Production and Analysis of Physical, Chemical and Physico-Chemical properties of biochar from various feed stock sources

ABASTRACT

Biochar was derived from a range of biomass materials and its physical and physicochemical characteristics were assessed. Due to the pyrolysis of various biomass products, such as grass, cotton stalks, coconut husk, coconut shell, paddy straw, rice husk, Eichhornia, sugarcane bagasse, and neem wood in the pyrolysis unit. The biochars' characteristics were extremely diverse. Prosopis is superior to other biochars in terms of pore space, pH, EC, CEC, organic C, total N, Mg, available nutrients, and carbon fractions, as evidenced by the large amount of biochar that was recovered from it.

Prosopis wood biochar, which can function as a soil enhancer and improve the physical properties of the soil, is superior than cotton stalk biochar and drymatter biomass biochars. It can also increase nutrient availability and retention. Given its higher recovery and diffusion, Prosopis' resource can be used. As a result of the substantial differences between the various biomass, characterizing biochar made from each one is necessary before mass producing it for agricultural application.

Keywords: Biochar, coconut, paddy, *Eichhornia*and wood,crop productivity,low grade carbon,soil nutrient,toxic nutrients,plant nutrient

INTRODUCTION

Different biomass products are burned in a pyrolysis process to produce biochar, a stable form of carbon.Due to its capacity to enhance soil nutrient content, boost crop productivity, and store carbon within the soil, it is generating more and more interest. Since the biomass contains low grade carbon, it is easily degraded. But pyrolysis creates pyrogenic carbon in biochar. Consequently, they persist in the soil for a prolonged period. Biochar is meticulously pulverized charcoal. that has a very large surface area to promote bacteria and improve plant nutrient availability (Winsley, 2007). Low charcoal inputs at 0.5 t ha-1 had discernible impactson a variety of crop types, while higher rates of charcoal application led to inhibition (as reported by Glaser *et al.*, 2002). The addition of biochar to soil has the ability to change the microbial populations and functional groups in the soil (Pietikeinen*et al.*, 2000). The use of biochar can reduce the amount of toxic nutrients and pesticides that enter Groundwater, along with the flow of soil erosion into surface waters, as indicated by Lehmann in 2007. The prospective usage of biochar and its effects on natural ecosystems could be facilitated by characterising its many sources. Possibility of using wastes and hazardous weeds as feedstock to make biochar. In order to characterise biochar made from various biomass, the study was carried out.

MATERIALS AND METHODS

Ten different types of biomass were pyrolyzed to make samples of biochar, including wooden biomass such as Prosopis wood, neem wood, coconut shell, and husk, stalk biomass such as cotton stalk, and dry matter biomass such as paddy straw, sugarcane bagasse, rice husk, grass weeds, and Eichhornia. The campus of PAJANCOA & RI in the Karaikal region of Pondicherry is where all of the biomass was gathered. Dryed and divided into 5 cm pieces, the wood biomass. Eichhornia plants underwent a process where they were rinsed with water, cut into small fragments, and subsequently dried.A metal drum measuring 57 cm in diameter and 87 cm in height was employed in the construction of a kiln designed specifically for the production of biochar.A top inlet was supplied to load the input, and a bottom outlet was provided to collect the pyrolyzed end product. Ten rectangular apertures at the bottom of the kiln were used to control air entry. To exhaust the smoke, a vent of 115 cm in height was added at the top. The various biomasses' initial weights were noted and loaded through the inlet. Closing the entrance will slow down air entry and lessen the likelihood that various biomass will burn to ash once the intensity of the smoke has decreased as demonstrated by its thickness. When the flame turned blue, mud was used to seal all of the kiln's openings in order to keep the smoke completely contained within the drum, as the process came to an end, all of the biomass had been transformed into char. The biochar substance was then removed, allowed to cool, and sifted using a 2mm sieve for comprehensive physical, physico-chemical, and chemical examinations.

The biochar obtained from the chosen biomass was subjected to a comprehensive analysis of its physical characteristics, including moisture content. The Gravimetric method, as detailed by Jackson in 1973, was used to ascertain the moisture content. To estimate the ash content, the Proximate analysis method was employed, also following Jackson's 1973 guidelines. The bulk density, particle density, and porosity of the biochar were calculated using the cylinder method, as described by Piper in 1966.

Physico-chemical characteristics, such as soil pH and electrical conductivity (EC), were assessed using a 1:2.5 soil and water suspension and pH and EC meters, respectively, in accordance with Jackson's 1973 instructions. The biochar's cation exchange capacity was determined using the modified ammonium acetate displacement method in conjunction with its cation exchange ability, following the guidelines by Sumner and Miller in 1996. Total carbon content was assessed using the loss on ignition method, and Organic carbon content was assessed using the chromic acid wet digestion method outlined by Walkley and Black in 1934.

The total nitrogen content was determined by utilizing the Macro Kjeldahl's technique with di-acid digestion, following the procedure outlined by Piper in 1966.Jackson (1973) used colorimetry to measure total P using the Vanadomolybdate yellow color method (triple acid digestion). By applying flame photometry in conjunction with triple acid digestion, total K was estimated (Jackson, 1973). Versenate titration was used to estimate the total amounts of Ca and Mg (Jackson, 1973). Total S was determined by BaCl2 was used to test the sample after di acid digestion (Piper, 1966).Nutrients that are readily accessible, such as nitrogen, phosphorus, potassium, and carbon fractions (WSC, HWSC, and POXC), were assessed according to established protocols.

