Impact of Biochar on Soil Physical Properties

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Full Length Research Paper

Impact of Biochar on Soil Physical Properties

Zeeshan Aslam*, Muhammad Khalid and Muhammad Aon

Research Fellow and Ph.D scholar, Institute of Soil and Environmental Sciences, University of Agriculture, Faisalabad Pakistan.

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Biochar is a carbonaceous recalcitrant product of biomass produced through the process of pyrolysis. It can be used as a tool to improve the soil properties for a long period of time as compared to other organic amendments. Although the role of biochar on soil chemical properties is well known there is scarce information about impacts of biochar on soil physical properties. The objectives of this review are to 1) collect all the available data on the significance of biochar for soil physical properties 2) describe all possible mechanisms by which biochar improve soil physical properties 3) to highlight the areas where future research is needed. After review it is concluded that application of biochar at 1-2 % (W/W) decreases the soil bulk density, increases soil porosity and infiltration rate by increasing the total soil porosity. In the same way biochar application increases water holding capacity of soil but it varies with respect to soil texture. The possible mechanisms behind these improvements in soil physical properties by biochar application are high porosity, adsorptive nature of biochar, provision of habitat to microorganisms and increase in total soil organic carbon contents. However improvements in soil physical properties by biochar addition into the soil changes with respect to soil type where biochar was applied, kind of biochar used (on the basis of feed stock and pyrolysis conditions) and the rate of biochar applied.

Key words: Biochar, Soil physical properties, Organic carbon.

INTRODUCTION

Soil physical conditions have a direct effect on soil productivity for crop production by determining water holding capacity, aeration and soil strength limitations for root activity (Benjamin et al., 2003). Soil having good structure, porosity, hydraulic conductivity, bulk density and strength provide good medium for growthto beneficial microorganisms, better nutrient and water movement into the soil profile, higher nutrient and water retention and more root growthultimately provide higher yield as compared to degraded soil having poor physical properties (Abdallah et al., 1998).Soil organic matter is one of the main factors affecting physical properties of soil. Organic matter improves soil structure by increasing soil aggregation, increases soil porosity due to its high porous nature, boast up nutrient and water retention due to its high adsorption capacity and high surface area all these results in betterroot growth and crop yield. Soil having more in organic matter concentration results better physical properties and yield as compared to soil which is low in organic matter concentration (Bowman et al., 1990).

There has been a rapid increase in human population over the past decades. This has resulted in increaseddemand for food, fiber and raw materials to meet human needs hence there is urgent need to strengthen agriculture production in order to secure food supply. This has given rise to marked intensification in agriculture which results in more decomposition of organic matter and ultimately degraded the soil physical properties (Middleton et al., 1992; Reynolds et al., 2002). Anthropogenic activities cause harsh agro-climatic conditions especially high temperature. High temperature promotes rapid decomposition of soil organic matter which acts as soil conditioner results in degradation of soil (Raul et al., 1997).

To improve the soil physical properties and fertility there is a need to increase the soil organic carbon contents. For this purpose integrated use of organic and

*Corresponding Author Email: zeshan2456@yahoo.com.

Table 1. Effect of different types and different rates of biochar on soil porosity of different typesof soil.

Soil Type	Type of biochar	Study type (Scale)	Application rate of Biochar %	Soil Porosity % or cm^3 cm^{-3}	Reference
Loamy sand soil	Peanut hulls Slow pyrolysis(500^{0}C)	Laboratory	0 25 50 75 100	0.50[a] 0.55[b] 0.61[c] 0.69[d] 0.78[e]	*(Leonard Githinji, 2013)*
Silt loam	Corn stover (CS) CS (350 ^{o}C) CS (550 ^{o}C)	Column	1.73 1.13 1	Increase 13[a] 10[a] 19[b]	*(Herath et al., 2013)*
Allophanic	Pine biochar Fast pyrolysis (650 ^{o}C)	Laboratory	0 12.5 25	69.64[a] 71.28[a] 72.05[a]	*(Rahman et al., 2011)*
Silt loam	Birch (*Betulapendula)* 400^{o}C	Field	0 1.2	50.9 52.8	*(Karhu et al*., 2011)

inorganic fertilizer is becoming an emerging trend (Vanlauwe et al., 2004). Organic fertilizers such as compost, manure, biogas slurry are used now a days as a source of organic carbon but there rate of decomposition is very high (Palm et al., 2001). There is need a need to use such organic fertilizer which is recalcitrant to decomposition for a long period of time and maintain the soil organic carbon status.

