Hydration efficiency and wettability of two biochars

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Abstract

The ability to capture and retain water is an important feature for substrate components. Suitable wettability of these components can lead to a more uniform distribution of water and nutrients within the plant root zone. Biochars are considered porous materials with both external and internal pores which makes them a potential substrate component with water retention properties. For this study, biochars were produced from two feedstocks, pine wood chips (*Pinus taeda* L.) and rice hulls (*Oryza sativa* L.), through gasification at a production temperature of 745°C with a residency of three hours. Unadulterated samples of both feedstocks were compared to their respective biochar counterparts to distinguish the effects of charring on hydration efficiency and wettability, as well as determine the biochars water-holding capacities. The charring process did not adversely affect hydration efficiency in the pine wood chip biochar, as the pine wood chip feedstock had nearly identical wetting curves to its biochar. Rice hulls had a very low ability to capture and retain water. Both biochars had an increase in water-holding capacity compared to their respective feedstocks; however, this did not appear to have a positive effect on initial wettability as both biochars never reached their water-holding capacities within ten irrigation events. This could indicate issues with hydrophobicity in biochars. However, this tested the biochars alone without other substrate components. Combining biochar with other components may change the receptiveness of biochar's porous surface to hydration.

Keywords: gasifier, pine wood chips, rice hulls

INTRODUCTION

Production of greenhouse and nursery plants relies on substrates that have the ability to capture and retain water efficiently in order to create a uniform distribution of water and nutrients in the plant root zone area. Biochars can be considered porous substrate components with both external and internal pores providing a potential impact on water retention (Gray et al., 2014). Depending on the feedstock and production conditions, biochars have shown to be hydrophobic and hydrophilic (Leon et al., 2013; Gray et al., 2014) and in some cases increasing water content at permanent wilting point (Abel et al., 2013). Gray et al. (2014) reported biochars produced at low temperatures from hazelnut shells and Douglas fir chips took up less water than high temperature biochars suggesting a difference in surface hydrophobicity, and the Douglas fir biochars took up more water than the hazelnut shell biochars due to greater porosity within the biochars. Therefore, designing biochars for optimal water-holding capacities requires two considerations during the biochar production: creating adequate porosity through feedstock selection and determining a production temperature or method that reduces hydrophobicity to an acceptable level.

Two feedstocks were used to produce biochar in a top-lit updraft (TLUD) gasifier. Previous examinations of these biochars reported difficultly in fully hydrating the material to get the full effect of biochar on pH (Judd, 2016). The objective of this research was to determine the water-holding capacities and wettability of these two gasified biochars and compare them to the feedstock materials.

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MATERIALS AND METHODS

The biochars were produced at NC State University with a TLUD gasifier with materials and dimensions listed by Boyette et al. (2012). The feedstocks received for the gasification process were pine wood chips (PWC) and rice hulls (RH). The feedstock was then ignited with lighter fluid sprayed in three concentric circles on top of the feedstock and the lid of the reactor was sealed shut to control the oxygen in reactor/combustion of the feedstock. Combustion was sustained by regulating the amount of air entering from the bottom and passing up through the material (12 $m^3 \cdot min^{-1}$). Once the flame front reached the bottom of the gasifier, the air flow was shut off and compressed nitrogen gas was then forced through the biochar in the reactor from the bottom for 24 h to extinguish the flame and prevent any flare up as the biochar cooled. This process was then repeated for the second feedstock.

Internal temperature in the middle of the reactor was recorded with a data logger. For the pine wood chips, the maximum internal temperature was 745 and 705°C for the rice hulls. The entire gasification process took 4.68 h for pine wood chips and 2.97 h for rice hulls. The total mass of pine wood chips loaded into the reactor was 746 kg and only 645 kg for rice hulls. The final mass of the pine wood chip biochar (PBC) after charring was 528 kg, indicating 29% of the biomass was consumed. The final mass of rice hull biochar (RBC) was 542 kg, showing a 16% loss of biomass.

