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ORIGINAL RESEARCH

Agro-environmental characterization of biochar issued from crop wastes in the humid forest zone of Cameroon

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Abstract

Purpose Crop wastes are underused organic resources due to low heating value and slow decomposition rates. However, conversion to biochar through pyrolysis could offer agronomic and environmental benefits. The study compared the pyrolysis of biochar from crop wastes, assessed their physicochemical properties for the purposeful use to improve soil fertility, crop productivity and their carbon sequestration potential.

Methods Biochar was produced from crop wastes such as cassava residues, corncobs, rice husk, sawdust, coffee husk, and peanut using an Elsa barrel pyrolyser. Standard laboratory procedures were used to analyze pH, CEC, total carbon and nitrogen and exchangeable cations.

Results The biochars were high in nutrients containing 4.17–18.15 g kg^{-1} N, 22.26–42.51 mg kg^{-1} P, 2.48–4.18 cmol kg^{-1} K and pH 7.78–10.81 units. It is evident that adding biochar to acidic soil containing 0.79 g kg^{-1} N, 7.41 mg kg^{-1} P, 1.42 cmol kg^{-1} K and pH of 5.68 could increase soil fertility and plant productivity. Carbon dioxide reduction potential ranged from 94.46 to 313.42 CO_2 eq kg^{-1}. This implies that the concept and technique of producing biochar could be a valuable way of reducing carbon emissions into the atmosphere thereby mitigating climate change.

Conclusion Crop wastes and by-products which constitute a nuisance could be used to produce a very useful by-product, biochar whose quality depends on the substrate from which it is produced. Recycling crop wastes to biochar is strongly recommended to smallholder farmers for use in agriculture to improve fertility and crop productivity due to their high nutrient content and soil fertility attributes.

Keywords Biochar · Cassava · Carbon dioxide emissions · Coffee husk · Pyrolysis · Soil fertility

Introduction

Currently, a large percentage of organic resources produced globally are inefficiently used and not recycled (Rajaie and Tavakoly 2016). In Cameroon for example, food crops such as maize (*Zea mays*), rice (*Orita sativa*) and cassava (*Manihot esculenta* Crantz) are widely cultivated for subsistence alongside vegetables such as amaranth (*Amaranthus cruentus*) (Njukwe et al. 2014; Tata et al. 2016). These food crops generate wastes such as corncob, rice husk and groundnut husk which are not used as fuel because of their low heating value and the volume of smoke produced (Kung et al. 2015; Kumer et al. 2015). Low bulk density and slow decomposition also limit their use in agriculture as a soil amendment (Steiner et al. 2010; Enders et al. 2012) whereas they contain appreciable quantities of soil nutrients such as N, P, K which could offer both agronomic and environmental benefits (Lin et al. 2012; Chaudhuri et al. 2016).

Coffee husk and pulp, rice husk and straw and corncob and stover are commonly burned in the field, dumped in waterways or piled to rot around processing units (Draper and Tomlinson 2015). These disposal approaches lead to air pollution, eutrophication of water resources with toxic

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algal blooms resulting from leaching of nutrients in the wastes (Dotaniya et al. 2016; Rajaie and Tavakoly 2016). According to the International Biochar Initiative (2016), natural decomposition of crop wastes account for about 10% global methane emissions (CH_4) and 1% nitrous oxide emissions. Open burning has been estimated to contribute about 40 Mt CO_2 equivalents (International Biochar Initiative 2016; Kung et al. 2015; Kumer et al. 2015). Biochar is a carbon-rich material produced by pyrolysis (thermochemical conversion) of organic materials such as agricultural residues of plant and animal origin, forestry and wastes from food-related industries in a controlled low-oxygen environment (Steiner et al. 2010; Sohi et al. 2010; Shackley et al. 2011). This process known as pyrolysis has recently attracted attention as a means to add value to organic wastes for agricultural use (Rafiq et al. 2016). Studies have shown that biochar has physiochemical properties suitable for soil improvement and reduction of carbon dioxide emissions in the environment (Kumer et al. 2015). When added to acidic soils, biochar like other organic fertilizers (green manure, animal manure and compost) influences soil characteristics such as soil pH and bulk density (Djousse et al. 2016; Siamak et al. 2017). Studies have shown that adding biochar to soils increases soil organic matter (SOM) and organic carbon which then enhances nutrient supply to plants and promote plant growth (Weyers and Spokas 2014; Dotaniya et al. 2016). Growing interest in biochar has also been associated with its carbon sequestration ability, to reduce CO_2 emissions by slowing down the return of photosynthetically fixed carbon to the atmosphere (Enders et al. 2012). This can in the long run assist developing countries like Cameroon to meet its 35% greenhouse gas emission reduction target by 2035 (Homagain et al. 2016). However, the choice of the pyrolyser can compromise the quality and quantity of the biochar produced as well as their adoption by farmers (Abrishamkesh et al. 2015; Hussein et al. 2015; Rajaie and Tavakoly 2016). Table 1 compares the advantages and disadvantages of different pyrolysers used to produce biochar.

The design of biomass carbonizers, gasifiers or pyrolysers is an emerging concept that will add value to wastes and attract large and small-scale farmers to adopt biochar (Hussein et al. 2015). It is also important to document the characteristic of biochar produced from crop wastes to ensure their safety and suitability for use in agriculture as soil amendments and in Environmental management as a tool to mitigate climate change and wastes problems (Shackley et al. 2011). Therefore, the main objective of this study was to assess the physico-chemical properties of biochar produced from crop wastes for their purposeful use in enhancing soil fertility and mitigating climate change. The specific objectives were: (1) compare the pyrolysis of biochar from different crop wastes, and (2) to assess their carbon sequestration potential. The study hypothesized that carbonizing crop wastes generates nutrient-rich biochars with high fertilization and carbon sequestration potential.

Table 1 Comparison of different types of pyrolysers for biochar production. Source: Hussein et al. (2015); Homagain et al. (2016)

Type of pyrolyser	Advantages	Disadvantages
Batch pyrolysers Elsa pyrolysis barrels, brick, concrete and metal kilns	Simple, cheap and portable Feedstock flexibility Many types of feedstocks can be pyrolysed Easy to operate: easy to start up and control during operation Time-saving Shorter carbonization time (< 1 h)	Health and safety Fire and hot surfaces poses risk of skin burns and fire outbreak Low yields Small quantity of biochar produced are likely not of interest to farmers
Retorts	Higher yields Consumer-driven technologies Easy to operate, start up and control during operation Time-saving, shorter carbonization time (< 1 h)	Not flexible: very few feedstocks (rice husk) can be pyrolysed Release of pyrolysis gas and vapors to atmosphere resulting in environmental pollution Health and safety: Release of toxic or irritant smoke
Screw type and continues pyrolysers	Higher yields; feedstock flexibility; cogeneration of char and energy; easy to operate; combined char and energy generation; portable or stationary unit (depending on size)	Expensive and very complex Slow: longer carbonization time (> 1 h)
Paddle drum pyrolysers	Feedstock flexibility Biochar and energy production; available as either portable or stationary unit (depending on size) Higher yields, heat integration and possible cogeneration of char and energy	More complex and expensive Slow, longer carbonization time (> 1 h)

Materials and methods

Location of study site

The study was carried out at the IRAD Nkolbisson experimental field site, located in the Center Region of Cameroon between latitude 03°51′N and longitude 11°27′E at an altitude of 300 m above sea level. At Nkolbisson, the climate is humid tropical equatorial type with bimodal rainfall pattern. The area is characterized by average annual rainfall of 1670 mm and average annual temperature of 23.5 °C. The main soil type in the study area is rhodic ferralsol which is generally acidic, low in organic matter and deficient in exchangeable cation (Yerima and Van Ranst 2005). The livelihood activity comes from agriculture, hunting and harvesting of non-timber forest products (Tata et al. 2016). The main cash crops cultivated include; coffee and cocoa while maize, cassava, yam and bean mixed crop cropping are also practiced (Ngome et al. 2013).

