WHAT HAVE WE LEARNED ABOUT BIOCHAR SINCE BIOFUELWATCH 2011 REPORT WAS PUBLISHED?

UPDATE BY RACHEL SMOLKER, JANUARY 2020

biofuelwatch

In 2011 Biofuelwatch published Biochar: A Critical Review of Science and Policy.[1] In that report we highlighted the uncertainties about biochar including the large land area that would be required to supply biomass for a global scale impact, the contradictory results to date with respect to any long-term carbon sequestration potential (thousands of years as claimed by many proponents who blithely extrapolated from ancient Terra Preta). We highlighted the lack of field studies under natural conditions as opposed to lab incubation studies which do not necessarily translate to natural conditions.

Given recent attention to biochar, for example in the context of the IPCC land sector mitigation report,[2] we decided it would be important to update our understanding. We therefore recently reviewed literature published since publication of our report. What we have concluded from that review is that 1) there has been a massive proliferation of studies of biochar over the past several years reflecting a greatly expanded interest and an influx of funding to soil science researchers. 2) There has been a widening of the scope of proclaimed “uses” for biochar – no longer just for carbon sequestration, but now for many other applications including increasing water retention in soils, improving nutrient uptake in agriculture, reducing fertilizer use and reducing emissions from fertilizer applications, use as feed for cattle to reduce methane emissions, and more. One gets the impression that (for some inexplicable reason) there is great interest in finding ***something*** useful to do with biochar.

As was the case when we published our report, review of the subsequent published literature reveals that results from studies are extremely variable – fair to say all over the map. Many studies are very specific to a certain soil type, a particular condition or crop, under variously specific controlled conditions, and usually over very short time periods.

One can only conclude from this high variability that we are still very far from having a reliable understanding of biochar's impacts – both the impacts on soils and plant growth resulting from application of biochar, and impacts from land use change to supply biomass for the production of biochar.

The representation of biochar as a "workable" approach to land sector mitigation by scientific bodies such as the IPCC, given such a lack of consistent reliable research results is highly premature and unfortunate.

INCONSISTENT RESULTS

While researchers have focused considerable attention on the nature of the biochar itself, Schmidt et al (2011) had earlier pointed to the key role of environmental conditions, stating: "*persistence of soil organic carbon is primarily not a molecular property [of biochar] but an ecosystem property*". The variability of results which has subsequently become only more evident supports this "ecosystem property" interpretation, and fits with research demonstrating remarkably wide variation in soil properties and microbial communities even from one microsite to the next and over time, and also the varying effects of weather, moisture and temperature, among other ecosystem conditions, all of which appear to affect the performance of biochar.[3]

This has only been further confirmed more recently. For example, Wang et al (2016) report: "*biochar degradation depends on the soil characteristics, but the details of these interactions still require specific mechanistic investigation*".[4]

He et al (2017) conducted a meta analysis of GHG fluxes from soils based on 91 published studies and report that biochar additions to soils "significantly ***increased*** GWP by 46.22%". They point out that results from lab incubation studies differ from field studies, and point to a "*lack of field-scale studies especially those lasting at least two successive seasons.*"

In addition they provide a good overview of the many mechanisms proposed to explain the widely divergent results for biochar in literature:

"*The contradictory reports of changes in size and even direction of soil GHG emissions when biochar is applied and the diversity of mechanisms proposed suggest that biochar effects may depend on many factors including soil properties, experimental methods, artificial cultivation management, biochar application rate and biochar physicochemical properties (Hilscher & Knicker 2011; Lorenz& Lal 2014). These factors may determine to what extent biochar alters soil C and N transformation processes and consequently soil GHG emissions. However, how these factors contribute to the variable response of soil GHG emissions to biochar application across the globe still remains unclear. If these factors are not adequately addressed the effects of biochar application on mitigating global warming cannot be fully understood.*"[5]

PRIMING

Biochar proponents have long claimed biochar carbon remains stable for thousands of years based on extrapolation from ancient Terra Preta soils. This claim has been the basis for advocating that soil carbon sequestration, using biochar, can effectively address climate change.

However, following application of biochar to soils, carbon emissions result from both the decomposition of the biochar itself, and from "priming" – the decomposition of pre-existing soil organic matter (SOM) stimulated by microbes that proliferate as a result of biochar addition. Priming can result in some cases in a net decrease rather than an increase in total soil carbon. "*Pyrogenic carbon (biochar) amendment is increasingly discussed as a method to increase soil fertility while sequestering atmospheric carbon (C). However, both increased and decreased C mineralization has been observed following biochar additions to soils.*"[6]

A number of more recent studies have used stable C isotope labeling which allows researchers to differentiate between emissions resulting from biochar decomposition vs soil organic matter decomposition, or other sources (litter, added glucose etc).