STATISTICAL ANALYSIS

Each biomass sample's data underwent individual examination, and the analytical results were analyzed statistically using the WASP software, following the methodology outlined by Gomez and Gomez in 1976.

RESULTS AND DISCUSSION

Physical properties

The biochar yields from a variety of biomass sources ranged from 9.39 to 39.50 percent, and their production order was as follows: Prosopis wood > cotton stalk > neem wood > Eichhornia > coconut shell > coconut husk > paddy straw > sugarcane bagasse > rice husk > grass biochar. This variability can be attributed to the higher concentrations of cellulose, hemicellulose, and lignin in Prosopis wood compared to other biomass sources (Tanaka, 1963; Sohi *et al.*, 2009). Shenbagavalli and Mahimairaja (2012) also noted that Prosopis wood had notably high cellulose (36%), substantial hemicellulose (31%), and moderate lignin

(22%) content. Different biochar sources exhibited ash contents ranging from 0.87 to 22.7 percent and moisture contents ranging from 1.60 to 14.60 percent. Paddy straw-based biochar had the highest ash content (22.70 %), while wood and stalk biochars had lower ash content compared to those derived from dry matter biomass. This is consistent with the findings of Singh *et al*. (2010) and Wang *et al.* (2013), who attributed higher ash concentrations in crop straw-derived biochars to the presence of various inorganic components. There were significant variations in bulk density, particle density, and pore space among different biomass types, with bulk density ranging from 0.15 to 0.62 Mg m^{-3}, particle density from 0.40 to 0.96 Mg m^{-3}, and pore space from 18.41 to 85.54 percent. Dry matter biomass biochars exhibited higher bulk density compared to wood and stalk biomass biochars, whereas wood and stalk biomass biochars had higher particle density. Dry matter biomass biochars had a lower pore percentage compared to wood and stalk biomass biochars (Table 1).

Physico - Chemical properties

At a solid-to-water ratio of 1:10, pH values ranged between 7.20 and 10.31 (Jackson, 1973). Generally, the biochars had an alkaline pH, with biochar from wood and stalk biomass exhibiting higher pH levels compared to biochar from dry matter biomass (see Fig. 2). This alkalinity was a result of salt hydrolysis, particularly involving calcium (Ca), magnesium (Mg), and potassium (K). These variations were commonly observed in biochars produced from various biomass sources (Singh *et al.*, 2010; Lehmann, 2007; Angaleeswari and Kamaludeen, 2017; Pandian *et al.*, 2016; Shalini *et al.*, 2017).

There was a notable fluctuation in electrical conductivity (EC), ranging from 1.37 to 3.87 dS m^{-1}(Fig. 2a). Biochar derived from dry matter biomass sources (e.g., coconut husk, rice husk, sugarcane bagasse, Eichhornia, paddy straw, and grass) had higher levels of soluble salts compared to biochar produced from wood and stalk biomass. The elevated EC could be attributed to the high concentration of carbonate ions from alkali and alkaline earth metals, varying levels of silica, heavy metals, sesquioxides, phosphate, and low concentrations of organic and inorganic nitrogen (Sellamuthu *et al.*, 2018; Shenbagavalli and Mahimairaja, 2012; Rajakumar, 2019).

The Cation Exchange Capacity (CEC) of biochar ranged from 11.43 cmol (p+) kg-1 to 20.61 cmol (p+) kg^{-1}, as shown in Figure 2b. Biochar, primarily composed of amorphous graphene sheets with a polyaromatic structure, has the ability to bind a variety of organic chemicals, both polar and non-polar molecules, as well as inorganic ions. This property arises from the multiple reactive surfaces formed during pyrolysis (Yang *et al.*, 2016). In comparison between biochars from dry matter biomass and those from wood and stalk biomass, the former exhibited a higher CEC.

The carbon content of biochar exhibited significant variation, ranging from 27.7 to 66.7 g kg^{-1}, as depicted in Figure 2c. Biochars produced from dry matter biomass had lower carbon content compared to those from wood and stalk biomass. This difference may be attributed to the presence of cellulose, hemicellulose, and lignin, which are three biological constituents. Additionally, charred biomass contains aliphatic and oxidized carbon structures that are more easily broken down, alongside the refractory aromatic ring structure (Schmidt and Noack, 2000). The carbon content of a biochar particle can vary depending on its carbon properties (Lehmann, 2007).

The Carbon-to-Nitrogen (C/N) ratio displayed a wide range, spanning from 69.47:1 to 129.40 :1, as observed in Figure 2e. For instance, grass biochar had a higher C/N ratio (128.0:1) in comparison to Prosopis wood biochar, which had a significantly lower ratio (69.47:1). Similar values have been reported by Novak *et al*. (2009), Rondon *et al*. (2007), and Cheng *et al*. (2006). The organic carbon content of biochar ranged from 0.11 to 0.69 percent, with biochars from wood and stalk biomass exhibiting higher levels of organic carbon compared to those from dry matter biomass, a trend commonly observed in biochars from various feedstocks (Novak *et al*., 2009; Rondon *et al*., 2007) (Table 1).

Chemical properties

Based on the chemical analysis, the biochars exhibited varying total nitrogen content, ranging from 0.26 to 0.93 percent, with the highest nitrogen levels found in Prosopis wood and neem wood biochars. Neem wood biochar and Eichhornia contained higher levels of total phosphorus. The entire potassium content ranged from 1.07 to 2.51 percent. Biochars from dry matter biomass had higher total potassium values compared to those from wood and stalk biomass. Additionally, significant amounts of secondary nutrients such as calcium, magnesium, and sulfur were present, ranging from 1.68to 0.23, 0.99 to 0.21, and 0.58 to 0.10 percent, respectively. The substantial variations in biochar's chemical composition can be attributed to differences in feedstock sources, both organic and inorganic constituents, and production methods, which align with similar observations made by Lima and Marshall (2005), Chan and Xu (2009), and Sellamuthu *et al*. (2018).

