Production and Characterization of Biochars from Slow Pyrolysis of Different Biomass Materials to Evaluate Properties as Soil Amendments

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Biochar, a carbon (C)-rich solid material produced by the thermo-chemical conversion of biomass in an oxygen-limited environment, has been attracting interest due to its potential as a soil amendment. In this study, biomass materials derived from rice (Oryza sativa) straw (RS), rice hull (RH), water hyacinth (Eichhornia crassipes) (WH), and mahogany flower receptacles (Swietenia macrophylla) (MFR) were slowly pyrolyzed under temperatures ranging from 300–650°C using a biochar producing stove. The morphological characteristics and physicochemical properties of biochars were studied using the Brunauer-Emmett-Teller (BET) automated nitrogen multilayer physisorption system, field emission–transmission electron microscopy (FE-TEM), and X-ray energy dispersive spectrometry (EDS). Biochars originating from light materials (RS and WH) showed higher concentrations of essential plant nutrients such as nitrogen (N), phosphorus (P), and potassium (K). The biochar originating from woody MFR had low concentrations of essential plant nutrients. The surface area of the materials was in the 0.473–78.208 m²/g range. The RS and RH biochars demonstrated high surface area with 45.511 and 78.208 m²/g, respectively. The WH biochar showed a low surface area of 9.845 m²/g while the surface area of the MFR biochar was particularly very low at 0.473 m²/g. The high angle annular bright-field (HAABF) images, spectra, and elemental X-ray maps of all the four biochars revealed areas high in carbon, potassium, chlorine, calcium, magnesium, silicon, and aluminum. These biochar properties and mineral agglomerates suggest that biochars can be used as a soil amendment to improve soil fertility.

Keywords: biomass wastes, pyrolysis, soil amendment, soil fertility, waste management

INTRODUCTION

There are numerous studies reported in the literature that apply different techniques and processes to convert biomass into useful products. One of which is through biochar production, which is beneficial in agriculture and a solution for waste management. The abundance and availability of agri-industrial products make them good raw materials for biochar production. It has been estimated that the volume of residues in the Philippines, from rice, coconut, palm oil, sugar, and wood industries is 16 M tons/yr (Shead 2017). Some of the appropriate biomass waste materials that can be used for biochar production include crop residues (coconut husks, coir dust, bagasse, rice hulls, rice straws, sawdust, corn husks, corn cobs), woods (bamboo, mahogany flower receptacles, pine, eucalyptus tree), and animal manures (swine, cattle, chicken, horse).

Biochar is a charcoal-like product of thermal degradation of biomass in limited presence or absence of oxygen (pyrolysis) that could be used as a soil amendment to improve soil health and crop productivity (Lehmann and...
Biochar can be made from various waste biomass sources under different processing conditions that play important roles in the structural evolution of biochar during rearrangement of the solid phase. The qualities of biochar are mainly dependent on the chemical and physical properties of the feedstock and the final heat treatment temperature. It is also dependent to a lesser extent on the rate of heating, stove pressure and atmosphere, and the type of pre- or post-treatment (Amonette and Joseph 2009).

Depending upon the residence time, peak temperature, and heating rate, the pyrolysis process is subdivided into three categories: slow, intermediate, and fast pyrolysis. Slow pyrolysis is the most commonly preferred method to produce biochar, with gas as a co-product (Manyà et al. 2016; Song and Guo 2012). However, there are dissimilarities in the literature on the temperature requirements for slow pyrolysis. Demirbas and Arin (2002) describe slow pyrolysis as a conventional type of pyrolysis characterized by a slow heating rate of about 0.1–1°C/s between 5–30 min temperatures of 400–500 °C, wherein char is formed along with small amounts of liquid and gaseous products. Other authors defined slow pyrolysis as a thermochemical decomposition process during which feedstock biomass is combusted in the absence of oxygen at temperatures 300–700 °C (Lehmann and Joseph 2009), 350–800 °C (Inyang et al. 2010), and 350–650 °C (Zheng et al. 2010). The residence time also varies from min to h (Inyang et al. 2010). Slow pyrolysis is a relatively simple and robust process that can be applied to small-scale and farm-based production of biochar (Zheng et al. 2010; Song and Guo 2012; Manyà et al. 2016). There are pyrolysis ovens for any need, from camp stoves to industrial-sized units that are being used in creating electricity and heating large buildings. Small pyrolytic stoves are being employed in developing countries to reduce the smoke from open fires inside homes, efficiently burn materials, and produce a soil amendment at the same time (Zheng et al. 2010).

