Recycling of nutrient-loaded biochars produced from agricultural residues as soil promoters for Gomphrena growth

S Wongrod*, A Watcharawittaya and S Vinitnantharat

Environmental Technology Program, School of Energy, Environment and Materials, King Mongkut's University of Technology Thonburi, Bangkok, 10140, Thailand

*Corresponding author: suchanya.won@mail.kmutt.ac.th

Abstract. Biochar has been recognized as a potential media for soil amendment regarding its high surface area and retention capacity to slowly release nutrients to soils. However, the recycling of biochar after domestic water treatment towards agricultural application is still not well known. Therefore, this research studied the role of nutrient-loaded biochars produced from agricultural residues after canal water treatment as soil promoters for Gomphrena growth. Corncob, coconut husk, coconut shell and rice straw derived biochars were separately produced in a kiln (~378 °C) (namely CC, CH, CS and RS, respectively) and a pyrolysis reactor (500 °C) (namely CC-P, CH-P, CS-P and RS-P, respectively). The CH biochar was further modified with chitosan to improve its surface properties (labeled as CHC). The CH and CHC biochars after canal water treatment at lab and pilot scales are labeled as CH-column, CHC-column, CH-pilot and CHC-pilot, respectively. The loaded and unloaded biochars were further added in aquaculture sediment and loamy soil at 0.4, 0.7 and 1% mass ratio for Gomphrena growth. From the results, biochars amended in soil and sediment significantly improved seed germinations of Gomphrena, compared to control treatments. RS 0.4% amended in soil and sediment showed the highest seedling height (~2.5 cm) among all biochars, in accordance with its releases of K\(^{+}\), PO\(_4^{3-}\) and NO\(_3^{-}\) into solution at high concentrations. Gomphrena growth in sediment amended with CH-column 1.0% biochar was comparable to unloaded biochar, indicating that loaded biochar can provide nutrients without harming the plant. In addition, chitosan modification induced higher plant growth in sediment amended with CHC-column 1.0% than with unmodified biochar. Gomphrena germination was also improved in CH-pilot and CHC-pilot biochars amended in sediments with maximum seedling heights of 3.5 and 4.2 cm, respectively. This is likely due to the abilities of CH-pilot and CHC-pilot biochars to release N (NH\(_4^{+}\), NO\(_3^{-}\)) and total P of 0.106 and 0.111 mgN/L, and 0.770 and 0.637 mgP/L, respectively. This study revealed that the nutrient-loaded biochars can be used to sustain soil fertility through gradual releases of nutrients and thus promote the recycling of agricultural residues.

Keywords: Agricultural residues, Biochar, Gomphrena, Nutrient recycle
1. Introduction

After agricultural production, the large amounts of agricultural residues are often remained in the field, and thereby the agricultural waste management is required. Biochar production from agricultural residues is one of the alternative approaches to recycle the by-product agricultural wastes and provide value-added products (i.e., biochar, syngas and bio-oil). Biochar is a solid char obtained from thermal conversion processes (e.g., gasification, pyrolysis and hydrothermal carbonization) of organic wastes under oxygen-limited condition [1]. Biochars can be used as an active sorbent to remove excessive nutrients from water due to their high porosities and surface areas [2].

Chemical fertilizers are often used in agriculture which result in the spreading of nitrogen, phosphorus, potassium and metal pollutants (e.g., arsenic, cadmium, chromium, iron, manganese, lead, and zinc) in the field, and thus increasing the risk of environmental pollution [3, 4]. Hence, the nutrient-loaded biochars after water treatment can be applied as soil promoters for plant growth to close the nutrient recycle loop and provide alternatives to cleaner agricultural activities. Therefore, this research aimed to study the roles of nutrient-loaded biochars produced from corncob, coconut husk, coconut shell and rice straw after canal water treatment as soil promoters to recycle the agricultural residues and recover nutrients for Gomphrena growth in loamy soil and aquaculture sediment.

2. Material and Methods

2.1. Biochar production and modification

Four types of agricultural residues, i.e., corncob, coconut husk, coconut shell and rice straw were used in this research. These agricultural residues were obtained from Central Thailand (Samut Songkhram, Samut Sakhon and Samut Prakan Provinces), which was not far away from aquaculture farm where the sediment was collected. Corncob, coconut husk, coconut shell and rice straw derived biochars were produced under 2 different processes, i.e., by using a 200-L oil drum kiln (~378 °C) (labeled as CC, CH, CS and RS, respectively), and a pyrolysis reactor (500 °C) (labeled as CC-P, CH-P, CS-P and RS-P, respectively).