Biochar contained readily available nutrients in the amounts of 42.16 mg kg^{-1} of nitrogen, 74.69 mg kg^{-1} of phosphorus, and 349 mg kg^{-1} of potassium. Biochars from wood and stalk biomass had higher levels of available nutrients compared to those from dry matter biomass. Among the nutrients, available potassium content was comparatively higher than nitrogen and phosphorus content, as per Pandian *et al*. (2016) (see Fig. 3, 3a). Biochars from wood and stalk biomass also had higher values of the carbon components: water-soluble carbon, hot water-soluble carbon, and permanganate-oxidizable carbon, compared to biochars from dry matter biomass (Fig. 3b) (see Table 2).

There are opportunities to improve the management of soil systems by utilizing the residues from charcoal production more effectively (Lehman *et al.*, 2006). Biochar has been commonly used in tree nurseries and is recommended as an amendment (Jaenicke, 1999). The technology's ease of use is facilitated by the fact that the particle size of biochar appears to have minimal impact on its influence on soil fertility and crop yield (Lehmann *et al*., 2003).

Conclusions

Prosopis wood biochar, with its soil-conditioning properties and capacity to enhance nutrient provision and retention, outperforms cotton stalk biochar and biochars derived from dry matter biomass.The resource of Prosopis wood can be utilized because of the higher recovery and its dispersion. It is possible to conclude that depending on the sources of biomass used to make the biochar, the nature and characteristics of the substance will vary. In order to use biochar in agriculture, it is necessary to study the characteristics of each unique source before mass producing it.

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

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
Coconut husk	19.20	10.17	0.95	0.15	0.42	18.41	9.84	2.92	15.70	66.7	0.43	82.35
Coconut shell	24.46	14.60	12.30	0.39	0.50	37.86	9.60	3.12	18.29	60.9	0.48	80.86
Paddy straw	10.01	11.23	22.70	0.53	0.74	44.77	9.92	2.75	15.62	52.0	0.32	92.07
Rice husk	15.95	7.35	21.71	0.36	0.46	39.12	9.26	1.72	12.27	33.1	0.39	129.40
Sugarcane bagasse	10.48	2.08	5.95	0.26	0.52	53.72	8.51	2.32	15.20	32.4	0.22	113.14
Eichhornia	25.91	3.16	15.35	0.38	0.48	85.54	8.59	2.07	13.80	46.0	0.54	74.77
Grass	9.39	12.91	7.57	0.62	0.40	58.28	7.20	1.36	11.43	33.5	0.11	105.83
Cotton stalk	33.32	1.60	2.13	0.34	0.80	56.34	9.14	3.18	18.78	27.7	0.59	75.16
Prosopis wood	39.50	12.45	0.99	0.46	0.96	72.44	10.31	3.86	20.61	64.0	0.69	69.47
Neem wood	28.12	11.60	0.87	0.43	0.65	63.77	10.02	3.22	19.86	60.0	0.62	71.23
Maximum	**39.50**	**14.60**	**22.7**	**0.62**	**0.96**	**85.54**	**10.31**	**3.86**	**20.61**	**66.7**	**0.69**	**129.40**
Minimum	**9.39**	**1.60**	**0.87**	**0.15**	**0.40**	**18.41**	**7.20**	**1.36**	**11.43**	**27.7**	**0.11**	**69.47**
Mean	**21.63**	**8.71**	**9.05**	**0.39**	**0.59**	**53.02**	**9.23**	**2.65**	**16.15**	**47.63**	**0.43**	**89.42**
S.D	**10.39**	**4.83**	**8.52**	**0.13**	**0.18**	**19.08**	**0.93**	**0.77**	**3.15**	**14.99**	**0.18**	**20.29**

Table 2. Chemical properties of biochar from different biomass

Biomass	Total N (%)	Total P (%)	Total K (%)	Total Ca (%)	Total Mg (%)	Total S (%)	Available N (mg kg $^{-1}$)	Available P (mg kg $^{-1}$)	Available K (mg kg $^{-1}$)	WSC (mg kg $^{-1}$)	HWSC (mg kg $^{-1}$)	POXC (mg kg $^{-1}$)
Coconut husk	0.82	0.47	2.35	0.42	0.25	0.16	15.43	41.93	314.00	63.44	111.66	605.19
Coconut shell	0.76	0.37	2.51	1.50	0.27	0.37	8.47	43.61	338.00	75.73	103.59	658.34
Paddy straw	0.57	0.25	1.53	0.36	0.32	0.18	22.41	27.05	171.00	57.15	81.31	321.79
Rice husk	0.26	0.14	1.33	0.45	0.62	0.24	26.64	16.91	189.00	52.49	75.63	361.62
Sugarcane bagasse	0.29	0.12	1.35	0.91	0.21	0.28	11.29	37.86	212.00	36.24	43.59	300.29
Eichhornia	0.62	0.74	2.05	1.18	0.68	0.58	30.88	57.46	282.00	45.72	90.47	488.47
Grass	0.32	0.13	1.07	0.23	0.35	0.10	12.62	16.57	160.00	23.77	37.15	306.19
Cotton stalk	0.37	0.23	1.50	0.95	0.96	0.20	37.83	62.87	229.00	124.20	206.34	663.85
Prosopis wood	0.93	0.18	1.31	1.04	0.99	0.26	42.16	74.69	349.00	153.98	256.04	736.41
Neem wood	0.85	0.91	1.29	1.68	0.80	0.23	40.70	59.83	309.00	137.76	241.93	690.02
Maximum	**0.93**	**0.91**	**2.51**	**1.68**	**0.99**	**0.58**	**42.16**	**74.69**	**349.00**	**153.98**	**256.04**	**736.41**
Minimum	**0.26**	**0.12**	**1.07**	**0.23**	**0.21**	**0.10**	**8.47**	**16.57**	**160.00**	**23.77**	**37.15**	**300.29**
Mean	**0.57**	**0.35**	**1.62**	**0.87**	**0.54**	**0.26**	**24.84**	**43.87**	**255.30**	**77.05**	**124.77**	**513.21**
S.D	**0.25**	**0.27**	**0.49**	**0.50**	**0.30**	**0.13**	**12.72**	**19.84**	**71.34**	**45.33**	**80.26**	**176.92**