Wang et al (2016) provided a meta-analysis, looking at both the rate of biochar decomposition and the rate of soil organic matter decomposition in a subset of studies using C13 or C14 labeling which enabled differentiation of sources of C emissions from soils.[7] They point out that their analysis was undertaken because "*the extent of biochar decomposition and its mean residence time (MRT) in soils means its stability remains nearly unknown*" [this is direct quote]. They report that biochar decomposition rate depends on experimental duration (higher shortly following application and slowing over time), feedstock, pyrolysis temperature and soil clay content. Soil organic matter decomposition was markedly accelerated by application of biochar to sandy, low fertility soils. The authors reported that about 3% of biochar carbon is "labile" and rapidly released following application. The rest, (97%) of biochar carbon they presume could remain stable for over 500 years based on extrapolation from the rate of decomposition during the study period. (Note that such extrapolation would assume stable environmental conditions).

SHORT TERM LAB INCUBATION STUDIES CANNOT TRANSLATE TO NATURAL CONDITIONS

It still remains highly problematic that the bulk of biochar studies are very short term, and done in laboratory or controlled conditions with few lasting more than just a year or two - under "real world" conditions. This was the case when we did our initial analysis and still remains the case.

Ameloot et al (2014) state: "*Most studies looking into the effect of amendment of biochar on soil microbial functioning employ short- term laboratory studies and probably describe relatively transient phenomena.*" After completing a 5-year (hardly long term!) study of biochar in various natural field conditions, they conclude: "*In contrast to many short-term laboratory studies, it therefore seems unlikely that biochar would still function as a substrate 1-4 years after incorporation in the field.*"[8]

Keith et al further point out that: "*Thus far, priming effects between soil and biochar have been predominately assessed in the exclusion of plants.*"[9]

Extrapolating from laboratory incubation studies under controlled conditions, without plants or exposure to natural environmental conditions, cannot be a basis for claims that biochar can be used on a large scale as an effective tool for "climate mitigation"!

VAST AREAS OF LAND REQUIRED FOR BIOMASS FEEDSTOCK

The vast supply of biomass that would be required to produce significant quantities of biochar would have huge implications, globally, on land use – a concern that has been long discussed in the context of large scale bioenergy, or BECCS. Woolf et al (2010) claimed that biochar could reduce global emissions of greenhouse gases by 12% annually, and that claim continues to be widely cited.[10]

The authors claimed to control against food insecurity, loss of habitat and land degradation in coming to this very large technical potential. It is however based on the assumption (hidden within supplementary materials to the article) of conversion of an area approximately 556 million hectares of "abandoned cropland" that could be converted to crops and trees to produce biochar. In addition to tropical grasslands that could be turned into short-rotation tree plantations to produce both biochar and animal fodder. This massive scale of land conversion would have very significant consequences for biodiversity and human rights.[11]

Any global scale biochar initiative would require not only access to land for biomass, but also massive infrastructure, capacity to harvest and transport large quantities of biomass from virtually all landscapes, process it into biochar in a multitude of pyrolysis facilities, and then redistribute and apply (tilling) the biochar over vast tracts of land.

Our concerns regarding land use change implications of large scale biochar implementation remain.

NEGATIVE EMISSIONS CLAIM DEPENDS ON NONEXISTENT SIMULTANEOUS ENERGY GENERATION DURING PRODUCTION

It is frequently claimed that biochar production is a byproduct of energy generation using pyrolysis. The claimed energy production is included in carbon accounting for biochar "benefits", sometimes referred to as delivering "negative emissions" or even included among approaches for "climate geoengineering".[12]

Co-production of biochar with energy in "modern advanced" facilities, remains technically unproven. Production of biochar is essentially the same as producing charcoal, an ancient technology practiced the world over to produce cooking fuel, and a major cause of pollution and deforestation. In fact many studies of "biochar" are in fact studies of charcoal residues from wildfires or old cook fires. Both use pyrolysis (limiting oxygen supply during combustion). Pyrolysis results in conversion of biomass in part to either a gas (syngas) or bio-oil (depending on how hot and for how long) and the remainder as solid char. The term "biochar" implies use of modern commercial scale pyrolysis, and would theoretically make use of the resulting syngas/bio-oil for energy production and the application of the resulting char to soils rather than as cooking fuel.

However, there is an inherent trade-off: maximizing energy (syngas/bio-oil) production through pyrolysis mean minimizing biochar production and vice-versa. There is evidence that pyrolysis processes that are optimised for biochars suitable for crops co-produce poor-quality bio-oils for energy, i.e. that the aims of making high-quality biochar and high-quality bio-oil may be incompatible.

Further, only a couple of companies worldwide have managed to use pyrolysis for any sort of bioenergy production on a commercial scale whatsoever. It has proven technically challenging, and most attempts to scale up pyrolysis have failed. See our briefing[13] for a review of the technical challenges.

Without energy co-production, charcoal/biochar production remains extremely inefficient.

