Production and characterization of biochar from different sources of biomass

KANAGASUPPURATHINAM[1], COUMARAVEL[2], BAGATHI AMMAL[3], SARAVANANE[4]
[1,2,3]Department of Soil Science and Agricultural Chemistry
P.J.N. College of Agriculture and Research Institute, Karaikal-609 603, U.T. of Pondicherry
INDIA
[4]Department of Agronomy
P.J.N. College of Agriculture and Research Institute, Karaikal-609 603, U.T. of Pondicherry.
INDIA

Abstract: The biochar was produced from different biomass and characterize it for physical and physicochemical properties**.** Biochar is produced from the pyrolysis of a variety of biomass materials *viz.,* Coconut husk, coconut shell, paddy straw, rice husk, eichhornia, sugarcane bagasse, grass, cotton stalks, prosopis and neem wood in pyrolysis unit. The biochars differed much in their characteristics. Recovery of biochar was high in Prosopis showed its superiority over others in providing high pore space, higher pH, EC, CEC, organic C, total N, Mg, available nutrients and carbon fractions. The wood biochar *viz*., Prosopis wood biochar as superior one that can act as a soil conditioner and has the capacity to enhance supplying and retaining nutrients and by providing other benefits such as improving soil physical properties followed by cotton stalk biochar and drymatter biomass biochars. Considering the higher recovery and its distribution, resource of Prosopis can be harnessed. Due to the wide variations noticed among the different biomass, characterisation of biochar from each biomass becomes a pre requisite before mass production for agriculture purpose.

Keywords: Biochar, biomass, Soil Science, Agricultural Chemistry
Received: March 21, 2022. Revised: October 18, 2022. Accepted: November 11, 2022. Published: December 29, 2022.

1. Introduction

Biochar, a stable form of carbon, is produced from pyrolysis of different biomass materials. It is attracting growing interest because of its potential to improve soil nutrients status, increase crop yield and sequester carbon (C) in the soil. The carbon in the biomass is subjected to easy degradation since they contain low grade carbon. But in biochar, pyrogenic carbon is formed by pyrolysis. Hence they remain in the soil for long periods. Biochar is finely ground charcoal which offers an extremely high surface area to support microbiota and increase nutrient availability for plants (Winsley, 2007). Marked impacts of low charcoal additions (0.5 t ha^{-1}) on various crop species were noticed, but inhibition at higher rates (Glaser *et al.,* 2001). Biochar additions to soil have the potential to alter soil microbial populations and to shift functional groups (Pietikeinen *et al.,* 2000). The infiltration of harmful quantities of nutrients and pesticides into ground water and soil erosion runoff into surface waters can be limited with the use of biochar (Lehmann, 2007). Characterizing different sources of biochar could pave the way for its potential use and its impact on natural ecosystem. Possibly the wastes and obnoxious weeds can also be used as feed stock to prepare biochar. Hence the study was conducted to characterize biochar from different biomass.

