

Biochar:

An eco-friendly residue management approach

Shiv Vendra Singh¹, Sumit Chaturvedi², V C Dhyani³ and Debarati Datta⁴

Govind Ballabh Pant University of Agriculture and Technology, Pantnagar, Uttarakhand 263 145

Crop residue management is a common problem encountered by farmers due to numerous reasons. Traditional management practices, viz. residue burning and incorporation both are giving rise to new issues like nutrient losses, deterioration in soil properties, hindrance in machinery operation, nutrient immobilization etc. Pyrolysis of biomass under controlled conditions into biochar, which is a heterogeneous substance rich in carbon with high surface area, CEC porosity and other nutrients provides a novel residue management option with long-term carbon stabilization. Besides these a large portion of residue is being utilized for bio oil, fossil fuel, biogas and other purposes. Agricultural residue, traditionally considered as trash or agricultural waste, is being considered as a valuable resource for renewable energy and if the current trend continues, agricultural residue will be a co-product of crop production with higher economic values worldwide.

Key words: Biochar, Greenhouse gas emission, Terra-preta soils

CROP residue management is a common problem encountered by farmers due to shorter turnaround period, lack of requisite machinery for crop residue incorporation in the smaller landholdings and increased combine harvesting leaving behind a large amount of unmanaged crop residue in the field. Residue retention has positive effects on physico-chemical and biological properties of soil by increasing the hydraulic conductivity, reducing bulk density of soil by modifying soil structure and aggregation, modulating seasonal soil temperature, reducing the runoff flow and surface crusting and enhancing infiltration, reducing run off, acting as nutrient reservoir, preventing leaching of nutrients, increasing cation exchange capacity (CEC), increasing microbial biomass and enhancing enzymatic activities. Recycling of residues of wider C:N ratio leads to initial nutrient immobilization which causes the poor nutrient availability to the plant and farmers have to apply an additional nutrient dose to overcome

such problem. Residue burning ease the farm mechanical operations and management of insect pest and weeds, by both eliminating them directly and by altering their natural habitat as well as reducing turnaround period. Hence, farmers of Indo Gangetic plains (IGP) prefer burning the rice stalk in the field instead of harvesting and collecting for future uses. Beside the benefit of clean cultivation, burning leads to soil nutrient losses, negative impact on soil properties (elevation of soil temperature, microbial death and loss of macro and micro-nutrient from top layer of soil) and rise the emission of greenhouse and other gases (CO₂, CO, N₂O, NO_x and other hydrocarbons). In Punjab alone, some 70 to 80 million tonnes of rice and wheat straw are burned annually, releasing approximately 140 million tonnes of CO₂ into the atmosphere, in addition to methane, nitrous oxide and air pollutants. Burning of wheat and paddy straws alone contributes to about 42% of GHG emission. So, a reduction in

agricultural gasses CH₄ and N₂O emission becomes important and judicious residue management is one of the options.

The Biochar is a fine-grained, carbon-rich, porous product remaining after plant biomass has been subjected to thermo-chemical conversion process (pyrolysis) at low temperatures (~350–700°C) in an environment with little or no oxygen. Biochar is not pure carbon, but rather an activated charcoal containing high carbon (C), hydrogen (H), oxygen (O), nitrogen (N) and ash in different proportions. Hence, conversion of organic waste to produce biochar using the pyrolysis process is one of the viable options that can enhance natural rates of carbon sequestration in the soil, reduce farm waste and improve the soil physico-chemical properties, water holding capacity, nutrient adsorption capacity etc.

