Biochar carbon: can chemical lability predict biological lability?

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Introduction

Despite a wealth of biochar incubation studies in the literature, efforts to predict the portion of biochar carbon (BC) mineralized following soil application remain stymied by variability in biochar properties and the complexity of interactions between soil C and BC. In particular, understanding the relationship between chemically labile BC and biologically labile BC is vital to accelerate research in this area.
*Here, we test the hypothesis that **hot water-extractable BC can be used to predict biologically labile** (readily bioavailable) **BC.***

Methods

Biochars & Biochar Properties

1. Biochars produced from 5 feedstocks through 4 pyrolysis processes were chosen (9 total; Table 1)*
2. Biochars were ground to <0.5 mm then washed with acid (0.05 M HCl), $CaCl_2$ and water (Milli-Q) to remove carbonates and other soluble salts.
3. Subsamples of the acid-washed biochars were analyzed for labile BC (biochar carbon) 3 ways:
   a) Extracted with water at 80-85C (80:1 wt:wt)
   b) Proximate analysis (Aller et al 2017)
   c) Elemental analysis using a Vario Microcube combustion analyzer

Biochar	Feedstock	Pyrolysis process	Source
CF	Corn stover	Fast pyrolysis	Avello Bioenergy
CS	Corn stover	Slow pyrolysis	Iowa State University
GG	Switchgrass	Gasification	Biochar Solutions, Inc
GS	Switchgrass	Slow pyrolysis	Iowa State University
HA	Hardwood	Autothermal pyrolysis	Iowa State University
HF	Hardwood	Fast pyrolysis	Dynamotive Energy Systems
HS	Hardwood	Slow pyrolysis	Cowboy Charcoal
MF	Macadamia nut shell	Fast pyrolysis	Biochar Brokers
SF	Soybean straw	Fast pyrolysis	BioCentury Research Farm

Table 1 Biochar feedstocks, pyrolysis processes, and elemental composition.
*All biochars were produced at 500-550°C, with 2 exceptions: 1) GG was produced at 800-850°C, and HS was produced at 600-650°C.

Laboratory Incubation

1. Acid-washed biochars (2 g) were weighed into serum vials with crushed, clean glass (18 g, >0.5 mm) to create 10% biochar mixtures. In addition, controls with glass particles only (20 g) were prepared.
2. A microbial inoculant and Hoagland's nutrient solution were added, then water (Milli-Q) was added to bring the samples to field capacity (-1/3 bar matric potential).
3. Samples were pre-incubated at 30°C for 7 days to allow biochar to equilibrate with glass and microbes.
4. Half of the samples received ^{13}C-labelled glucose (0.015 g C, at 25% enrichment) approximately monthly on days 8, 38, 71, 100, 130, 175 and 238 (0.105 g glucose-C total per sample).
5. Additional nitrogen was added as NH_4NO_3 on day 329 to prevent N immobilization.
6. Throughout the 448-day incubation, 30°C temperature and -1/3 bar matric potential were maintained.
7. Gas samples were collected from serum vial headspaces in sets of 3, over 2-24 h intervals for a total of 4-96 h per gas accumulation period. Samples were collected frequently at first, and then less frequently as CO_2 emission rates decreased.
8. Gas samples (11.5 mL) were stored in Exetainer vials (6 mL)
9. $^{12}CO_2$ and $^{13}CO_2$ concentrations were measured by injection on a tunable diode laser absorption spectroscopy (TDLAS, TGA100A, Campbell Scientific, Inc., Logan, UT, USA)