2. Materials and methods

Biochar samples were prepared from the pyrolysis of ten different biomass wood biomass like prosopis wood, neem wood, coconut shell and coconut husk and stalk biomass like cotton stalk and dry matter biomass like paddy straw, sugarcane bagasse, rice husk, grass weeds & eichhornia.. All the biomass was collected from PAJANCOA & RI, campus Karaikal district, Pondicherry. The wood biomass were chopped to 5 cm pieces and dried. Eichhornia plants were washed with water and chopped into small pieces and dried. The production of biochar was carried out in kiln designed and fabricated exclusively for the purpose using metallic drum of 87 cm height and 57 cm diameter. An inlet was provided at the top to load the input and an outlet on the bottom side to collect the pyrolysed final product. Air entry into the kiln was regulated by giving ten rectangular holes at the bottom. A vent of 115 cm height was attached at the top to exhaust the smoke. The initial weight of the different biomasses were recorded and was loaded through the inlet. Once the intensity of smoke got reduced as evidenced from its thickness, closed the inlet to slow down the entry of air and thereby reducing the chances of different biomass getting burnt to ash. When the flame turned blue, closed all the holes of the kiln with mud for sustaining the smoke fully inside the drum. At the end of the process all the biomass was turned into char. Biochar material were taken out, cooled and sieved in a 2mm sieve which was taken for all physical, physico-chemical and chemical analysis. Biochar derived from the selected biomass were characterized for its physical properties *viz.,* recovery, Moisture was determined by Gravimetric method (Jackson, 1973). Ash was estimated by Proximate analysis (Jackson, 1973). Bulk density, particle density and porosity of biochar was determined by cylinder method (Piper 1966). Physico-chemical properties *viz.,* Soil pH and EC was measured in a 1: 2.5 soil-water suspension by using pH and EC meter, respectively (Jackson 1973). Cation exchange capacity of the biochar was determined using a combination of the modified ammonium acetate displacement method (Sumner and Miller 1996). Organic carbon was determined by chromic acid wet digestion method outlined by Walkley and Black (1934) and total carbon was determined by loss on ignition method (Piper, 1966). Chemical properties of Total N was estimated by Macro Kjeldahl's method (di-acid digestion) Piper, 1966. Total P was determined by Vanadomolybdate yellow colour method (triple acid digestion) using Colorimetry (Jackson, 1973). Total K was estimated by Triple acid digestion using Flame photometry (Jackson, 1973). Total Ca and Mg was determined by Versenate titration method (Jackson, 1973). Total S was estimated by Di acid digested sample was quantified by using $BaCl_2$ (Piper, 1966). Available nutrients *viz.,* nitrogen, phosphorous, potassium and carbon fractions *viz.,* WSC, HWSC and POXC as per standard procedures.

3. Statistical analysis

The data from each biomass samples were analyzed separately. The analytical data were subjected to statistical scrutiny following the procedure outlined by Gomez and Gomez (1976), using WASP package.

4. Results and Discussion

Physical properties

The yield of biochars derived from different biomass materials ranged from 9.48 to 38.52 per cent and it was followed in the order as Prosopis wood > cotton stalk > neem wood > eichhornia > coconut shell > coconut husk > paddy straw > sugarcane bagasse > rice husk >grass biochar. This might be attributed to the presence of higher cellulose, hemicelluloses and lignin in Prosopis wood than other biomass (Tanaka, 1963; Sohi *et al*., 2009). Shenbagavalli and Mahimairaja, (2012) also reported that the

Prosopis wood had very high in cellulose (36%), high in hemicellulose (31%) and medium in lignin (22%) content. The moisture and ash content of different sources of biochar ranged from 1.40 to 14.63 per cent and 0.81 to 21.69 per cent respectively. Highest ash content was observed in paddy straw biochar (21.69 %). The wood and stalk biochars recorded lower ash content than dry matter biomass biochars. The high ash content of crop straw-derived biochars was mainly due to the accumulation of enrichment of various inorganic components (Singh *et al.,* 2010 and Wang *et al.,* 2013). The bulk density of different biochar ranged from 0.14 to 0.61 Mg m^{-3} particle density from 0.41 to 0.97 Mg m^{-3} and pore space from 17.39 to 84.52 per cent wide variations of bulk density and particle density and pore space was observed from different type of biomass. Dry matter biomass biochars registered higher bulk density than the biochars produced from Wood and stalk biomass. The particle density of Wood and stalk biomass biochars registered higher value than the biochars produced from dry matter biomass. Among different biochars, dry matter biomass recorded lower percent pore space than the Wood and stalk biomass biochars. (Table 1).

