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Impact of biochar amendment on soil water soluble carbon in the context of extreme hydrological events

Daoyuan Wang [a], [b], [*], Deirdre E. Griffin [a], Sanjai J. Parikh [a], Kate M. Scow [a]

[a] Department of Land, Air and Water Resources, University of California, Davis, 95616, United States
[b] College of Environmental Science & Engineering, Donghua University, Shanghai, 201620, China

HIGHLIGHTS

- Biochar can release water soluble C and increase soil pH and ionic strength.
- Dry conditions and wet-dry cycles can increase soil water soluble C.
- Biochar can enhance water soluble C release from native soil organic matter under dry and wet-dry cycle conditions.

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ABSTRACT

Biochar amendments to soil have been promoted as a low cost carbon (C) sequestration strategy as well as a way to increase nutrient retention and remediate contaminants. If biochar is to become part of a long-term management strategy, it is important to consider its positive and negative impacts, and their trade-offs, on soil organic matter (SOM) and soluble C under different hydrological conditions such as prolonged drought or frequent wet-dry cycles. A 52-week incubation experiment measuring the influence of biochar on soil water soluble C under different soil moisture conditions (wet, dry, or wet-dry cycles) indicated that, in general, dry and wet-dry cycles increased water soluble C, and biochar addition further increased release of water soluble C from native SOM. Biochar amendment appeared to increase transformation of native SOM to water soluble C, based on specific ultraviolet absorption (SUVA) and C stable isotope composition; however, the increased amount of water soluble C from native SOM is less than 1% of total biochar C. The impacts of biochar on water soluble C need to be carefully considered when applying biochar to agricultural soil.

1. Introduction

As a major challenge of our time, climate change is expected to have long-term impacts on soil hydrological processes (Vrochidou et al., 2013). Extreme hydrological events, such as extended periods of drought, increased flooding, and more frequent wet-dry cycles, will in turn influence soil nutrient leaching (Bloor and Bardgett, 2012), the stability of soil organic matter (SOM) (Schmitt and Glaser, 2011) and soil microbial activities (Hueso et al., 2012).

Soil water soluble C molecules make up a small part of total SOM, but they play important roles in many soil microbial activities (Hennion, 2000; Marshall Clark and Kenna, 2001; Smolander and Kitunen, 2002; Peterson et al., 2013). Drought events have been shown to destabilize soil C stocks (Fenner and Freeman, 2011) and increase soluble C (Acero et al., 2009). Rapid wetting events enhance microbial activity in soils through what is known as the "Birch effect" (Birch, 1958; Bottner, 1985). Increased soil microbial activities may also increase production of water soluble molecules (Guggenberger and Zech, 1994; Guggenberger et al., 1994).

Biochar is a mostly recalcitrant, carbonaceous product obtained from pyrolysis of biomass under limited or no oxygen (Lehmann et al., 2011). Some biochars are byproducts of energy acquisition processes, such as the synthesis of bio-oil (Özçimen and Karaosmanoğlu, 2004) and syngas (Gaunt and Lehmann, 2008). Previous researches indicated that biochar soil amendment can increase soil water holding capacity of sandy soil (Karhu et al.,

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[*] Corresponding author. Department of Land, Air and Water Resources, 3310 PES Building, University of California, Davis, One Shields Ave., Davis, CA, 95616, United States.

E-mail addresses: dyuwang@ucdavis.edu, dywang17@gmail.com (D. Wang).

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2011), influence soil cation exchange capacity (Van Zwieten et al., 2010), increase crop yields (Asai et al., 2009; Vaccari et al., 2011) and alter greenhouse emissions from soil (Spokas and Reicosky, 2009; Roberts et al., 2010).

The potential degradation of biochar after application to soil is a concern if it is to be used as a C sequestration tool. Biological and abiotic processes are both involved in biochar degradation (Bruun et al., 2011; Kasin and Ohlson, 2013; Mukome et al., 2014), though the mechanisms involved are not well understood (Kuzyakov et al., 2009; Zimmerman, 2010). Biochar amendment can increase the priming effect of native soil C, but the interaction between biochar and native soil C varies across different systems and also depends on biochar C composition (Cross and Sohi, 2011). It is also unclear how soil hydrological events impact the biochar itself and its interactions with native organic C.

The objective of this study was to investigate the impacts of biochar amendment on the amount and composition of soluble C in an agricultural soil under conditions of dry and wet-dry cycles. We hypothesized that (1) biochar can influence soil chemical properties including water soluble C concentration and composition, and (2) both dry and wet-dry cycles treatments can increase water soluble C and change its properties.

2. Materials and methods

2.1. Soil and biochar

In January 2012, we sampled the top 15 cm of a Yolo silt loam soil (fine-silty, mixed, nonacid, thermic Typic Xerorthent) from Plot 6—1 (conventionally managed, irrigated, unfertilized wheat/fallow treatment) at the Russell Ranch Sustainable Agricultural Research Facility (http://asi.ucdavis.edu/rr), University of California, Davis. The soil samples were air dried, sieved to pass through a 2 mm mesh, sealed in glass bottles, and stored at room temperature until use. The soil was a silt loam (42.75% sand, 35.20% silt and 22.05% clay) with 10.18 g organic C kg^{-1}, 1.15 g kg^{-1} total N content, 11.0 mg kg^{-1} Olsen-P content, 20.6 cmol kg^{-1} cation exchange capacity and pH of 6.7. The soil measurements were performed by the Analytical Lab, University of California, Davis.