Biochar and Terra-preta soils concept

Biochar production is modeled

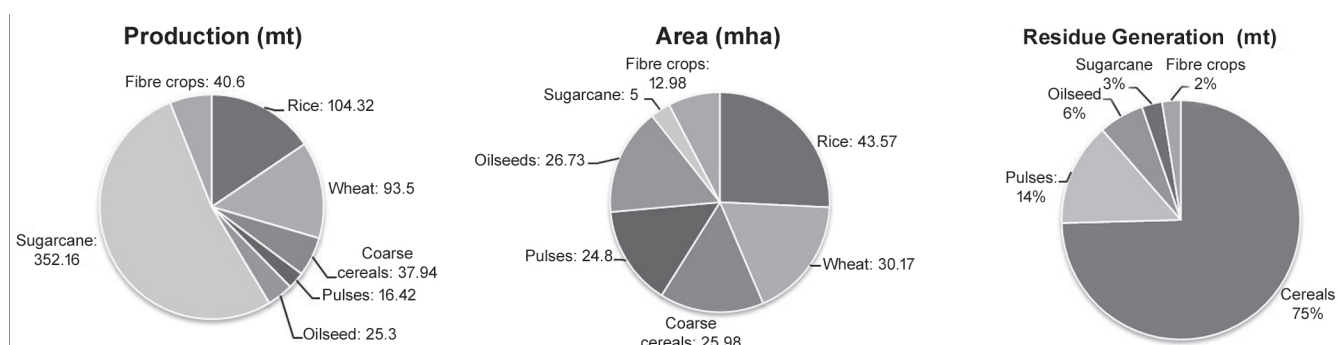


Fig. 1. Scenario of Agriculture in India with respect to crop production, area and residue generation (Directorate of Economics & Statistics, MA&FW, New Delhi (4th Advance Estimate-2015-16); Ministry of New and Renewable Energy, 2009)

after a process begun thousands of years ago in the Amazon Basin, where islands of rich, fertile soils called terra-preta (dark earth) were created by indigenous people. Anthropologists speculate placing of charcoal in soil resulted in soils with high fertility and carbon content, often containing shards of broken pottery. These soils continue to hold carbon today and remain so nutrient rich that they have been dug up and sold as potting soil in Brazilian markets.

The central quality of biochar that makes it attractive as a soil amendment is its highly porous structure and higher surface area (Table 1), potentially responsible for improved water retention, nutrient holding and increased soil surface area. The use of biochar in agriculture is not new; in ancient times farmers used it to enhance the production of agricultural crops. One such example is the slash and burn cultivation, which is still practiced in some parts of North East India. In order to sequester carbon, a material must have long residence time and should be resistant to chemical processes such as oxidation to CO₂ or reduction to methane. Such partially burnt products, more commonly called pyrogenic carbon or black carbon, may act as an important long-term carbon sink because their microbial decomposition and chemical transformation are probably slow.

Preparation of biochar

There are different ways to make biochar, but all of them involve heating biomass with little or no oxygen to drive off volatile gasses, leaving carbon behind. This simple

process is called thermal decomposition usually achieved from pyrolysis or gasification. Pyrolysis is the temperature driven chemical decomposition of biomass without combustion. In commercial biochar pyrolysis systems, the process occurs in three steps:

1. Moisture and some volatiles are lost.
2. Unreacted residues are converted to volatiles, gasses and biochar.
3. There is a slow chemical rearrangement (thermo-chemical change) of the biochar.

Effect of biochar on soil properties

Soil pH: The exchangeable acidity is high with a subsequent low pH, it interferes many soil processes. Ameliorating ability of biochar depends on pyrolytic conditions (higher pyrolytic temperature i.e. >400°C helps to produce alkaline pH), feedstock and soil properties. Biochar has a liming ability due to its

intrinsically high pH and high basic cations retained from the initial feedstock, including Ca, Mg and K showing soil pH increment especially in acidic soil which attributed from the integration of highly alkaline nature of biochar, high base cation releasing protons into the soil solution elevating availability of CaCO₃. Incorporation of biochar to soil increases the NH₄⁺ adsorption subsequently decrease nitrification which in turns conquer the discharge of H⁺ concentration to the soil and relieve soil acidification.

Cation exchange capacity: The intrinsic CEC of biochar is higher than whole soil, clays or soil organic matter. Biochar addition increases soil CEC most probably due to high surface area, high porosity, possessing organic materials of variable charges having potential to increase soil CEC and base saturation.

Total porosity: Biochar itself has very low bulk density which is

Table 1. Basic properties of biochar produced from different biomass

Properties of biochar	Wheat straw biochar	Rice straw biochar
Biochar yield (%)	35-45	30-40
Volatile content (%)	10-20	8-22
Ash content (%)	25-45	20-35
Surface area (m ² /g)	50-150	50-150
pH	7-9	8.0-10.0
EC (dS/m)	1.4-2.5	2.0-3.5
Bulk density (g/cc)	0.20-0.22	0.20-0.22
Carbon (%)	50-60	35-50
Oxygen (%)	5-10	8-12
O/C	0.1-0.2	0.2-0.3
Nitrogen (%)	0.8-1.5	0.6-2.5
Phosphorus (%)	0.2-0.5	0.1-0.5
Potash (%)	3.0-4.0	2.0-4.5
Calcium (%)	0.5-1.0	0.5-1.0
Magnesium (%)	0.4-1.0	0.5-1.0
Zinc (ppm)	40-80	50-100
Iron (ppm)	100-350	100-300
Manganese (ppm)	100-200	100-500

supposed to increase the soil pore volume mainly attributing to the dilution effect of a low bulk density amendment to the soil although the biochar also has the significant effect on macroaggregate formation

Soil moisture holding capacity: Where biochar has been applied, soils show higher water-holding capacity, improved water retention, increased plant-available water, increased plant resilience in drought conditions, and greater crop productivity per unit of water. The crop yield benefits of adding biochar to agricultural practices can be seen in different ways:

- Under highly managed irrigation, an expected outcome would be reduction in amount of water needed.
- In systems that are limited in control, an expected outcome would be mitigating undesired moisture stress.

