneficial for maintaining soil fertility and reducing atmospheric pollution with carbon dioxide and methane gases. Effectiveness of biochar depends on the type of biomass and temperature used at pyrolysis. Types of woody biomass produce coarser biochar, while leafy biomass, grasses produce finer biochar. Temperatures exceeding 500oC will produce more ash than biochar. Biochar has biochemical characteristics, aromatic structure and chemical content. Thus it can function to improve physical, chemical and absorbent properties. Aromatic structures are useful in slowing decomposition so that they hold carbon in the soil for long periods. Thus it can slow down the release of carbon and methane into the atmosphere.

Keywords: *atmosphere, biochar, biomass, carbondioxide, pyrolysis*

Abstrak: Biochar (arang hayati) adalah suatu produk arang yang dihasilkan dengan cara pemanasan biomass pada suhu berkisar antara 400 oC – 500 oC pada kondisi tanpa oksigen atau oksigen minimal (pyrolisis). Biochar mempunyai karakteristik memiliki jumlah karbon aromatic tinggi yang sukar didekomposisi oleh mikroorganisme. Penggunaan biochar di daerah tropis sangat bermanfaat untuk memelihara kesuburan tanah dan mengurangi pencemaran atmosfir dengan gas-gas karbon dioksida dan metana. Keefektifan biochar tergantung pada jenis biomass dan suhu yang digunakan pada saat pyrolisis. Jenis biomass kayu menghasilkan biochar lebih kasar, sedangkan biomass daun-daunan, rumput-rumputan menghasilkan biochar yang lebih halus. Suhu melebihi 500 oC akan lebih banyak menghasilkan abu dibandingkan biochar. Biochar mempunyai karakteristik biokimia, struktur aromatic dan kandungan kimia. Dengan demikian dapat berfungsi untuk memperbaiki sifat fisik, kimia dan sebagai absorben. Struktur aromatic bermanfaat dalam perlambatan dekomposisi sehingga menahan karbon dalam tanah dalam jangka waktu lama. Dengan demikian dapat memperlambat penglepasan karbon dan metan ke atmosfer.

Kata Kunci: *atmosfer, biochar, biomass, karbondioksida, pyrolisis*

Introduction

Soil is the result of weathering processes of rocks that are influenced by climate, organisms at various topographies over a certain period of time. These factors will influence the weathering process of minerals present in rocks. Weathering of minerals gradually over time releases nutrients into the soil. Some of the easily soluble and slow-dissolved nutrients can be leached into the soil profile and lost from the soil carried in runoff water after rain, and others are taken by plants to maintain their growth. The elements taken by agricultural crops are carried along with the harvest, washed away and lost with erosion. The dynamics of these nutrients will change the balance of nutrients in the soil.

With the process of weathering, leaching and reduced nutrient elements in the soil resulting in conditions of plant growth in general become stunted, which is shown by stunted root growth, slow growth rate and not resistant to pest and disease attacks. The result is that crop yields qualitatively and quantitatively decrease. Generally these characteristics are shown in soils that have undergone further weathering, such as the Alfisols, Ultisols and Oxisols. Continuous planting in the soils of the Alfisols, Ultisols and Oxisols orders has resulted in an acceleration in the decline of soil organic matter in the topsoil after several years of land clearing (Brams 1971, Juo *et al.*, 1995b in Hossner & Jou, 1999), soil pH decreases and Ca, Mg can exchange also decreases, and is triggered by the use of fertilizers that are acidic (Cunningham 1963, Adepetu *et al.,* 1979, Juo & Kang 1989, Bache & Heathcote 1969, Kang & Balasubramanian 1990, Pichot *et al., 1981*, Juo *et al.,* 1995a in Hossner & Jou, 1999).

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Ultisols have characteristics of low organic matter content (0.2 - 1.0%), acidic pH (4.5 - 5.9) and low cation exchange capacity (CEC, 2-8 cmol kg-1). Similarly, Oxisols soils have a low fertility rate. Low soil organic matter results in poor soil structure which can inhibit root penetration in soils and low groundwater holding capacity thereby limiting agricultural productivity (Novak, Busscher, & Ducey., 2009). Thus to maintain sustainable crop production on these lands with the availability of nutrients in the soil that meet the needs of plants must be balanced with addition from outside in the form of inorganic fertilization (artificial fertilizer and lime) and organic fertilizer (plant residues, green manure and manure). Several publications show that chemical fertilization alone on Ultisol and Oxisol cannot sustain agricultural yields because these soils are dominated by Kaolinite clay minerals which are low in resistance to nutrients (Hossner & Juo, 1999). Whereas organic fertilizer is very useful in improving physical, chemical and biological soil characteristics, so that fertilizing efficiency can be achieved.