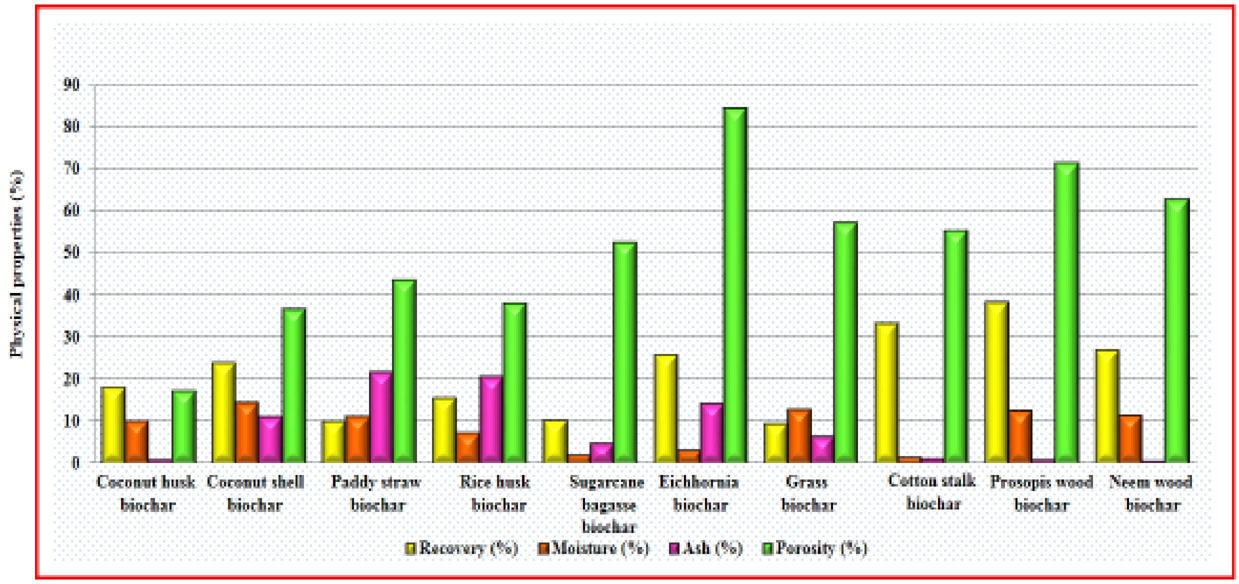

Fig. 1. *Physical properties of biochar from different biomass (per cent)*

Fig. 1a. *Physical properties of biochar from different biomass (Mg* m^{-3}*)*

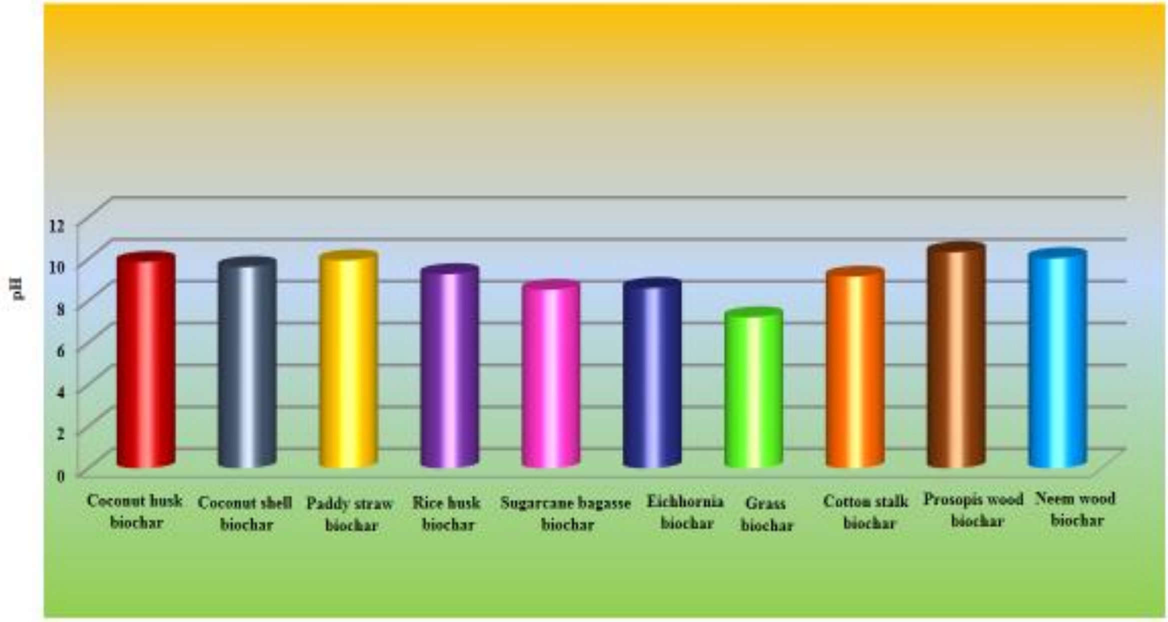