Sources of crop waste, collection and preparation

Crop wastes used in the study were the most available and accessible wastes in the study area with high potential to negatively impact the environment. These include; sawdust, rice husk, coffee and groundnut husk, cassava and corncobs. Apart from the chemical composition of feedstock, the availability of drying and storage facilities and means of transportation were also taken into account (Abrishamkesh et al. 2015; Djousse et al. 2016). Furthermore, competition for other uses of each waste was also considered among their multiple uses since crop wastes such as sawdust and corncobs were the major energy sources providing domestic energy in the study area. Cassava residues (leftovers of roots and stems of cassava after the edible parts mainly the starchy tuberous roots have been harvested on the farm), was collected from IRAD experimental farm in Nkolbisson. The material was then cut into small pieces and piled in a greenhouse to dry. Corncob was sourced from IRAD maize store house in Nkolbisson and Dschang located in the Western highland agroecological zone. Rice husk was collected from rice mill waste streams in the city of Bamenda and Sanchou, Dschang located in the Western highland agroecological zone and transported to Nkolbisson. Coffee husk was transported from a coffee agro-processing unit in Sanchou, Dschang in the Western highland agroecological zone. Sawdust was collected from sawmill waste streams around Yaoundé city in the humid forest zone with bimodal rainfall pattern. The wastes were sun dried to $<25\%$ moisture. No specific permission was required before collection because these were waste products having no use for the owners.

Production of biochar from crop waste

Approximately 400 kg of each crop waste (feed stock) was sourced. Three Elsa barrels were constructed and used to produce the biochar (Fig. 1a). The experiment was run several times in a completely randomized design. The feed stocks were packed in the barrels on a dry weight basis. The Elsa barrel was a 250-l metal cylinder opened on one end with a removable circular steel plate (Fig. 1a). The open end was perforated to supply secondary air required for the combustion. The perforations were made with 3 cm L-shaped holes separated by spacing of 3 cm. Equally 3 cm plus mark holes were perforated on the closed end of the barrel for supplying primary air. The removable steel plate was also perforated with additional brass fittings for chimney. Semi-circular metal arms were fixed on both sides of the barrel to facilitate transportation and emptying of the barrel.

The pyrolysis process began when the feedstock were packed in the barrel and then ignited by spreading small amount of a starter fluid (kerosene) over the top of the feedstock and touched off with a glowing match stick so that the top lights uniformly (Fig. 1c). Once the top layer was lit, the circular steel plate was then placed on the open end and the chimney added (Fig. 1). Shortly, combustion begins carbonizing the feedstock descending towards the closed end of the barrel. The low oxygen in the system prevented the complete burning of the feedstock and produced biochar via the process of carbonization (Djousse et al. 2016). The exothermic process that occurred during the process from secondary combustion in the charred pellet bed (Olivier 2010; Hussein et al. 2015) was detected through a thin colorless smoke coming out of the chimney. When the pyrolysis flames reached the bottom or closed end of the barrel, smoke, red pyrolysis flame illuminating and biochar particles were seen falling off through the plus marking holes at the bottom of the barrel. At this point, all the feedstock had been converted to biochar and pyrolysis ended. Afterwards, the biochar was then poured out on a clean surface and the flame in the biochar extinguished with clean water (Fig. 1).

Characterization of biochar

The carbonization time was determined by measuring the time, the feedstock in the barrel was lit and the time the barrel was emptied of the biochar. Carbonization temperature was monitored using HANNA HI-935005k-thermocouple from the surface of the barrel (Billa et al. 2017). The quantity feedstock and the resultant biochar produced were measured using an electronic balance. Then 500 g sample of each biochar was milled and passed through a 2-mm sieve and

Rice husk residue Corncob Cassava residue

a Barrel filled with corncob **b** Fitting the chimney **c** Carbonization process

d Retort pyrolyser **e** Quenching fire in the biochar **f** Sawdust and Sawdust biochar

i Ricehusk biochar **j** Corncob biochar **k** Cassava biochar

Fig. 1 Biochar production from selected crop wastes using the Elsa pyrolysis barrel. Source: Billa et al. (2017)

packed in plastic bags for analyses in the laboratory. The physicochemical characteristics of the biochars samples were analyzed in the Laboratory for Plant, Soil and Water Analysis (LAPSEE) at IRAD Nkolbisson, Cameroon. Moisture content was evaluated by drying a 100 g subsample in an oven at 105 °C to constant weight (ASTM 2009). The bulk density was determined using the core method while pH was measured with a glass electrode in a 1:5 biochar water ratio (ASTM 2009). Organic carbon was determined by chromic acid digestion and spectrophotometric analysis (Heanes 1984). Total N was determined by a wet acid digestion method and analyzed by colorimetric analysis (Anderson and Ingram 1993). Available phosphorus was extracted using Bray extractant and analyzed using the molybdate blue procedure (Murphy and Riley 1962). Exchangeable cations (Mg, Ca, Na and K) were extracted using the ammonium acetate (NH_4OAC, pH: 7) and determined by flame atomic absorption spectrophotometry (ASTM 2009). Cation exchange capacity (CEC) was determined using ammonium acetate.

Estimation of the CO_2 reduction potential of the biochar

The amount of CO_2 (CO_2 eq kg^{-1}) that would have been emitted in to the atmosphere, if the crop waste had decomposed naturally or openly burned was also estimated (Sohi et al. 2010). Biochar yield (Eq. 1) was calculated as the ratio of the weight of biochar (M2) to the weight of feedstock (M1) (Allyson 2011).

$$\text{Biochar yield (Bw \%)} = \frac{M2}{M1} \times 100. \tag{1}$$

Further, the total potential carbon (TPC) was calculated by multiplying of the biochar yield and the total carbon content obtained from laboratory analysis (Sandip and Harsha 2013) (Eq. 2).

$$\text{TPC} = \text{biochar yield} \times \text{carbon content of biochar.} \tag{2}$$

Finally, the carbon dioxide reduction potential (CO_2 eq kg^{-1}) was estimated by multiplying the total potential carbon by the carbon stability coefficient (80%) and CO_2 fraction (molecular mass of CO_2 (44 g $mole^{-1}$) and the mass of carbon (12 g $mole^{-1}$) (Allyson 2011) (Eq. 3).

$$\text{Carbondioxide reduction potential} = \text{TCP} \times \frac{80}{100} \times \frac{44}{12}. \tag{3}$$

Statistical analysis

All data collected were subjected to analysis of variance (ANOVA), using the IBM SPSS Statistics 20.0 software. Results were expressed as means while the means were compared using Tukey test at 5% threshold level. Pearson correlation at 0.01 and 0.05, respectively, was used to highlight the relationships between the parameters. Preparation and computation of graphs, figures and tables were done in Microsoft Excel 2010.