In the wet tropical climate, the decomposition process takes place very quickly, so that when organic fertilizer is added to the soil it is quickly decomposed into an inorganic form. This results in the half-life of organic matter in the soil does not last long, so the soil organic matter content decreases again. One source of organic material that is more resistant to weathering is biochar, which has porous properties, contains alkaline elements and is resistant to weathering so that it can store carbon for a long time. positive impact of the use of biochar is that in addition to improving the physical, chemical and biological properties of the soil it can also reduce the release of carbon dioxide which can ultimately reduce greenhouse gases in the atmosphere and the greenhouse effect (Sinar Tani, 2008).

Soil that has Undergone Further Weathering

1. Soil Formation

Soil comes from weathering rocks (igneous rocks, old sediments and metamorphoses) and softer and loose rocks such as volcanic ash, new sediments and others. Weathering of rock surfaces produces softer materials called regoliths. Furthermore, through the process of soil formation, the top of the regolith is transformed into soil (Hardjowigeno, 1987). In the process of soil formation is influenced by five factors, namely climate, origin material, topography, organism and time. In the wet-tropics, climatic factors (rainfall and temperature) have the greatest effect on changes in soil properties. Temperature increases the rate of weathering reactions and water (from rainfall) provides the medium where the weathering reactions occur. Examples of weathering K-feldspar minerals become kaolinite and gibsite minerals (Garels & Christ, 1965 in Uehara & Gilman, 1981). If weathering soils lasts long under hot and wet conditions resulting in the dissolution of permanently charged minerals and partly leaves insoluble deposits that are not available for sustainable crop production (Uehera & Gilmann, 1981). This condition is present in soils that have undergone further weathering, such as Ultisols and Oxisols soils.

2. Order Soils of Ultisols and Oxisols

According to Hardjowigeno (1987), Ultisols are soils where clay deposits in the horizon carry (Argillic) are acidic, base saturation is low at a depth of 180 cm from the ground surface that is less than 35%. The intensive weathering of primary minerals results in a large amount of Ca and Mg being washed from the soil, washing heavy clay to the horizon below, noticeably yellowish or reddish in color because it contains Fe oxide. Due to the high acidity and low amount of nutrients of Ca, Mg and K, this soil is often referred to as poor soil, making it less suitable for agriculture without the use of fertilizer and lime. With the addition of the outside, Ultisols soil becomes more productive. These soil used to be called the Red-Yellow Podzolik land found in Indonesia. Sometimes also includes latosol soil and gray hydromorph. Oxisols are advanced soils in intertropic areas, contain minerals which cannot be weathered and are often rich in Al and Fe oxides. While the weathered minerals are low. High clay content but not active so that CEC is low (less than 16 me / 100g clay) (Hardjowigeno, 1987). Most of these soils are characterized by low soil fertility, due to the low availability of nutrients due to the retention of phosphorous minerals. Because of low soil fertility requires additional lime and fertilization (McDaniel, 2009).

Biochar, Its Characteristics and Effects on Soil Properties and Environmental Mitigation

Biochar (biological charcoal) is a charcoal product that produced by heating biomass at temperatures ranging from 400ºC-500ºC under conditions without oxygen or minimal oxygen (pyrolysis). Biochar has the characteristics of having a high amount of aromatic carbon that is difficult to decompose by microorganisms, generally structured porous, has a large surface area and interacts with minerals, other types of soil organic matter and soil biota (Major & James, 2009). Biochar is not a substitute for fertilizer and is not in the form of ash, but when mixed with soil can improve soil properties, increase soil productivity and develop sustainable agriculture. Besides that biochar also enlarges the return of atmospheric CO2 into the soil. It is expected that over time there will be a balance between carbon released into the air and carbon sequestered in the soil (carbon sequestration) thereby reducing greenhouse gases in the atmosphere and reducing global warming (Sinar Tani, 2008)

Source of inspiration for the use of biochar on agricultural land is the discovery of terra petra (black soil) in the Amazon region, South America. This soil is able to support agricultural production in the long term, because it has a topsoil that is rich in carbon. This carbon comes from the cultural heritage of native Ameridian people who settled in the region (Glaser & Haumaier, 2001).