Fig. 2. *pH of biochar from different biomass*

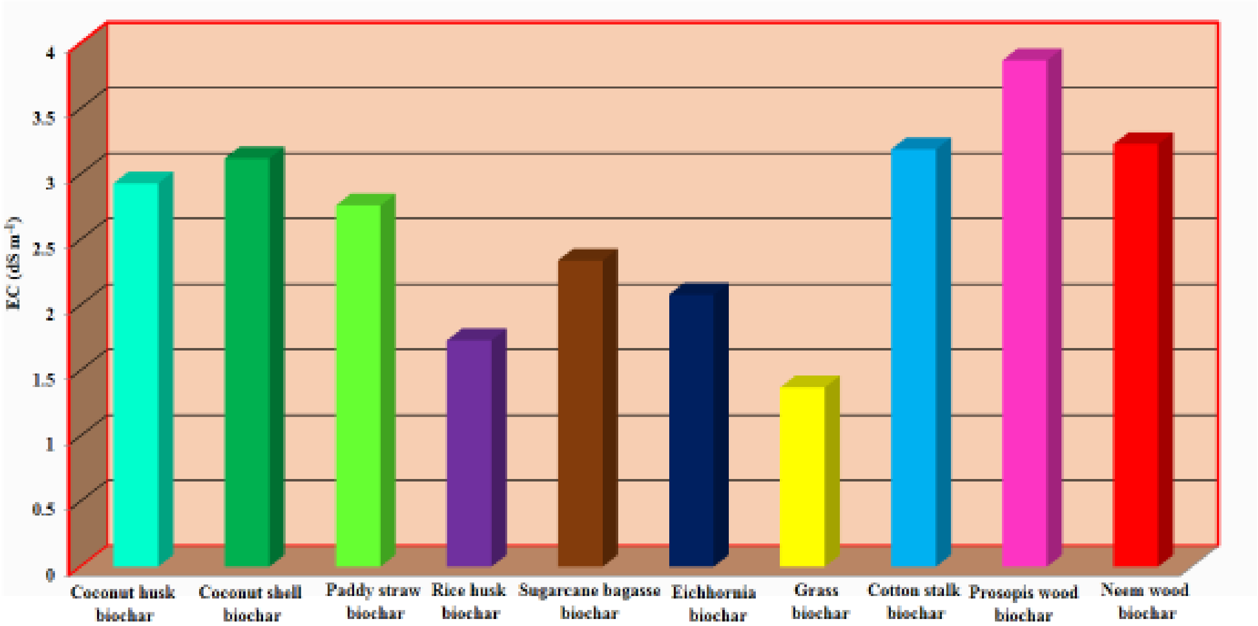

Fig. 2a. *EC of biochar from different biomass (dS* m^{-1}*)*

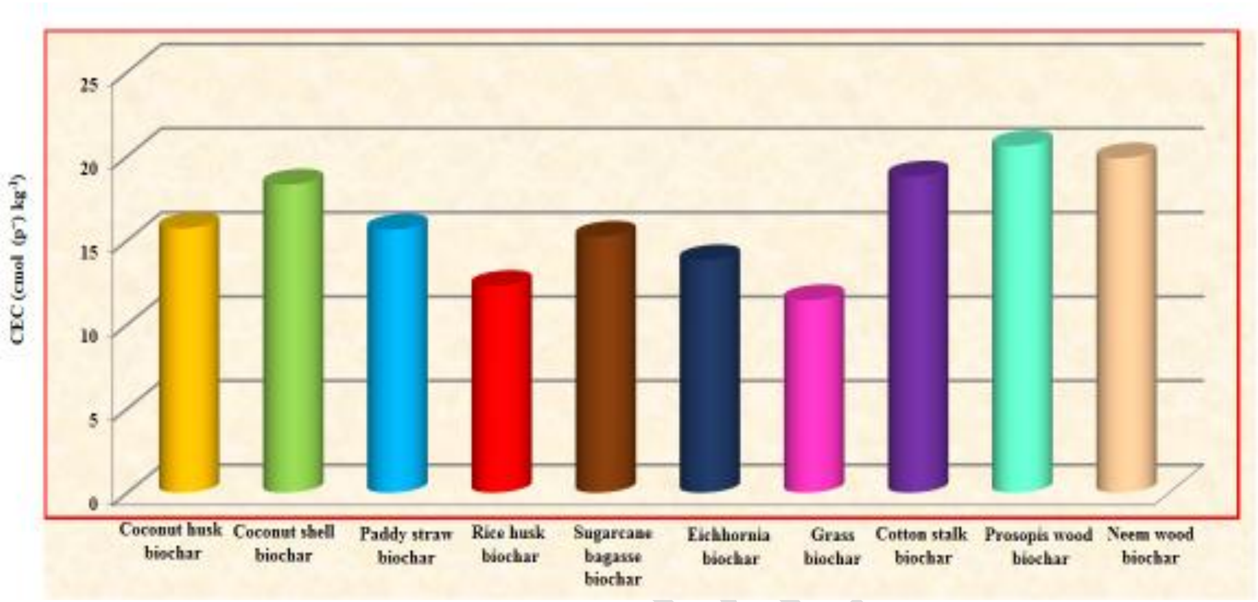

Fig. 2b. *CEC of biochar from different biomass (cmol (p^+) kg^{-1})*

