



# Modeling simple experiments of biochar erosion from soil



C. Wang, M.T. Walter\*, J.-Y. Parlange

Department of Biological and Environmental Engineering, Cornell University, Ithaca, NY 14850, United States

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## SUMMARY

Biochar is often promoted as an amendment to improve soil quality. However, researchers have recently noted that biochar and similar substances preferentially erode from soil, which may reduce its effectiveness. Identifying the erosion mechanisms may help develop strategies for retaining biochar in soil. To investigate the role of raindrop impact biochar erosion, we applied the Hairsine–Rose erosion model to small-scale experiments that simulated rainfall on a simple biochar–soil mixture. The Hairsine–Rose model simulated the biochar concentrations in runoff well for the early part of the experiments but under-predicted the concentrations for longer times. At the end of the simulated rainfall experiments, biochar content in the soil increased with depth in the soil column from 1% near the surface to 8% in underlying soil layers; similar distributions have been observed for soil, which drives upwards diffusion. By superimposing the Wallach diffusion model on the Hairsine–Rose model we were able to simulate biochar concentrations at both short and long times. We speculate that the relatively dense sand particles are displacing the biochar and we are investigating this further. Our findings suggest that long-term sequestration of biochar in soil is unlikely in soils or parts of the landscape with limited infiltration capacity.

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## 1. Introduction

Recently, biochar, also referred to as bio-char, agrichar, and agri-char, and similar to charcoal, black carbon, and pyrogenic carbon, has been popular as a soil amendment because it has been shown to have many beneficial impacts on soil quality. These include: improved biological nitrogen fixation and nutrient retention and bio-availability (Glaser et al., 2002; Chan et al., 2007; Rondon et al., 2007), reduced plant availability of pesticides (Yu et al., 2009; Kookana, 2010), immobilization of phytotoxic heavy metals (Beesley et al., 2010; Uchimiya et al., 2010), improved plant resistance to pathogens (Elad et al., 2010), decreased non-point source nitrogen and phosphorous pollution (Lehmann et al., 2006). Biochar has also been found to be a potentially effective remedy to polycyclic aromatic hydrocarbon-contaminated soil (Beesley et al., 2010; Chen and Yuan, 2011). Amending soils with biochar is also promoted as a way to sequester carbon in the soil (Lehmann et al., 2006; Lehmann, 2007). However, the specific impacts on soil can vary for biochar produced from different sources or under different pyrolysis conditions (Singh et al., 2010; Uchimiya et al., 2010).

Cheng et al. (2008), Nguyen et al. (2008, 2010), Cheng and Lehmann (2009) and Major et al. (2010) speculate that large amounts of biochar are lost to storm runoff. But few researchers have

investigated biochar erosion mechanisms. Rumpel et al. (2006a) measured the black carbon content along a slope and showed that black carbon tends to be eroded down-slope. In another study, Rumpel et al. (2006b) found more evidence that black carbon was preferentially eroded from the soil; specifically, black carbon content in eroded sediments collected at the outlet of the watershed was twice that found in the original soil. Rainfall experiments on meter-scale plots with black carbon deposited on the surface illustrated the importance of splash erosion on black carbon loss (Rumpel et al., 2009). Indeed, although there are carbon fluxes associated with black carbon loss, e.g. CO<sub>2</sub> emissions, erosion appears to be the largest mechanism of black carbon loss and it is poorly quantified in current models (Foeroid et al., 2011).

Perhaps the main reason why biochar is such a popular soil remedy is that it is a potentially affective way to sequester carbon (Lehmann, 2007). This is because it is very stable as compared to biomass (Lehmann, 2007). Also its fabrication can substitute fossil fuel burning as a power source, which is the primary anthropogenic carbon source to the atmosphere (Lehmann et al., 2006; Lehmann, 2007). Furthermore, biochar benefits soil fertility and crop productivity, which may attract farmers to apply it to soil (Lehmann et al., 2006).

However, preferential erosion may limit the potential benefits of amending soils with biochar, the underpinning processes of which are poorly understood (Rumpel et al., 2006a, 2006b, 2009; Major et al., 2010; Foeroid et al., 2011). To begin to address this

\* Corresponding author. Tel.: +1 607 255 2488; fax: +1 607 255 4080.  
E-mail address: [mtw@cornell.edu](mailto:mtw@cornell.edu) (M.T. Walter).

knowledge gap, we carried-out small scale experiments to isolate the biochar erosion process during rainfall–runoff conditions. We predicated our experiments on the hypothesis that biochar particles behave similarly to fine sediments in the rainsplash erosion process (see Heilig et al., 2001 and Gao et al., 2003 and 2005 for similar experimental studies with fine sediments).