Results and discussion

Efficiency of the pyrolysis unit

The result from the biochar production study showed that many types of crop wastes can be effectively converted to biochar using the Elsa barrel compared to other methods such as the Japan retort method (Fig. 1d) where only rice husk could be carbonized. Table 2 shows the pyrolysis conditions during the production of biochar from forestry and crop wastes using the Elsa barrel.

From Table 2, carbonization time and temperature varied significantly ($P < 0.05$) for each crop waste (feedstock). The carbonization temperature (measured using a k-type thermocouple) was highest for corncob (620 °C). This observation is in line with studies carried out by Peng et al. (2011) of various crop residues pyrolysed under similar conditions. The short retention time and high temperature also showed that pyrolysis was fast. The Elsa barrel could only take a maximum quantity of 5 kg for rice husk and approximately 48 min to produce 2 kg of biochar. The short carbonization time for rice husk, coffee and groundnut husk could be due to the small quantity, dry, brittle nature and less dense material which burn much easier and faster as compared to the densely packed and woody biomass corncob and cassava which required high temperature and longer carbonization time (Joseph et al. 2013; Domingues et al. 2017).

Biochar yield refers to the percentage of usable material (biochar) recovered from a given crop waste or residue

Table 2 Pyrolysis conditions of producing biochar from forestry and crop wastes in the Elsa barrel

Pyrolysis condition	Biochar					
	Cassava	Corncob	Rice husk	Coffee	Ground nut	Sawdust
Carbonization temperature (°C)	600^{b}	650^{a}	450^{c}	490^{c}	$580^{a,b}$	$520^{b,c}$
Carbonization time (min)	56^{a}	58^{a}	48^{b}	$50^{b,c}$	$52^{b,c}$	54^{b}
Quantity of feedstock pyrolysed (kg)	$25–30^{a}$	$24–30^{a}$	5^{c}	5^{c}	10^{b}	10^{b}
Quantity of biochar produced (kg)	$8–9^{a}$	$7–9^{a}$	$2–3^{c}$	3^{b}	$4–5^{b}$	$3–4^{b}$
Biochar yield (%)	31.44^{d}	26.88^{e}	46.53^{a}	45.83^{a}	34.50^{c}	42.23^{b}

The letters in superscript compare the means of the different biochars. The same letters in a row are not significantly different according to Tukey at $P > 5\%$

(Joseph et al. 2013). From Table 2, rice husk biochar (RHb) recorded the highest yield (46.43%) and was significantly different ($P < 0.05$) from the other biochars except coffee biochar with yield of 45.83%. It was also observed that biochar yield decreased as the pyrolysis temperature increased (Table 2). Cassava and corncob biochar recorded the lowest yield of 26.88% and 31.44%, respectively. The high yield of rice husk biochar could be due to the partial burning of the residue as a result of the hard compact shell of rice husk (Domingues et al. 2017). Rice husk has high silicon content (Si) and therefore, the high yield of rice husk could be due to the endothermic reaction of silicon–carbon bonds which is difficult to break with the low temperature (Guo and Chen 2014). The low biochar yield of corncobs and cassava could be due to the complete burning of lignocellulose material due to high pyrolysis temperature according to Domingues et al. (2017).

Ash, moisture and volatile matter of the biochars after pyrolysis

Table 3 presents the ash, volatile matter, moisture and bulk density of the biochar issued from the various crop wastes carbonized.

From Table 3, biochar from corncob had significantly high ash content (23.4%). Ash from organic waste is rich in potassium, calcium and magnesium which are suitable for plant growth (Weyers and Spokas 2014). The ash content in the biochar increased with temperature with a positive significant correlation coefficient of 0.439^{*} at $P < 0.01$ (Table 4). This could be due to the high organic and inorganic products released during the pyrolysis (Enders et al. 2012).

Biochars produced at lower temperatures contain large quantities of volatile matter (Table 3). The increase in volatile matter ($r = 0.642^{**}$, Table 4) could be due to modification the functional groups by pyrolysis temperatures (Domingues et al. 2017). Volatile matter is composed of easily degradable aliphatic carbon compounds with C–H (750–900 cm^{-1}) and C–O (2950–2850 cm^{-1}) stretching (Jindo et al. 2014). Consequently, these biochars could be suitable for use as soil amendment to improve soil fertility as they contain substrates which are suitable source of carbon and energy for soil microorganisms (Khodadad et al. 2011; Lehmann et al. 2011). Higher-temperature pyrolysis destroys suitable functional groups and produces aromatic carbon compounds with C–H, C=C, C–C, and C–O stretching (3050–3000 cm^{-1}, 1380–1450 cm^{-1} and 1580–1700 cm^{-1}) that are highly recalcitrant and decompose slowly (Jindo et al. 2014). Such biochars (cassava and corncobs) according to Peng et al. (2011) are suitable for carbon sequestration.

Results from Table 3 also shows that the bulk density (BD) of the biochars were very low (max. 0.24 g cm^{-3}), close to the values for peat and soil organic matter (Lin et al. 2012; Rajkovich et al. 2012). The bulk densities were also significantly lower than the acidic soils of the study area (1.42 g cm^{-3}) (Billa et al. 2017). The low bulk density in especially rice husk, groundnut and sawdust biochar indicates that addition of the biochar to compact soils would increase soil aeration, water infiltration, and root penetration (Ameloot et al. 2013; Djousse et al. 2016) but, may increase

Table 3 Ash, volatile matter and moisture content of biochar issued from crop wastes

Measured parameter	Biochar					
	Corncob	Cassava	Rice husk	Coffee	Peanut	Sawdust
Ash content (%)	23.41^{a}	17.12^{b}	$11.16^{d,c}$	$12.79^{c,d}$	$16.40^{c,b}$	$13.28^{b,c}$
Volatile matter (%)	4.34^{d}	$5.32^{c,d}$	19.42^{a}	12.50^{b}	6.82^{c}	6.19^{c}
Moisture content (%)	6.52^{d}	7.20^{c}	11.00^{a}	9.62^{b}	9.41^{b}	11.62^{a}
Bulk density (g cm^{-3})	0.14^{f}	0.19^{d}	0.22^{b}	0.18^{e}	0.20^{c}	0.24^{a}

The letters in superscript compare the means. The same letters in a row denote non-significance ($P > 0.05$) according to Tukey

Table 4 Correlation matrix among the physical properties biochar issued from crop wastes

	Temperature	Biochar yield	Moisture content	Ash	Volatile matter	Bulk density
Temperature	1					
Biochar yield	-0.588^{**}	1				
Moisture	-0.508^{*}	0.847^{**}	1			
Ash content	0.439^{*}	-0.881^{**}	-0.773^{**}	1		
Volatile matter	0.642^{**}	-0.881^{**}	-0.729^{**}	0.902^{**}	1	
Bulk density	0.153	0.254	0.243	0.233	−0.166	1

*, **Correlation is significant at the 0.05, 0.01 level, respectively

transportation costs as the case for rice husk, groundnut husk and coffee (Rajkovich et al. 2012). Moisture content was in the order of sawdust (11.6%) > rice husk (11%) > coffee husk (9.6%), > groundnut husk (9.4%) > cassava (9.6%) > and corncobs (9.6%). Biochar with high moisture content will retain more water and create a suitable environment for microbial activity and plant growth (Lehmann et al. 2011; Ameloot et al. 2013). Table 4 shows the correlation matrix among the physical properties biochar derived from crop wastes.