Biocahr is a carbonaceous product obtained through the thermal decomposition of biomass in the absence of oxygen or little oxygen at high temperature. It has good physical properties i.e. high porosity, large surface area (Van Zwieten et al., 2010). It is recalcitrant to decomposition because of its aromatic structure and crystalline graphing sheet present in its structure. It recalcitrant period in soil is 10-1000 times more than organic matter (Christopher et al., 2010). The properties of biocahr depend upon the type of biomass used for feed stock and pyrolysis conditions i.e. charring time, rate and temperature (Mukherjee and Lal, 2013). Biocahr produced through woody feed stock is coarser and more recalcitrant as compared to that produced through agronomic residues. Similarly if biochar produced at high temperature then it has fewer nutrients and high micro pores as compared to that produced at low temperature that has more nutrients and less micro pores (Lehmann et al., 2009). A specific type of biochar has specific properties Sospecific type of biochar improves physical properties of specific type of soil and under specific climatic conditions (Herth et al., 2013).

Effect of biochar on soil physical properties

Effect of biochar on soil porosity

The pore space or porosity of soil is defined as the ratio of the pore volume to total soil volume. It is very important soil attribute affecting plant growth. There are three types of pores present in soil (macr, meso and micro pores) classified on the basis of size. These are important for aeration, movement and retention of nutrient as well as water and also provide refuge to microbes inside the soil. The overall porosity of soil increased by application of biochar but this increases in porosity was depend on type of biocahr used and soil type where biochar was applied (Herth et al., 2013). Relative contribution of three types of pores varies in total increment of soil porosity depending upon biochar and soil type (Leonard Githinji, 2013). This increase in soil porosity was due to high porous nature of biochar (Mukherjee et al., 2013). Some scientist described that soil porosity will decreased by biochar application due to clogging of soil pore by biochar dust. Fallowing table showed the effect of different types and rate of biochar application on soil porosity of different soils.

Effect of Biochar on Soil Bulk Density

Bulk density is a measurement of how tightly soil particles are pressed together. It is a ratio of mass of oven dry soil to bulk volume (volume of soil particles + volume of pore spaces). Bulk density of soil has a significant effect on soil properties as well as on plant growth e.g. a soil having high bulk density (>1.6 Mg cm^{-3}) has less capacity to absorb water and provide great penetration resistance to plant root into the soil ultimately soil characteristic as well as plant growth will be effected (A.M Goodman and A.R Ennos, 1998). According to Mukherjee et al., (2013) biochar application decreased the soil bulk density because porosity of biochar is very high and when it used in soil it significantly decrease bulk density by increasing the pore volume. Leonard Githinji (2013) concluded that by increasing the rate of biochar application bulk density was also significantly decreased.

Table 2. Effect of different types and different rates of biochar on soil bulk density of different typesof soil

Soil Type	Type of biochar	Study type (Scale)	Application rate of Biochar %	Bulk Density (g cm^{-3})	Reference
Loamy sand	Pecan shells 700 ^0C	Laboratory	0 2.1	1.52^a 1.45^b	*(Bussher et al., 2011)*
Loamy sand soil	Peanut Hulls Slow pyrolysis 400 ^0C	Laboratory	0 25 50 75 100	1.30^a 1.15^b 0.85^c 0.60^d 0.38^e	*(Leonard Githinji, 2013)*
Anthrosol	Wheat straw 350-550 ^oC	Field	0 1.1 2.2 4.4	0.99^a 0.96^a 0.91^b 0.89^b	*(Mankasingh et al., 2011)*
Silt loam	Corn stover (CS) CS (350 ^oC) CS (550 ^oC)	Column	0 1.73 1.13 1	1.01^a 0.93^b 0.94^b 0.91^b	*(Herath et al., 2013)*

