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Short communication

Production and characterisation of biochar from different organic materials

Ammu Punnoose[1] and S. Anitha[2*]

[1]*Department of Agronomy, College of Horticulture, Kerala Agricultural University, Thrissur 680 656, Kerala, India*
[2]*Water Management Research Unit, KAU, Vellanikkara, Thrissur 680 656, Kerala, India*

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Abstract

An investigation entitled 'Production characterisation and quality assessment of biochar' was conducted to assess the effect of production methods and materials used on the character of biochar at Plant Propagation & Nursery Management Unit (PPNMU), Vellanikkara, Thrissur during 2014-15. Woody wild growth, coconut petiole and herbal waste residues left after composting were the three materials used for biochar production. Biochar was produced using heap and drum methods. Biochar was characterised by physical and chemical distinctiveness. Methods of production and materials used had significant influence on the characteristics of biochar. Drum method gave higher biochar recovery, high porosity and water holding capacity compared to heap method. Porosity, water holding capacity and carbon content were higher in biochar produced from woody wild growth. All biochars showed alkaline pH with the highest pH in coconut petiole biochar, An overall increase in NPK content was noticed in biochar compared to the feedstock materials.

Key words: Crop residues, Biochar, Pyrolysis, Soil amendment

Crop residues in fields can cause considerable crop management problems if they accumulate. Composting is a viable option for crop residue management. However composting of plant twigs and woody plant residues is difficult as they take longer time for decomposition. Conversion of crop residue biomass into biochar and using the char as a soil amendment is a nascent approach and suggested as an alternative to composting and crop residue burning (Srinivasarao et al., 2013). Biochar is produced by controlled burning of biomass with little or no oxygen, known as pyrolysis. When biochar is applied to soil, it can increase the soil's carbon content permanently and would establish a carbon sink for atmospheric CO_2 and that carbon is sequestered for centuries. In Indian conditions, there is immense scope for converting millions of tonnes of crop residues which are not used as fodder or fuel into biochar and using the same for enriching soil carbon (Srinivasarao et al., 2013). Biochar has been shown to be very beneficial in highly weathered tropical soils, soils with low pH, or soils with low cation exchange capacity (Lehmann and Rondon, 2006). The properties of biochar depend on the agricultural feedstock that is being pyrolized, and the production method (Atland, 2014). Biochar has the potential to increase the conventional agricultural productivity by stabilizing soil organic matter. The central quality of biochar and char that makes it attractive as a soil amendment is its highly porous structure, potentially responsible for improved water retention and increased soil surface area (Srinivasarao et al., 2013). Research results on production, characterization and use of biochar as soil amendment is scanty. Hence the present study was conducted to produce biochar by heap and drum methods using crop residues *viz*. woody wild growth, coconut petiole and herbal waste residue left after composting and to study the effect of production methods and feedstock materials on the physical and chemical characteristics of biochar.

*Author for correspondences: Phone-9446433292; E-mail: anitha.sarala@gmail.com

Table 1. Initial NPK content of the feedstock materials used for the biochar production

Material	N (%)	P (%)	K (%)
Woody wild growth	0.35	0.06	0.44
Coconut petiole	0.35	0.14	1.06
Herbal waste residue	0.52	0.23	0.14

The experiment was conducted at Coconut Development Farm of PPNMU, KAU, Vellanikkara during 2014-15. Biochar was produced by heap and drum method using various biological materials *viz.,* woody wild growth, coconut petiole and herbal waste residue. Woody wild growth and coconut petiole of matured leaves were collected from Coconut Development Farm, Vellanikkara, Thrissur. Woody wild growth included the undecomposable hard stems of *Gliricidia maculata*, *Citrus aurantium* (Kattu neeroli), *Macaranga peltata*, *Artocarpus heterophyllus* (Jack), *Caesalpinia sappan* and *Ficus hispida*. All these were cut into pieces of similar size and shade dried to facilitate uniform burning. Herbal waste residue was the undecomposed waste left after the composting of herbal waste obtained from Oushadi, Thrissur. Materials having similar size were sorted out and used for biochar production.

For the heap method, the feedstock materials were heaped inside a kiln specially fabricated for biochar production. After heaping the materials inside the kiln, they were lit and the lid was closed after spreading the fire to allow anaerobic burning. Smoke was allowed to escape through the vents. After the escape of the smoke, the vents were closed and the sides of the lid were plastered using mud. Here there was a direct burning of materials at 300^0C. The lid was opened on the next day to collect biochar.

