INTERIM REPORT

Biochar for the Colorado agriculture industry: a research assessment of energy, economic and environmental benefits

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Abstract

Biochar has the potential to improve both the environmental and economic sustainability of many agricultural systems. When produced as a bio-energy co-product, from agricultural wastes and amended to soils, biochar may yield economic and environmental benefits for the agricultural industry, potentially reducing inputs and increasing crop production while offsetting GHG emissions. Colorado appears to be an ideal location to adopt a biochar industry, though a complete assessment of biochar's potential benefits and drawbacks at the local level is still needed. We are conducting a one year multidisciplinary research project that investigates, with a thorough scientific approach and state-of-the art methodology, the energetic, environmental and economic aspects of adopting biochar in the Colorado agricultural-industry. The work is progressing smoothly and some laboratory and greenhouse experiments have already been completed, with major findings presented (3 oral presentations and 2 posters) at the American Chemical Society (ACS) meeting. Also several manuscripts are in progress. Facilities and protocols for on-site biochar synthesis have been identified, methods for characterizing the agronomic properties of different biochar varieties have been compiled and tested, and a prototype integrated lifecycle and economic assessment tool has been developed. In summary, this project is progressing well towards its major objectives and will contribute to the basic scientific understanding of biochar. Additionally, it will model biochar's potential economic and environmental benefits to the state's agriculture and energy sector.

a. Work completed to date

We have successfully completed: 1) a short-term laboratory incubation experiment to determine the effects of biochar additions to soils, in interactions with soil N availability, on NH_4 and NO_3 leaching, and greenhouse gas (GHGs, i.e. CO_2, CH_4 and N_2O) efflux; 2) a greenhouse trial on wheat crop to assess if biochar additions to soils benefited crop production and if benefits resulted from improved soil pH conditions. A longer term laboratory incubation to investigate the effects of biochar additions on the priming of soil organic matter and C sequestration, as well as on the overall GHG balance is in progress. Laboratory equipment and experimental protocols associated with synthesizing biochar from raw biomass have been identified, and it is anticipated that charring and characterization of a preliminary set of

Colorado-relevant biomass feedstocks will be completed soon. 3) A prototype of an integrated lifecycle and economic assessment tool has been developed, and preliminary technical estimates of lifecycle greenhouse gas balances for a variety of small-scale biochar-producing systems have been completed. 4) We have developed a detailed first draft of a stochastic enterprise budget. We have identified the line item cost estimates (eg. transportation and non-market values of GHG emissions). We are now modeling the likelihood that the costs, or market prices, will occur. This serves to generate a range of profitability estimates. We meet weekly within the smaller research teams to discuss work progress. Additionally we have periodic all participants group meetings to report progress, integrate activities and plan future work.

b. Progress towards expected outcomes

We have made significant progress towards the expected outcomes. Research findings to date have been presented at the ACS annual conferences, and will also be presented at the ASA-CSSA-SSSA annual conference in October. We have prepared the first draft of an extension publication on the market for biochar in Colorado. We anticipate that this publication will enter the review process within the next 30 days.

We have also been able to leverage preliminary results from this project to submit a grant proposal to a U.S. Department of Agriculture and Department of Energy pre-proposal. The proposed project will evaluate the economic impact of biochar and biomass on the Western Slope of Colorado, in order to make progress towards stimulating regional economic development. Our proposal was submitted in cooperation with the Flux Farm Foundation, who is one of the collaborators on our ACRE project. We were only one of 50 teams of a field of 250 invited to submit a full proposal, due on November 22, 2011.

c. Preliminary findings

Our *laboratory experiments* were conducted using oak-wood derived char produced by fast pyrolysis at 550°C. The char was sieved to obtain two size fractions: > 250μm (BC1) and < 250 μm (BC2). We used four different soils varying for OM content and texture. One experiment was conducted over a period of 4 months, on two of these soils with two N addition levels and two biochar types. The other is still in progress, and is conducted on the four soils, one char type (<250 μm) and five addition rates (0, 1, 5, 10 and 20 % by weight). The findings #1-3 derive from both experiments.

1. <u>Effects on soil N dynamics</u>

Biochar addition significantly changed soil N dynamics over time in fertilizer amended soils, but differently for the two soils. Over the entire experiment, biochar addition significantly

decreased cumulative extractable NO_3 ($p < 0.0001$) but had mixed effects on NH_4 ($p=0.027$). The larger sized BC significantly reduced N (NO_3 & NH_4) during the first extraction event in the sandy soil, but had no effect on the loam soil. Nitrate leaching peaked between day 15 and 23 in all treatments but the fertilizer biochar treatment in the loam soil, which sustained greater losses 2-3 months in the incubation.

The effects of biochar on soil N dynamics were also reflected in N_2O emissions. In the loamy soil, biochar significantly reduced N_2O flux, and also shifted peak N_2O flux from the second sampling to the 15th day of the incubation. The larger biochar addition to the sandy soil significantly decreased the N_2O flux on day 23.

These data confirm results of the companion experiment looking at biochar addition rate effects, where N_2O emissions were suppressed in 3 of the 4 soils, although the response to addition rate varied from 20% to 94% reduction depending on soil type.

