A Meta-Analysis of Plant Biomass Response to Biochar

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Key words: *Biochar, soil, plant response*

Introduction

Estimates of biochar's potential magnitude as a strategy for mitigating climate change must be based in part on its economic costs and benefits [1], which include improvement of crop yields [2, 3]. A meta-analysis of experimental results was undertaken to determine (a) average plant response to biochar (BC) at varying concentrations in soil; (b) if there are BC concentrations beyond which plants show declining or negative response; (c) whether biomass charring temperature (as a proxy for aromaticity, conjugation, and thus recalcitrance [4]) influences biomass response.

Data on plant growth, char properties, and soil properties were extracted from 19 studies examining first-year effects of BC [5-23], and analyzed via multiple regression. Constituent studies contained 96 "experiments", defined here as a set of treatments in which only BC addition amount varies. Plant biomass response was calculated as the percentage increase or decrease of a BC treatment from its zero-BC control. Subsets of the data were taken to examine response in fertilized versus non-fertilized experiments and tropical versus temperate environments. For all subsets, three application ranges were examined: 0-10 t ha^{-1}, 10-40 t ha^{-1}, and 40+ t ha^{-1}.

Gaps in reported data precluded a model specification with all soil and char variables. Thus, models took the form $BM = \beta_1 BC + \beta_2 F + \beta_3 pH_s + \beta_4 HTT + \varepsilon$, where BM is plant biomass response (as a percentage change from control), BC is biochar application rate in tons/hectare, F is presence or absence of fertilization (categorical; 0 or 1), pH_s is initial soil pH, and HTT is BC production temperature. Where too few studies reported HTT to run the model with at least half of observations (tropical studies above 10 t/ha), a proxy HTT was derived by regressing BC pH on HTT for observations reporting both, and using the fitted value for those studies missing HTT data.

Results and Discussion

Positive, significant ($p<.05$) β values for BC were predicted up to 10 t ha^{-1} for all sub-sets except unfertilized treatments (Figure 1). Above 10 t ha^{-1}, BM approached zero.

Across all studies, HTT was statistically significant ($p<.05$) and positively correlated to BM in the 0-10 t ha^{-1} range. Also in the 0-10 t ha^{-1} range, pH_s was negatively correlated to BM and significant in the fertilized subset. F was significant only in the tropical subset.

In addition, change in pH was a very strong predictor of biomass response in acid soils, while neutral and alkaline soils showed little change in pH on BC addition (Figure 2). A similar relationship was observed for cation exchange capacity (not shown).

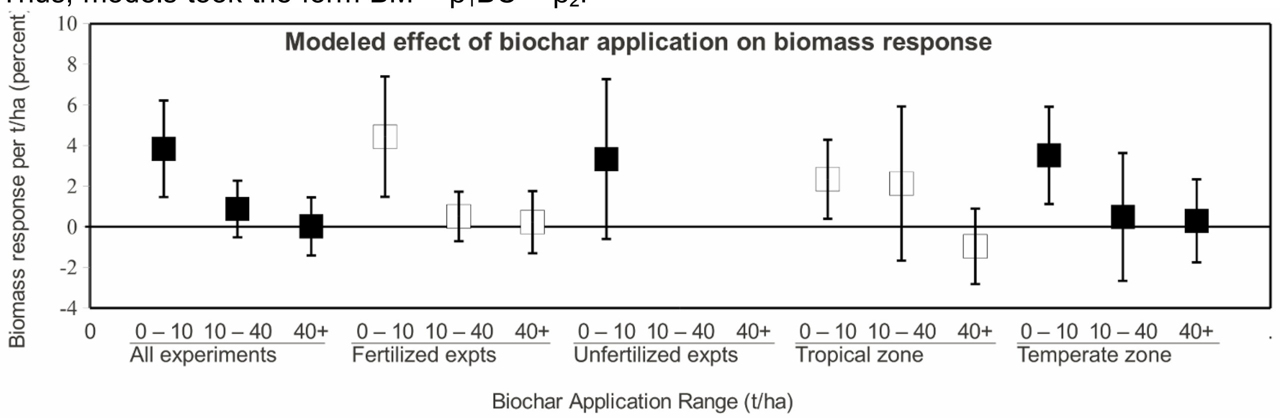

Figure 1. Average plant response to BC across application ranges, and experiment sub-sets.

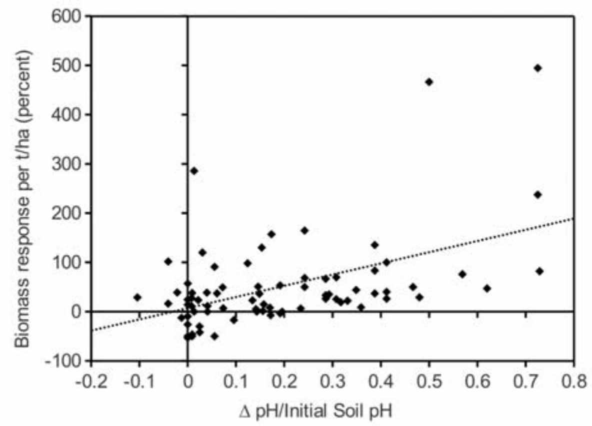

Figure 2. Biomass response to change in soil pH on addition of biochar.

Conclusions

Caution is warranted in interpreting these results due to gaps in data, few observations, and the lack of sufficient studies on multi-year effects of BC. Despite these limitations however, modeled average biomass response to moderate amounts of BC is large and significant. While biomass response diminishes at higher application ranges, it is not immediately possible to draw conclusions regarding accumulation of stable biochar in soil over many years and applications, due to the chemical alteration undergone by BC over time [24], which is not reflected here.

These results also re-confirm that pyrolysis processes and soil properties are very important determinants of biomass response to BC. As noted elsewhere [2], the greatest agronomic opportunities from biochar production may be in acidic and low-CEC soils, while positive correlation between plant response and HTT suggests that agronomic and C sequestration goals may be synergistic in many cases.

Generalized estimates of plant response to BC across broad climatic, soil and management conditions are important for estimating BC's potential as a climate change mitigation strategy. As such, these results provide estimates which may be useful in modeling the economic costs and benefits of biochar vis a vis other climate change mitigation options. However, further studies are required to better understand biomass response in a more specific range of contexts, to higher BC application rates, or to longer-term accumulation of BC in soil.

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