Physical, Chemical and Bilogical Properties of Biochar

Department of Soil & Environmental Sciences, College of Agriculture, University of Sargodha, Sargodha

Biochar(Introduction)

- Biochar has been recently recognized as a multifunctional material related to carbon sequestration, contaminant immobilization, greenhouse gas reduction, soil fertilization, and water filtration. (Ahmad et al. 2012; Awad et al. 2012; Bolan et al. 2012; Lehmann and Joseph 2009).
- Biochars are mainly composed of carbon. The organic portion of biochar has a high carbon content, and the inorganic portion mainly contains minerals such as Ca, Mg, K, and inorganic carbonates (carbonate ion), depending on its feedstock type.

Biochar(Introduction)

- The complex and heterogeneous chemical and physical composition of biochars provides an excellent platform for contaminant removal.
- The chemical composition of biochars depends on the type of feedstock and pyrolysis conditions (e.g., residence time, temperature, heating rate, and reactor type); thus, not all biochar is the same and it is difficult to define the exact chemical composition of biochar (Lehmann and Joseph 2009).

Origin and Emergence of Biochar

- The origin of biochar extends back to the pre-Columbian era, when the ancient Amerindian communities in the Brazilian Amazon region first made dark earth soils (Terra Preta de Indio [black earth of the Indian]), also known as terra preta, through slash-and-char (Lehmann and Joseph 2009). These soils are characterized by high carbon content, up to 150 g C/kg soil, compared to the surrounding soils (20–30 g C/kg soil) (Glaser et al. 2002; Smith 1980).

Biochar (Definition)

- A solid material obtained from the thermo chemical conversion of biomass in an oxygen-limited environment (International Biochar initiative) A carbon-rich product when biomass such as wood, manure, or leaves is heated in a closed container with little or no air (Lehmann and Joseph, 2009)

Char and Charcoal VS Hydrochar

- The term *char is used to denote any solid product resulting* from the natural and synthetic organic material decomposition (Fitzer et al. 1995). Biochar and charcoal have been distinguished considering the end use (Lehmann and Joseph 2009): charcoal is used as fuel and energy, whereas biochar is directed toward environmental management and carbon sequestration.
- Hydro char is produced from biomass hydrothermal carbonization (Libra et al. 2010). In general, dry biomass (up to 10% moisture) is used to produce carbonization, pyrolysis, or gasification biochars, whereas hydrothermal (wet) biomass carbonization under pressure is used to produce hydro chars.

Origin of Terra Preta and Its Research

- The origin of biochar is connected to the Amazon River basin where thousands of raised platforms of black and very fertile soil patches were first discovered by the explorer Herbert Smith in 1879 (Marris 2006). In relation to its dark color and origin, the soil was named Terra Preta de Indio (black earth of the Indian). Today, even addition of chemical fertilizers cannot maintain crop yields into a third consecutive growing season, yet these dark earths have retained their fertility for centuries. chemical and physical properties and cultural origin of terra preta. Field studies have provided evidence that terra preta was created through the use of slash-and-char techniques (Lehmann and Joseph 2009).

Properties of Biochar

1. Physical properties of biochar
2. Chemical properties of biochar
3. Biological properties of biochar

1. Physical properties of biochar

- The physical properties of biochars contribute to their function as a tool for environmental management. Their physical characteristics can be both directly and indirectly related to the way in which they affect soil systems(Brady and Weil, 2008). When biochar is present in the soil mixture, its contribution to the physical nature of the system may be significant, influencing depth, texture, structure, porosity and consistency through changing the bulk surface area, pore-size distribution, particle-size distribution, density and packing.

Soil surface areas and biochar

- Surface area is a very important soil characteristic as it influences all of the essential functions for fertility, including water, air, nutrient cycling and microbial activity. The limited capacity of sandy soil to store water and plant nutrients is partly related to the relatively small surface area of its soil particles. High organic matter contents have been demonstrated to overcome the problem of too much water held in a clay soil, and also increase the water contents in a sandy soil (Troeh and Thompson, 2005).