Biochar pH

The most important chemical difference between biochar and other organic amendments is the pH (Lehmann et al. 2011). The resulting pH of the biochars ranged from slightly alkaline (7.78) to very alkaline (10.81) units (Fig. 2).

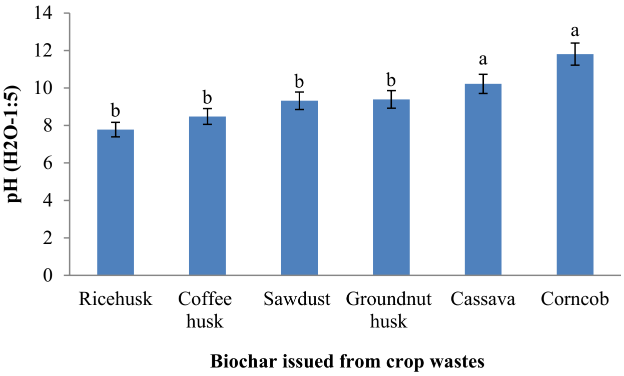

Fig. 2 pH (H_2O) of biochar issued from crop wastes. The letters in superscript compare the mean ± SD of the treatments. The same letters on a bar are not significant according to Tukey test at $P > 0.05$

The pH was also observed to increase with carbonization temperature ($r = 0.911^{**}$, Table 5) due to the production of ash during pyrolysis (Lehmann et al. 2011; Enders et al. 2012). The high pH of the biochars in Fig. 2 could be due to the high ash content. Ash residues contain carbonates and bicarbonates of cations such as Ca^{2+}, Mg^{2+}, Na^{2+}, and K^+ (Weyers and Spokas 2014; Domingues et al. 2017). Variability in pH causes changes in the availability of hydrogen, iron and aluminum ions which affects the interaction and transport of water and nutrients across the plants cell membrane (Bayu et al. 2015). For example, under acidic soil conditions, precipitation reactions occur between inorganic phosphorus (HPO_4^{2-}) with aluminum (Al) and iron (Fe) forming Al–P and Fe–P minerals rendering P unavailable to plants (Bayu et al. 2015). Baronti et al. (2014) reported that soils with higher pH tend to increase P availability by decreasing Al^{+3} and H^+ ions in cation exchange sites. It could be reasonably assumed that adding these biochars to acidic soils will likely create and favorable chemical environment through precipitation, biosorption, speciation, complexation and hydrolysis process for plant roots in their growing medium (Sohi et al. 2010; Peng et al. 2011; Rajaie and Tavakoly 2016). As such, the use of biochar from crop wastes should be kept in mind when planning soil nutrient management programs.

Cation exchange capacity (CEC)

Cation exchange capacity (CEC) is a measure of the ability of a soil to hold exchangeable cations such as calcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^+), and sodium (Na^+) while the electrical conductivity (EC) signifies the level of soluble salts in a sample. Figure 3 presents the CEC and EC of biochar pyrolysed from crop wastes.

Table 5 Correlation matrix among chemical properties of crop wastes derived biochar

	Temp	pH	EC	CEC	Total C	Total N	OM	Av. P	Mg	K	Na	Ca
Temp	1											
pH	0.911^{**}	1										
EC	-0.093^{ns}	-0.257^{ns}	1									
CEC	0.597^{**}	0.541^{*}	0.305^{ns}	1								
TC	0.649^{**}	0.659^{**}	0.279^{ns}	0.371^{ns}	1							
T N	-0.877^{**}	-0.469^{*}	-0.423^{*}	-0.703^{**}	-0.474^{*}	1						
OM	0.610^{**}	0.585^{**}	0.228	0.740^{**}	0.660^{**}	-0.563^{**}	1					
P	0.061^{ns}	0.107^{ns}	0.106^{ns}	0.288^{ns}	0.400^{ns}	-0.396^{ns}	0.683^{**}	1				
Mg	-0.524^{*}	-0.556^{**}	-0.173^{ns}	0.048^{ns}	-0.704^{**}	0.272^{ns}	-0.111^{ns}	0.193^{ns}	1			
K	0.397^{ns}	0.257^{ns}	0.031^{ns}	0.141^{ns}	-0.017^{ns}	0.257^{ns}	-0.175^{ns}	-0.791^{**}	-0.300^{ns}	1		
Na	-0.465^{*}	-0.582^{**}	-0.364^{ns}	-0.536^{*}	-0.640^{**}	0.938^{**}	-0.502^{*}	-0.323^{ns}	0.550^{**}	0.204^{ns}	1	
Ca	-0.342^{ns}	-0.529^{*}	-0.141^{ns}	-0.138^{ns}	-0.664^{**}	0.708^{**}	-0.345^{ns}	-0.369^{ns}	0.683^{**}	0.372^{ns}	0.878^{**}	1

ns not significant, *OM* organic matter

*,**Correlation is significant at the 0.05, 0.01 levels

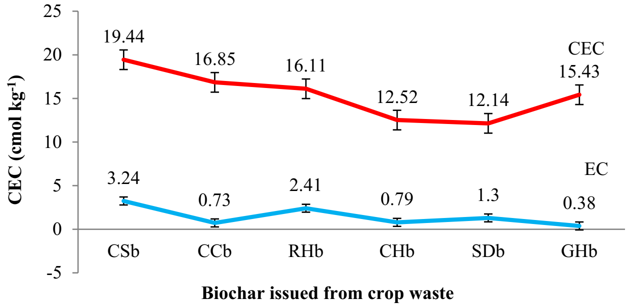

Fig. 3 Cation exchange capacity and electronic conductivity of biochars issued from crop wastes. *CSb* cassava biochar, *CCb* corncob biochar, *RHb* rice husk biochar, *CHb* coffee husk biochar, *SDb* sawdust biochar, *GHb* groundnut husk biochar

The CEC was significant and varied between 15.20 and 19.53 cmol kg^{-1} (Fig. 3). The CEC was significantly low in sawdust and coffee husk waste biochars, respectively. However, biochar produced from cassava cuttings at 600 °C had the highest CEC value (19.53 cmol kg^{-1}). The CEC of the biochar was also correlated with temperature ($r = 0.588^{**}$, Table 5), and organic matter content ($r = 0.740^{**}$, Table 5). The observed high CEC could be attributed to the high negative charge potential of surface functional groups such as ketones, aldehydes and carboxylic acids produced during pyrolysis (Kung et al. 2015). Kung et al. (2015) also observed high CEC of biochar and explained that CEC value was due to the presence of acid functional groups. One can convincingly conclude that, soils amended with biochar will have a high CEC which will provide optimum exchange between the nutrients in soil and plant roots.