Biochar can be made from various types of biomass raw materials which include the remnants of agricultural products, leaf debris, bisolid, animal dung, and some industrial waste such as the remnants of paper making, and so on. All these ingredients must be dry. Biomass feedstock and pyrolysis conditions determine the quality of the biochar produced. According to Verheijen et al. (2010) those important factors that determine the characteristics of biochar are:

1. Structure and chemical composition of the biomass raw material is related to the structure and chemical composition of the biochar produced, therefore it is described in its behavior, function and effect in the soil;
2. The length of physical and chemical changes experienced by biomass during pyrolysis depends on the conditions (especially temperature and survival time).

In summary, some important components in various biomass raw materials are presented in Table 1.

Table 1. Summary of important (weighted) components in biochar raw materials

	Ash	Lignin Weight	Cellulose
Wheat Straw	11.2	14	38
Corn residue	2.8 – 6.8	15	39
Switchgrass	6	18	32
Wood (poplar,willow, oak)	0.27-1	26-30	38 -45

Source: Brown *et al.,* 2009 in Verheijen *et al.*, 2010

Cellulose and lignin undergo thermal degradation at temperatures ranging from 240ºC-350ºC and 280ºC-500ºC, respectively (Sjostrom, 1993; Demirbas, 2004 in Verheijen, 2010). Therefore the relative proportions of each component will determine how long the biomass structure lasts during pyrolysis. Biomass which contains a lot of lignin will produce the highest biochar. Biomass with high mineral content such as grass, wheat bran, and straw usually produces biochar which is rich in ash. Biomass containing ash up to 24% or even 41% by weight, such as husks, bran (Amonette & Joseph, 2009 in Verheijen, 2010). The mineral content of the biomass raw material is still largely retained in biochar, because what is lost is C, H and O during the combustion process.

Table 2. Example of nutrients proportions (g kg-1) in each raw material

Nutrients	Ca ($g\ kg^{-1}$)	Mg ($g\ kg^{-1}$)	K ($g\ kg^{-1}$)	P ($g\ kg^{-1}$)
Wheat Straw	7.70	4.30	2.90	0.21
Corncob	0.18	1.70	9.40	0.45
Cornstalk	4.70	5.90	0.03	2.10
Olive cake	97.0	20.0	-	-
Forest residue	130	19.0	-	-

Source: Chan & Xu, 2009 in Verheijen, 2010

Biochar made from animal manure has greater nutrient content than raw wood. While biochar from wood raw material is more resistant to weathering so it can last a long time in the soil. Higher pyrolysis temperature will produce a number of micro pores with greater adsorption capacity so that it is good to be used for adsorption of toxic compounds and soil rehabilitation (Azocleantech, 2009). Pyrolysis temperature of the source of biomass raw material will determine the magnitude of each component produced, namely gas, liquid and solids. The resulting gas can be flammable, including methane and other hydrocarbons which can be cooled by condensation and in the form of oil / tar residues that contain little water and this liquid gas can be used as fuel. Solid part is biochar which can be used to improve the soil.

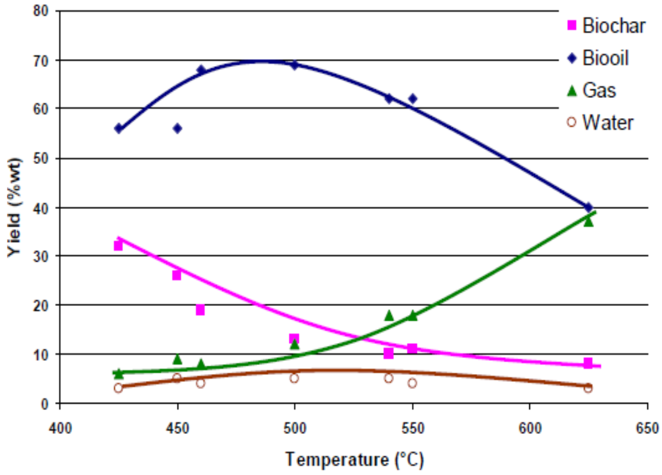

Figure 1. Graph illustrating the relative proportions of the final product after rapid pyrolysis of raw poplar aspen at a temperature range (Source: IEA, 2007 in Verheijen, 2010)

Biochar Characteristics

Heterogeneous combination of biomass raw material and the large range of chemical reactions that occur during the manufacturing process, making biochar a product with a unique set of structures and chemical characteristics. These properties are related to their influence on the properties of the soil and its processes in the soil. Warming at temperatures of 250 and 350^{o}C will degrade cellulose, resulting in a rough C amorphous matrix, with an increase in the temperature of the carbon aromatic portion of the biochar, due to increased loss of volatile materials (initially water, followed by hydrocarbons, tar vapors, H^2, CO and CO^2), and conversion from alkyl and O-alkyl C to arylC, at 330^{o}C polyaromatic grapheme sheet formed laterally. At temperatures above 600°C the carbonization process is more dominant.