Physico -Chemical properties

The pH measured in 1:10 solid water suspension (Jackson, 1973), varied from 7.21 to 10.32. The pH of biochars was alkaline in nature; wood and stalk biomass biochars registered higher pH than dry matter biomass biochar. Hydrolysis of salts and Ca, Mg and K would make the biochar alkaline. Such variation was commonly reported for a variety of biochar produced from different biomass (Singh *et al*., 2010; Lehmann, 2007; Angaleeswari and Kamaludeen., 2017; Pandian *et al*., 2016 and Shalini *et al*., 2017). Wide variation of EC was observed which varied from 1.37 to 3.87 dS m^{-1}. The wood and stalk biomass biochar registered higher soluble salts than the biochars produced from dry matter biomass (coconut husk, rice husk, sugarcane bagasse, eichhornia, paddy straw and grass). The high EC could be attributed to high concentration of CO_3 of alkali and alkaline earth metals, variable amount of silica, heavy metals, sesquioxides, phosphate and small amount of organic and inorganic N present in the biochar. (Sellamuthu *et al*., 2018; Shenbagavalli and Mahimairaja, 2012 and Rajakumar, 2019).

The CEC of biochar ranged from 11.44 cmol (p^+) kg^{-1} to 20.60 cmol (p^+) kg^{-1}. Since biochar consists largely of amorphous graphene sheets with a polyaromatic structure during the process of pyrolysis, which give rise to large amounts of reactive surfaces where a wide variety of organic (both polar and non-polar) molecules and inorganic ions can sorb (Yang *et al*., 2016). The wood and stalk biomass biochars registered higher CEC than the biochars produced from dry matter biomass. The C content of biochar varied widely, from 26.7 to 65.9 g kg^{-1}. The wood and stalk biomass biochars registered higher C than the biochars produced from dry matter biomass. The higher C content could be attributed due to presence of its biochemical constituent's *viz.,* cellulose, hemicellulose and lignin. Charred biomass consists not only of recalcitrant aromatic ring structure, but also of more easily degraded aliphatic and oxidized C structure (Schmidt and Noack, 2000). The range of carbon within a biochar particle may depend on the C properties (Lehmann, 2007). The C/N ratio also varied significantly, between 68.47: 1 and 128.0: 1. While grass biochar resulted in greater C/N ratio (128.0: 1), than the Prosopis wood biochar resulted in relatively lesser (68.47: 1). It is comparable to the value reported by (Novak *et al.,* 2009; Rondon *et al.,* 2007; Cheng *et al*., 2006). The organic C of biochar ranged from 0.10 to 0.68 per cent. The wood and stalk biomass biochars registered higher organic C than the biochars produced from dry matter biomass. Such a variation was commonly reported for a variety of biochar produced from different biomass (Novak *et al.,* 2009 and Rondon *et al.,* 2007) (Table 1).

Chemical properties

The results of chemical properties revealed that total nitrogen content in the biochars varied from 0.25 to 0.92 per cent, and the N content was relatively higher in Prosopis wood biochar, closely followed by neem wood Biochar. Total P were found higher in neem wood biochar followed by eichhornia. The total K was ranged from 1.03 to 2.41 per cent. The dry matter biomass biochars registered higher total K than the biochars produced from the wood and stalk biomass. In addition, it also contained significant amount of secondary nutrients *viz*. Ca, Mg and S, varied from 1.66 to 0.21, 0.98 to 0.20 and 0.59 to 0.10 per cent respectively. Huge variation in the chemical composition could be attributed due to the difference in feed stocks, organic and inorganic constituents of biochar and conditions under which the various types of biochar are produced. Similar types of results were also reported by Lima and Marshall (2005), Chan and Xu (2009) and Sellamuthu *et al*. (2018). The content of available nutrients in biochar was 42.15 mg kg^{-1} N, 74.67 mg kg^{-1} P and 351 mg kg^{-1} K. The wood and stalk biomass biochars registered higher available nutrients than the biochars produced from dry matter biomass. Pandian *et al*. (2016) reported that among the nutrients, the available K content was relatively higher than N and P. The wood and stalk biomass biochars registered higher value of carbon fractions of biochar *viz*., Water soluble carbon carbon, hot water soluble carbon and permanganate oxidizable carbon than the biochars produced from dry matter biomass (Table 2).

