Biochar: A Critical Review of Science and Policy

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Biofuelwatch

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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 added to soils. 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 report takes a critical look at the claims made about biochar, reviews the science underlying them and provides an overview of what biochar advocates are seeking in terms of policies and supports.

CONTENTS

Executive Summary

What is biochar?

The International Biochar Initiative (IBI), the main biochar advocacy group, 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*"(tinyurl.com/c7uktq4). By that definition, the term 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 two very experimental technologies: Hydro-thermal carbonization and flash carbonization. However, both the science about and the advocacy for biochar generally refer to biochar produced through modern pyrolysis, in which energy is captured and a significant proportion, usually 12-40% of the original biomass, is retained as char – not the same as 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'.

It is increasingly evident that the effects of biochar on soils, crops and soil carbon depend partly on different biochars physical and chemical properties, and partly on the highly varied soil and ecosystem properties. Yet few of the studies on which claims about biochar are based actually were studies of char residues from modern pyrolysis – a reflection of the the fact that modern pyrolysis has not so far proven commercially viable. Rather they tend to be studies of traditional charcoal, charcoal and soot remains from wildfires or swidden agriculture, or even soot deposited from fossil fuel burning. Because of the very different characteristics of these materials and their interactions with an 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 analysis and 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 no longer known. Simply adding one ingredient, charcoal, to soils, generally in the context of monoculture cropping practices, is very different 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 neither well understood nor 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 geoengineering as a means of "carbon dioxide removal", to "enhance" the global carbon cycle. Such large-scale visions would entail conversion of large areas 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 have been performed.

Biochar field trials and soil carbon

Is the claim that biochar will remain stable in soils for hundreds or even thousands of years supported by evidence? Even the scant number of relevant field studies that have been done do not support any such a claim. 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, but nonetheless, results were as follows:

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 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.

A recent scientific review by 14 soil scientists from 12 research institutes published in *Nature* (tinyurl.com/62xxmmr) points to the role of ecosystem properties in determining the stability of carbon in soils and concludes that it is impossible to predict how stable different forms of carbon will be in soils from looking at their molecular structure or at laboratory studies – yet predictions about biochar carbon being 'stable' strongly rely on doing just that. The article points out that “It remains largely unknown why some SOM [soil organic matter' persists for millennia whereas other SOM decomposes readily”. It shows that some cases types of soil carbon which appear particularly unstable in a laboratory can remain stable in soils for long periods whereas types of carbon which appear very 'recalcitrant', including black carbon (i.e. the carbon found in biochar), can sometimes decompose faster than other soil carbon. The authors (amongst them the Chair and an Advisory Board member of the IBI) state: “*Sequestration strategies based on adding recalcitrant material to soils, whether through plant selection for recalcitrant tissues or through biochar amendments must be re-evaluated.*”

Claims about biochar being a reliable means of sequestering carbon in soils are thus not borne out by recent scientific findings.

Further, the production of biochar requires massive quantities of biomass since only between about 12-40% of the carbon is retained in char. The climate impacts of harvesting, transporting, pyrolyzing, and ploughing in such large amounts of charcoal into soils would contribute hugely to emissions, even before considering likely direct and indirect impacts of large-scale land-conversion.

Another concern is that biochar particles can be very small, or can break down over time to become very small – small enough to become airborne, and, like soot, contribute to global warming by reducing albedo (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 the climate by reducing nitrous oxide emissions from soils, but evidence for this is extremely sparse – based largely on a single field test in which very large amounts of biochar was applied to cow urine in a pasture.

Biochar and soil fertility: claims versus science

The claim that biochar improves crop yields and reduces the need for mineral fertilisers is used to support the idea that biochar is beneficial to climate (lessening fertiliser demand and, if biochar is made from residues demand for land and thus, it is claimed, deforestation) and also that it will benefit peasant farmers (for whom fertilisers are inaccessible). There are a number of possible ways in which biochar could potentially 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.