Hydration efficiency measurements were conducted following the procedures described by Fonteno et al. (2013) and Fields et al. (2014). Three replicates of PWC and RH were tested at an initial moisture content (MC) of 12% (RH) or 14% (PWC); these samples were removed from the bulk feedstock before the charring process. Three replicates of PBC and RBC were tested at a moisture content of 8%; these samples were removed from the reactor after the charring process was completed. The sampling times and different moisture contents were done in this manner to imitate growers receiving these materials and immediately adding them to substrate, and what effect these components would have on wettability. Samples were placed in a transparent cylinder (5 cm i.d. × 15 cm) with a mesh screen attached to the bottom. Water was added for each hydration event through a separatory funnel filled with 200 mL of water that was allowed to flow through a valve into a diffuser above the sample, into the sample, and then leached water was collected in a 250 mL beaker beneath the cylinder. Each material had its hydration efficiency described with wettability curves as determined by Fields et al. (2014). After the tenth hydration event was completed, cylinders were placed into the NC State University Porometer method to measure container capacity. A measure of initial hydration was the percentage of container capacity (CC) that was attained in a sample after one hydration event.

RESULTS AND DISCUSSION

The PWC took three to four hydration events to reach near CC (Figure 1). The charring process did not adversely affect this process, with the PBC having nearly identical wetting curves as the PWC. In fact, the CC for PBC was slightly higher at 41%, than the PWC at 34%. These values were similar to materials, such as PWC, that were separately produced and tested by Fields et al. (2014).

Rice hulls had a very low ability to capture and retain water. RH captured between 12 and 15% water by volume on the first and all subsequent hydration events, although the CC was measured at 30% (Figure 2). The charring process greatly increased the CC to over 60%, however, the hydration events never captured more than 30% by volume.

Both biochars, PBC and RBC, increase the water-holding capacities (CC), but appear to not have a positive effect on initial wettability to reach those CCs. It should be noted that these tests were done “as is” where all materials had a low moisture content. Increasing the moisture content may have improved the materials’ ability to capture water.