A better utilization of residues from charcoal production itself provides opportunities for a combination with a biochar soil management system (Lehman *et al.,* 2006). Biochar has been widely applied in tree nurseries and is a recommended amendment (Jaenicke, 1999). The particle size of the biochar appears to play a minor role in its effect on soil fertility and crop production (Lehmann *et al.,* 2003), which simplifies the application of the technology.

5. Conclusions

The wood biochar *viz*., Prosopis wood biochar as superior one that can act as a soil conditioner and has the capacity to enhance supplying and retaining nutrients and by providing other benefits such as improving soil physical properties followed by cotton stalk biochar and drymatter biomass biochars. Considering the higher recovery and its distribution, resource of Prosopis wood can be harnessed. It can be concluded that nature and properties of biochar varies with the sources of biomass prepared. Hence, before mass production of biochar, characteristics of the individual source have to be studied and utilised for agriculture purpose.

Table 1.Physical and Physico - Chemical properties of biochar from different biomass

Sl. No.	Biomass	Physical Properties						Physico - Chemical Properties					
		Recovery (%)	Moisture (%)	Ash (%)	B.D (Mg m^{-3})	P.D (Mg m^{-3})	Porosity (%)	pH	EC (dS m^{-1})	CEC (cmol (p+) kg^{-1})	Total C (%)	Organic C (%)	C:N ratio
1	Coconut husk	18.30	10.11	0.92	0.14	0.43	17.39	9.85	2.93	15.71	65.9	0.42	81.35
2	Coconut shell	24.10	14.63	11.30	0.38	0.51	36.84	9.61	3.12	18.30	59.9	0.47	79.86
3	Paddy straw	10.01	11.24	21.69	0.52	0.75	43.75	9.93	2.76	15.63	51.0	0.31	91.07
4	Rice husk	15.80	7.31	20.71	0.35	0.47	38.10	9.27	1.73	12.28	32.1	0.38	128.40
5	Sugarcane bagasse	10.41	2.01	4.95	0.25	0.53	52.70	8.52	2.34	15.21	31.4	0.21	112.14
6	Eichhornia	25.83	3.16	14.35	0.37	0.49	84.52	8.60	2.08	13.81	45.0	0.53	73.77
7	Grass	9.48	12.82	6.57	0.61	0.41	57.26	7.21	1.37	11.44	32.5	0.10	104.83
8	Cotton stalk	33.30	1.40	1.13	0.33	0.81	55.32	9.15	3.19	18.79	26.7	0.58	74.16
9	Prosopis wood	38.52	12.65	0.90	0.45	0.97	71.42	10.32	3.87	20.60	63.0	0.68	68.47
10	Neem wood	27.10	11.59	0.81	0.42	0.66	62.75	10.03	3.23	19.87	59.0	0.61	70.23
	Maximum	**38.52**	**14.63**	**21.69**	**0.61**	**0.97**	**84.52**	**10.32**	**3.87**	**20.60**	**65.9**	**0.68**	**128.40**
	Minimum	**9.48**	**1.40**	**0.81**	**0.14**	**0.41**	**17.39**	**7.21**	**1.37**	**11.44**	**26.7**	**0.10**	**68.47**
	Mean	**21.28**	**8.69**	**8.33**	**0.38**	**0.60**	**52.01**	**9.25**	**2.66**	**16.16**	**46.65**	**0.43**	**88.43**
	S.D	**10.16**	**4.89**	**8.24**	**0.13**	**0.19**	**19.09**	**0.94**	**0.77**	**3.14**	**15.02**	**0.19**	**20.29**