Field trials looking at biochar impacts on soil fertility impacts to date are all short or medium term (up to four years) and therefore not representative of the impacts over time. Seven of the eleven field trials that we found looked at impacts on crop yields. Results were highly variable – in some cases biochar appeared to increase yields, in others it reduced them - depending on the type of biochar, the soil, the type of crops tested and what else was also added to the plots (fertilisers, compost etc). Results also varied over time from year to year following biochar application. Overall, there is 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 since that they must first invest in producing, or purchasing the biochar. So far, very little commercial production of biochar is underway. Efficient pyrolysis units are costly, difficult to operate and control and there is scant evidence of any practical benefits from biochar use.

Biochar policy trends

What does the biochar lobby seek? The push for commercial scale biochar production continues to focus largely on securing funding to scale up production and securing carbon offsets, subsidies, public loan guarantees, public-private finance and private investments for biochar research, development and deployment.

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." They promote a range of biochar applications - from biochar for backyard gardening, to pyrolysis cook stoves or "slash and char" as a replacement for traditional "slash and burn" (swidden) practices, to global scale deployment for climate geo-engineering. All have in common the need for public and private finance and supports to ramp up production.

Biochar as "good for the poor"

Based on the, unproven, assumption that biochar does in fact 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. A separate report by researcher Benoit Ndameu and Biofuelwatch (tinyurl.com/d26d3o3) assessed one such trial by the Biochar Fund, in south-western Cameroon, to understand the perspective of participating farmers. The trials, which turned out to have involved a small fraction of the number of participants publicly claimed, had been abandoned after a single harvest, with only preliminary data made available. Some 18 months on, many participants were still expecting a continuation of the project and financial rewards from it – they had invested a lot

of work for free and in some cases appear to have rented the land for the trial plots. They had been made to expect to benefit financially from the imminent sale of carbon credits from the project, even though no carbon markets yet offer such credits and no evidence of any efforts by Biochar Fund to secure further funding for the project was found. Nonetheless, Biochar Fund had used proclaimed success in Cameroon to obtain funding for another biochar project – linked to REDD (reducing deforestation and forest degradation) in DR Congo. As in Cameroon, that project proposal, too refers to "reducing deforestation from slash-and burn" by improving soil fertility.

Some companies and advocates, such as "WorldStove" promote use of 'micro-gasifier' cook stoves that retain biochar, as an alternative to open fire cooking. However, peer-reviewed data comparing different modern cook stoves are scarce. Interim results from a stoves testing programme by the US Environmental Protection Agency show that efficiencies and emissions differ substantially between different stove models (including ones using the same general principle) and according to the moisture of the fuel burnt. Some micro-gasifier stoves can achieve high levels of efficiency with low emissions, however those which gasify the char as well make more of the energy in biomass available for cooking. Furthermore, 'biochar cook stoves' are still in the early development stages and serious challenges remain with designing clean, fuel-efficient stoves that meet practical needs for cooking.

The "pro-poor" rhetoric adopted by some leading biochar advocates fits neatly into the current discourse about an African Green Revolution or 'Evergreen Revolution' both of which seek to liberalise agricultural trade while 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 and carbon marketing approaches.

Biochar advocates policy aims

High hopes were placed on funding for biochar from carbon markets – despite growing awareness of the failures of carbon trading, which can at best offer a 'zero sum game' – allowing for additional fossil fuel burning and emissions in the North in exchange for presumed 'greenhouse gas savings', mainly from projects in the South. In reality, the effects have been even worse: Carbon trading has rewarded some of the most polluting industries in Southern countries, from coal and steel companies to oil palm and industrial livestock companies with extra profits from carbon finance and has been subject to fraud. Carbon markets are facing an increasingly uncertain future. The Clean Development Mechanism (CDM), on which the IBI had initially focussed much of its attention, has shrunk by half since 2009 and there are serious questions whether it can survive without a comprehensive post-2012 UN climate agreement. 97% of carbon trading worldwide is linked to the EU Emission Trade Scheme, which specifically excludes land based "sinks" including soils until at least 2020 – and industry analysts are predicting a collapse of that market, too. Voluntary and other regional carbon trading schemes are very small and proposals to include biochar have not been seriously considered by any of them. Prospects for significant carbon market finance thus appear to be dim, despite World Bank efforts to promote the development of new carbon trading mechanisms and the inclusion of soils and agriculture within them. While efforts to get carbon finance for biochar continue, new avenues for potential support are also being explored. These include:

1) Taking advantage of the growing impetus within climate policy to broadly include agriculture, forestry and 'other land use', in a 'landscape approach', with numerous, often market- based initiatives within and outside of the UN process. For example, the inclusion of soils and agriculture in general into REDD (Reducing Emissions from Deforestation and Degradation) has been proposed. Particularly prominent are proposals for 'Climate-Smart Agriculture' put forward by the UN Food and Agriculture Organisation (FAO), World Bank and other institutions. This concept, discussed in some detail in Chapter 4, seeks to leverage a range of funding mechanisms, both from public and private-sectors, including carbon finance amongst other sources – for 'transforming' agriculture, placing particular emphasis on (supposedly) quantifiable greenhouse gas emission reductions and carbon sequestration, including in soils. Although biochar has not so far played a prominent role in those proposals, those developments could eventually offer supports for biochar.

2) Developing biochar carbon offset methodologies for unregulated and small-scale carbon offset schemes with a view of using those as a springboard for accessing larger (future) carbon markets. So far however they have had no apparent success in this quest. However, ConocoPhillips has become the first corporation to offer consistent support for biochar, apparently in the hope of creating future biochar carbon offsets for the Alberta Offset System, which is effectively an offset scheme for the tar sands industry.

3) Promoting biochar as a climate geoengineering technology. Biochar features in many climate geoengineering reports and debates as a means of "carbon dioxide removal", though it has generally been met with some reserve, although it is attracting growing interest from some corporate interests and 'philanthropists', including Shell, Richard Branson (including through his Carbon War Room) and the Gates Foundation. The Carbon War Room and the Gates Foundation have supported biochar as well as geoengineering in general.

4) Obtaining funding for research and development: Biochar research and development and, to a lesser extent, deployment, have attracted relatively modest public finance, for example in US, Australia, New Zealand and UK.

5) Developing industry standards with the intent that anyone investing in or purchasing biochar can know approximately what they are buying – an essential first step towards commercialization as well as attracting finance for deployment.

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". 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. 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 have demonstrated interest.

Furthermore, biochar companies and advocates have been working to link up with fossil fuel interests – most prominently ConocoPhillips, but also coal companies interested in land reclamation, carbon offsets or, potentially, mixing byproducts from coal production with biochar.

Overall, biochar has remained a "nascent industry". Its' future will likely play out as a contest between opposing forces of massive hype, a 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.

Chapter 1: Introduction

As we face catastrophic impacts of climate change, efforts to “engineer” the climate are proliferating along with a host of technofix “solutions” for addressing the many consequences of climate change. Among these is the proposal to use soils as a medium for addressing climate change, by scaling up the use of biochar.

Indeed soils around the globe have been severely depleted of carbon as well as nutrients – in large part due to destructive industrial agriculture and tree plantations as well as logging practices, raising serious concerns over the future of food production. Soil depletion has led many to conclude that improving soils might contribute significantly to addressing climate change as well as other converging crisis, by sequestering carbon, boosting fertility, reducing fertiliser use, protecting waterways etc.

But is biochar a viable approach?

Biochar is essentially fine grained charcoal, added to soils. Advocates claim it can sequester carbon for hundreds or even thousands of years and that it improves soil fertility and provides various other benefits – they seek support in order to scale up production. A common vision amongst biochar supporters is that it should be scaled up to such a large scale that it can help to stabilise or even reduce atmospheric concentrations of carbon dioxide.

Research to date on biochar has had mixed results and clearly indicates that biochar is not one product but a wide range of chemically very different products which will have very different effects on different soils and in different conditions. Furthermore, recent soil science findings suggest that what happens to different types of carbon in soils cannot be predicted simply by looking at its chemical structures. Instead, it appears to primarily be an 'ecosystem function', i.e. depends on interactions with different soils and soil conditions.