The CH was further selected to modify with chitosan (labeled as CHC) to investigate if the biochar modification improves the biochar surface properties. From a previous study [5], the CH and CHC biochars were used to treat canal water and the loaded biochars after canal water treatment at lab and pilot scales are denoted as CH-column, CHC-column, CH-pilot and CHC-pilot, respectively.

2.2. Preparation of soil and sediment

Loamy soil (namely Din Lawoe) and aquaculture sediment (dried for 6 months in extensive farm) were collected from Bang Khun Thian and Phra Samut Chedi (Central Thailand) and were further used for Gomphrena growth.

2.3. Characterization of soil, sediment and biochar

2.3.1. Determination of pH, electrical conductivity and moisture content. To measure the pH value, 1 g of sample was added to 10 ml of deionized water. The mixed solution was shaken at 100 rpm and at 30 °C for 3 h and left for suspension before measuring the pH value by using a pH meter. The EC of soil and sediment was measured by the conductivity meter and the moisture content was obtained following the ASTM D3173 method.

2.3.2. Scanning electron microscopy analysis (SEM). The SEM images of biochars was analyzed at Kasetsart University (Thailand). The SEM analysis was performed at a magnification of 1200X and operated at 10.0 kV to obtain the information on the morphology of the biochars.
2.4. Amendment of Gomphrena growth with biochar in soil and sediment

The raw biochars (pre-treatment) and nutrient-loaded biochars after canal water treatment (post-treatment) were used as soil amendments for Gomphrena growth in soil and sediment. To determine the Gomphrena germination, the raw biochars (i.e., CC, CC-P, CH, CH-P, CHC, CS, CS-P, RS and RS-P) and the loaded biochars from post-treatments at lab scale (i.e., CC-column, CC-P-column, CH-column, CH-P-column, CHC-column, CS-column, CS-P-column, RS-column, and RS-P-column), and at pilot scale (CH-pilot and CHC-pilot) were separately applied to the soil and sediment in pot experiments.

For each treatment, the biochar was applied at different mass ratio (0.4, 0.7 and 1% wt/wt) for Gomphrena seedlings. All the experiments were performed in duplicate with the control treatments. The equal amounts of water were added in all pots to ensure the plant growing. The seedling height of Gomphrena in each pot was measured after 5 and 10 days of plantation.

3. Results and discussion

3.1. Soil and sediment characterization

The pH, EC and moisture content values of soil mixed with sediment was 6.67, 0.573 µS/cm, and 48.14%, respectively. The pH values of different agricultural residue-derived biochars are given in table 1. Results showed that the pH values of all biochars were ranging from 8.94 to 9.72, indicating the alkali properties of the biochars (table 1). Hence, application of biochar could increase the pH value of soil mixed with sediment, which consequently lead to the fertility of soil and sediment and the supplement of nutrients from the biochars to soil and sediment.

| Biochar         | Production reactor | pH in solution |
|-----------------|--------------------|----------------|
| Corn cob        | Kiln               | 8.97           |
|                 | Pyrolysis          | 9.08           |
| Coconut husk    | Kiln               | 9.75           |
|                 | Pyrolysis          | 8.99           |
| Coconut shell   | Kiln               | 9.02           |
|                 | Pyrolysis          | 9.72           |
| Rice straw      | Kiln               | 8.94           |
|                 | Pyrolysis          | 9.50           |

3.2. Scanning electron microscopy analysis (SEM)

The SEM images of biochars derived from corn cob (CC), coconut husk (CH), coconut shell (CS) and rice straw (RS) are illustrated in figure 1(a-d). Results showed that the CC, CH, CS and RS biochars had a lot of mesoporous structures ranging from 10 to 20 µm. The macropores of 100 µm was also detected on the CC, CS and CH biochars. In addition, the macropores was largely found in the RS biochar, particularly at the open-end of the sample (figure 1(d)). The presence of macropores in the biochar is important as more water can be adsorbed in the biochar and thus increasing the water holding capacity of the biochar [6].
Figure 1. SEM images of biochars derived from corncob (a), coconut husk (b), coconut shell biochar (c), and rice straw (d).