Results

Daily Biochar C Lost as CO_2

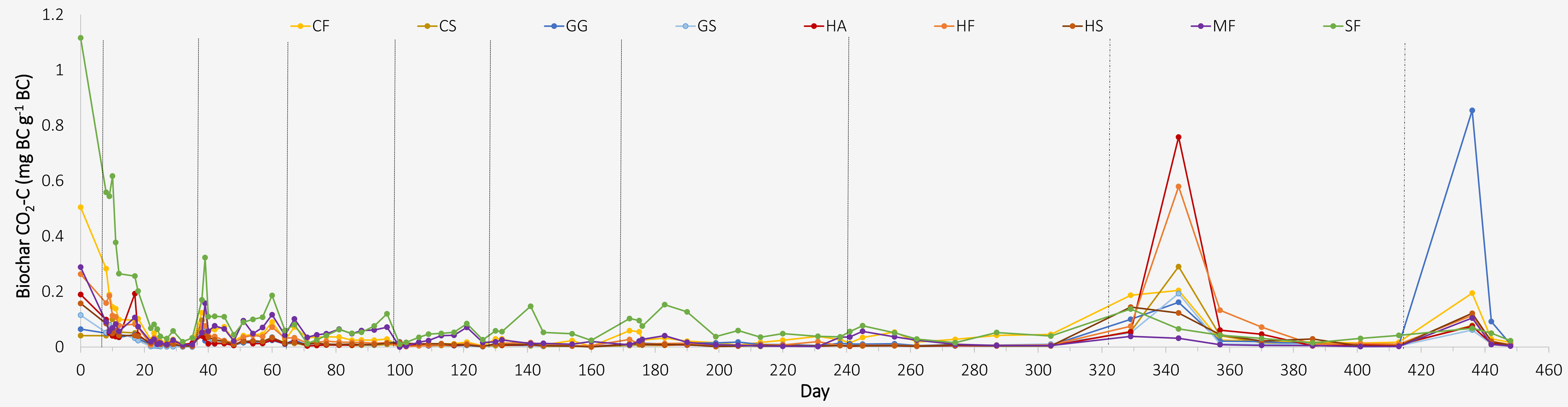

Figure 1: Daily rate of biochar CO_2-C emissions during incubation of the biochar + glucose samples. Each data point is an average for three replicate samples. Short dash lines indicate ^{13}C-labeled glucose additions. Dash-dot lines indicate supplemental N additions (1 mg N per 2 g biochar, as NH_4NO_3)