The biochar used was a walnut shell (WS) biochar that is commercially available, produced by Dixon Ridge Farms in Winters, CA. Detailed information on biochar characteristics and methods of analysis have been presented elsewhere (Mukome et al., 2013). The WS biochar was produced from walnut shells at a pyrolysis temperature of 900 °C, with 227.1 m^2 g^{-1} surface area, 40% ash content, 33.4 cmol g^{-1} cation exchange capacity and pH of 9.7. WS biochar was similarly processed as soil before use.

2.2. Incubation experiment setup

A laboratory incubation experiment was conducted from February 2012 to February 2013. Soil or biochar and soil mixtures totaling 200 g were placed in 500 mL Mason jars. Soils were equilibrated before the experiment began to avoid interference with measurements while the system was redistributing the added water. To do so, soil with different amounts of biochar were well mixed with water at the beginning of the experiment and pre-incubated for two weeks. The incubation experiment was conducted at 23 ± 1 °C.

The wet, dry and wet-dry cycles were conducted based on the water retention capacity of the soil (the soil moisture of different jars was adjusted as shown in Fig. 1). Based on soil water retention properties, we chose 80% of field capacity as the wet condition to keep the soil moist and have good aggregate structure. Dry and wet-dry cycle conditions were designed based on wet conditions and permanent wilting point. The field capacity and permanent wilting point of the Yolo silt loam soil were determined by measuring water retention using a pressure plate apparatus at 33 kPa and 1500 kPa, respectively (Dane and Hopmans, 2002).

The soil moisture content was adjusted weekly by oven-drying at 30 °C or rewetting by watering with distilled water gently and evenly to the desired soil moisture content. Soil moisture was monitored by weighing the jars. Biochar doses were 0, 0.5, and 1 g per 100 g dry soil (equivalent to approximately 0, 10, and 20 t ha^{-1}). These biochar amendment rates are feasible amounts of material to add in agricultural practice and still be affordable for farmers (Major, 2010).

Destructive sampling was conducted in triplicate at 4, 12, and 52 weeks. For wet-dry cycle treatments, sampling points were at the end of each dry period, before rewetting events.

2.3. Water soluble C characteristic and ion analysis

At each time point, 8 g of a representative soil sample was mixed with 40 mL of water in 50 mL polypropylene tubes and placed on an orbital shaker (250 rev min^{-1}, 1 h). Water (>18.2 MΩ cm) was supplied by a Barnstead Nanopure water system (Thermo Scientific, OH). After shaking, samples were centrifuged to remove suspended solids. Supernatant solutions were retained for water soluble C concentrations (mg L^{-1}) measurement by UV-persulfate oxidation (Teledyne-Tekmar Phoenix 8000). Specific UV absorbance (SUVA$_{254}$, L g^{-1} cm^{-1}) of water soluble C was determined by measuring absorbance at 254 nm using an UV/VIS spectrophotometer (UV mini-1240, Shimadzu, Japan). SUVA$_{254}$ index of each sample is defined as the UV absorbance at 254 nm measured in inverse meters (m^{-1}) divided by the dissolved organic matter concentration measured in milligrams per liter (mg L^{-1}). SUVA$_{254}$ was found to be strongly correlated with the aromaticity of organic matter of a water soluble C sample (Weishaar et al., 2003). A weighted average calculation was done based on aromaticity of water soluble C from soil and biochar to identify the source of water soluble C after incubation.

Major anions (Cl$^-$, SO$_4^{2-}$, Br$^-$ and NO$_3^-$, Dionex Ion Pac AS18 column) and cations (Na$^+$, K$^+$, Ca^{2+}, and Mg^{2+}, Dionex Ion Pac CS17 column) were analyzed using a Dionex ICS-2000 Ion Chromatography System (Dionex Corp., Sunnyvale, CA).

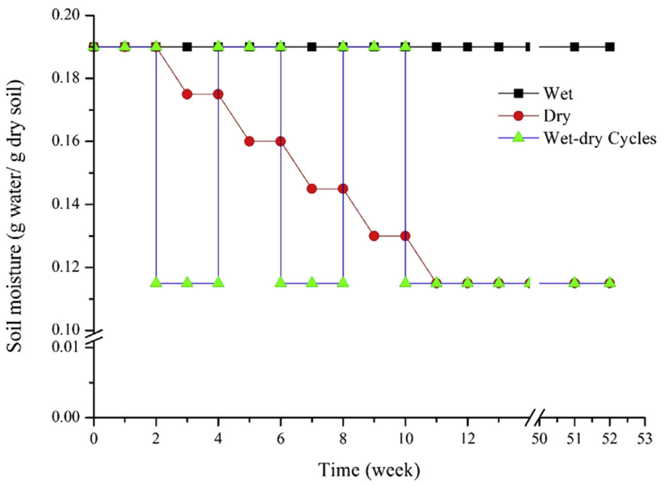

Fig. 1. Diagrammatic sketch of soil moisture change in different water treatments.