Studies have shown that salt stress or salinity negatively influence the growth and productivity of crops by reducing the accumulation of Na$^+$ in the seedlings, increasing chlorophyll loss and reduced photosynthesis efficiency (Hasanpour et al. 2014; Siamak et al. 2017). The low EC value in the biochar (Fig. 3) could be attributed to NH$_4^+$ volatilization and the release of humic substances caused by the high pyrolysis temperature (Kung et al. 2015; Rafiq et al. 2016). None of the biochars had salinity levels that could reduce transportation of water and nutrients into the plants when added to the soil. As depicted by Hasanpour et al. (2014) and Siamak et al. (2017), addition of these biochar to saline soils will eliminate potassium and phosphorus deficiency problems; reduce Na$^+$ agglomeration and enhance the activities of antioxidant enzymes thereby increasing the nutrient uptake by plant roots. Table 5 presents the correlation matrix among chemical properties of crop wastes derived biochar.

Total carbon (g kg^{-1}) and organic matter content (g kg^{-1}) of biochar samples

Plant nutrients of concern in the humid forest agroecological of Cameroon include; nitrogen, carbon, phosphorus, potassium, calcium, and magnesium (Ngome et al. 2013; Billa et al. 2017). The organic carbon content of the biochars varied from 57.59 to 93.38 g kg^{-1} (Fig. 4a).

From Fig. 4a, cassava biochar had the highest carbon content (93.38 g kg^{-1}) and was significantly different ($P < 0.05$) from the other biochars. There was no significant difference

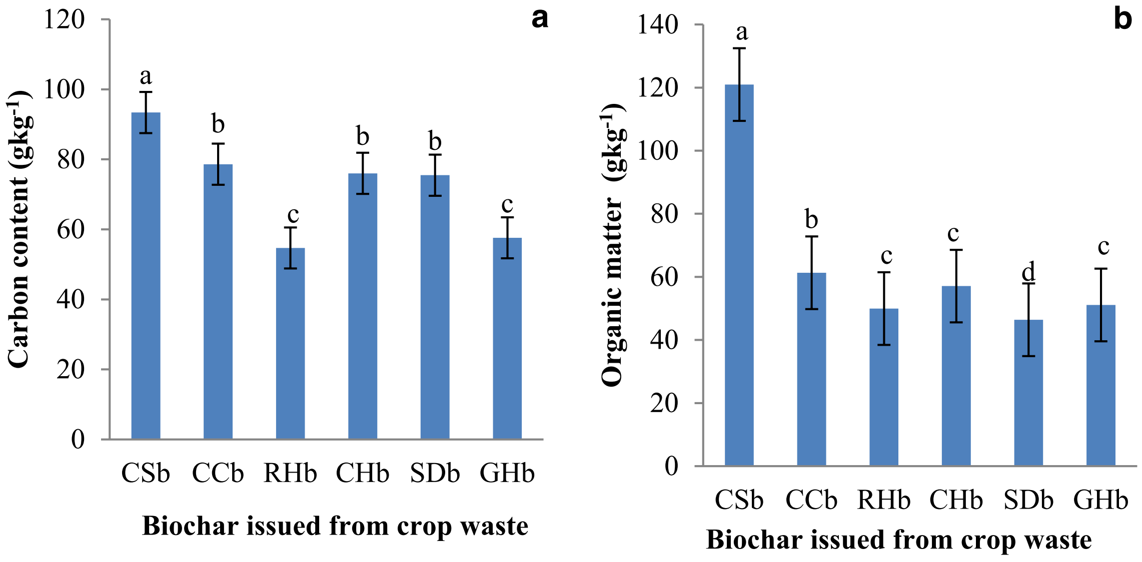

Fig. 4 Total carbon (**a**) and organic matter (**b**) content biochar issued from crop waste. The letters in superscript compare the mean ± SD of the treatments. The same letters on a bar are not significant according to Tukey test at $P > 0.05$. *CSb* cassava biochar, *CCb* corncob biochar, *RHb* rice husk biochar, *CHb* coffee husk biochar, *SDb* saw dust biochar, *GHb* groundnut husk biochar

($P > 0.05$) between corncobs, sawdust and coffee biochar (Fig. 4a). Considering the high C content, it could be concluded that in soils with very low organic material, the addition of biochar could be a fast, inexpensive and convenient solution to improve soil carbon content. These findings follow the same trend with those of Enders et al. (2012) regarding the carbon content and stability of biochar. Cassava generally has high carbohydrate content (31.6%) which may have influenced the high carbon content in the biochar.

The result in Fig. 4b depicts that biochar produced from cassava, corncob and coffee husk contained more organic matter than rice husk, groundnut husk and sawdust. The organic matter content was also positively correlated ($r=0.610^{**}$, $P < 0.05$, Table 5) with carbonization temperature. This variation may be attributed to the high accumulation of organic matter by the plants (Enders et al. 2012; Kung et al. 2015). Organic matter is rich in essential soil nutrients required for the production of cereal, vegetable, legume and tuber crops (Chaudhuri et al. 2016; Billa et al. 2017). Based on the results of this study, the purposive use of biochar in agriculture is central to maintain the buildup of soil organic matter (Chaudhuri et al. 2016) especially in regions with low soil organic matter as the case of the humid forest agroecological zone (Billa et al. 2017).

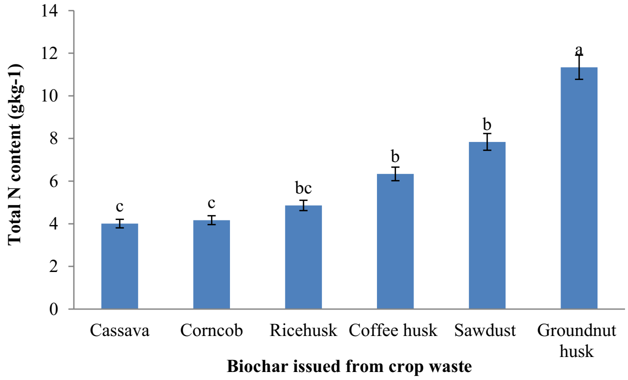

Fig. 5 N content of biochar issued from crop wastes. The letters in superscript compare the mean ± SD of the treatments. The same letters on a bar are not significantly different according to Tukey test at $P > 0.05$

Total nitrogen

Figure 5 highlights the nitrogen content in biochar produced from crop wastes.