BIOCHAR = BLACK CARBON, BREAKS DOWN, BECOMES AIR AND WATER BORNE AND IMPACTS ALBEDO

Biochar, like charcoal, soot, black carbon… all refer to "pyrogenic carbon": "*Pyrogenic carbon (PyC) is a general term describing thermochemically altered (pyrolyzed) carbon derived from the incomplete combustion of organic matter during biomass burning and the consumption of fossil fuels. Ranging in size from macroscopic fragments to individual pyrogenic molecules, PyC is present in atmosphere, soils, sediments, ice, terrestrial water bodies, and the ocean*."[14]

Pyrogenic carbon degrades over time, sometimes rapidly, sometimes very slowly, via chemical transformation, microbial processes and other means, or it may be transported from place to place by water or air. While it is known that some charcoal remains from wildfires or ancient cook fires found in soils, for example, can be traced back for centuries, we cannot know what proportion has meanwhile degraded, transformed or otherwise disappeared. Recent studies show that in fact a very large proportion of pyrogenic carbon in soils is dissolved and transported out of soils and into waterways.[15]

This breakdown and environmental transport of black carbon/biochar particles makes it impossible to predict the ultimate long-term fate of biochar when added to soils.

Biochar is black and therefore darkens soils, reducing albedo, which could undermine proclaimed climate benefits. Verheijen et al 2013 state: "*Surface application of biochar resulted in strong reductions in soil surface albedo even at relatively low application rates.*"[16]

Meyer et al 2012 state: "*…The analysis resulted in a reduction of the overall climate mitigation benefit of biochar systems by 13–22% due to the albedo change as compared to an analysis which disregards the albedo effect.*"[17]

Biochar particles break down to produce dust that can become airborne black carbon. Ravi et al. 2016 state:

"*…black carbon emissions from soils amended with biochar may counteract the negative emission potential due to the impacts on air quality, climate, and biogeochemical cycles…. Our results demonstrate for the first time, that biochar addition signicantly increases particulate matter emissions from the two soils and the sand studied... Considering the impact of black carbon aerosols for air quality and global climate, the emissions resulting from biochar-amended soils and their downwind impacts are important factors to consider in biochar-based carbon sequestration, remediation and soil quality improvement programs.*"[18]

BIOCHAR IN AGRICULTURE?

Studies of biochar as a tool to reduce emissions from agriculture, like those on soil carbon, are highly variable, indicating that it would be premature to promote wide adoption of its use as any effective "solution".

A 2017 review by Kamman et al repeatedly highlights the contradictory results, the lack of understanding of mechanisms, hence inability to control the effects of biochar on emissions of N_2O, CH_4 and its impacts as a fertilizer addition, livestock feed additive etc. The authors state: "*In spite of the extensive literature published during the past several years on the topic, knowing if a biochar will be effective in mitigating N_2O emissions in a certain agricultural field is still highly unpredictable*".[19]

Liu et al 2017 point out: "*…a comprehensive and quantitative understanding of biochar impacts on soil N cycle remains elusive… Besides, if the pyrolytic syngas is not purified, the biochar production process may be a potential source of N_2O and NO_x emissions which correspond to 2 to 4% and 3 to 24% of the feedstock-N, respectively. This study suggests that to make biochar beneficial for decreasing soil N effluxes, clean advanced pyrolysis technique and adapted use of biochar are of great importance.*"[20]

TOXINS

Increasing attention has been put to toxins associated with biochar.

Dutta et al 2016 state: "*Although biochar has been proposed as a 'carbon negative strategy' to mitigate the greenhouse gas emissions, the impacts of its application with respect to long-term persistence and bioavailability of hazardous components are not clear*".[21]

Koltowski et al 2015: "*Due to the high content of PAHs in biochars, their utilisation in agriculture is* *questioned. However, in the literature there is a lack of evidence whether and what amount of PAHs in biochar may create a threat to living organisms.*"[22]

Others have looked at metal contamination from biochar and its negative impacts on plant growth.[23]

An important study of the impacts of biochar on plant growth, by Viger et al 2015, reported: "*Positive growth effects were accompanied by down-regulation of a large suite of plant defense genes, including the jasmonic acid biosynthetic pathway, defensins and most categories of secondary metabolites. Such genes are critical for plant protection against insect and pathogen attack, as well as defense against stresses including drought.*"[24]

In sum, biochar remains an unproven approach that simply should not be incorporated as a viable option to climate mitigation at this stage. We concur with Ventura, et al 2015: "*Without a robust evidence base of field data, evaluating the carbon mitigation potential of biochar technology, its diffusion and social acceptance is not justified.*"[25] As is the case for any largescale bioenergy (or BECCS), biochar production as a tool for climate mitigation would require availability of vast quantities of biomass with all the serious negative implications for land use, food security and biodiversity entailed. Taking such risks makes no sense given that consistent demonstration of biochar's effectiveness for carbon sequestration or any other use still remains woefully lacking.

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