Table 2a. Physical characteristics of biochar as affected by production methods and feedstock materials

Treatments	Recovery (%)	Bulk density (g/cm^3)	Porosity (%)	Water holding capacity (%)
Method of production				
Heap	22.4	0.49	51.1	232.1
Drum	27.0	0.54	56.2	239.5
CD(0.05)	0.141	0.005	0.397	0.211
Materials used				
Woody wild growth	24.2	0.34	62.9	363.9
Coconut petiole	24.4	0.48	62.3	234.3
Herbal waste residue	25.5	0.74	35.7	109.2
CD(0.05)	0.173	0.006	0.486	0.258
Interaction	Sig	Sig	Sig	Sig

Table 2b. Interaction effect of production methods and materials used on the physical characteristics of biochar

Method x Material	Recovery (%)	Bulk density (g/cm^3)	Porosity (%)	Water holding capacity (%)
Heap -wild growth	21.8	0.30	58.4	350.7
Drum -wild growth	26.7	0.38	67.4	377.2
Heap -coconut petiole	20.5	0.38	67.0	252.8
Drum -coconut petiole	28.3	0.59	57.5	215.8
Heap -herbal waste	24.9	0.81	27.8	92.7
Drum -herbal waste	26.1	0.67	43.7	125.6
CD(0.05)	0.245	0.008	0.687	0.365

In drum method, two different sized drums, one large and the other small, were used. The materials were filled in the small drum and it was kept upside down inside the large drum to prevent the entry of air. Because of the size difference there was a gap between the two drums. Fuel materials filled in the gap were fired and burned for an hour. Here there was indirect burning *i.e.,* the biochar was produced by the heat received by burning the fuel materials and here the temperature involved was 400^{0}C. Biochar was collected on the next day.

Characterisation of biochar was done by measuring the recovery per cent (percentage of biochar produced from the initial feedstock), and physical and chemical characteristics using standard procedures. Physical properties such as bulk density (FCO, 1985), porosity and water holding capacity (Keen and Racksawski, 1921); chemical characteristics like pH and total C% (FCO,1985), total N% (Jackson, 1958), total P % and K% (FCO,1985) and cation exchange capacity (Hendershot and Duquette,1986) were analysed. The initial nutrient contents (NPK) of the feedstock materials were also analysed using standard procedures. The data were analysed statistically applying the techniques of analysis of variance using the statistical package MSTAT-c.

The result indicated that production methods and materials used had significant influence on the recovery percentage, physical and chemical characteristics of biochar. Recovery of biochar was significantly higher in drum method (27.0 %) compared to heap method (22.5%). This was because the direct burning in heap method resulted in conversion of some material in to ash. In drum method, biochar was produced by indirect burning which resulted in higher recovery. Among the materials used higher recovery was noted for herbal waste residue due to woody nature of herbal waste. Xie et al. (2015) noticed that the amount of biochar

Table 3a. Effect of production methods and materials used on chemical characteristics of biochar

Treatments	pH	Total carbon (%)	Total N (%)	Total P (%)	Total K (%)	CEC (cmols/kg)
Method of production						
Heap	8.9	47.7	0.64	0.18	0.56	8.2
Drum	9.1	45.85	0.55	0.18	0.54	8.3
CD(0.05)	0.092	0.831	0.025	NS	0.007	NS
Material						
Woody wild growth	8.6	50.98	0.61	0.22	0.53	8.2
Coconut petiole	10.0	44.10	0.35	0.12	0.63	10.4
Herbal waste residue	8.3	45.25	0.83	0.20	0.48	6.2
CD(0.05)	0.113	1.018	0.031	0.006	0.008	0.306
Interaction	Sig	Sig	Sig	Sig	Sig	Sig

Table 3b. Interaction effect of production method and materials used on chemical characteristics of biochar

Method x Material	pH	Total carbon (%)	Total N (%)	Total P (%)	Total K (%)	CEC (cmols/kg)
Heap -wild growth	8.4	52.6	0.7	0.22	0.54	8.2
Drum -wild growth	8.9	49.3	0.52	0.23	0.53	8.2
Heap -coconut petiole	10.2	44.1	0.35	0.11	0.67	10.5
Drum -coconut petiole	9.8	44.1	0.35	0.12	0.60	10.3
Heap -herbal waste	8.0	46.4	0.88	0.22	0.47	5.8
Drum -herbal waste	8.6	44.1	0.79	0.20	0.48	6.6
CD(0.05)	0.159	1.439	0.044	0.008	0.011	0.432

produced from a given amount of biomass will be higher for ligno cellulosic (wood derived) biomass and the thermal degradation of cellulosic and hemicellulosic content occurs first. The herbal waste residue used for biochar production was the undecomposed materials left after composting and contained more wood compared to the other materials.

Important physical characteristics of six biochar samples produced from the three materials using two methods of production are presented in Tables 2a and 2b. Bulk density showed a range of 0.30 to 0.81g/cc. Drum method showed significantly higher BD (0.546 g/cc) than heap method(0.499 g/cc). This may be due to the low carbon content in drum method. Brewer (2012) reported that biochar bulk density is low *ie*., around 0.2-0.5 g/cm3, and this can vary with feedstock and process. Feedstocks or processes that result in low char carbon contents will have significantly higher densities due to the mineral material contribution. Herbal waste residue showed significantly higher bulk density. This may be due to the low porosity and low carbon content in herbal waste residue. Porosity ranged from 27.8% to 67.4%. Higher porosity was recorded in the drum method (56.207%) of production confirming the result of Bagreev et al. (2001), who detected significant increase in porosity with increase in temperature. Among the materials woody wild growth biochar had higher porosity (62.915%) and there by water holding capacity. According to Asai et al. (2009) biochar usually has high total porosity and it can retain water in pores and thus retain water balance resulting in better nutrient availability. Highest porosity in drum method and woody wild growth biochar resulted in significantly higher water holding capacity. Water holding capacity was highest in the woody wild growth produced from the drum method (377.19%) which showed highest porosity (67.44%). Purakayastha et al. (2013) found that the water holding capacity of wheat biochar was highest (561%) followed by maize biochar (456%). The increase in porosity resulted in three fold increase in surface area which led to increased water holding capacity of biochar materials.

