A critical review of biochar science and policy

– Executive Summary –

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As the impacts of climate change escalate, efforts to develop new technologies and new approaches to reducing emissions are promoted. One proposal is to sequester carbon in soils using biochar. Biochar is essentially fine grained charcoal. Advocates claim that adding biochar to soils will store carbon safely away from the atmosphere for hundreds or even thousands of years, while boosting soil fertility and providing other benefits.

What is the basis of these claims?

Is biochar really a viable approach?

This briefing is a substantially expanded update of our 2009 “Biochar for Climate Mitigation: Fact or Fiction”. It takes a critical look at the claims around biochar, reviews the science underlying the claims, provides an overview of what biochar advocates are pushing for in terms of policies and supports, and presents an outline of the companies involved. It is an interim report, with the final version due to be published during the UN climate conference in Durban.

What is biochar?

The International Biochar Initiative (IBI), the main lobbying group consisting largely of academics, entrepreneurs, carbon offset and other consultants, defines biochar as “the carbon (C) rich product when biomass, such as wood, manure or leaves, is heated with little or no available oxygen...produced with the intent to be applied to soil as a means to improve soil health, to filter and retain nutrients from percolating soil water, and to provide carbon storage”. Biochar, under that definition, would include traditional charcoal, char produced through gasification (which turns solid biomass into syngas and leaves around 10% of it behind as char) and modern pyrolysis (which produces syngas and bio-oil, both of which can be captured for bioenergy, as well as varying amounts of char), as well as through a very experimental technology called hydro-thermal carbonisation. However, what is generally advocated as biochar is produced through modern pyrolysis, in which energy is captured and a significant proportion, usually 12-40% of the original biomass, is retained as char – and that is not identical to traditional charcoal. As the IBI's definition shows, biochar is defined by its purpose, not by its chemical properties. Chemically, the only common feature of different biochars is that they are forms of black carbon biomass, defined as the 'incomplete product of combustion'. The physical structures and chemical properties of different forms of black carbon, and thus different biochars, vary widely depending on what type of biomass it is made from, how it is made and various other factors.

It is increasingly evident that the performance of biochar in soils depends to large extent on precisely these properties. Yet, surprisingly, few of the studies on which claims about biochar are based actually utilised char residues from modern pyrolysis. Rather they looked at the use of traditional charcoal, or at charcoal and soot left over after wildfires or swidden agriculture, and some even at soot deposited after fossil fuel burning. Because of the very different characteristics of these materials, in combination with the even greater variation in soils, it may never be possible to draw general conclusions about the impact of biochar on soils and plant growth.

Field testing – by far the most relevant type of testing – is surprisingly lacking. Only around 13 peer-reviewed field studies, based on 11 different trials have been published; their results vary greatly, even within individual studies, and only two lasted longer than two years. The current evidence base is thus far too small for making reliable predictions about the impact of different biochars on different crops, in different soils and in different combinations with organic or mineral fertilisers.

Climate impacts of biochar: claims versus science

Biochar advocates base their claims that biochar will sequester carbon for hundreds or thousands of years on a combination of 1) laboratory incubation studies (in which soil samples with biochar are kept under warm to high temperatures and carbon losses are measured over time), 2) studies of old charcoal remains from wildfires and swidden agriculture and from Terra Preta. Terra Preta are soils created by indigenous peoples in the Central Amazon, hundreds to thousands of years ago, which still contain large amounts of black carbon and exhibit a high degree of fertility. Modern biochar however, bears little resemblance to this. Terra Preta soils were made using many different materials and a process which is no longer known. Simply adding one ingredient, charcoal, to soils, generally in the context of monoculture cropping practices, is not the same and the analogy is not supported by evidence. While it is clear that charcoal can in some cases be stable over long periods, it is also clear that this is not always the case, and that the reasons for this variability are not well understood or controllable.

Nonetheless, biochar advocates claim, for example, that biochar could sequester as much as 2.2 billion tonnes of carbon every year by 2050, that it can be useful for climate geo-engineering as a means of "carbon dioxide removal", and refer to biochar as a way of "enhancing" the global carbon cycle. Such large scale visions would entail large scale conversion of lands to grow biochar feedstocks, raising the potential for land grabs and expanding monocultures and deforestation. One recent report published in Nature Communications, co-authored by leading IBI members, claims a theoretical potential for biochar to reduce global emissions by 12% based on "sustainable" levels of biomass harvest – yet this included conversion of 556 million hectares of land.

These claims are alarming, especially given the dearth of scientific studies and the mixed results from those that were performed.

Biochar field trials and soil carbon

Is the claim that biochar will remain stable in soils for hundreds or even thousands of years accurate? This is a critical question, and any assumptions must be tested in field studies, ideally using pyrolysis biochar, rather than looking at charcoal remains from ancient wildfires and swidden agriculture practices or laboratory incubation studies, which are problematic.