Concerns about climate change and the improvement of soil quality in a sustainable manner have generated much interest in biochar (Verheijen et al. 2009). The global potential of biochar (non-fuel use of charcoal) reaches far beyond slash and char. The burning of biomass is a common practice that releases nearly all the C stored in the biomass as carbon dioxide (CO₂) without consequent organic C buildup in agricultural soils. Increasing interest in renewable energy raises the prospect to supply biochar from the pyrolysis of waste biomass. Pyrolysis would facilitate bio-energy production and C sequestration if the biochar is redistributed to agricultural fields. Thus, the use of crop residues as a potential source of energy production and C sequestration for improvement of soil quality are complementary, not competing (Steiner et al. 2007).

Biochar application to the soil has been reported to boost soil fertility and improve soil quality resulting in increased crop yields. Soil benefits include raising soil pH, increasing water holding capacity, improving porosity, and cation exchange capacity (CEC) and retaining nutrients (Novak et al. 2012).

The present study aims to determine the morphology, physical, and chemical properties of biochar derived from different biomass materials as a byproduct of slow pyrolysis using a biochar-producing stove. Such characterizations may serve as the basis for their use as soil amendments.

MATERIALS AND METHODS

Feedstock Collection and Preparation

The pre-processing and transportation of different biomass materials to the Agricultural System Institute (ASI) Demonstration and Composting Area, Pili Drive, University of the Philippines (UP) Los Baños were done upon identification of viable resources to be used as feedstocks. The following materials were collected from experimental fields at UP Los Baños campus: RS, RH, and MFR. Matured WH plants were obtained from the southern side of Laguna de Bay (Laguna Lake) at Barangay (Village) Malinta, Mayondon, Los Baños, Laguna, Philippines. All materials were first cleaned from foreign objects, air-dried, cut into small pieces (4–6 cm), and oven-dried at 60 °C and with 10–15% moisture (w/w) before pyrolysis.

Biochar Production and Biochar Yield Using Slow Pyrolysis Biochar-producing Stove

Production of biochars from different biomass materials was done separately using the pyrolytic biochar-producing stove. The weight of the sample used in each run was dependent on the physical properties of the biomass: 700 g for RS and WH, and 3.0 and 6.0 kg for RH and MFR, respectively. The oven-dried biomass was loaded into the feedstock-holding container inside the biochar-producing stove, allowing space between pieces to prevent compaction of biomass. This space was necessary for the pyrolysis process to allow the volatile gasses produced by the burning of the biomass to flow freely in the stove’s inner chamber. The feedstock was charred on temperatures starting from 300–650°C. The effective temperature of the biomass was measured at different time intervals using a K-type thermocouple and inserted into an inlet of the stove, as its value appeared on a display of the thermometer. The known residence time for each type of biomass material was obtained from the initial and design
optimization tests of the biochar-producing stove. At the end of every run, the flame on the burning biomass was turned off immediately by distilled water and the biochar inside the holding container was transferred to a cooling netted sieve for air drying. Once dried, the ash-free black C fractions (char) were kept for further processing and analysis. The development, descriptions, and other important details of the pyrolytic biochar-producing stove are not part of this paper.

The percentage of biochar yield was calculated using the equation described below (Sadaka et al. 2014):

\[
Yield_{biochar} = \frac{m_{biochar}}{m_{raw}} \times 100
\]

wherein \(Yield_{biochar}\) is the mass yield of biochar (%), \(m_{biochar}\) is the mass of biochar (kg), and \(m_{raw}\) is the mass of raw biomass (kg).