Many critically important issues remain very poorly understood; there are likely to be serious and unpredictable negative impacts of this technology if it is adopted on a large scale and there is certainly no “one-size-fit-all” biochar solution.

Soils are extremely diverse and dynamic. They play a fundamental role in supporting plant, microbe, insect and other communities, interacting with the atmosphere, regulating water cycles and more. Unfortunately, like other such schemes, to engineer biological systems, the biochar concept is based on a dangerously reductionist view of the natural world which fails to recognize and accommodate this ecological complexity and variation.

Biochar proponents make unsubstantiated claims and lobby for very significant supports to scale up biochar production. But these supports have largely not been forthcoming. Nonetheless, vigilance is required. The World Bank in particular is promoting the inclusion of soil carbon into existing and, above all, new carbon trading schemes. Biochar advocates have for several focussed on having biochar included in such future soil carbon offsets. Yet the future of all carbon markets is highly uncertain, with the UN's Clean Development Mechanism having shrunk by over 50% since 2009, the World Bank phasing out its existing Kyoto carbon funds, and with industry analysists predicting that the EU Emissions Trading Scheme (which accounts for 97% of all global carbon markets) is at risk of collapse. Many advocates of agricultural carbon markets – including the UN Food and Agriculture Organisation – are now promoting a more comprehensive mixed financing scheme for what they call 'Climate-Smart Agriculture', including carbon offsets, but also public-private partnerships, a re-direction of existing rural development and agricultural finance, overseas development aid, etc, focussing on a range of practices and technologies considered to mitigate climate change – many of them highly controversial. Biochar advocates are clearly looking for ways of having biochar included in any such finance. Likewise, as climate geo-engineering discussions are becoming more prominent and accepted, there is potential that biochar could move forward under that guise.

It is imperative that we do not repeat past errors by embracing poorly understood, inherently risky technologies such as biochar that will likely encourage expansion of industrial monocultures, result in more "land grabs" and human rights abuses, further contribute to the loss of biodiversity, and undermine an essential transition to better (agro-ecological) practices in agriculture and forestry.

We hope this report will generate a deeper understanding of the issues and more critical thinking about biochar.

Chapter 2: What is biochar and what are the claims?

The International Biochar Initiative (IBI) defines biochar as "*the carbon rich product when biomass 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.*"[1] They thus define biochar primarily by its purpose, not by its physical or chemical properties.

Biochar would generally be produced through a process called pyrolysis. This involves heating biomass with little or no available oxygen. Traditional charcoal-making is a form of pyrolysis, as is the charring of biomass during a wildfire. However modern pyrolysis systems seek to capture bioenergy, too, in the form of a liquid fuel (called pyrolysis or bio-oil) as well as a gas (called syngas). Depending on the particular pyrolysis process, generally between 12 and 40% of the original biomass carbon is left behind as (bio) char. Modern pyrolysis is being developed at different scales, ranging from large pyrolysis plants to pyrolytic cooking stoves ('biochar stoves'). Modern pyrolysis is largely still at the pilot- or demonstration stages. Particular problems include the fact that pyrolysis oil and syngas cannot be blended with fossil fuels, that syngas has very low energy density when compared to natural gas, and the fact the process is often highly inefficient.

Biochar can also be produced by means of gasification, which means exposing biomass to high temperatures with a controlled amount of oxygen or steam. This produces mainly syngas and less than 10% of the original biomass volume in (bio)char. That char can be retained, but is more commonly gasified further until only ash remains. In a recent review of small-scale gasification the authors state: "*In fact, it is possible to convert dry wood or rice husks into gas and electricity. However, it is not as easy as some manufacturers would like to make us believe... A comprehensive World Bank study in 1998 examined gasification plants installed in the 1980s and found that virtually all had been taken out of operation due to technical and economic problems*" – a situation which appears not to have changed much since then.[2]

Two other very much experimental methods which produce biochar are hydrothermal carbonization (HTC) and flash carbonization. HTC involves exposing biomass to moderately high temperatures in water, under pressure and together with a diluted acid which acts as a catalyst. This process, which is still in the very early research and development stages, produces no energy that can be captured. Instead, all of the carbon is turned into a type of biochar or 'bio-coal', with a great variety of chemical structures, depending on the catalyst used. It is being developed to a large part in the context of nanotechnology research. Flash carbonization involves lighting a fire under a tightly packed bed of biomass under pressure. This produces mainly energy and relatively little biochar.