Of the 11 field trials that exist, only 5 looked at what happens to soil carbon when biochar is added and one of those (tinyurl.com/3nvyg66) looked at 'charred soil' rather than what is usually regarded as biochar. The others were based on the application of traditional charcoal in soils, not modern pyrolysis biochar.

In a 4-year study in Colombia, two years after a large amount of biochar (20 tonnes per hectare) was applied, the plots with biochar held significantly *LESS* carbon than those without. In a separate two-year study from Colombia, biochar made no significant difference to soil carbon, except when an exceptionally large amount (116 tonnes per hectare) was used.

In an 18-months long trial in Western Kenya, Tithonia leaves, manure, sawdust and biochar were applied to different plots on four different soils (with different levels of existing soil carbon). At the end of the trial, soils amended with biochar had the highest overall carbon levels in only one out of four soil types.

In a study in Central Amazonia, biochar on its own and in most combinations with other fertilisers did not significantly improve soil carbon five months after it had been applied.

In the Philippines, adding biochar to three rice fields did raise soil carbon levels at two locations compared to unamended soil or soil amended with rice husks, but at a third location, the plots with the uncharred rice husks held more carbon than those with the biochar.

In summary, field study results so far suggest that biochar is not a reliable way to increase soil carbon. It is not clear what happened to the 'lost' carbon in these different studies. Some biochar carbon might not have been stable. Some biochar may have stimulated soil microbes which then turned existing soil organic carbon into CO_2 (called "priming"). Some may have been lost through water or wind erosion.

Relying on biochar as a means of regulating climate, would not appear to be a good bet. Further, the production of biochar requires massive quantities of biomass since only between about 12-40% of the carbon in biomass is retained in the char. The climate impacts of harvesting, pyrolysing, transporting and ploughing in such large amounts of charcoal would contribute hugely to overall emissions, even before considering the likely direct and climate impact of large-scale land-conversion for a future new significant demand for biomass and land for biochar.

Another concern about the impact of biochar on climate is that biochar particles can be very small, or break down to become very small over time – small enough to become airborne, where, like soot, they contribute to global warming by reducing albedo, that is by absorbing rather than reflecting energy from the sun. This effect could counter and reverse any theoretical gains from carbon sequestration through biochar. Finally, biochar advocates also claim that biochar will benefit climate by reducing nitrous oxide emissions from soils, but evidence for this is extremely sparse – based largely on a single field test wherein biochar was applied to cow urine in a pasture. Emissions were reduced only where extremely large amounts of biochar were applied.

Biochar and soil fertility: claims versus science

The claim that biochar improves crop yields and reduces the need for mineral fertilisers is critical since it forms the basis for claims about both climate benefits (lessening fertiliser demand) and for biochar benefitting small farmers, "the poor" or "peasant farmers". There are a number of possible ways that biochar can increase or decrease plant growth. These include stimulation of microbes which then outcompete plants for access to limited nitrogen, providing additional nutrients in the ash associated with biochar, altering soil pH, texture or water retention capacity, influencing microbe communities or increasing cation exchange capacity (which enhances the ability of plants to uptake nutrients). Some of these effects are short term, while others occur only over the long term.

Studies of soil fertility effects to date are all short term and therefore do not represent the impacts over time. Eight of the eleven field trials that we found looked at impacts on crop yields –

we rejected the study based on charred soil, leaving 7 relevant studies. The results were highly variable – in some cases biochar appeared to increase yields, in others reduce them - depending on the type of biochar, the soils, the type of crops tested and what else (fertilisers, compost etc) was added to the soil plots. Yield results also varied over time from year to year following biochar application. Overall, they provide very little support for any assumption that biochar can reliably increase crop yields. Farmers who seek to improve yields using biochar are therefore taking a significant risk, especially given that they must first invest in producing, or purchasing the biochar.

Biochar policy trends

What does the biochar lobby seek? The push for commercial scale biochar production continues to focus largely on 1) securing funding via carbon markets, and 2) securing subsidies for biochar research, development and deployment, including as a by-product of pyrolysis for bioenergy.

The main lobby group is the IBI, along with numerous regional biochar initiatives. These groups are comprised of academic researchers, business entrepreneurs, consultancies, bioenergy interests and a host of other "enthusiasts."

Advocates promote a range of biochar applications - from biochar for backyard gardening, to pyrolysis cookstoves for the poor, to global scale deployment for climate geo-engineering. All have in common the need for subsidies and supports to ramp up production.

Biochar as "good for the poor"

Based on the, unproven, assumption that biochar does in fact (on the whole) reliably improve soils fertility and therefore crop yields, biochar has been promoted as a technology for improving the livelihoods of subsistence farmers in the developing world.