**Physical and Chemical Analyses**

After the pyrolysis process, each biochar sample was pulverized by mortar and pestle to be homogenized and sieved to less than 0.5-mm-diameter mesh sieve. The pH of each biochar was measured using a glass electrode pH meter with biochar-water mixture at ratios 1:10 (w/v) and 1:4 (w/v) for MFR and the other three samples (RH, RS, and WH), respectively. The elemental analyses were carried out at the ASI Analytical Service Laboratory, UP Los Baños using the conventional procedures as follows: organic C by the Walkley and Black method (Jackson 1958), total N by the Kjeldahl method (Black 1965), total P by the vanadomolybdate method (Kitson and Mellon 1944), total K using a flame photometer (Greweling and Peech 1960), and others (Ca, Mg, Fe, Zn, Cu, and Mn) using an atomic absorption spectrophotometer (Russel et al 1957).

The physical properties of biochar were analyzed using Quanta Chrome Nova e2200 BET automated nitrogen multilayer physisorption system at the Nanotechnology Laboratory, UP Los Baños. Prior to analysis, each sample was thoroughly mixed and oven-dried for 24 h at 105 °C. From each dried sample, 100 mg was immediately transferred to a round bottom powder cell sample holder. Each sample was initially subjected to degassing at 300 °C at varying times as dictated by the automated system. After degassing, each sample was then subjected to multipoint BET analysis to determine the average surface area, average pore radius, and average pore volume.

The surface morphological changes of biochar samples were taken at different magnifications from 1,000–40,000x by using the JEOL JEM-2100F FE-TEM unit at the Materials Science Division, Industrial Technology Development Institute–Department of Science and Technology, DOST Compound, General Santos Avenue, Bicutan, Taguig City, Philippines. Scanning TEM analysis was performed in obtaining HAABF images. The X-ray EDS was made on the areas of interest of each biochar samples. The elements present and the corresponding weight percent (Wt%) of the area analyzed with EDX map analysis were listed.

**RESULTS**

**Biochar Production Using Slow Pyrolysis Biochar-producing Stove**

The nature and physicochemical qualities of the biomass materials offered a greater understanding on the residence time and yield of biochars. The feedstock derived from woody MFR materials had 75 min residence time with lesser biochar yield (Table 1). The high-lignin property of RH entailed 45 min to be converted into biochar. As both feedstocks consumed lengthier burning times compared with cellulosic light biomass materials, the residence time affected the biochar yield, resulting in 22% and 24%, respectively. Conversely, feedstocks originating from light biomass wastes – specifically, RS and WH – demonstrated a shorter time of burning, with the former surfacing the highest biochar yield (60%), which was then remotely followed by the latter (32%).

<table>
<thead>
<tr>
<th>Biomass</th>
<th>Residence time (min)</th>
<th>Biochar yield (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MFR</td>
<td>75</td>
<td>22.24 ± 0.65</td>
</tr>
<tr>
<td>RH</td>
<td>45</td>
<td>24.73 ± 3.64</td>
</tr>
<tr>
<td>RS</td>
<td>20</td>
<td>60.41 ± 0.41</td>
</tr>
<tr>
<td>WH</td>
<td>30</td>
<td>31.73 ± 1.97</td>
</tr>
</tbody>
</table>

**Biochar Properties**

Chemical properties. The conditions and experimental procedures – such as the variation in the overall characteristics of the feedstocks, residence time, and particle size of biomass – had their effects on the biochar properties. The disparities in the structural and chemical composition between biochars were highly variable, understandably taken from the characters of the original biomass materials. Some properties were pervasive throughout all samples, which includes the black color and basic pH, even up to strongly alkaline MFR biochar (pH 10.4). Biochars from light materials such as RS and WH showed higher concentrations of essential plant nutrients such as N, P, and K (Table 2). A high level of organic C (23.9%) and low concentrations of nutrients were observed in biochar originating from woody MFR.

