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Cross-scale modelling of the climate-change mitigation potential of biochar systems: Global implications of nano-scale processes

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With CO_2 emissions still tracking the upper bounds of projected emissions scenarios, it is becoming increasingly urgent to reduce net greenhouse gas (GHG) emissions, and increasingly likely that restricting future atmospheric GHG concentrations to within safe limits will require an eventual transition towards net negative GHG emissions. Few measures capable of providing negative emissions at a globally-significant scale are currently known. Two that are most often considered include carbon sequestration in biomass and soil, and biomass energy with carbon capture and storage (BECCS). In common with these two approaches, biochar also relies on the use of photosynthetically-bound carbon in biomass. But, because biomass and land are limited, it is critical that these resources are efficiently allocated between biomass/soil sequestration, bioenergy, BECCS, biochar, and other competing uses such as food, fiber and biodiversity.

In many situations, biochar can offer advantages that may make it the preferred use of a limited biomass supply. These advantages include that: 1) Biochar can provide valuable benefits to agriculture by improving soil fertility and crop production, and reducing fertlizer and irrigation requirements. 2) Biochar is significantly more stable than biomass or other forms of soil carbon, thus lowering the risk of future losses compared to sequestration in biomass or soil organic carbon. 3) Gases and volatiles produced by pyrolysis can be combusted for energy (which may offset fossil fuel emissions). 4) Biochar can further lower GHG emissions by reducing nitrous oxide emissions from soil and by enhancing net primary production.

Determining the optimal use of biomass requires that we are able to model not only the climate-change mitigation impact of each option, but also their economic and wider environmental impacts. Thus, what is required is a systems modelling approach that integrates components representing soil biogeochemistry, hydrology, crop production, land use, thermochemical conversion (to both biochar and energy products), climate, economics, and also the interactions between these components. Early efforts to model the life-cycle impacts of biochar systems have typically used simple empirical estimates of the strength of various feedback mechanisms, such as the impact of biochar on crop-growth, soil GHG fluxes, and native soil organic carbon. However, an environmental management perspective demands consideration of impacts over a longer time-scale and in broader agroecological situations than can be reliably extrapolated from simple empirical relationships derived from trials and experiments of inevitably limited scope and duration. Therefore, reliable quantification of long-term and large-scale impacts demands an understanding of the fundamental underlying mechanisms. Here, a systems-modelling approach that incorporates mechanistic assumptions will be described, and used to examine how uncertainties in the biogeochemical processes which drive the biochar-plant-soil interactions (particularly those responsible for priming, crop-growth and soil GHG emissions) translate into sensitivities of large scale and long-term impacts. This approach elucidates the aspects of process-level biochar biogeochemistry most critical to determining the large-scale GHG and economic impacts, and thus provides a useful guide to future model-led research.