From Fig. 5, biochar produced from groundnut husk had the highest nitrogen (N) content of 11.34 g kg^{-1}, followed by sawdust (7.84 g kg^{-1}). The low nitrogen content are observed in cassava biochar (4.01 g kg^{-1}), and corncob (4.17 g kg^{-1}) which contain approximately same amount of nitrogen. There was a significant difference ($P < 0.05$) in the total N content amongst the biochars which was also positively correlated ($r=0.610^{**}$, $P < 0.05$) with temperature. The low nitrogen in these biochars could be due to nitrogen volatilization during pyrolysis (Rafiq et al. 2016). The N content in rice husk (4.86 g kg^{-1}) could be due to reduced volatilization as a result of low temperature. The significantly higher Nitrogen content in groundnut husk biochar could be due to the inherent characteristic of high nitrogen uptake by the plant (Kung et al. 2015). Djousse et al. (2016) investigated the influence of pyrolysis temperature on Eucalyptus bark and corncob biochar and observed similar patterns. However, the N values in the biochar samples were higher those of the soils in the humid forest area (Billa et al. 2017). The results show that it is time change the fertilization policy in the humid forest area. Biochar could be progressively added to reduce the use of dolomitic lime (30% CaO, 20% MgO), (Baronti et al. 2014; Chaudhuri et al. 2016).

Available phosphorus and exchangeable cations

The analysis of the biochars (Table 6) showed that, biochar could be an affordable local alternative to commercial liming material to ameliorate soil acidity (Bayu et al. 2015). The levels of available P in the biochar were optimum (Table 6). This could be due changes of the organic P in the residues into inorganic P during pyrolysis (Ameloot et al. 2013).

Table 6 Available phosphorus and exchangeable cations content of soil and biochar

Measured parameter	Biochar issued from crop waste					
	Cassava	Corncob	Rice husk	Coffee husk	Sawdust	Groundnut husk
Available P (mg kg^{-1})	11.45^{b}	10.68^{c}	12.26^{b}	15.83^{a,b}	10.61^{b,c}	20.50^{a}
Mg^{2+} (cmol kg^{-1})	4.43^{c}	5.43^{a}	6.66^{a}	5.76^{b}	5.23^{b}	5.46^{b}
K^{+} (cmol kg^{-1})	3.41^{b}	2.16^{c}	3.48^{b}	4.36^{b,c}	2.17^{c}	5.43^{a}
Na^{+} (cmol kg^{-1})	2.63^{d}	2.16^{e}	3.13^{c}	4.24^{b}	3.72^{c}	6.16^{a}
Ca^{2+} (cmol kg^{-1})	3.63^{c}	4.83^{b}	10.83^{a}	8.54^{a,b}	4.86^{b}	11.02^{a}

The letters in superscript compare means of the different biochars. The same letters in a row are not significant according to Tukey test at $P > 0.05$

Groundnut husk biochar (GHb) recorded the highest available phosphorus content and exchangeable cation and was also significantly different ($P < 0.05$) from the other biochars (Table 6). Available P contents the biochars were higher than that of the soil of the study area (Billa et al. 2017). However, P content had a non-significant correlation with carbonization temperature ($r = -0.061$, $P > 0.01$, Table 5). The exchangeable cations (Ca^+, Mg^{2+}, and Na^+) contents in the biochars were higher than those of the adjacent soils of the study area (Billa et al. 2017). Soil acidity is due to one of the following factors: calcium or magnesium deficiency, aluminum and manganese toxicity or where hydrogen concentrations may inhibit or reverse cations uptake by plant roots (Baronti et al. 2014; Bayu et al. 2015). Also, the fixation and/or entrapment at specific sites between clay layers tend to be higher under acid conditions due to the presence of soluble aluminum that occupies the binding sites (Baronti et al. 2014). As liming is very expensive for most smallholder farmers, the use of biochar produced from these crop wastes could supply the required Ca^+ and Mg^{2+} which is more economical than calcitic lime or high calcium lime (50–56% CaO, 1–4% MgO), dolomitic lime (30% CaO, 20% MgO), gypsum ($CaSO_4{\cdot}2H_2O$) and hydrated lime (60% CaO, 12% MgO) (Baronti et al. 2014; Dotaniya et al. 2016). Also biochar issued from coffee, groundnut and rice husk would be a suitable biochar to enhance K, Ca, Mg, and Na availability, respectively (Baronti et al. 2014; Bayu et al. 2015). In addition, other properties of biochar such as bulk density, moisture and nutrient retention, and high CEC could help improve soil functions, as microbial activity and soil structure (Baronti et al. 2014; Chaudhuri et al. 2016). Therefore, the production of food crops such as cassava, rice and maize in the humid forest agroecological zone could be increased through the addition of biochar.

Nutrient content of some crop wastes in the humid forest

Adamu et al. (2014) define crop waste or residues as stems, leaves, roots and other plant parts (e.g., straws, stover and haulms) that are usually abandoned in the field after harvesting or piled around processing units after processing (e.g., groundnut shells, rice husks, corncobs, and coffee husk). Table 7 shows the quantity of plant nutrient in the residues of some cereals, legume, roots and tuber crops.

Table 7 shows that crop wastes contain large quantities of both N, P and K. During plant growth and development, a large percentage about 25% of nitrogen (N) and phosphorus (P), and 75% of potassium (K) uptake by agricultural crops are retained in crop residues, making them valuable nutrient sources (Enders et al. 2012; Adamu et al. 2014; Kumer et al. 2015). Open burning of crop wastes contributes significant greenhouse gas (GHG) emissions, such as carbon dioxide, monoxide, nitrous oxide (N_2O), sulphur dioxide (SO_2), methane (CH_4) along with particulate matter and hydrocarbons (Adamu et al. 2014). These trace gases have adverse impacts on air pollution and water quality as well as on human and animal health (Kumer et al. 2015). Open burning also results in the loss of plant nutrients and thus adversely affect soil properties (International Biochar Initiative 2016). Pyrolysis causes the decomposition of the functional groups and improves other properties such as such as surface area, porosity, adsorption, and recalcitrant chemical character in the biochars (Rajkovich et al. 2012). It will therefore be more sustainable to convert crop wastes to biochar for use in agriculture rather than open burning as means of waste disposal.

Carbon dioxide emission reduction potential

During plant growth and development, CO_2 is removed from the atmosphere through photosynthesis and converted into starch in the chloroplast (Adamu et al. 2014; Kumer et al. 2015). However, the same CO_2 is converted back in the atmosphere by natural aerobic decomposition and natural carbon cycles are not adequate enough to handle the billions of metric tons emitted on annual bases (International Biochar Initiative 2016). Figure 6 shows the quantity of CO_2 (CO_2 eq kg^{-1}) captured and stored in biochar that would have been emitted into the atmosphere if the crop wastes had decomposed naturally.