Biochar nano-porosity

- The pore-size distribution of activated carbons has long been recognized as an important factor for industrial application. It is logical that this physical feature of biochars will also be of importance to their behaviour in soil processes. The relationship between total surface area and pore-size distribution is logical.
- Micropores contribute most to the surface area of biochars and are responsible for the high adsorptive capacities for molecules of small dimensions such as gases and common solvents (Rouquerol et al, 1999).

Biochar macroporosity

- In the past, when biochars and activated carbons were assessed mainly for their role as adsorbents, macrospores (>50nm diameter) were considered to be only important as feeder pores for the transport of adsorbate molecules to the meso- and micro-pores. Macropores are also relevant to the movement of roots through soil and as habitats for a vast variety of soil microbes.

Particle-size distribution

- The particle sizes of the biochar resulting from the pyrolysis of organic material are highly dependent upon the nature of the original material. Due to both shrinkage and attrition during pyrolysis, particle sizes of the organic matter feedstock are likely to be greater than the resultant biochar. In some cases, particles may agglomerate; therefore, increased particle sizes are also found (Cetin et al, 2004). Depending upon the mechanical intensity of the pyrolysis technology employed, a degree of attrition of the biomass particles will occur during processing. This is especially true in the post-handling of the material as the biochar is significantly more friable than the original biomass.

Biochar density

- Two types of density of biochars can be studied: the solid density and the bulk or apparent density. Solid density is the density on a molecular level, related to the degree of packing of the C structure. Bulk density is that of the material consisting of multiple particles and includes the macro porosity within each particle and the inter-particle voids. Often, an increase in solid density is accompanied by a decrease in apparent densities as porosity develops during pyrolysis. The relationship between the two types of densities, who reported that apparent densities increased with the development of porosities from 8.3 to 24 per cent at pyrolysis temperatures up to 800°C(Guo and Lua, 1998).

Mechanical strength

- The mechanical strength of biochar is related to its solid density. Therefore, the increased molecular order of pyrolysed biomass gives it a higher mechanical strength than the biomass feedstock from which it was derived. Mechanical strength is a characteristic used for defining the quality of activated carbon as it relates to its ability to withstand wear and tear during use. Agricultural wastes, such as nut shells and fruit stones are of interest as activated carbons because of their high mechanical strength and hardness. These properties can be explained by high lignin and low ash contents (Aygun et al, 2003).

2. Chemical properties of Biochar

- **Elemental ratios**
- **C-nuclear magnetic resonance (NMR) spectroscopy**
- **Macro-elements**
- **Micro-elements**
- **Acidity (pH)**
- **Salt levels**

Elemental ratios

- The H/C ratio of unburned fuel materials, such as cellulose or lignin, is approximately 1.5, and used molar H/C ratios of 0.2 to define 'black carbon'. Graetz and Skjemstad (2003) concluded that temperatures during biomass burning are predominantly greater than 400°C and that chars formed during these temperatures are likely to have H/C ratios of 0.5. Consequently, biochar production is often assessed through changes in the elemental concentrations of C, H, O and N and associated ratios. Specifically, H/C and O/C ratios are used to measure the degree of aromaticity and maturation, as is often illustrated in van Krevelen diagrams (Baldock and Smernik, 2002; Braadbaart et al, 2004, Hammes et al, 2006).

C-nuclear magnetic resonance (NMR) spectroscopy

- Several studies have focused on determining the chemical structure and composition of natural and laboratory-produced biochars. For example, Baldock and Smernik (2002) investigated the chemical changes that occurred in wood, heated to temperatures of 150°C, 200°C, 250°C, 300°C and 350°C in a muffle furnace. While heating to 150°C did not alter C or N concentrations, at temperatures of >150°C, C concentrations increased progressively, while N concentrations were greatest at 300°C.