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The MFR biochar is closely followed by WH biochar in exhibiting high organic C (18.5%). Interestingly, among the four biochars, WH biochar demonstrated the highest concentrations of essential macronutrients (N, P, K, Ca, and Mg) and micronutrients (Fe, Cu, and Mn). Between the rice residues, the pH of the RH was lower than the RS with pH 7.3 and 9.6, respectively. Contrariwise, the organic C in RH was extremely low with only 5.4% C, which is far behind of RS with 12.7% C.

**BET physisorption analysis.** The physical properties of biochars contribute to their functions as a tool for agricultural and environmental management. The porosity and surface area represent the physical properties of biochar and connect strongly with adsorption and water retention abilities. In the present study, the porosity of the biochar samples was highly variable. The biochars derived from light materials demonstrated higher porosity than the biochar from woody material (Table 3). Both rice residues, RS and RH, showed a high surface area of 45.511 and 78.208 m²/g, respectively. Comparison among the variety of origins, apparent differences were observed on the surface area of biochars derived from MFR and WH biomass materials. The surface area of MFR with 0.473 m²/g was particularly very low, and the pore volume was almost negligible (0.004 cm³/g) when measured up to WH having 9.845 m²/g and 0.017 cm³/g properties. Interestingly, the average pore size of the three biochars (WH, RS, and RH) with 19.2 Å is apparently analogous to 17 Å of MFR. In soil environments, biochars with small particle size and high internal porosity are expected to contribute most to the enhancement of soil quality. The biochars with relatively low surface areas and porosity may not be ideal for soil quality amelioration.

**DISCUSSION**

Biochar Production Using Slow Pyrolysis Biochar-producing Stove

Several factors are known to influence the products of pyrolysis. One of which is the residence time of the material in the pyrolysis chamber. Novak et al. (2012) reported that residence time influences the degree of the thermal conversion of the received solid product as well as the vapor. The type of organic material and the conditions under which biochar is produced also greatly affect its relative quality as a soil amendment. Feedstock and temperature during pyrolysis can influence molecular structure and pore size distribution of the biochar product, which all affect biochar sorption characteristics. Studies

Table 2. Chemical properties of different biochars using the pyrolytic biochar-producing stove.

<table>
<thead>
<tr>
<th>Biochars</th>
<th>pH</th>
<th>Organic C (%)</th>
<th>P (%)</th>
<th>K (%)</th>
<th>Ca (%)</th>
<th>Mg (%)</th>
<th>Fe (%)</th>
<th>Zn (%)</th>
<th>Cu (%)</th>
<th>Mn (%)</th>
<th>Lignin (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MFR</td>
<td>10.4±0.41</td>
<td>0.5±0.03</td>
<td>23.9±0.10</td>
<td>0.2±0.02</td>
<td>0.3±0.02</td>
<td>0.9±0.04</td>
<td>0.8±0.03</td>
<td>0.1±0.01</td>
<td>15±0.94</td>
<td>9±0.26</td>
<td>48±1.25</td>
</tr>
<tr>
<td>RH</td>
<td>7.3±0.06</td>
<td>0.9±0.02</td>
<td>5.4±0.09</td>
<td>0.3±0.01</td>
<td>0.6±0.04</td>
<td>0.2±0.02</td>
<td>0.3±0.03</td>
<td>0.2±0.00</td>
<td>180±0.82</td>
<td>6±0.13</td>
<td>315±2.49</td>
</tr>
<tr>
<td>RS</td>
<td>9.6±0.07</td>
<td>1.1±0.10</td>
<td>12.7±0.99</td>
<td>0.5±0.02</td>
<td>1.9±0.02</td>
<td>0.2±0.01</td>
<td>0.2±0.03</td>
<td>0.2±0.03</td>
<td>18±1.24</td>
<td>3±0.10</td>
<td>58±1.63</td>
</tr>
<tr>
<td>WH</td>
<td>9.8±0.07</td>
<td>1.5±0.11</td>
<td>18.5±0.03</td>
<td>0.9±0.02</td>
<td>10.1±0.04</td>
<td>3.1±0.02</td>
<td>2.5±0.11</td>
<td>0.3±0.03</td>
<td>158±2.49</td>
<td>15±0.16</td>
<td>654±1.70</td>
</tr>
</tbody>
</table>

Table 3. Surface area and porosity of the biochar samples.