## 2. Experimental design

One part ground-biochar (<250  $\mu\text{m}$ ) was saturated with deionized water. We used a vacuum pump to remove air trapped in the biochar suspension to ensure a saturated state when it was mixed into the sand (250–300  $\mu\text{m}$ ) matrix. The suspended biochar was mixed with nine parts sand to obtain a simple, well-mixed, biochar-amended soil, which was saturated with deionized water. The sand provides an idealized model soil matrix for our experiments without the potential complications of a more realistically complex soil. The soil was packed into a 7.6 cm diameter and 10.6 cm tall plexiglass column with 4 holes at the same height (3.9 cm) placed evenly around the column (Fig. 1) and leveled utilizing a shaking table, and excess water was poured off (set-up adopted from Gao et al., 2003, 2004, 2005).

After measuring the rainfall rate, we protected the study area from rain with an umbrella, and set-up the soil column. Ponding water was added carefully following the process described by Heilig et al. (2001), but the ponding depth varied slightly between different experiments.

We collected 0.5 ml runoff samples from the ponded water using a pipette. The first sample was extracted before removing the umbrella. Then we removed the umbrella, collected samples every 15 s initially and, as the runoff became visually less biochar laden, we lengthened the sampling interval to 30 s, 2 min, 5 min, 30 min and 1 h; the decision to change the sampling time during the experiment was made qualitatively by the researcher operating the pipette. Both rainfall rate and ponding depth were measured before and after each experimental run: we used the average rates and depths in our model (Table 1). Note, all unsampled runoff was allowed to accumulate in a plastic tub, which we checked to make

sure no substantial amounts of sand were being lost from the soil column.

In suspension the biochar particles tended to flocculate, which made it difficult to measure concentrations by spectrometry as Heilig et al. (2001) and Gao et al. (2003, 2005) did for clay. Biochar concentration of each runoff sample was acquired by the difference between the weight of the empty cuvette and the cuvette plus oven dried sample (60 °C to constant weight).

We also did four separate experiments: (1) for determining soil moisture and soil bulk density, (2) initial and (3) final fractions of biochar in soil, and (4) visually verifying the depletion of biochar in the shield layer. For (1) we placed a known volume of soil-biochar mixture in Petri dish and obtained the wet weight minus the Petri dish. Then we dried it at 105 °C for 72 h, and got the dry weight plus Petri dish until the weight stabilized. We used the wet and dried masses and known volume to determine the soil moisture and wet and dry bulk densities. For (2) we divided the pre-experimental soil into two layers, dried them at 105 °C for 24 h in weighed crucibles, weighed the dry weight plus crucibles, combusted them at 950 °C for 3 h, and got the residual weight plus crucible until the weight stabilized with continued combustion. We determined the carbon content by the difference between the masses before and after combustion. For (3) we divided a soil column after a 4-h rainfall into a shield layer and 5 approximately 0.6-cm underlying layers, conducted the same drying, weighing and combusting procedure as in (2). Since a small part of sand is combustible and a small part of biochar is incombustible, we used a sample of pure dry sand and a sample of pure dry biochar to be control in the drying, weighing, and combusting procedure (see Wang, 2013 for details). For (4) we replaced the dark-colored sand in the main experiment with white sand and videoed and photographed the soil during and after the rainfall event.

## 3. Hairsine–Rose model description

Since the biochar we are considering is composed of small, light-weight particles, we adopted the simple form of the

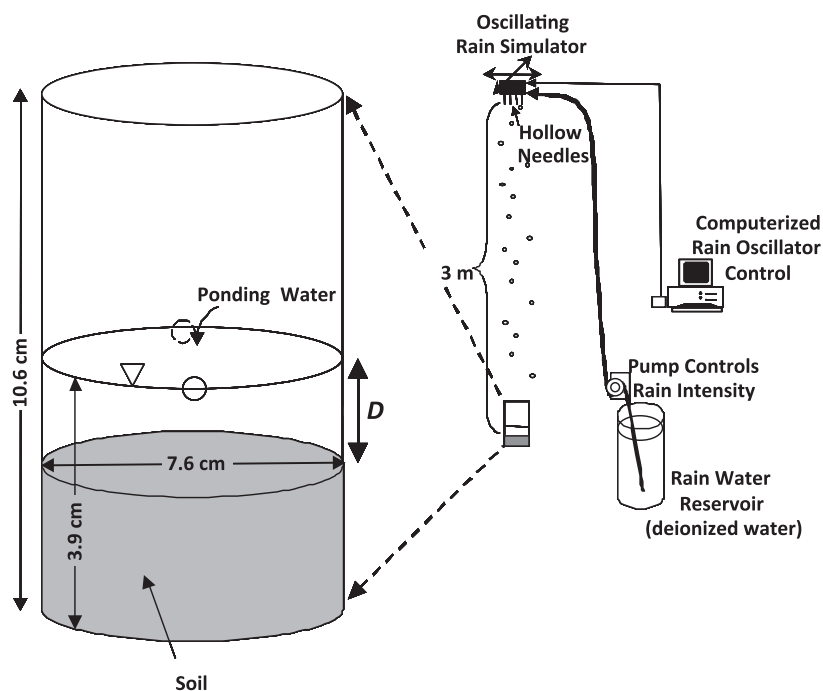


Fig. 1. Experiment set-up, adopted from Gao et al. (2003, 2004, 2005).

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