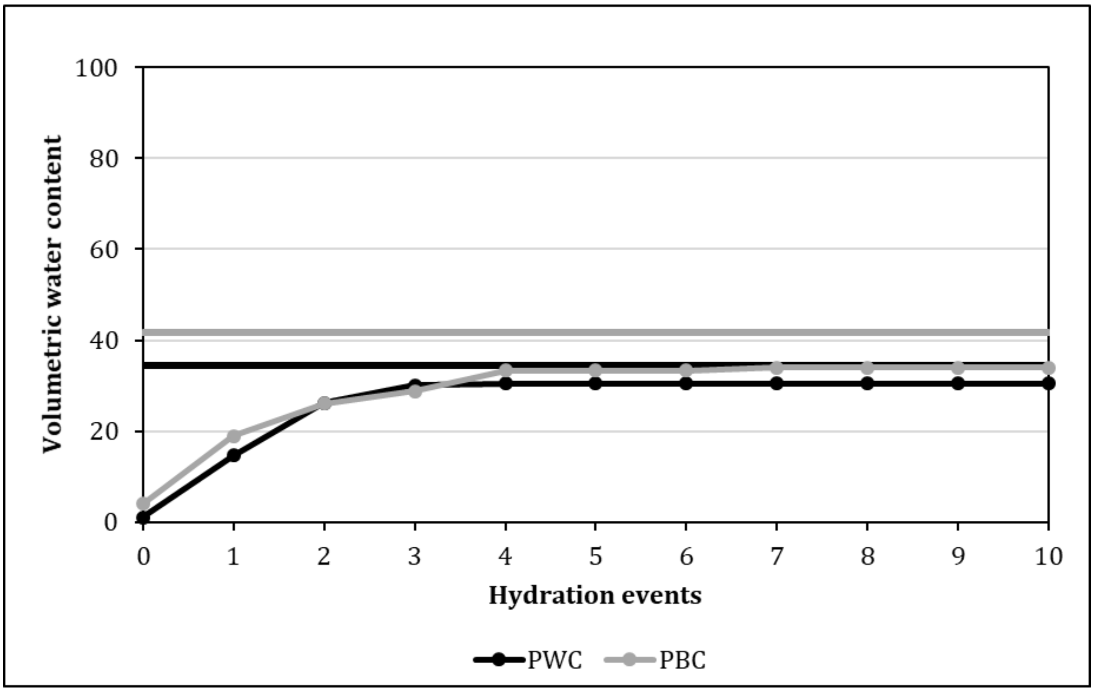

Figure 1. Hydration efficiency curves for pine wood chip feedstock (PWC) compared to biochar produced from pine wood chips (PBC); with container capacity represented as horizontal solid lines for each material.

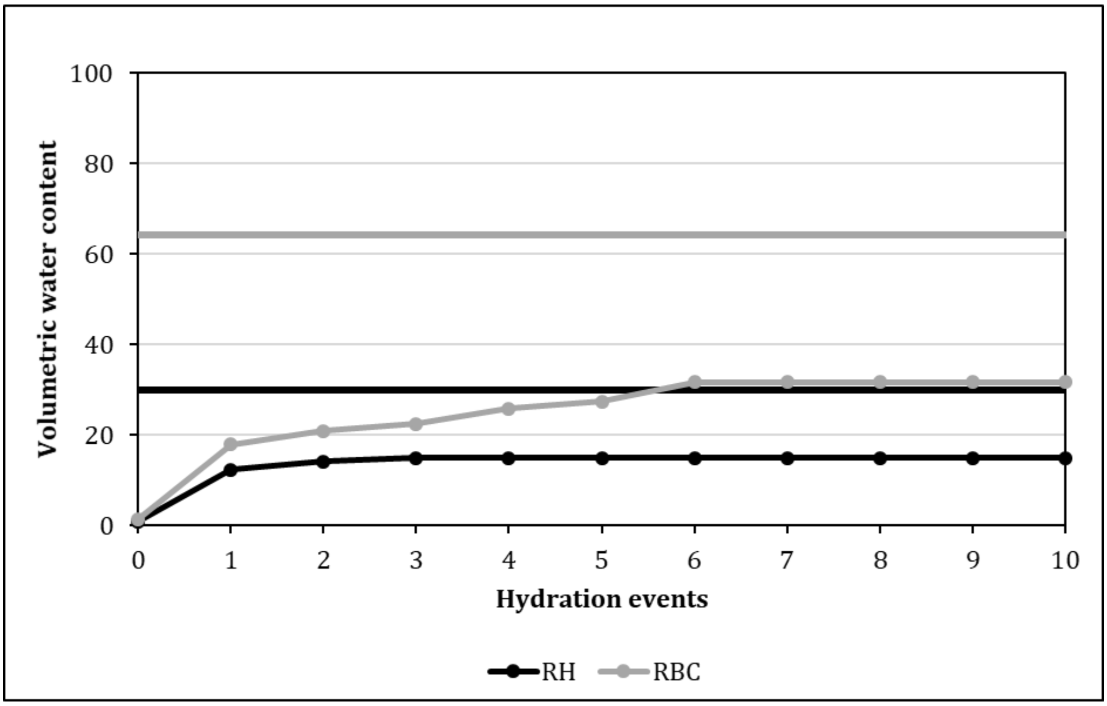

Figure 2. Hydration efficiency curves for rice hull feedstock (RH) compared to biochar produced from rice hulls (RBC); with container capacity represented as horizontal solid lines for each material.

CONCLUSIONS

Both biochar materials had a greater difference between their final volumetric water content and CC, therefore both PBC and RBC did not reach their full water-holding efficiencies after ten irrigation events. This suggests that these biochars used directly from the gasifier may exhibit hydrophobicity to the point that initial wetting of substrates with these biochars are not being fully hydrated and may require more wetting events before the biochars surmount their hydrophobicity. However, biochar has unique features with their internal and external pores as seen in Figure 3. These pores may have had an influence on the higher container capacities compared to their feedstocks.