Table 2. Chemical properties of biochar from different biomass

Sl. No.	Biomass	Total N	Total P	Total K	Total Ca	Total Mg	Total S	Available N	Available P	Available K	WSC	HWSC	POXC
		(%)						(mg kg $^{-1}$)					
1	Coconut husk	0.81	0.45	2.25	0.40	0.24	0.17	15.42	41.90	316.00	63.43	111.64	605.19
2	Coconut shell	0.75	0.35	2.41	1.48	0.26	0.38	8.46	43.59	340.00	75.72	103.57	658.34
3	Paddy straw	0.56	0.23	1.43	0.34	0.31	0.19	22.40	27.03	173.00	57.14	81.29	321.79
4	Rice husk	0.25	0.12	1.23	0.43	0.61	0.25	26.63	16.89	191.00	52.48	75.61	361.62
5	Sugarcane bagasse	0.28	0.10	1.25	0.89	0.20	0.29	11.28	37.84	214.00	36.23	43.57	300.29
6	Eichhornia	0.61	0.72	2.03	1.16	0.67	0.59	30.87	57.44	284.00	45.71	90.45	488.47
7	Grass	0.31	0.11	1.03	0.21	0.34	0.10	12.61	16.55	162.00	23.76	37.13	306.19
8	Cotton stalk	0.36	0.21	1.40	0.93	0.95	0.30	37.82	62.85	231.00	124.19	206.32	663.85
9	Prosopis wood	0.92	0.16	1.21	1.02	0.98	0.36	42.15	74.67	351.00	153.97	256.02	736.41
10	Neem wood	0.84	0.89	1.19	1.66	0.79	0.33	40.69	59.81	311.00	137.75	241.91	690.02
	Maximum	**0.92**	**0.89**	**2.41**	**1.66**	**0.98**	**0.59**	**42.15**	**74.67**	**351.00**	**153.97**	**256.02**	**736.41**
	Minimum	**0.25**	**0.10**	**1.03**	**0.21**	**0.20**	**0.10**	**8.46**	**16.55**	**162.00**	**23.76**	**37.13**	**300.29**
	Mean	**0.57**	**0.33**	**1.54**	**0.85**	**0.54**	**0.29**	**24.83**	**43.86**	**257.30**	**77.04**	**124.80**	**513.20**
	S.D	**0.25**	**0.28**	**0.50**	**0.49**	**0.30**	**0.14**	**12.71**	**19.85**	**71.35**	**45.33**	**80.26**	**176.93**

References

[1]. Angalaeeswari, K. and S.P.B. Kamaludeen. 2017. Production and characterization of coconut shell and mesquite wood biochar. **Int. J. Chem. Stud., 5:** 442-446.

[2]. Cheng, C., J. Lehmann, J. E. Thies, S.D. Burton and M.H. Engelhard. 2006. Oxidation of black carbon by biotic and abiotic processes. **Org. Geochem., 37:** 1477-1488.

[3]. Glaser, B., J. Lehmann and J. Zech. 2002. Ameliorating physical and chemical properties of highly weathered soils in the tropics with charcoal –**A review. Biol. Fert. Soil. 35:** 219–230.

[4]. Gomez, K.A. and A.A. Gomez. 1976. Statistical Procedures for Agricultural Research with Emphasis on Rice. IRRI, Los Banos, Manila, Philippines, pp.303.

[5]. Jackson, M.L. 1973. Soil chemical analysis. Prentice Hall of India Private Limited, New Delhi, pp.496.

[6]. Jaenicke, H. 1999. Good Tree Nursing Practices: Practical Guidelines for Research Nurseries, International Centre for Research in Agroforestry, Nairobi.

[7]. Kimetu, J.M., Lehmann, J., Ngoze, S. O., Mugendi, D. N., Kinyangi, J. M., Riha, S., Verchot, L., Recha, J. W., and Pell, A. N., 2008. Reversibility of soil productivity decline with organic matter of differing quality along a degradation gradient. **Ecosystems 11(5):** 726-739.

[8]. Lehmann, J. 2007. A handful of carbon. Nature, 447, 143-144.

[9]. Lehmann, J., D.C. Kern, B. Glaser and W. I. Woods. 2003. Biochar and carbon sequestration. *In:* Amazonian Dark Earths: Origin, Properties, Management. Kluwer Academic Publishers, Netherlands, pp. 523.