Soil nutrient retention: Biochar having huge surface area, porosity and CEC possess the capacity to adsorb NH_4^+ , reduce the NH_4^+ concentration in soil solution that is available to ammonium oxidizers. A change in pore size distribution in the biochar amended soil can also have an important influence on bacterial community composition. The biochar acts as a sink, limiting the availability of NH_4^+-N to heterotrophic and autotrophic microbes (nitrifiers). This suggests that an important influence of biochar on soil processes results from its capacity to sequester inorganic N, primarily NH_4^+ and ultimately the nutrient loss from the soil can be minimized.

Soil microbial properties: Biochar provides a suitable habitat for soil microorganisms enhancing soil microbial activity. High surface area and hydrophobicity of biochar are known to facilitate better activity, higher retention, and microbial diversity. Biochar also contains some aromatic hydrocarbon compounds which sometimes suppress the bacterial population while increasing the fungal growth.

Improved soil productivity: Biochar has the ability to improve the

earth's soil resource by increasing productivity and crop yields by reducing the need for some chemical and fertilizer inputs and potentially providing other soil benefits. Applied to the soil in a finely ground form, biochar's vast surface area and complex pore structure provides a secure habitat for beneficial microbial activity that is important for crop to flourish. As the biochar have ability to retain the nutrient by means of adsorption on high surface area and high CEC due to development of surface charges which means that less fertilizer needs to be applied which reduces the cost of producing the crop. But not all soils react the same to biochar and it frequently can take up to an year to see results.

Effect on greenhouse gas emission

CO₂ emission: Long-time CO₂ sequestration by biomass processing and production of the BC and the storage of the BC in soil seems to be particularly promising. Sources dealing with the global carbon balance on Earth reports, a huge imbalance in emission and absorption of the carbon by all possible ways leading to continuous increase in atmospheric CO₂ concentration. Amending soils with biochar can potentially reduce atmospheric CO₂ concentrations and combat climate change by holding carbon exceeding stability of biochar in soil that of un-charred organic matter.

N₂O emission: Biochar may reduce emissions of nitrous oxide either by inhibiting soil microbial activity, alter microbial community composition, or changed the partitioning of N through proteolysis, ammonification, or nitrification pathways, and subsequently reduced N assimilation by microbes resulting the decreased mineralization, or decreased the ratio of gross N mineralization to gross N immobilization rates in the soil. Biochar may contribute to reduced CO₂-C emissions by reduced root biomass which could result from low net N mineralization and hence low inorganic N availability in soils. Biochar addition also affects the composition of soil bacterial

population, increase those of families involved with reduction of NO_3^- to NH_4^+ , N_2 fixation, and denitrification but decrease those involved in nitrification of NO_3^- to NO_2^- .

CH₄ emission: In a field, biochar reduces methane emission up to 90% as compared to non-amended and residue incorporated soils indicating towards the biochar's potential to mitigate climate change by reducing the negative effects of greenhouse gasses from the soil. Biochar may suppress CH₄ emissions by increasing soil pH while influencing microbial activities and at the same time biochar also improves soil aeration and increases oxygen content resulting in an increase in soil redox potential making conditions favourable for methanotrophs and decrease in CH₄ emissions.

SUMMARY

Efficient use of biomass by converting it to a useful resource (highly stable carbon compound known as biochar) of soil amendment/nutrients is one way to manage soil health and fertility. Biochar in agricultural systems can enhance natural rates of carbon sequestration, reducing waste, improve the soil quality, conventional agricultural productivity, soil physical properties, nutrient availability, soil microbial activities, crop productivity and mitigate GHG emissions from agricultural soils. To promote the application of biochar as a soil amendment and also as a climate change abatement option, research, development and demonstration on biochar production and application in agriculture system, it is necessary to develop low-cost biochar production units to make the technology affordable for small and marginal farmers.

¹PhD Scholar; Department of Agronomy, College of Agriculture, Govind Ballabh Pant University of Agriculture and Technology, Pantnagar, Uttarakhand 263145. ²Associate Professor, Department of Agronomy, College of Agriculture, Govind Ballabh Pant University of Agriculture and Technology, Pantnagar, Uttarakhand 263145. Corresponding author's email: shiv1992gbpuat@gmail.com.