3.3. Biochar effect on seed germination

Figure 2 shows the plant height of Gomphrena after adding the nutrient-loaded biochars (at lab scale) in soil and sediment at 0.4, 0.7 and 1% mass ratio. From the results, the Gomphrena growth was increased with the addition of biochar and the seedling heights were significantly higher, compared to the control treatment (no biochar) where the Gomphrena growth was much slower and the shoot was shorter.

After 5 days of plant growing, the RS 0.4% showed the highest seedling height (~2.3 cm) among all the biochars (figure 2), in accordance with the releases of K⁺, PO₄³⁻ and NO₃⁻ from the RS 0.4% into solution at high concentrations [5]. In addition, the plant heights were continuously increased after 10 days. Based on the biochar addition to soil and sediment at different mass ratio, the CH 1.0% showed the highest seedling height among 3 ratios (0.4, 0.7 and 1% wt/wt), while the RS and CC biochars at 0.4% and the CS biochar at 0.7% wt/wt were the most suitable mass ratios for the Gomphrena growth, among other mass ratios.
Figure 2. The effect of nutrient-loaded biochar application (post-treatment at lab scale) at different mass ratio (0.4, 0.7 and 1%) amended in loamy soil mixed with sediment on seedling heights of Gomphrena at 5 and 10 days (CS; coconut shell biochar, RS; rice straw biochar, CC; corncob biochar, and CH; coconut husk).

Figure 3 illustrates the plant height of Gomphrena after applying the nutrient-loaded biochars with and without chitosan modification in sediment at 5 and 10 days. The results showed that the Gomphrena was able to grow in the sediment amended with the loaded biochar from post-treatment (pilot scale). In addition, the Gomphrena germination was improved in the CH-pilot and CHC-pilot biochars amended in sediment with maximum seedling heights of 3.5 and 4.2 cm, respectively, after 10 days of plant growing. The increases of seedling heights can be linked to the properties of the CH-pilot and CHC-pilot biochars to release N (NH$_4^+$, NO$_3^-$) and total P of 0.106 and 0.111 mgN/L, and 0.770 and 0.637 mgP/L, respectively [5].

Figure 3. The effect of nutrient-loaded biochar application (post-treatment at pilot scale) amended in sediment on seedling heights of Gomphrena at 5
and 10 days (CH-pilot; nutrient-loaded biochar from coconut husk, and CHC-pilot; nutrient-loaded biochar from coconut husk with chitosan modification).

4. Conclusions
This study demonstrated a potential application of nutrient-loaded biochars from agricultural residues as soil promoters for Gomphrena growth. Overall, the addition of biochars in soil and sediment significantly improved the Gomphrena seedlings due to the releases of K\(^+\), PO\(_4\)\(^{3-}\) and NO\(_3\)\(^-\) from the biochars. In addition, the Gomphrena growth amended with the nutrient-loaded biochar from lab scale at 1.0% dosage rate was comparable to the raw biochar, highlighting that the loaded biochar can be potentially applied to soil and sediment without harming the plant growth. Gomphrena germination was also improved in the sediment amended with the nutrient-loaded biochar (pilot scale) modified with chitosan (CHC-pilot) with maximum seedling heights of 4.2 cm. This can be linked to the releases of N (NH\(_4\)\(^+\), NO\(_3\)\(^-\)) and total P of 0.111 mgN/L and 0.637 mgP/L, respectively, from the CHC-pilot biochar. To sum up, the nutrient-loaded biochars after canal water treatment can be potentially used for soil fertility and Gomphrena growth enhancement, which promote the recycling of agricultural residues.

Acknowledgments
This research work was financially supported by the Newton Fund via the Biotechnology and Biological Sciences Research Council (BBSRC) of the United Kingdom (BB/P027709/1) and the Thailand Research Fund (RDG6030006).

References
[1] Zhang Z, Zhu Z, Shen B and Li L 2019 Energy 171 581–598.
[2] Mohan D, Sarswat A, Ok Y S and Pittman C U 2014 Bioresour. Technol. 160 191–202.
[3] Nisa K, Siringo-ringro L, Muyassir and Zaitun 2019 IOP Conf. Ser. Mater. Sci. Eng. 506 1–14.
[4] Savci S 2012 Int. J. Environ. Sci. Dev. 3 77–79.
[5] Vinittanatharat S 2018 Valorisation of agricultural wastes in the Thai rural economy for bioenergy production, nutrient recycling and water pollution control in aquaculture (TRF Thailand) chapter 4 pp 46–103.
[6] Burrell L D, Zehetner F, Rampazzo N, Wimmer B and Soja G 2016 Geoderma 282 96–102.