<table>
<thead>
<tr>
<th>Biochar(s)</th>
<th>Average surface area (m²/g)</th>
<th>Average pore size/radius (Å)</th>
<th>Average pore volume (cm³/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MFR</td>
<td>0.473</td>
<td>17.070</td>
<td>0.004</td>
</tr>
<tr>
<td>RH</td>
<td>78.208</td>
<td>19.264</td>
<td>0.011</td>
</tr>
<tr>
<td>RS</td>
<td>45.511</td>
<td>19.227</td>
<td>0.035</td>
</tr>
<tr>
<td>WH</td>
<td>9.845</td>
<td>19.167</td>
<td>0.017</td>
</tr>
</tbody>
</table>

**HAABF images and EDS analysis.** The results of analyses of all the biochars derived from biomass materials using FE-TEM showed heterogeneity at both the micron and nanometer scales. The HAABF spectrum on the areas of interest in all biochar samples is presented in Figures 1–4. Listed also are the elements present and the corresponding weight percent (Wt%) of the area analyzed using the X-ray EDS line scan analysis on all biochars. The EDS indicated the presence of other phases in the biochars that are high in C and the other elements (Ca, K, Al, and Si) that are highly dependent on the type of biochars. It is interesting to note the presence of high C in MFR biochar (86.3%), closely followed by RS (80.8%) and WH (72.9%) in the HAABF spectrums. The very low C (3.1%) was shown in RH.
Figure 1. TEM image of MFR biochar at 10,000x magnification (a). Bright field TEM image of MFR particle at 40,000x magnification (b). HAABF image and spectrum (c). HAABF elemental map (d) from the area of interest A.

Figure 2. TEM image of WH biochar at 10,000x magnification (a). Bright-field TEM image of WH particle at 40,000x magnification (b). HAABF image and spectrum (c). HAABF elemental map (d) from the area of interest A.
Figure 3. TEM image of RS biochar at 1,200x magnification (a). Bright-field TEM image of RS particle at 40,000x magnification (b). HAABF image and spectrum (c). HAABF elemental map (d) from the area of interest A.

Figure 4. TEM image of RH biochar at 6,000x magnification (a). Bright-field TEM image of RH particle at 40,000x magnification (b). HAABF image and spectrum (c). HAABF elemental map (d) from the area of interest A.
of Basta et al. (2011) reported that the yield of biochar is highly dependent on the pyrolysis conditions (e.g. temperature, heating rate, heating time) and is also greatly influenced by the chemical and physical properties of the raw biomass material.

It was shown in this study that the biochar yields were affected by the type of feedstocks charred under slow pyrolysis temperatures. The low biochar yield of woody MFR biomass is consistent with the reports of other workers. Jindo and co-authors (2014) used two types of biochar and found that the biochar derived from woody materials (wood chips of apple and oak tree) showed low yields compared to biochars originating from RS and RH. Joseph et al. (2013) explained that such results are might be due to the differences in compositions of the original agricultural material since rice plants are enriched with Si while recalcitrant Cs such as the lignin content are predominantly contained in woody plants.

**Biochar Properties**

**Chemical properties.** Biochars can be produced from a wide range of biomass materials and under different conditions resulting in products of varying properties. The structural and chemical composition of biochar shown in this study is dependent on the combination of the feedstock type and duration of pyrolysis. These findings were consistent with those of Lehmann and Joseph (2009) and Liu and Zhang (2012) that the properties of biochars are greatly dependent on the production procedure and type of raw material. It is well documented that biochar physical and chemical attributes vary as a function of the pyrolysis process conditions (temperature and residence time), the qualities (chemical and physical) of feedstock, and organic chemical constituents (digestible organic matter, lignin, cellulose, hemicellulose, and their ratios) in the biomass materials. The magnitude of changes in the elemental composition of biochars varies in different studies. The variability in biochar physical and chemical properties depends on the material used to produce it (feedstock), the availability of oxygen, and the temperatures achieved during pyrolysis (Amonette and Joseph 2009).