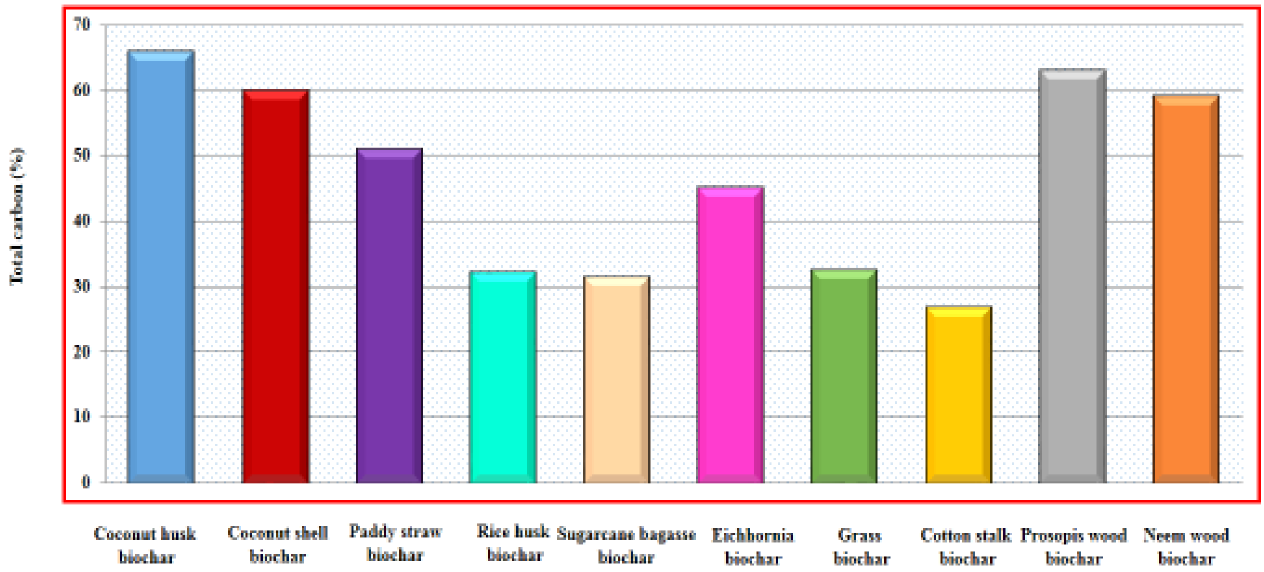

Fig. 2c. *Total carbon content of biochar from different biomass (per cent)*

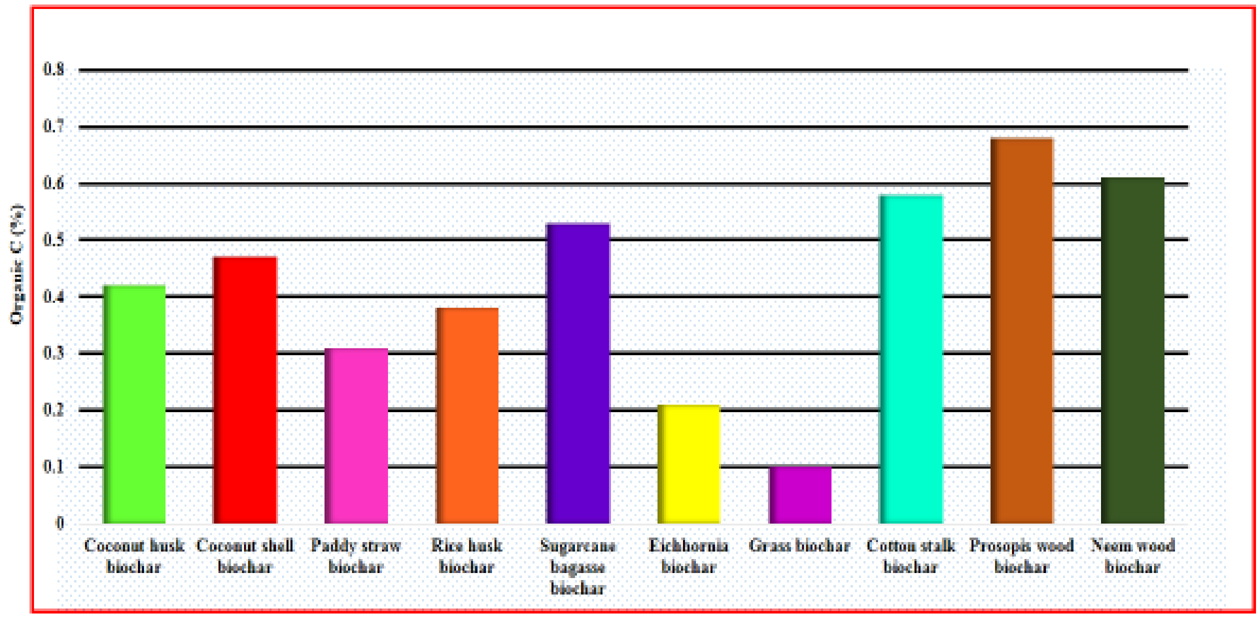

Fig. 2d. *Organic carbon content of biochar from different biomass (per cent)*