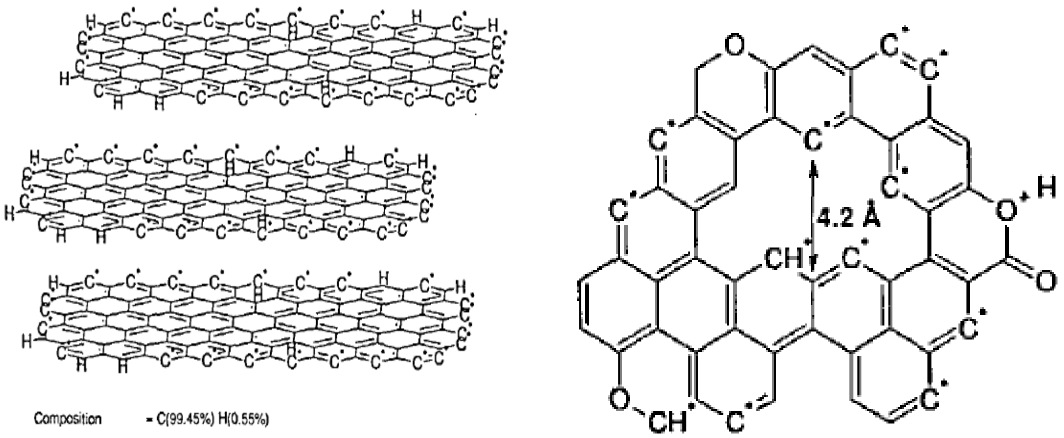

Figure 2. Charcoal structure; model of microcrystalline graphite structure (left) and aromatic structures containing oxygen and free carbon radicals (right)

Various biochar chemical compositions contain unstable and stable components. Carbon, volatile materials, mineral materials (ash) and water vapor are the usual constituents.

Table 3. Range of relative proportions of the four main biochar components (% Weight) as commonly available for various sources of materials and pyrolysis conditions

Component	Proportion (weight/weight)
Fixed carbon	50-90
Material that evaporates	0-40
Water vapor	1-15
Ash (mineral material)	0.5 - 5

Sources: Brown, 2009; Antal & Gronli, 2003 in Verheijen, 2010

Relative proportion of biochar components determines the chemical and physical properties and their overall function. For example, biochar which is rougher and more resistant to weathering comes from raw materials made from wood. Conversely animal dung and seaweed are usually finer and less weathering resistant (lower mechanical strength), but rich in nutrients, therefore more easily degraded by microorganisms in the environment (Sohi *et al*., 2009 in Verheijen, 2010). Besides the feasibility of the biochar produced is determined by the factors above, the high carbon content and aromatic structure must be constant, this shows its chemical stability.

The large distribution of grains in biochar also has the effect of determining the suitability of each biochar product for specific uses (Downie *et al*., 2009 in Verheijen, 2010) as well as for the selection of appropriate usage methods. In addition it affects the storage and transportation. Biochar from wood raw materials has a coarser grain distribution, whereas those derived from sorghum, or corn and animal dung have smaller distributions resulting in easily damaged structures (Sohie *et al*., 2009 in Verheijen, 2010).

During the heating process occurs the release of volatile compounds leaving the cavities which form an extensive inter-pore network in biochar. Biochar pores are classified into three categories according to their internal diameter (ID), namely; macro pore (ID> 50 nm), medium pore (2nm <ID <50nm) and micro pore (ID <2nm). Cation exchange capacity (CEC) ranges from very small up to 40 $cmol_c$ g^{-1} and changes as it is mixed into the soil (Lehmann, 2007 in Verheijen, 2010). While the pH is relatively homogeneous ranging from neutral to basic. Chan & Xu (2009) in Verheijen (2010) report that pH values in a wide range are in accordance with the origin of biomass raw material, where the average pH is 8.1 in the pH range 6.2 - 9.6. The lowest pH in biochar from green waste and bark, the highest from biochar from poultry litter.