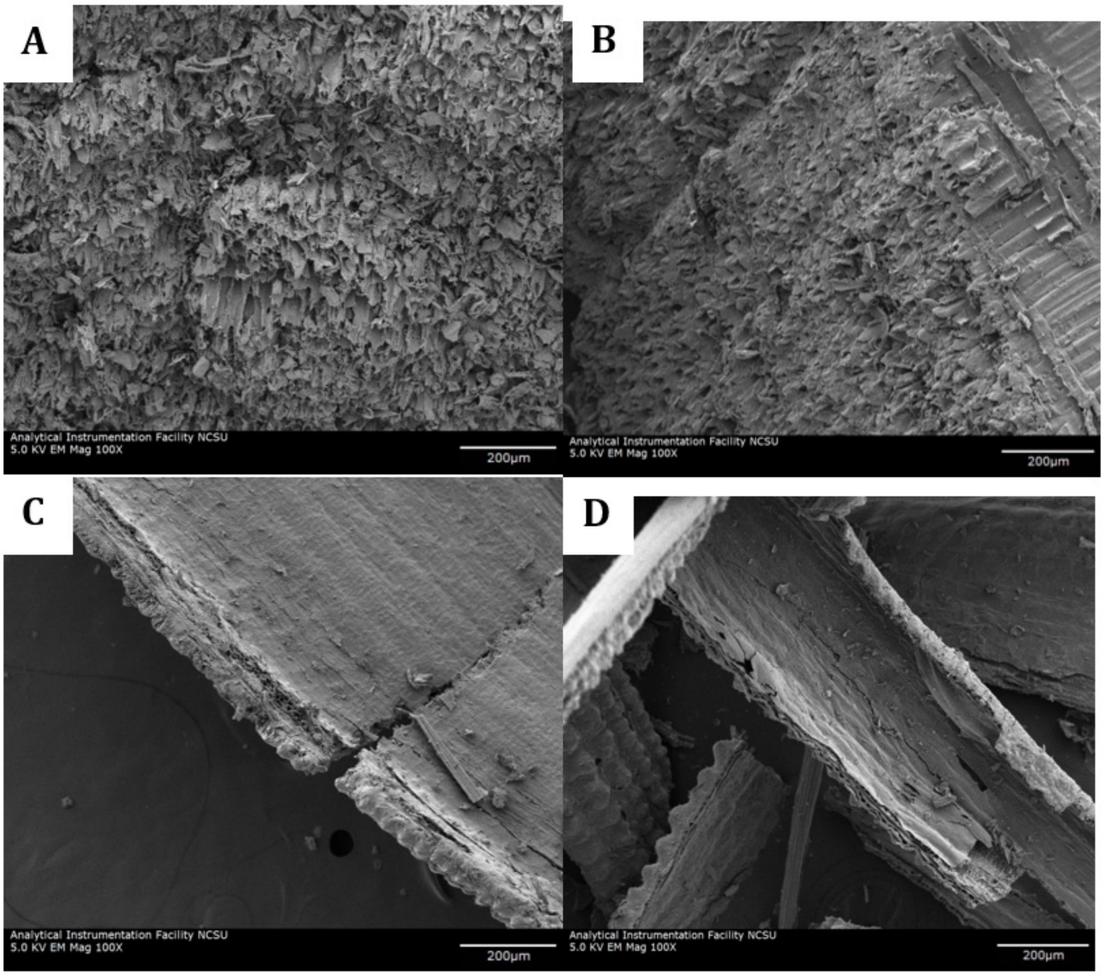

Figure 3. Surface view of (A) pine wood chips (PWC) and (B) pine wood biochar (PBC) at 100× magnification through scanning electron microscopy. Surface view of (C) rice hulls (RH) and (D) rice hull biochar (RBC) at 100× magnification through scanning electron microscopy completed at the Analytical Instrumentation Facility (AIF) at Raleigh, NC.

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