Of the three methods described, pyrolysis is by far the most important. No studies exist about biochars produced through gasification. Only two papers appear to have been published that look at HTC char and soil carbon and only one paper each has been published about the impacts of HTC char and flash carbonization char on soil fertility and neither of those two found any positive impacts[3]. As for the stability of HTC carbon, one of the papers reported that the carbon was likely to be lost as CO2 within 4-29 years on average, i.e. that it was anything but stable[4]. The other supports this by stating that HTC char "will probably decompose faster than char from dry pyrolysis", cites evidence that a particular fungi has been found to decompose such char and calls for more research[5]. However, as we shall see in Chapter 3, for all types of carbon found in or added to soils, their long-term fate cannot be predicted just from looking at their properties and molecular structures.

Some companies use the term "biochar" to refer to the use of charcoal as fuel (generally a "coal substitute"), in some cases materials made not only from biomass but also municipal waste, tires and coal dust.[6] This use of the term, however, is not endorsed by the IBI.

The carbon in biochar, charcoal, and even coal, is all "black carbon". There is a broad spectrum of different forms black carbon can take, each of which confers different properties. Many factors influence the physical and chemical characteristics of black carbon, including the type of biomass used, the temperature to which it is heated, how it is cooled and other variables. Exactly where biochar falls on this spectrum, is ambiguous. What is clear, however, is that in fact these precise details of the physical and chemical nature of black carbon referred to and used as "biochar", has major implications on how soils and plants are influenced, making it a focus of much research. This is further discussed in detail in chapter 3.

In general it would seem that the most useful working definition of biochar might be 'char left behind after modern biomass pyrolysis' - after all, that is what biochar advocates actually promote. Unfortunately, this is not reflected in most biochar studies. Modern pyrolysis is largely still at the pilot stages, i.e. it does not exist at a commercial scale and biochar produced this way is still difficult to obtain. Of the 13 peer-reviewed biochar field studies (based on 11 different trials) which we found in the literature[a] only two used biochar from modern pyrolysis; all of the others looked at traditional charcoal which was ground up, often by crushing it under the wheels of a tractor. Many studies about 'biochar properties' are not even confined to charcoal or biochar that has been produced intentionally but instead look at charcoal remains from wildfires or swidden agriculture, or in some cases even at carbon deposited as soot from biomass or

Terra preta

According to the UN Food and Agriculture Organization (FAO), some terra preta soils (also called "Amazon Dark Earths") may be at least 2,500 years old. They are found in patches, generally along the Amazon and tributaries, and are otherwise surrounded by the infertile soils typical of this region. Researchers have found evidence of "garden cities" along the Berbice River in Guyana Amazon: areas with rich Terra Preta soils where a large variety of trees, shrubs and perrenial crops were grown in long crop cycles with intercropping and seasonal flooding. The soils contain large amounts of turtle shells, fish and mammal bones, pottery shards, kitchen waste and human excreta – as well as charcoal. These provide insights into the production of Terra Preta, but as the FAO states: "*The knowledge systems and culture linked to the Terra Preta management are unique but have unfortunately been lost. Amazon Dark Earths are, however, still an important, yet threatened resource, as well as an agricultural heritage that needs better scientific understanding*".

Many soils around the world contain charcoal – from wildfires and in some cases a result of swidden cultivation in the past. British researchers have begun studying ancient dark, carbon-rich soils in several West African countries, the African Dark Earths Project. Problematically, the project aims to combine studying "*indigenous knowledge and practices*" with "*the value now attributed to biochar for soil enhancement, carbon sequestration and clean energy production*". As with terra preta, this raises the concern of indigenous knowledge being appropriated and used to help attract subsidies and carbon offsets for biochar entrepreneurs and companies in the North. Various patent applications and trademarks for biochar and 'terra preta' production have already been submitted.