Effect of Biochar on Soil Properties

Physical properties that are affected are soil structure, soil texture, large pore distribution and density related to soil aeration and ground water holding capacity, plant growth. The chemical properties that are affected are CEC, pH and nutrient content. While the biological nature is on the bacteria fixation N and mycorrhoea. Biochar serves to hold nutrients in the soil. Nutrients that are retained in the soil and which are available to plants are mainly by adsorption on minerals and organics. Biochar cannot change certain soil minerals, but can change the amount of organic matter in the soil. Typically, the ability of the soil to hold cations and release back to plants (CEC) increases with increasing amounts of organic matter in the soil, biochar is able to function well for that. However, biochar has a greater ability than other organic materials to absorb cations per unit of carbon (Sombroek *et al*., 1993 in Lehman, 2008), due to its greater surface area, greater negative charge, greater charge density (Liang *et al*., 2006 in Lehman, 2008).

Compared to other organic matter in the soil, biochar is also able to absorb pospat strongly, even though pospat anion. These properties make biochar a unique substance, resist exchange and therefore nutrients become available to plants in the soil, and improve crop yields while reducing nutrient pollution to the environment (Lehman, 2008).

Effect of Biochar on Environmental Mitigation

Very direct effect of the combination of pyrolysis and biochar application on soil is the return of CO_2 from the atmosphere. Carbon dioxide is assimilated by plants through photosynthesis, then pyrolyzed, producing energy from the captured gas, while the remaining biochar is stored and then stored in the soil. If new CO_2 is bound by plants, biochar is added to clean carbon deposits. The proportion of carbon stored in biochar during pyrolysis varies depending on the temperature of the pyrolysis and the type of raw material used (Lehmann *et al.*, 2006).

Right temperature range for biochar production through pyrolysis is 400-550°C. In addition to temperature, differences in raw materials are used while fixed temperature can change the initial recovery of carbon from 30% to 64% (Lehmann *et al.*, 2006 in Lehmann, 2008), where the average carbon recovery rate generally ranges from 50%. Biochar is unstable in the soil, because with time there will be weathering and release of CO_2 into the atmosphere. However, the time required for weathering is very long compared to other forms of soil organic carbon and the addition of unauthorized organic matter (Baldock & Smernik 2002, in Lehmann, 2008). The amount of carbon that can be stored is not limited by soil properties such as clay content and mineralogy, whereas organic soils are very influential. Return of plant raw materials in the form of biochar into the soil can reduce emissions of nitric oxide (NOx), and methane, where the results of research in the greenhouse show that NOx emissions have been reduced by 80% and methane emissions are really suppressed by the addition of 20 g/kg biochar for forage grass stands (Rondon *et al.,* 2005 in Lehmann, 2008)

Low nitrification is a potential mechanism, possibly due to the lower mineralization resulting from a higher C:N ratio. However, in forest soils, the addition of biochar has recently been found to reduce nitrogen mineralization due to adsorption and inactivation of secondary plant compounds, which usually decreases microbial activity (Deluca *et al.*, 2006 in Lehmann, 2008). With the decrease in microbial activity will inhibit the conversion of N-organic into inorganic form, which in the process can produce CO_2, which is a source of gas emissions in the atmosphere.

In connection with energy savings, the use of biochar can be aimed at carbon stocks in the soil. From the results of the provisional calculation biochar can balance carbon and energy and is very beneficial for animals, corn or switchgrass which is around 3-9 kg of energy produced every energy invested (Gaunt & Lehmann, data is not published). The current ratio for ethanol to 0.7-2.2 kg C (C kg) -1 (Pimentel & Patzek 2005; Metzger 2006) and for burning biomass, for C kg 10-13 (C kg) -1 (Willow; Keoleian & Volk 2005). It should be noted that in the latter way it only produces heat rather than liquid fuel. This means that pyrolysis can produce 3-9 times more energy and at the same time, about half of the carbon can be stored in the soil. Therefore the use of biochar to meet energy needs, climate mitigation and increase soil fertility requires broad support from various parties.

Conclusion

Biochar is a biological charcoal product that is produced through the pyrolysis process at temperatures of 400ºC - 500ºC, which has the advantageous nature when given to the soil, it can also reduce the influence of global climate. Biochar is made from various biomass sources with easy and modern technology. Biochar quality is determined by biomass raw material and pyrolysis. Biochar in the soil has a longer weathering, so to know its behavior in the soil requires research with various sources of biomass raw material in different environmental conditions over a long period.

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