Macro-elements

- Macro-elements are the most important nutrients for plants. They occur naturally in the soil to some extent and can be supplemented with fertilisers, manure and compost. Legumes are able to bind nitrogen. The macro-elements are calcium (Ca), magnesium (Mg), potassium (K), sulphur (S), phosphate (P), nitrogen (N), sodium (Na).

Micro-elements

- Trace elements are nutrients that plants need in small doses. The trace elements are boron (B), copper (Cu), manganese (Mn), cobalt (Co), silicon (Si), zinc (Zn), iron (Fe) and molybdenum (Mo). Signs of shortage occur when the disappearance of trace elements through the crops is not compensated adequately with supplements by means of fertiliser, manure or compost, or when the availability of certain elements is limited by the pH or mineral imbalance in the soil. It is difficult to solve a lack of trace elements in the plant at source, as many shortages are the result of a shortage or surplus of another mineral in the soil.

Acidity (pH)

- Acidity (pH) is a measure of the concentration of free hydrogen ions (H^+). A high concentration in the soil signifies a low pH, whilst a low concentration equals a high pH. Soils and other substances with a pH below 6 are called acidic, whilst those with a pH above 6 are known as base or alkaline. The form in which macro-elements and micro-elements occur in the soil depends on the pH. This means that the pH exercises a significant influence on the availability of nutrients for plants, as plants cannot absorb macro-elements and micro-elements in all their forms. A pH that is less than 4.5 restricts the availability of a number of elements. Soil-life activity and consequently the mineralisation of organic matter are limited in that situation

Salt levels

- The salt level is the sum of all the mineral salts that are present in the soil. They can originate from the soil itself, fertiliser, organic manure and in coastal areas from salt marshes or tidal marshes. When the salt levels in the soil are higher than in the cells of the plant roots, the moisture is drawn from the roots and the fine hair roots die off. Over time this impedes the moisture and nutrients absorption by the plant and causes reduced growth or death of the plant. Crops vary in the extent to which they tolerate salt and the salt levels at which they can still provide a good yield. Some crops grow well in salty soils

3. Biological properties of Biochar

- Decades of research in Japan and recent studies in the US have shown that biochar stimulates the activity of a variety of agriculturally important soil microorganisms and can greatly affect the microbiological properties of soils (Ogawa et al, 1983; Pietikäinen et al, 2000).The presence and size distribution of pores in biochar provides a suitable habitat for many microorganisms by protecting them from predation and desiccation and by providing many of their diverse carbon (C), energy and mineral nutrient needs (Saito and Muramoto, 2002;Warnock et al, 2007).

Biochar as a habitat for soil microorganisms

- The porous structure of biochar, its high internal surface area and its ability to adsorb soluble organic matter, gases and inorganic nutrients are likely to provide a highly suitable habitat for microbes to colonize, grow and reproduce, particularly for bacteria, actinomycetes and arbuscular mycorrhizal fungi.

Biochar as a substrate for the soil biota

- Soil organic C plays a pivotal role in nutrient cycling and in improving plant-available water reserves, soil buffering capacity and soil structure (Horwath, 2007). Researchers used to regard biochar as a relatively inert substance that was altered very little by chemical or biochemical processes over time (Nichols et al, 2000). However, biochar surface properties do change with time and it is slowly mineralized over long periods of time. Even though biochar is not strictly inert, decomposition rates are much slower than for uncharred organic matter.

Use of biochar as an inoculant carrier

- Many microorganisms have been used to increase crop production through batch culturing, adding the inoculum to an appropriate carrier and either placing the inoculum in the planting furrow or adhering it to seeds immediately prior to planting. Both mutualistic and free-living N2-fixing bacteria, other plant growth promoting rhizobacteria (PGPR), such as *Paenibacillus, Bacillus and Pseudomonas, and saprophytic and mycorrhizal* fungi have been used as inoculants applied to field soils. Ogawa (1994) has used biochar as a carrier substrate for both rhizobia and for arbuscular mycorrhizal (AM) over the past 20+ years with excellent success.


Thank You