Results in Fig. 6 show that, the quantity of carbon dioxide emissions that can be sequestered if crop residues are carbonized to biochar differed significantly ($P < 0.05$)

Table 7 Quantity of essential plant nutrients in some crop wastes. Sources: Enders et al. (2012), Adamu et al. (2014) and Kumer et al. (2015)

Crop waste	Total carbon ($g\ kg^{-1}$)	Total nitrogen	P ($mg\ kg^{-1}$)	Mg ($g\ kg^{-1}$)	K	Na	Ca
Cassava stems	834	48.54	27	21	817	35	16
Rice husk	400	36.55	22	24	140	31	11
Corncob	600	20.03	35	29	68	15	15
Coffee husk	541	26.34	27	10	48	10	33
Groundnut husk	600	65.33	59	18	54	61	13
Sawdust	456	23.62	86	52	21	37	12

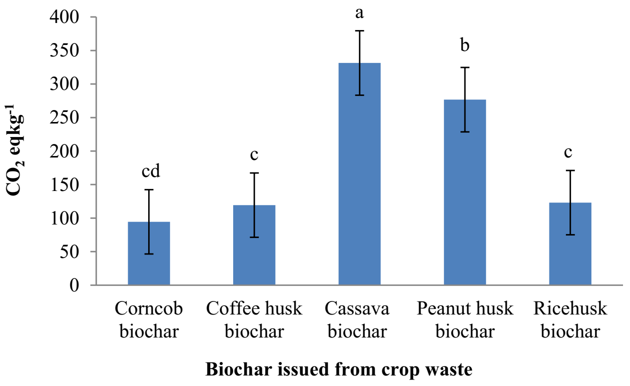

Fig. 6 Quantity of CO_2 captured in the biochar issued from crop wastes. Bars display the standard error of the means

between in the biochars. However, cassava biochar (CSb) recorded the highest carbon dioxide value of 331.42 CO_2 eq kg^{-1} followed by groundnut husk biochar with 276.69 CO_2 eq kg^{-1}; sawdust with 114.07 CO_2 eq kg^{-1} and rice husk biochar with 123.10 CO_2 eq kg^{-1}. These findings correlate with Sandip and Harsha (2013). Corncob biochar unexpectedly recorded the lowest CO_2 reduction potential 94.46 CO_2 eq kg^{-1}. Allyson (2011) also obtained lower values for corncobs. The study is also in line with Domingues et al. (2017) that the pyrolysis of crop wastes produces a more stable form of carbon (biochar) which is resistant to natural decomposition and therefore reduces CO_2 emissions (Fig. 6). This carbon would have otherwise been rapidly mineralized to carbon dioxide if either left to decompose naturally or burned openly. According to Draper and Tomlinson (2015) and the International Biochar Initiative (2016), biochar production can capture up to 50% of the initial carbon in the original biomass compared to the low amounts retained during open burning (3%) or $< 20\%$ after natural decomposition. The results further indicates that cassava biochar (CSb) with highest organic carbon (98.38 g kg^{-1}) could be the most preferred biochar amongst the other biochars for mitigating climate change through carbon sequestration (Fig. 6). This could be due to large quantity of atmospheric carbon dioxide (331.42 CO_2 eq kg^{-1}) converted into a more stable form of organic carbon which is resistant to degradation with a longer residence time (Guo and Chen 2014). As biological carbon cycles are not adequate enough to handle the billions of metric tons of CO_2 emitted on annual bases, addition of biochar derived from crop wastes could be promoted as a strategy to increase soil carbon (C) sequestration while also mitigating climate change through reducing atmospheric carbon dioxide (CO_2) emission (Bayu et al. 2015).

Conclusion

The biodegradable fraction of products, wastes and residues from agriculture (including green waste and animal manures), forestry and related food processing wastes, as well as the biodegradable fraction of industrial and municipal wastes that cause pollution problems threatening human and environmental health could be used to produce a valuable product, biochar using Elsa pyrolysis technology. Biochar contains essential plant nutrients such as potassium, carbon, and magnesium as well as properties (alkaline pH and high CEC) that could be optimized for used as a soil amendment to improve the fertility of poor and acidic soils and increase crop yields. Biochar issued from coffee, groundnut and rice husk are the most appropriate due to their high K, Ca, Mg, and Na contents. The high carbon content further shows that biochar has the potential to reduce CO_2 emissions in the atmosphere. Therefore, recycling of crop wastes to biochar is strongly recommended to smallholder farmers for use in agriculture to improve fertility and crop productivity while mitigating climate change through carbon sequestration.

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Compliance with ethical standards

Conflict of interest The authors have not declared any conflict of interests.

References

Abrishamkesh S, Gorji M, Asadi H, Bagheri MGH, Pourbabaee AA (2015) Effects of rice husk biochar application on the properties of alkaline soil and lentil growth. Plant Soil Environ 61(11):475–482. https://doi.org/10.17221/117/2015-PSE

Adamu UK, Almu H, Adam IA, Sani SA (2014) Evaluation of nutrient composition of some cereals and legumes crops residues as compost materials. Bayero J Pure Appl Sci 7(2):52–54. https://doi.org/10.4314/bajopas.v7i2.10

Allyson S (2011) Biochar production for carbon sequestration. Dissertation. Worcester Polytechnique Institute

Ameloot N, Graber ER, Verheijen FGA, DeNeve S (2013) Interactions between biochar stability and soil organisms. Eur J Soil Sci 64:379–390. https://doi.org/10.1111/ejss.12064

Anderson JM, Ingram JSI (1993) Tropical soil biology and fertility: a handbook of methods of analysis, 2nd edn. CAB International, Wallingford

ASTM (2009) Standard method for chemical analysis of wood charcoal D1762-84. American Society for Testing and Materials (ASTM) Philadelphia, Philadelphia

Baronti S, Vaccari FP, Miglietta F, Genesio I (2014) Impact of biochar application on plant water relations in (*Vitis viniera* L.). Euro J Agro 53:38–44

Bayu D, Gezahegn B, Tulu S (2015) Characterization of biochar produced at different temperatures and its effect on acidic nitosol of Jimma, Southwest Ethiopia. Intl J Soil Sci 10:63–73. https://doi.org/10.3923/ijss.2015.63.73

Billa SF, Ngome AF, Tsi EA, Tata NP (2017) Waterleaf (*Talinum triangulare*) response to biochar application in a humid-tropical forest soil. J Soil Sci Environ Manage 8(5):95–103. https://doi.org/10.5897/JSSEM2017.0638

Chaudhuri PS, Paul TK, Dey A, Datta M, Dey SK (2016) Effects of rubber leaf litter vermicompost on earthworm population and yield of pineapple (*Ananas comosus*) in West Tripura, India. Int J Recycl Org Waste Agric 5:93–103. https://doi.org/10.1007/s40093-016-0120-z

Djousse BMK, Allaire SE, Munson BA (2016) Quantifying the influence of Eucalyptus bark and corncob biochars on the physical properties of an oxisol under maize cultivation in Dschang Cameroon. 5th North American Biochar Symposium

Domingues RR, Trugilho PF, Silva CA (2017) Properties of biochar derived from wood and high nutrient biomasses with the aim of agronomic and environmental benefits. PLoS One 12(5):1–19. https://doi.org/10.1371/journal.pone.0176884

Dotaniya ML, Datta SC, Biswas DR, Dotaniya CK, Meena BL, Rajendiran S, Regar KL, Lata M (2016) Use of sugarcane industrial by-products for improving sugarcane productivity and soil health. Int J Recycl Org Waste Agric 5:185–194. https://doi.org/10.1007/s40093-016-0132-8

Draper K, Tomlinson T (2015) The potential for biochar to deliver greater sustainability for coffee cultivation and processing: a white paper. Ithaka Institute for Carbon Intelligence and International Biochar Initiative, p 24