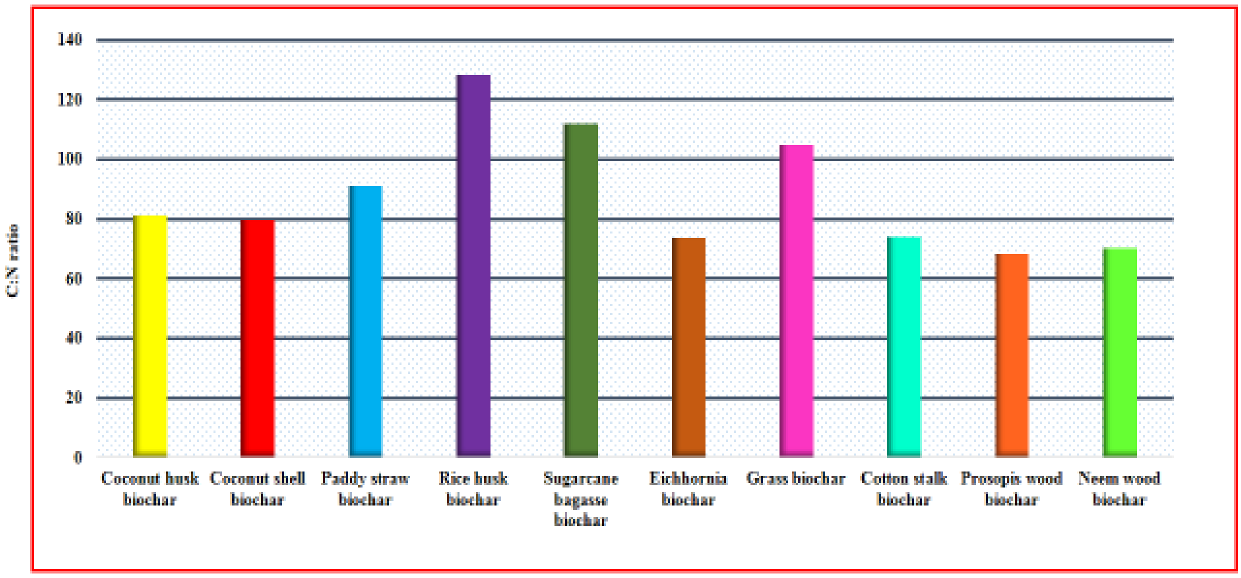

Fig. 2e. *C:N ratio of biochar from different biomas*

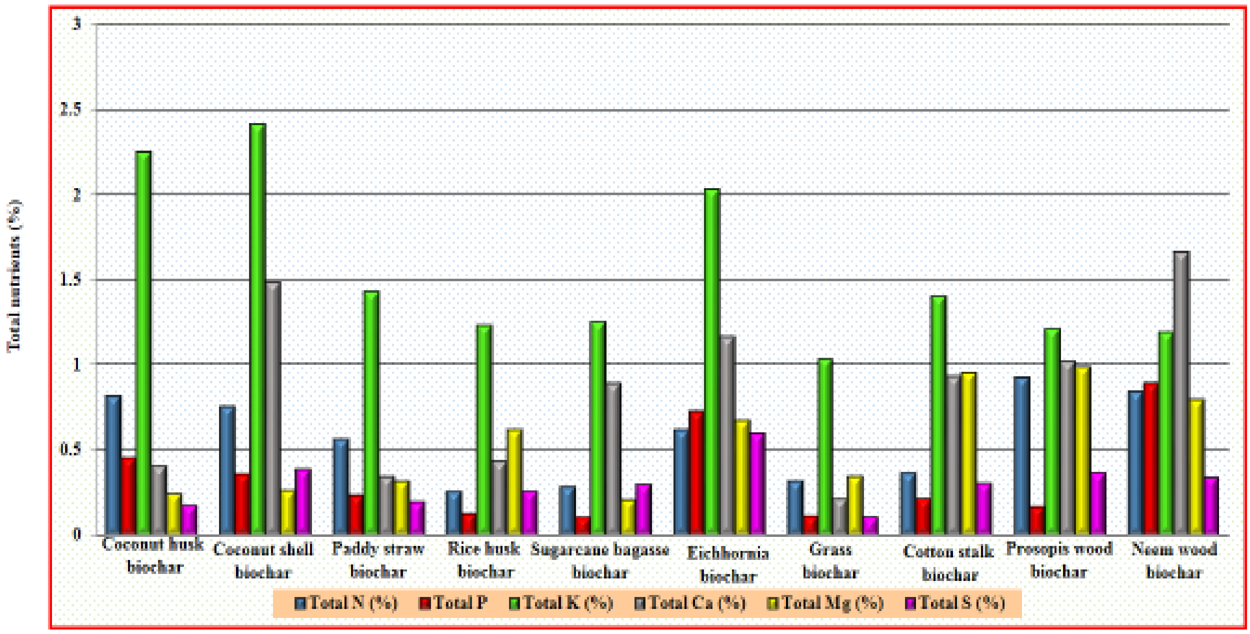

Fig.3. *Total nutrient content of biochar from different biomass (per cent)*