Important chemical characteristics of biochar are presented in the Table 3a and 3b. All the biochars recorded alkaline pH. The pH ranged from 8.0 to 10.2. pH of the biochar materials produced in drum method was significantly higher (9.1) may be due to comparatively higher temperature in drum method. High temperature biochar recorded higher pH (Gundale and DeLuca, 2006). Coconut petiole biochar exhibited higher pH (10.2) among the different biochar materials. Cation exchange capacity (CEC) gives an idea of nutrient holding capacity of biochar. The CEC of biochar varied from 5.8 to 10.48 cmols/kg. Materials used had significant influence on CEC. The highest CEC was noticed in coconut petiole biochar (10.37cmols/kg) may be due to an increased concentration of alkaline metals (Ca^{2+} Mg^{2+} and K^{+}) oxides in the biochar. The CEC varies significantly between terrestrial-derived biomass from different feedstocks, ranging from 4.5 to 40 cmol/kg (Uzoma et al., 2011). No variation was observed due to method of production on CEC of biochar. Most biochars recorded relatively high CEC, in part due to their negative surface charge and resultant affinity for soil cations including most heavy metals (Xie et al., 2015). High porosity also resulted in high CEC of the biochar materials.

Carbon content of biochar varied with production method and materials used for the production of biochar. Significantly higher carbon content was recorded in heap method of production (47.7%). Feng et al. (2012) also noted a similar result in the corn stock biochar its total carbon content decreased with increase in pyrolysis temperature from 56.8% at 300^{0}C to 48.4% at 500^{0}C. Woody wild growth biochar which had lowest recovery percentage had the highest per cent of carbon (50.98%). A similar result was obtained for corncob biochar which had the lowest yield but the highest per cent of carbon (Stoyle, 2011).

Nitrogen content of the biochar varied with method of production and materials used. Total nitrogen content in the biochar materials was higher in the heap method (0.64%) than drum method (0.55%). De Luca et al. (2009) reported that biochar produced at higher temperature showed nutrient depletion due to volatilization. This may be the reason for decreased N content in drum method. Also N content in biochar generally decreases with pyrolysis temperature (Feng et al., 2012). N content of coconut petiole biochar was almost similar to that of coconut petiole used as feed stock. For woody wild growth and herbal waste residue biochar, an increase in N content was observed when compared with feedstock material. This increase in N content can be explained by the enrichment of N- containing compounds during pyrolysis (Keiluweit et al., 2010). Nitrogen content was concentrated with charring temperature and duration, ranging from 0.97 to 1.73% (Peng et al., 2011).

Production method caused no significant variation in P content. Feedstock materials produced variation in P content of biochar. Biochar from woody wild growth recorded higher P content (0.22%). Except in case of woody wild growth biochars P content got decreased compared to feedstock materials. Usually in case of P, the content increases with pyrolysis as P volatilize only at a temperature of 700^0 to 800^0 C but in certain cases during pyrolysis increasing temperature, loss of elements such as N, P and cations occurs through volatilization which is accompanied by complex changes in the structural forms of carbon and microporosity of biochar materials (Chun et al., 2004).

Potassium content of biochar produced from heap method (0.56%) was higher than drum method (0.53%). This may be due to the higher temperature during pyrolysis in drum method. Biochar K content was higher than its feedstock except for coconut petiole. Exceptionally high K content of the coconut petiole was got reduced as a result of pyrolysis. Still, coconut petiole biochar recorded highest K content (0.63%). This may be due to the high initial K content in coconut petiole. Biochar produced through heap method recorded the highest K content. The reduced K content in drum method may be due to elemental decomposition as a result of higher temperature. Similar result was reported by Sukartono et al. (2011), who characterized coconut shell biochar and noted that it contained 0.84 percent K.

Results of the study indicated that types of feedstock and production methods have a major impact on the properties and composition of biochar. Drum method of production resulted in better physical and chemical characteristics of biochar. Biochar produced from woody wild growth showed lower bulk density, high porosity, and water holding capacity, total carbon and an increase in nutrient content compared to feedstock. The beneficial characters of biochar such as low bulk density, high porosity and water holding capacity make biochar a suitable material for water and nutrient management. High pH, high CEC, high carbon content and increased content of NPK after pyrolysis make the biochar a good soil amendment. High carbon content may leads to increased C/N ratio and immobilization of nutrients. Hence immediate effect of biochar on crops needs to be studied.

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