Enders A, Hanley K, Whitman T, Joseph S, Lehmann J (2012) Characterization of biochars to evaluate recalcitrance and agronomic performance. Biores Technol 114:644–653. https://doi.org/10.1016/j.biortech.2012.03.022

Guo J, Chen B (2014) New insights on the molecular mechanism for the recalcitrance of biochar: interactive effects of carbon and silicon components. Environ Sci Technol 48:9103–9112. https://doi.org/10.1021/es405647e

Hasanpour Z, Karimi HR, Mirdehghan SH (2014) Effects of salinity and water stress on echophysiological parameters and micronutrients concentration of pomegranate (*Punica granatum L.*). J Plant Nutr 38(5):795–807. https://doi.org/10.1080/01904167.2014.944711

Heanes DL (1984) Determination of organic C in soils by an improved chromic acid digestion and spectrophotometric procedure. Commun Soil Sci Plant Anal 15:1191–1213. https://doi.org/10.1080/00103628409367551

Homagain K, Shahi C, Luckai N, Sharma M (2016) Life cycle cost and economic assessment of biochar-based bioenergy production and biochar land application in Northwestern Ontario, Canada. J For Res 26:799–809. https://doi.org/10.1186/s40663-016-0081-8

Hussein KN, Sarah EH, Cornelissen G, Bachmann RT (2015) Sustainable technologies for small-scale biochar production—a review. J Sustain Bioenergy Syst 5:10–31. https://doi.org/10.4236/jsbs.2015.51002

IBI (International Biochar Initiative) (2016) Biochar can help renew the Earth. www.biochar-international.org. Accessed 20 Sept 2017

Jindo K, Mizumoto H, Sawada Y, Sanchez MAM, Sonoki T (2014) Physical and chemical characterization of biochars derived from different agricultural residues. Biogeosciences 11:6613–6621. https://doi.org/10.5194/bg-11-6613-2014

Joseph S, Graber ER, Chia C, Hook J (2013) Shifting paradigms: development of high-efficiency biochar fertilizers based on nano-structures and soluble components. Carbon Manag 4:323–343

Khodadad CLM, Zimmerman AR, Green SJ, Uthandi S, Foster JS (2011) Taxa-specific changes in soil microbial community composition induced by pyrogenic carbon amendments. Soil Biol Biochem 43:385–392. https://doi.org/10.1016/j.soilbio.2010.11.005

Kumer P, Kumer S, Joshi L (2015) Socio-economic and environmental implication of agricultural residue burning. A case study of Punjab India. Springer Briefs Environ Sci 4:13–25. https://doi.org/10.1007/978-81-322-2014-5-2

Kung CC, Kong F, Choi Y (2015) Pyrolysis and biochar potential using crop residues and agricultural wastes in China. Ecol Ind 51:139–145

Lehmann J, Rillig MC, Thies J, Masiello AC, Hockaday WC, Crowley D (2011) Biochar effects on soil biota – a review. Soil Biol Biochem 43:1812–1836. https://doi.org/10.1016/j.soilbio.2011.04.022

Lin Y, Munroe P, Joseph S, Henderson R, Ziolkowski A (2012) Water extractable organic carbon in untreated and chemical treated biochars. Chemosphere 87:151–157. https://doi.org/10.1016/j.chemosphere.2011.12.007

Murphy J, Riley JP (1962) A modified single solution method for determination of phosphate in natural waters. Anal Chim Acta 27:31–36. https://doi.org/10.1016/S0003-2670(00)88444-5

Ngome AF, Amougou MFC, Tata PI, Ndindeng SA, Njeudeng TS (2013) Effects of Cassava cultivation on soil quality indicators in the humid forest zone of Cameroon. Greener J Agri Sci 3:451–457. https://doi.org/10.15580/GJAS.2013.6.030613519

Njukwe E, Onadipe O, Kirscht B, Mbairanodji A (2014) Cassava processing among small-holder farmers in Cameroon : opportunities and challenges. Int J Agric Pol Res 2:113–124. http://cgspace.cgiar.org.handle.net/10568/75905. Accessed 20 Sept 2017

Olivier P (2010) Small-scale production of food, fuel, feed and fertilizer; a strategy for the sustainable management of biodegradable waste. http://www.mekarn.org/workshops/pakse/html/olivier.docx. Accessed 20 Sept 2017

Peng X, Ye LL, Wang CH, Zhou H, Sun B (2011) Temperature and duration dependent rice straw-derived biochar: characteristics and its effects on soil properties of an Ultisol in southern China. Soil Tillage Res 112:48–58. https://doi.org/10.1016/j.still.2011.01.002

Rafiq MK, Bachmann RT, Rafiq MT, Shang Z, Joseph S, Long R (2016) Influence of pyrolysis temperature on physico-chemical properties of corn stover (*Zea mays L.*). PLoS One 11(6):1–17. https://doi.org/10.1371/journal.pone.0156894

Rajaie M, Tavakoly AR (2016) Effects of municipal waste compost and nitrogen fertilizer on growth and mineral composition of tomato. Int J Recycl Org Waste Agric 5:339–347. https://doi.org/10.1007/s40093-016-0144-4

Rajkovich S, Enders A, Hanley K, Hyland C, Zimmerman AR, Lehmann J (2012) Corn growth and nitrogen nutrition after additions of biochars with varying properties to a temperate soil. Bio Fert Soils 48(3):271–284. https://doi.org/10.1007/s00374-011-0624-7

Sandip G, Harsha MW (2013) Generation of biochar from crop residues. Int J Emerg Technol Adv Eng 3(3):566–570

Shackley S, Hammond J, Gaunt J, Ibarrola R (2011) Feasibility and costs of biochar deployment in the UK. Carbon Manag 2(3):335–356. https://doi.org/10.4155/CMT.11.22.2011.1758-3004

Siamak SB, Safoora D, Glenn CW (2017) Vermi-compost leachate reduces some negative effects of salt stress in pomegranate. Int J Recycl Org Waste Agric. https://doi.org/10.1007/s40093-017-0173-7

Sohi SP, Krull E, Lopez-Capel E, Bol R (2010) A review of biochar and its use and function in soil. Adv Agron 105:47–82. https://doi.org/10.1016/S0065-2113(10)05002-9

Steiner C, Das KC, Nathan M, Lakly D (2010) Reducing nitrogen loss during poultry litter composting using biochar. J Environ Qual 39:1236–1242. https://doi.org/10.2134/jeq2009.0337

Tata PI, Afari-Sefa V, Ngome AF, Billa SF (2016) Policy and institutional frameworks impacting on vegetable seed production and distribution systems in Cameroon. J Crop Improve 30:196–216. https://doi.org/10.1080/15427528.2016.1141134

Weyers SL, Spokas KA (2014) Crop residue decomposition in Minnesota biochar-amended plots. Solid Earth 5:499–507. https://doi.org/10.5194/se-5-499-2014

Yerima BPK, Van Ranst E (2005) Major soil classification systems used in the tropics: soil in Cameroon. Trafford Publishing, Trafford, p 295