Table 3. Effect of different types and different rates of biochar on soil aggregation of different types of soil

Soil Type	Type of biochar	Study type (Scale)	Application rate of Biochar %	Bulk Density (g cm^{-3})	Reference
Loamy sand	Pecan shells 700 ^0C	Laboratory	0 2.1	14.3^a 12.9^a	*(Busscher et al., 2011)*
Albicluvisol	Hydrochar 220 ^0C	Laboratory	Laboratory 0 5 10 Greenhouse 0 5 10	49.8 69 65.1 10.3 20.8 33,8	(George et *al*., 2012)
Loamy sand	Peanut Hulls Slow pyrolysis 400 ^0C	Laboratory	0 .5 1 2	9.95^a 9.53^a 10.7^b 9.23^a	*(Busscher et al., 2010)*

Table 4. Effect of different types and different rates of biochar on water retention capacity of different types of soil

Soil Type	Type of biochar	ST Study type (Scale)	Application rate of Biochar %	Water Retention Capacity		Reference
				%	g cm^{-3}	
Sandy loam	Pondersoa Pine 450 ^oC	Laboratory	0 0.5 1 5		11.9^a 12.4^a 13^a 18.8^b	(*Briggs et al*., 2012)

Effect of Biochar on Soil Aggregation

Soil colloidal particles adhere together depends upon net attractive forces among them this is called soil aggregation. This property is very important from soil structure point of view. A soil which is well aggregated has a good structure and as a result provide good medium for nutrient and water movement into the soil and uptake by plants (Borselli et al., 1996). Dorioz et al., (1993) described that certain polysaccharides secreted by microorganisms also increase the adherence of soil colloidal particles. Application of biochar provides refuge to microorganisms and also prevents them from predators and desiccation. The microorganisms secrete polysaccharides which increase soil aggregation (Angers et al., 1993).

Table 4. Contd.

Sandy soil	Black locust 300 ^{o}C 400 ^{o}C 500 ^{o}C	Laboratory	0 10 t/ha 300 ^{o}C 400 ^{o}C 500 ^{o}C 20 t/ha 300 ^{o}C 400 ^{o}C 500 ^{o}C		0.28 0.285^{b} 0.315^{b} 0.37^{a} 0.39^{b} 0.42^{b} 0.53^{a}	*(Uzoma et., 2010)*
Allophanic soil	Pine biochar Fast pyrolysis 630 ^{0}C	Laboratory	Soil A 0 25 t /ha 50 t/ha Soil B 0 25 t/ha 50 t/ha	 90.14 93.34 98.23 87.35 91.48 92.98		*(Rahman et al., 2011)*

Effect of biochar on soil water holding capacity

Soil water retention capacity is the maximum amount/quantity of water that a soil can hold or retain. It is very important property with respect to formers point of view as well as plant growth. If a soil can hold large amount water it decrease the irrigation frequency of crop and also plant grow well this type of soil. It was investigated that biochar application boast up the available water content of the soil up to 97 percent and saturated water contents 56 percent (Uzoma et al., 2011). Laird et al., (2010) described that the biochar amended soil retained 15 % more moisture contents as compared controlled treatment. According to E. H. Tryon (1948) biochar application into the soil increased the water retention capacity of the soil but it is texture dependent. There is significantly increased in soil water retention capacity in case of sandy soil by biochar application but there little and no increased in loamy and clay soil respectively. Herth et al., (2013) described experimentally that biochar application increased the water retention capacity of the soil because it increase soil porosity and also due to adsorptive nature of biochar. Uzoma et al., (2011) said that there were hydrophilic functional groups present on the surface of the graphyne sheet of the biochar and also on the pores.

CONCLUSION

Application of biochar improve soil physical properties but this will depend on the kind of bichar (depend upon pyrolysis conditions and type of biomass) used, soil type where biochar applied and the rate of biochar application.

Research Priorities

There are fallowing research priorities from this review

1-As biochar increases water retention capacity of soil and it is also recalcitrant so can be used to reduce the irrigation frequency of crops
2-Selection of suitable type of biocahr for a specific soil type
3-Further research on mechanisms is needed that how biochar improve different soil physical properties

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