Total C Lost as CO_2

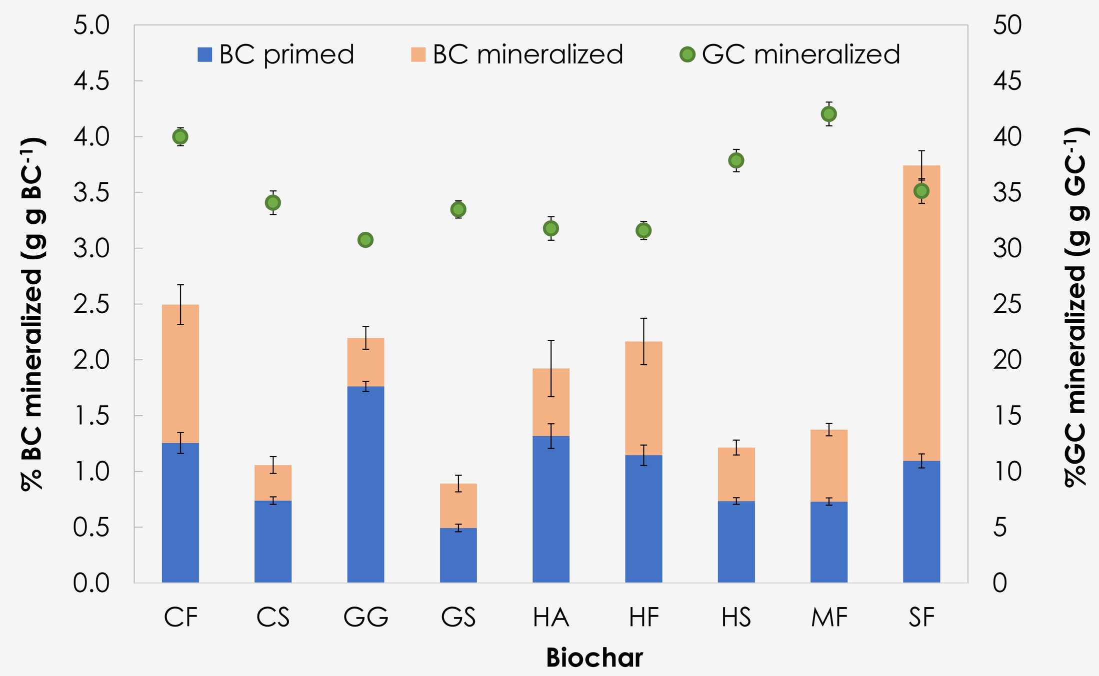

Figure 2 Biochar C primed (blue bars) as %BC, biochar C mineralized without the addition of glucose (light orange bars) as %BC, and glucose C mineralized as a percent of total glucose C (green circles; secondary y axis). Data obtained from the 448-d incubation study of studied (acid-washed) biochars. Error bars represent standard error (n=3).

Biologically vs. Chemically Labile BC

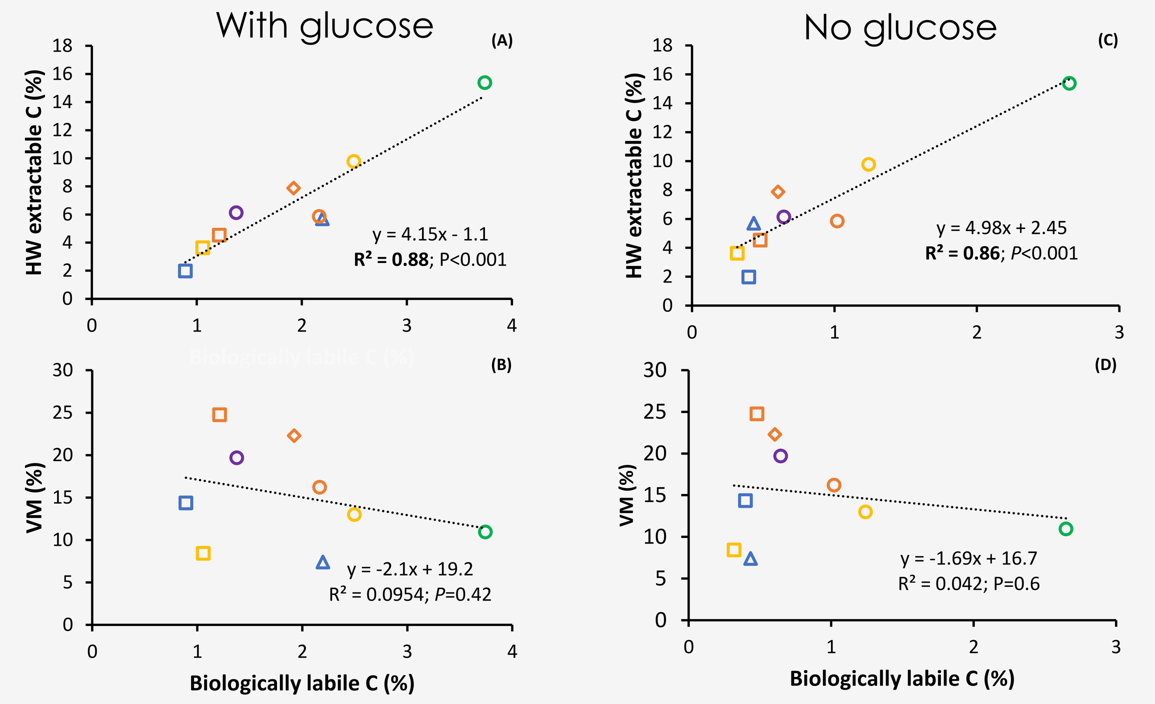

Figure 3 Hot water-extractable C and VM (volatile matter) measured before the incubation (acid-washed biochars) compared with biologically labile C mineralized during the 448-d incubation study with glucose added (A & B) and without glucose added (C & D) biochars. Shapes correspond with pyrolysis methods: squares = slow pyrolysis; circles = fast pyrolysis; triangle = gasification; diamond = autothermal pyrolysis. Colors correspond with feedstocks: yellow = corn stover; orange = hardwood; green = soybean; blue = switchgrass; purple = macadamia nut.