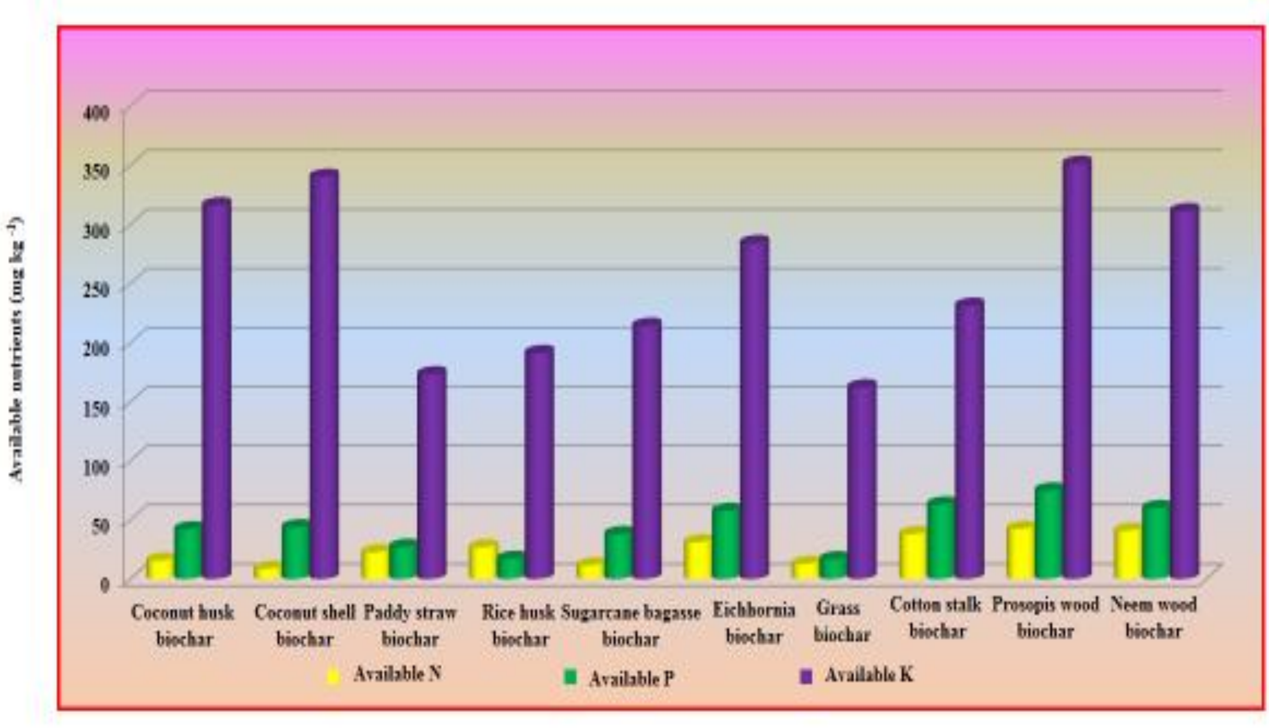

Fig. 3a. *Available nutrient content of biochar from different biomass (mg kg $^{-1}$)*

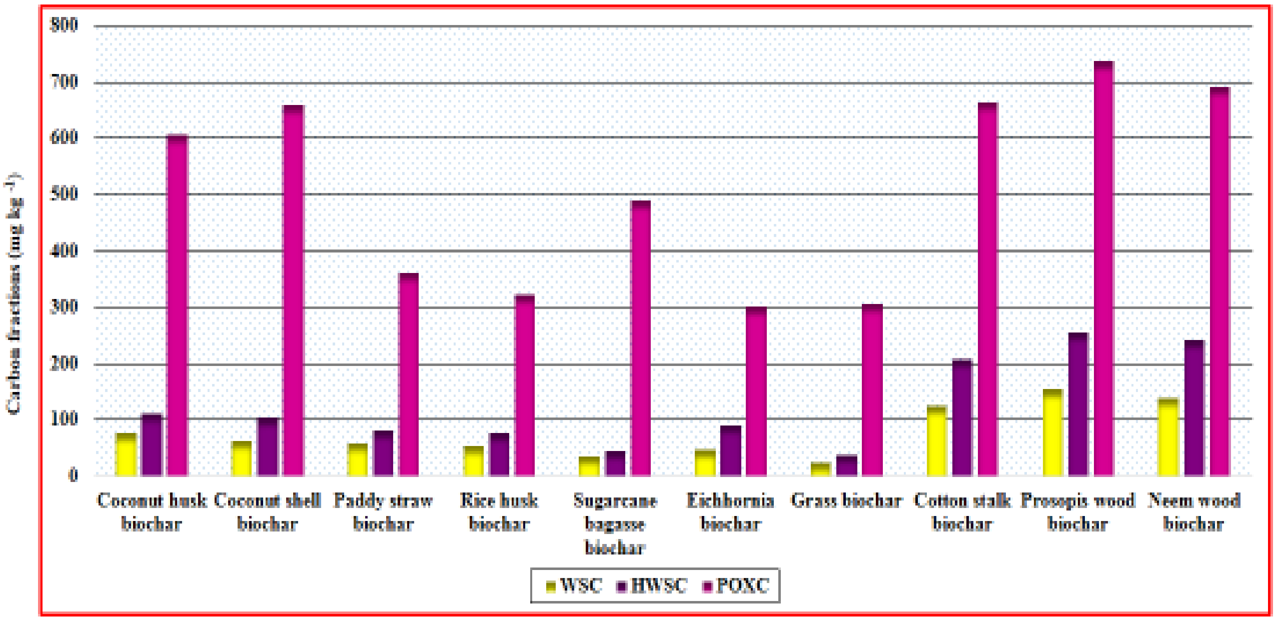

Fig. 3b. *Carbon fractions of biochar from different biomass (mg kg $^{-1}$)*