Traditional terra preta-type methods appear to be a lost art - according to an agronomist with 35 years experience working with small farmers across different states in Brazil, the deliberate use of charcoal as a soil amendment was never encountered (she had only heard about biochar in the context of carbon offsets). Elsewhere there are anecdotal reports that farmers in the Batibo region of Cameroon use charcoal made by burning mounds of grass covered by earth as a soil amendment. The indigenous Munda communities in Northern India reportedly add charcoal from cooking stoves with burnt grass and farmyard manure to their soils.

[a] See Appendix; note that the definition of a 'field study' used here is one where biochar has been newly applied to plots of soils on which crops or other plants are then grown.

fossil fuel burning[7].

Biochar advocates claim that burying charcoal in soils is a viable means of sequestering carbon for hundreds or even thousands of years. According to the IBI, biochar could sequester 2.2 billion tonnes of carbon every year by 2050 and that carbon would be stored in soils for hundreds or thousands of years. This and similar claims are repeated over and over in biochar literature. In addition, they state that using syngas and pyrolysis oils to displace burning of fossil fuels, will further reduce carbon in the atmosphere. Advocates claim that using biomass is carbon neutral, but that biochar goes yet further to be "carbon negative" because not only will trees/plants grow back, but also some portion of the carbon from each generation of biomass produced and charred will supposedly be more or less permanently sequestered.

Carbon Negative

Biochar advocates refer to biochar as a "carbon negative" technology, a logic based first on the false assumption that burning biomass for energy is "carbon neutral", and second that biochar is guaranteed to further sequester carbon in soils for long time periods, taking it a step further as carbon "negative". Both steps in this logic are simply false. The bioenergy industry is being challenged by a growing volume of scientific literature and rising public awareness that the resulting emissions are in many, if not most cases, even higher than those from using fossil fuels, particularly when all indirect as well as direct impacts are considered. Even if those emissions may eventually be re-sequestered by new plant growth, the time frame for regrowth is long – in the case of forest biomass many decades or even centuries. This time lag between emissions from harvest and burning to regrowth is referred to as a "carbon debt". In the US state of Massachussetts, citizens opposing the construction of 5 new biomass incinerators demanded that the state commission a study – the Manomet Biomass Sustainability and Carbon Policy Report". A key finding of this report: after 40 years, the net GHG emissions from biomass burned for electricity are still worse than coal, even when considering forest regrowth, and worse than those from burning natural gas even after 90 years. A study by European scientists from the Joanneum Research Institute found that, when biomass was sourced from trees felled for that purpose in "sustainably managed forests" in Europe, bioenergy would lead to a carbon debt of around 200 years. And in September 2011, the European Environment Agency's Scientific Committee strongly criticised the EU's accounting for biomass as being generally 'carbon neutral', warning that: "*The potential consequences of this bioenergy accounting error are immense. Based on the assumption that all burning of biomass would not add carbon to the air, several reports have suggested that bioenergy could or should provide 20% to 50% of the world's energy needs in coming decades. Doing so would require doubling or tripling the total amount of plant material currently harvested from the planet's land...Indeed, current harvests, while immensely valuable for human well-being, have already caused enormous loss of habitat by affecting perhaps 75% of the world's ice- and desert-free land, depleting water supplies, and releasing large quantities of carbon into the air.*"

The second step in the logic – from "neutral to negative" is clearly flawed given the lack of evidence for biochar remaining stable in soils for long periods, reviewed in chapter 3. There is a strong possibility that large scale implementation of biochar could result in very large emissions from harvest, soil disturbance and transport of biomass, from the pyrolysis process and combustion of syngas and bio-oil products, from more transport as biochar is redistributed, from more soil disturbance as it is tilled into soils, and finally from the oxidation of some- potentially large- portion of the biochar and from the "priming" effect that biochar has – causing oxidation of pre-existing soil organic matter. All of those combined could result in a massive increase in emissions, far from being "carbon negative".