2. <u>Effects on soil priming and C sequestration</u>

In both our incubation experiments, biochar additions resulted in greater CO_2 efflux from the system, but the respiration efficiency, i.e. the amount of CO2 released per unit C in the system was significantly reduced. Also BC addition reduced the mineralization of native soil organic matter (i.e. negative priming) and overall CO_2 losses accounted for only 1-2 % of char additions. Thus BC addition to soils resulted in significant C sequestration in the soil, with the amount of C being sequestered linearly related to the rate of BC addition and independent of soil type.

3. <u>Effects on the net GHG balance</u>

In our experiments we also quantified emissions of GHGs as well as C remaining in soils as a result of BC amendments. For all of the four soils investigated, BC additions resulted in negative GHG balances as a result of C sequestration in soils rather than reduction of GHG emissions. The effect was proportional to BC addition rates.

Biochar addition to soils produced no consistent effect on GHG emissions and reflects the variety of responses reported in the literature for individual studies. Our data suggest that decreases in N_2O after biochar addition to soils can contribute to reduced GHG emissions from soils. In these soils, the addition of the larger biochar generally resulted in increased emissions (3 of 4 treatments) where the fine biochar resulted in decreased GHG emissions (3 of 4 treatments). Since biochar addition alters the soil chemical and physical properties it is difficult to isolate the reason for the apparent difference in response. However, it could be due to the larger particle sizes increasing soil aeration, providing habitat for soil microbes, or be a byproduct of a slightly greater inherent N concentration. Biochar addition to soils may have

beneficial N_2O reductions, but this response appears varied, even in short-term incubations with the same biochar applied to soils.

4. Effects on wheat growth

A full factorial *greenhouse experiment* was conducted with 3 soils and 5 amendments, and all treatments in 12 replicates. The three soils varied for pH (from 5.2 to 8.2) and the amendments consisted in three different biochar also varying for pH (from 9.5 to 11.7), a lime treatment and a control. Lime and certain biochar treatments increased pH of acid and neutral soils by more than 1 unit. Biochar treatments always performed positive or neutral with respect to control, with significant yield increases in acid and neutral soil from straw and stover char, while pine char addition had no effect on biomass. Biochar treatments had no effect on yields from alkaline soils, whereas liming significantly reduced yield. The observed divergence between biochar and liming treatment response suggests significant non-pH mediated benefits from char addition.

5. Effects on Char Production

Prototype biochar lifecycle assessment tool has been created to evaluate energy fluxes and GHG emissions associated with feedstock transport, gasification/pyrolysis, energy co-production, and biochar soil incorporation, as well as the embodied energy and emissions of the pyrolysis/gasification equipment. The assessment tool is unique in that it considers direct air pollutant emissions from the pyrolysis equipment, a potential drawback of smaller pyrolysis systems that has been largely neglected in the biochar lifecycle assessment literature to date. Preliminary lifecycle GHG emission projects that small-scale systems without some form of energy co-generation will be greenhouse gas neutral at best, as the direct carbon sequestration value of the biochar produced is likely offset by emissions from energy inputs into the production lifecycle. Furthermore, systems with insufficient pyrolysis gas flaring are expected to be strong net GHG sources due to the high global warming potential (GWP) of exhaust pollutants such as methane and elemental carbon particulate matter. However, the efficient co-production of energy and biochar for soil incorporation is projected to have significant greenhouse gas mitigation value, sequestering or avoiding a total of approximately 1 ton of CO_2 equivalent GHGs for every ton of feedstock biomass consumed.

6. Effects on economic feasibility

Preliminary results indicate that there is a broad range of non-market value for GHG emissions. At this writing, it appears that environmental regulation of GHG emissions will be necessary to make this project economically feasible in the next 1-3 years. Due sluggish national macroeconomic conditions, it is unlikely that a market for GHG emissions (such as carbon) will emerge without government intervention. As our research team gains a better understanding

of the effect of engineering variables on the economic variables (such as cost), we believe that we will discover engineering enhancements that might directly improve economic feasibility, and profitability.

d. Problems being encountered

No major problems were encountered in the execution of the laboratory experiments and greenhouse trial. We are confident that we will complete the projects within the expected time frame and produce the major proposed deliverables.

e. Next step

We will continue with the data analyses and publication of the major findings from the performed/on-going experiment. Major effort will be put into the completion of the economic and life cycle analyses. In parallel, we anticipate commencing with biochar synthesis in-house soon, concentrating initially on local feedstocks of beetle-kill pine wood, wheat straw, and corn stover. First, small samples will be run on a thermogravimetric analyzer with mass spectrometer (TGA-MS) that will allow us to collect detailed mass and energy balance data on the pyrolysis process at a variety of pyrolysis temperatures and heating rates. This data will be incorporated in the integrated assessment model, improving conversion process modeling for the feedstocks in question. Once optimal pyrolysis conditions have been identified in the TGA-MS, these conditions will be replicated at larger scale in a laboratory kiln, yielding larger samples of biochar for analysis and possible future experimental work. These samples will be evaluated in the laboratory for pH, lime equivalence, and nutrient content, and this data in turn will be integrated into the assessment model in order to predict agronomic response. Thus, the char lifecycle will be fully modeled from synthesis to field incorporation using laboratory data specific to the Colorado-relevant feedstocks, allowing the identification of environmentally and economically-optimal feedstock materials and conversion processes. We are continuing to update our economic model with price and cost data information.

f. Anticipated changes to project time line

We do not anticipate any major change to the project time line