Modeled Biochar C Half Lives vs. H:C Ratios

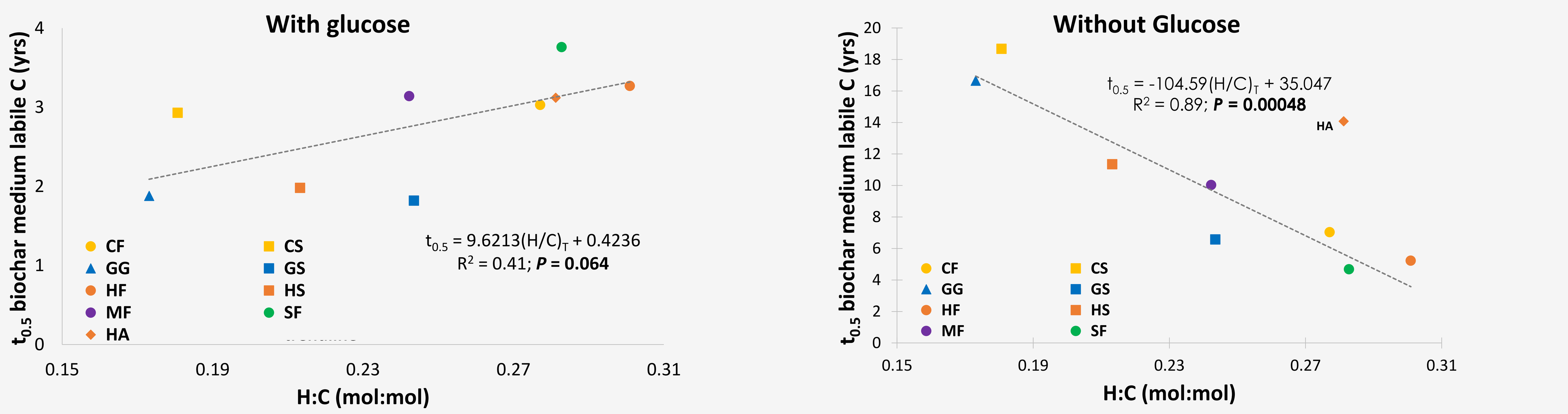

Figure 4 Relationship between the acid-washed biochar H:C molar ratio and predicted half-lives of biochar medium labile C studied here for glucose and non-glucose samples, assuming the half-life of recalcitrant biochar C fraction is 500 yrs. Figure represents the equation of predicting the half-life of biochar medium labile C directly from the H:C (mol:mol) ratio of biochar for non-glucose samples (except HA biochar).

Discussion

•**With glucose**, BC mineralized (including priming) decreased in the order SF > CF > GG > HF > HA > MF > HS > CS > GS
•**With glucose**, more fast pyrolysis BC was mineralized compared with slow pyrolysis biochars (CF>CS; HF > HS)
•**Without glucose**, BC mineralized decreased in the order SF > CF > HF > MF > HA > HS > GG > GS > CS
•**BC primed** (difference between with and without glucose) decreased in the order GG > HA > HF > HS > CF > CS > SF > MF > GS
•More BC was primed from fast pyrolysis biochars than slow pyrpolysis biochars
•>50% of biologically labile (mineralized) BC was primed for all but the soybean fast pyrolysis (SF) biochar
•Hot-water extractable BC was a better predictor of biologically labile BC than H:C ratio or %VM (volatile matter)

Conclusions

•**Hot water-extractable carbon** may be a good predictor of biologically labile biochar carbon (BC)
•**H:C ratio** may also predict biologically labile BC, but it does not account for priming as well as hot water-extractable BC
•**More research is needed** to determine if hot water-extractable BC can predict biologically labile BC in a wider range of contexts, including:
   a) When biochars are produced at a wider range of temperatures
   b) When biochars are produced from more diverse feedstocks
   c) Under different temperatures and moistures
   d) With different non-BC substrates
   e) In a soil matrix, interacting with various minerals, organic matter, and nutrients