In this study, the pH level of the biochar samples ranges from almost neutral to highly alkaline (7.30–10.4). These pH levels are similar to the values reported for biochars produced from sugar beet and sugarcane bagasse (Inyang et al. 2010) and pea pod, cauliflower leaf, and orange peel wastes (Stella Mary et al. 2016). Between biochars derived from rice residues, the pH of the RS was higher than that of RH. The result might be ascribed to the high ash content of RS (48.94%) compared to that of RH (16.75%). Keiluwiet et al. (2010) reported the higher ash content of RS biochar than that derived from other residues in their studies. The high pH of RS is supported by the high level of K which is the main component of ash. RS could be ideally used for biochar production as the high amount of ash can provide additional fertilizer effects. Stella Mary et al. (2016) cited that high pH can decrease soil acidity, creating a more favorable habitat for many plants and microbes. Subsequent oxidation of the biochar surfaces will create carboxylate groups such that the biochar becomes a weak acid. In soil environments, the biochar will initially act as a liming agent raising the soil pH by dissolving the ash and releasing the base cations on the soil solution. Among the four biochar samples, the highest essential plant nutrients were found in WH biochar. It may be assumed that these mineral constituents can provide nutrients to soil and improve crop productivity.

**BET physisorption analysis.** The high average pore size, pore volume, and surface area of the biochars from light biomass materials compared to woody MFR may be explained by many contributing factors. Khodadad and co-workers (2011) described biochar made from wood less biologically labile and contains relatively higher proportions of more aromatic organic matter when compared to other original materials of agricultural residues. Biochars derived from the woody material are coarse and highly resistant in nature with higher C contents (Basta et al. 2011).

In the present study, BET analysis showed that biochars from RH, RS, and WH have higher surface areas and shorter residence periods compared to woody MFR. The very low surface area of MFR biochar is elaborately explained by the reports of Song and Guo (2012) that the high content of inorganic ash in the biochar may be filled or blocked access to micropores, resulting in relatively low surface area. Contrarywise, Bagreev et al. (2001) argued that high temperatures and longer residence time resulted in high porosity and a three-fold increase in surface area that has been linked to the creation of micropores formed during the loss of water molecules through dihydroxylation.

The highly porous structure and large surface area is the key physical feature of most biochars. Verheijen et al. (2009) discussed that these same parameters are also key in determining particle size and pore size distribution in biochar, ultimately influencing its functional behavior, mobility, and fate in the environment. Under this scenario, Atkinson et al. (2010) added that this structure can provide refugia for beneficial soil micro-organisms such as mycorrhizae and bacteria, which influences the binding of important nutritive cations and anions. This binding can enhance the availability of macro-nutrients such as N and P. In the present study, the high amount of macro- and micronutrients and high surface area are noticeably all found on biochars originating from light materials. The porosity and surface area represent the
physical properties of biochar and may connect strongly with adsorption, and water retention abilities. Thus, these properties have the potential to improve soil quality. The physical properties of biochar are key to understanding the way biochar functions within the soil and its potential to act as a route to sequester atmospheric CO₂. Lehmann and Joseph (2009) further explain that the porosity and surface area of biochar will have very important effects on its nutrient retention capacity by surface binding of both cations and anions to its surfaces. Atkinson and co-workers (2010) expound that larger macropores of biochars are keys to its function in soil (i.e. aeration and hydrology) and provide habitat niches for microbes; wherein the smaller pores are involved in adsorption and transport of molecules. The physical characteristics of biochar can be both, directly and indirectly, related to how they affect the soil systems. Their incorporation in soils influences soil structure, texture, porosity, particle size distribution, and density (Basta et al. 2011).