Dozens of biochar projects – dubbed trials without constituting scientific field trials - are underway in Southern countries, most of them initiated by Northern companies or organisations, some with open support from the IBI.

Some, such as "Worldstove" promote use of 'micro-gasifier' cookstoves which retain biochar, as an option to traditional open fire cooking. Although such stoves will be more fuel efficient that open fires and some improved biomass stoves, they are less fuel efficient than micro-gasifier stoves which do not retain char but burn it to ash. No independent assessments exist but reports suggest that 'biochar cookstoves' are still in the early development stages and that there continue to be serious challenges with designing ones which are clean, fuel-efficient and with a design compatible with the different practical needs for cooking (e.g. being able to moderate temperatures), and which allow the char to be removed safely. No independent audit of modern biomass stoves has been undertaken. It is, however, clear that the quantity of biochar produced by these stoves is too small to offer a family the prospect of improved crop yields. A family would need to use a biochar stove for several decades in order to produce the quantity of biochar generally considered necessary to impact on soil fertility (even short term) on one hectare of land.

Biochar is also promoted under the guise of providing an option ("slash and char") to traditional swidden ('slash and burn') agriculture practices. A project with funding linked to REDD (reducing emissions from deforestation and forest degradation) is underway in DR Congo. The claim is that biochar will improve and maintain soil fertility so that farmers can continue to grow on plots already cleared, rather than moving on to clear new forest area. This approach links in with various REDD strategies under which traditional swidden agriculture by indigenous peoples and other forest communities and small farmers, and thus their livelihoods and land rights, are being targeted, on the misleading premise that traditional farming practices, rather than the expansion of industrial crop and tree monocultures and industrial logging, bear much of the responsibility for tropical forest destruction.

The "pro-poor" rhetoric adopted by some leading biochar advocates fits neatly into the current discourse about an African Green Revolution or an "Evergreen Revolution", which have been criticised as another vehicle to liberalise agricultural trade whilst further replacing traditional farming knowledge and agro-biodiversity with top-down 'knowledge' and 'expertise', including GMOs and a range of, largely unproven 'soil carbon conservation' techno-fixes. Cornell University and the Gates Foundation play an important role in this context, as well as in the promotion of biochar.

Questions must be asked about the impact of participation in these trials on livelihoods. Are subjects fully informed? Are proper safety precautions used? Does participation end up costing farmers in terms of diverting their land and labour? There are no independent assessments of these projects, and for quite a few no updated results have been made available, raising the possibility they have been abandoned.

These "pro-poor" projects – replete with images of smiling farmers standing alongside lush plots of maize and other crops, are used to spearhead social and political acceptance of biochar, and then to advocate for larger scale implementation.

The IBI's policy focus

So far, however, very little commercial production of biochar is underway. This is partly because pyrolysis units are costly and difficult to operate and control and because there are no guarantees of any practical benefits from biochar use. High hopes were placed on funding for biochar from carbon markets – despite growing awareness of the failures of carbon trading, both at a fundamental level (since it can at best offer a 'zero sum game' and not reduce emissions and since it allows polluting companies in the North to offload responsibility for addressing climate change to Southern countries and communities), and at an 'operational' level, with growing awareness of failure to reduce emissions, fraud and growing publicity about harmful 'offset' projects. The Clean Development Mechanism (CDM) on which the IBI had originally focussed their efforts now faces an uncertain future, with a recent global drop in carbon trading and serious questions whether the CDM can survive without a comprehensive post-2012 UN climate agreement, which seems increasingly unlikely. In this new context, the IBI if focussing primarily on 1) developing industry standards with the intent that anyone investing in or purchasing biochar can know approximately what type of product they are buying – an essential first step towards commercialization. Such standards will face difficulty given that there is currently little scientific basis for predicting what different biochars will do to different soils. 2) Taking advantage of the growing impetus to focus more broadly on agriculture, forestry and 'other land use', in a most likely (carbon-)market based 'landscape approach', with numerous initiatives within and outside of the UN process. The IBI has responded by shifting away from a near exclusive focus on marketing the carbon sequestration "potential" of biochar, to a broader approach that would enable advocates to promote a "landscape based approach" that will "allow for the multiple ancillary benefits of biochar systems to be considered and acknowledged", and provide broader scope for advocacy. 3) Developing biochar carbon offset methodologies for unregulated or smaller carbon offset schemes with a view of using those as a springboard for accessing larger (future) carbon markets. This IBI strategy is being strongly supported by the Carbon War Room, founded by Richard Branson, and by ConocoPhillips Canada.

What specific policy supports have been won and which are being sought?