[10]. Lehmann, J., J. Gaunt and M. Rondon. (2006) Bio-char sequestration in terrestrial ecosystems - a review. **Mitig. Adapt. Strat. Gle., 11:** 403–427.

[11]. Lima I.M and W.E. Marshall. 2005. Granular activated carbons from broiler manure: physical, chemical and adsorptive properties. **Biores. Techno., 96:** 699-706.

[12]. Novak, J. M., W.J. Busscher, D.L. Laird, M. Ahmedna, D.W. Watts, and M.A. Niandou. 2009. Impact of biochar amendment on fertility of a southeastern coastal plain soil. **Soil Sci., 174:** 105-112.

[13]. Pandian, K., P. Subramaniayan, P. Gnasekaran and S. Chitraputhirapillai. 2016. "Effect of biochar amendment on soil physical, chemical and biological properties and groundnut yield in rainfed Alfisol of semiarid tropics." **Archives of Agronomy and Soil Science, 62(9):** 1293-1310.

[14]. Pietikeinen, J., Kiikkil, O. and Fritze, H. 2000. Charcoal as a habitat for microbes and its effects on the microbial community of the underlying humus, Oikos, 89, 231–242.

[15]. Piper, C.S. 1966. Soil and Plant Analysis. Hans Publishers, Bombay, India, pp. 368.

[16]. Rajakumar, R. 2019. Aggrading lateritic soils (Ultisol) using biochar. Ph. D (Ag.) thesis, Kerala Agricultural university, Thrissur.

[17]. Rondon, M.A., J. Lehmann, J. Ramirez and M. Hurtado. 2007. Biological nitrogen fixation by common beans (*Phaseolus vulgaris* L.) increases with biochar additions. **Biol. Fertil. Soils 43:** 699-708.

[18]. Schmidt, M.W. and A.G. Noack. 2000. Black carbon in soils and sediments: analysis, distribution, implications, and current challenges. **Global Biogeochem. Cyc., 14:** 77–94.

[19]. Sellamuthu, K.M., S. Suryia, V.P. Duraisami, R. Mahendran and Venkatachalam, P. 2018. Characterization of Biochar from Different Sources of Plant Communities. **Int. J. Curr. Microbiol. App. Sci. 7(03):** 891-898.
[20]. Shalini, R., S. Pugalendhi, P. Subramanian, and N. Gopal. 2017. "Characteristic study on biochar production from biological substrates by slow pyrolysis for carbon sequestration." **Int. J. Curr. Microbiol. App. Sci., 6 (4):** 314-323.
[21]. Shenbagavalli, S. and S. Mahimairaja. 2012. Production and characterization of biochar from different biological wastes. **Int. J. Plant Anim. Environ. Sci., 1:** 197-201.
[22]. Singh, B., B.P. Singh and L.C. Annette. 2010. Characterisation and evaluation of biochars for their application as a soil amendment. **Aus. J. Soil Res., 48:** 516- 525.
[23]. Sohi, S, E. Loez Capel, E. Krull and Bo, R. 2009. Biochar's role in soil and climate change: a review of research needs. CSIRO Land and Water Science 2009, Report, 64.
[24]. Tanaka, S. 1963. Fundamental study on wood carbonization. Bulletin of Experimental Forest of Hokkaido University, pp.17.
[25]. Wang, Y., H. Yuting, Z. Xu, W. Shenqiang and X. Guangxi. 2013. Comparisons of biochar properties from wood material and crop residues at different temperatures and residence time. **Energ. Fuel., 27(10):** 5890-5899.
[26]. Winsley P., 2007. Biochar and Bionenergy Production for Climate Change. New Zealand Science Review, 64 (1): 1-10.
[27]. Yang, X., J. Liu, K. McGrouther, H. Huang, K. Lu, X. Guo, L. He, X. Lin, L. Che, Z. Ye and H. Wang. 2016. Effect of biochar on the extractability of heavy metals (Cd, Cu, Pb, and Zn) and enzyme activity in soil. **Environ. Sci. Pollut. Res., 23:** 974-984.