HAABF images and EDS analysis. The micro and nanostructures of biochars are also affected by many of the same parameters affecting the chemical and physical properties (Solomon et al. 2012), such that structures of biochars are highly heterogeneous and complex (Joseph et al. 2013). The TEM photographs of biochars at varying magnifications in Figures 1–4 present the many pores over the surface, forming a system of developed pore structures. Copper peaks in all spectrums are from the TEM grid. It is assumed that more well-developed pores are present in rice residues because RS and RH possessed high BET surface area and adsorptive capacity compared to WH and MFR.

The HAABF images, spectrum, and elemental X-ray maps of all biochars revealed areas high in C and other minerals rich in K, Cl, Ca, Mg, Si, and Al. Rice plants are rich in Si, which is strongly related to the ash content of its biochars. Both rice residues showed the high silica presence on the surface of biochars particularly the dominance of silica in the biochar derived from rice hull. Jindo et al. (2014) reported that the biochars obtained from rice materials (RH and RS) show unique chemical properties because of the incorporation of silica elements into its chemical structure. This favors the formation of the Si-C bonds, thereby converting Si from amorphous to crystalline form as the results of an increase in the pyrolysis temperature. On the other hand, several workers (Liu and Zhang 2012; Joseph et al. 2013) mentioned that the recalcitrant carbons such as lignin are the main component in woody feedstocks. Such finding is realized in MFR having the highest C among the feedstocks.

According to Atkinson et al. (2010), the quantities of key mineral elements within these biochars can be directly related to the levels of these components in the feedstock prior to burning. The TEM micron images of WH and RS shown in Figures 2 and 3, respectively, display a distinct combination of fine and coarse cellulosic structures of its original biochar. The European Biochar Foundation (2012) explained that biochar C is made up of easily degradable organic C compounds and very stable, poly-condensed aromatic C structures (black C). The black C content is an important criterion for characterizing biochar and it also reflects the biochar’s stability in the soil. The utility of biochar for a specific application depends on its inherent properties. For example, biochar with high recalcitrance may function in C fixation (Zimmerman 2010), whereas those rich in available nutrients and minerals could be better used as a soil amendment to improve soil fertility (Graber et al. 2010).

The X-ray EDS of the four different biochar samples indicate that the WH biochar has more minerals (C, O, K, Cl, Ca, Mg, P, Si, Na, S, Mn, Al, Fe) followed by RH biochar (Si, O, Al, C, Fe, K, Ca, Mg), RS biochar (C, O, K, Si, Mn, Mg, Fe), and MFR biochar (C, Ca, O, P, Mg, K, Fe) where these mineral agglomerates are close to the values reported by Varela Milla et al. (2013) and Joseph et al. (2013). These results correspond to the report of McBeath et al. (2014) that these are likely to have follow-on effects in the performance of the biochars as soil amendments and as a C sink.

CONCLUSION

An on-station study was conducted to characterize four biomass wastes, viz. MFR, WH, RS, and RH. These feedstocks were slowly pyrolyzed using the biochar-producing stove at temperatures ranging from 300–650 °C. The pyrolysis conditions, residence time, and physical quality of feedstock affected the proportion of the weight of pyrolysis product to the weight of the original material. The compositional and crystallographic images substantiated that biochar mass has its elevated nutrients. Such findings confirmed that the use of biochar as a soil amendment will have positive effects on soil porosity, soil acidity, CEC, water holding capacity, and nutrient retention – all of which improve soil fertility and, thereby, plant growth.

ACKNOWLEDGMENTS

The author would like to thank the National Research Council of the Philippines–Department of Science and Technology for the research funds.

The author expresses special gratitude to Stephen Joseph of School of Materials Science and Engineering,
University of New South Wales, Sydney, NSW 2052, Australia; and to Engrs Jonathan Lacayanga and Walter Valdez of Bataan Peninsula State University, Bataan, Philippines.

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