In 2008 and 2009, the UN Commission to Combat Desertification (UNCCD) and around 20 countries submitted proposals to UNFCCC for biochar to be explicitly supported in a post-2012 agreement. Text was drafted, but later removed from a UNFCCC negotiating text. More recently, negotiations under 'Land Use, Land Use Change and Forestry' (LULUCF) have sought to extend Clean Development Mechanism (CDM) funding for soils, agriculture and landscapes generally. Some seek to extend the agreement on Reducing Emissions from Deforestation and Degradation

(REDD) to include not only forests but also soil and agriculture in general. The World Bank approved its first soil carbon offset project (not involving biochar) in November 2010 and is driving the development of new, barely regulated regional carbon markets which could eventually trade carbon offsets between each other. Soils, agriculture and forestry are to play a particularly strong role in those new markets.

Biochar proposals have been submitted to a number of regional and larger unregulated carbon market initiatives. A biochar methodology was submitted to the Verified Carbon Standard by UK biochar company Carbon Gold, but has not been progressed, although an alternative submission is expected. Another biochar proposal was apparently submitted to the Alberta Offset Scheme, which seeks to offset emissions primarily from tar sands extraction, but has not yet been published for consultation. The US considered national cap and trade legislation that would have included biochar among eligible offset technologies along with other biochar provisions (but failed to pass). Meanwhile, Australia, which has already made significant funding available for biochar research and development, is currently considering a "Carbon Farming Initiative" that would serve voluntary markets, with the consultation paper having embraced supports for biochar. China's Panda Standard is still in developmental stages, but the Sectoral Specifications for AFOLU specifically mention biochar. New Zealand has invested considerably in biochar research and development. Their Emission Trading Scheme is expected to include agriculture from 2013 and a biochar proposal is likely at that stage. The European Emissions Trading Scheme, currently the largest carbon market in the world, does not currently trade agriculture and soil carbon. However there are indications that this may change in future depending on international developments.

Countries including the US, Australia, New Zealand, UK and other European countries have invested significantly in biochar research and development. Within the US, biochar has been incorporated into a (currently dormant) legislative proposal for subsidies and significant funding for research and development on biochar, on soil and landscape carbon flow measurements, and on pyrolysis and other bioenergy technologies is coming from the US Department of Agriculture, US Forest Service and US Department of Energy. Europe's Joint Research Commission has presented biochar favourably and the EU has given financial support for biochar R&D and, in some cases deployment through its 7th Framework Programme and the EU Regional Development Fund.

Biochar companies

Several of the start-up companies involved with biochar, are more fundamentally in the business of bioenergy – producing ethanol, biodiesel, bioproducts, bioelectricity etc. Biochar is not necessarily the central focus of their mission, but may be produced as a by-product or secondary product, in hopes that it can also be made profitable or that it can be used to make claims about 'carbon negative energy' for PR purposes. This is clear from a review of some of the existent companies. CoolPlanet Biofuels, for example, seeks to develop second generation liquid biofuels along with small quantities of biochar. The char by-product is not a "waste" but rather Cool Planet aims to market it, and uses it as the basis for claiming its process to be "carbon negative". Others, like Eprida, promote a fertiliser produced by combining biochar with flue gases from fossil fuel combustion. Some, like US-based biofuel company ICM Inc. (which largely serves the ethanol industry) sell gasification units designed to process garbage (often costly to dispose of) – and refer to the ash/char by-product as biochar, "useful for carbon sequestration and as a soil amendment." Alterna bioenergy makes "biocarbon" for use as coal substitute and is co-owned with AllWoodFibre – a woodchip procurement company. For industrial agribusiness, plantation and forestry industries interest in biochar hinges on whether or not it can provide revenues from "waste" materials and by-products otherwise of little or no value. Interest has been impressed, for example, by representatives of the Malaysian and Indonesian palm oil industry and Indonesian pulp and paper companies, as well as by the Brazilian Agricultural Research Corporation, Embrapa and the International Rice Research Institute. The only multinational company which has lent its support to biochar, however, remains ConocoPhillips and their main interest appears to be in a new source of carbon offsets for their tar sands investments in Canada.

Overall, biochar has remained a "nascent industry" with few commercial producers, and growing scepticism. What remains key to biochar lobbyists, however, is that whatever the case, there is enough "hype" to create momentum that can be capitalised on.

To the extent that policy developments are influenced by science, biochar may face a rough road ahead – first of all because the science does not back the claims made about long term sequestration or fertility gains, and secondly because the "carbon negative" claim is likely to come under fire, as it is increasingly clear that harvesting enormous quantities of biomass results in enormous CO_2 emissions, along with other harms – and there is no guarantee that those emissions will be recycled back into ecosystems in a timely manner, if ever.

It appears that the future for biochar will play out largely as a battle between opposing forces of massive hype, the growing body of research which largely fails to support the hype, and on the ground experience. Making biochar economically viable is unlikely without massive subsidies, which so far have not materialised, but future potential exists, and vigilance is needed.