The assumption that biochar carbon will remain stable in soils for hundreds or thousands of years is based on an analogy between modern biochar and ancient Terra Preta soils. Terra Preta are soils made by indigenous peoples in the Amazon region long ago, using charcoal along with various other materials. Those soils remain highly fertile and carbon rich hundreds and even thousands of

years later. The processes involved in creating Terra Preta are no longer known, but likely bear little resemblance to modern biochar. The addition of modern biochar to soils as it is has been practiced in the limited number of field tests to date, involves industrial agriculture practices – monocultures, using some combination of biochar with synthetic fertilizers, manure, or both, as well as pesticides and other agrochemicals. Terra Preta soils contain charcoal, but this is likely the extent of any commonality.

Given that there are so many known, and likely more unknown differences between modern biochar practices and the creation of Terra Preta, it is a stretch to draw the analogy. Yet some companies even refer to their biochar products as "Terra preta", or make claims that use of their biochar will enable users to turn their soils into Terra preta.[8]

Many biochar advocates envision very large scale global deployment – even at the geo-engineering scale - confident that it can contribute significantly to reducing greenhouse gas emissions. This is discussed in more detail in Chapter 4.

In addition to the claims regarding the potential for biochar to sequester carbon, other claims are also made, including 1) that biochar improves soil fertility, therefore can increase crop yields and reduce fertilizer demand. 2) that biochar reduces N2O emissions from soils, 3) that deforestation can be reduced by transitioning from traditional slash and burn to "slash and char" agriculture, and 4) that pyrolytic (biochar producing) cookstoves can benefit the poor by providing more efficient and cleaner cookstoves while at the same time providing a soil amendment that will enhance yields. Each of these claims is also analyzed in more detail in the following chapters.

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1 www.biochar-international.org/biochar/faqs#question1

2 Dimpl, E, Blunck, M. 2010: Small-scale Electricity Generation From Biomass: Experience with Small-scale technologies for basic energy supply: Part 1: Biomass Gasification. GTZ, commissioned by the Federal Ministry for Economic Cooperation and Development

3 Technical, Economical, and Climate-Related Aspects of Biochar Production Technologies: A Literature Review, Sebastian Meyer et al, Environmental Science & Technology, 45, 2011

4 Effect of biochar amendment on soil carbon balance and soil microbial activity S. Steinbeiss et al, Soil Biology & Biochemistry 41 (2009)

5 Hydrothermal carbonization of biomass residuals: a comparative review of the chemistry, processes and applications of wet and dry pyrolysis, Judy A Libra et al, Biofuels (2011), 2(1)

6 See for example:www.carbonbrokersinternational.com/

7 See for example Black carbon contribution to stable humus in German arable soils, Sonja Brodowski et al, Geoderma 139 (2007) 220-228

8 See, for example: www.alibaba.com/product-free/113485176/Terra_Preta.html

Chapter 3: Does the science support the claims?

Part 1: Biochar and the carbon cycle

The UK Biochar Research Centre describes the key premise of biochar being promoted for climate change mitigation: "*Annually, plants draw down 15-20 times the amount of CO2 emitted from fossil fuels…Since the plant biomass is relatively constant globally, the magnitude of new plant growth must be approximately matched by harvests, litterfall, etc. Intercepting and stabilizing plant biomass production reduces the return of carbon to the atmosphere, with a relative reduction in atmospheric CO2*."[9]

Plants contain more than 80% as much carbon as the atmosphere, soils hold over 2.1 times as much[10]. However, ecosystems, including soils, tend to recycle carbon in the same way as they recycle nitrogen and other nutrients. This is not the full story: In recent decades, land-based ecosystems have drawn down or sequestered more than a quarter of all the carbon emitted annually from fossil fuel burning and deforestation, while oceans have been absorbing as much carbon again. This is a direct response to climate change, yet as the climate continues to warm rapidly and ecosystems are being degraded and destroyed further, the biosphere might well in the future release more carbon than it draws down, further accelerating warming[11]. The idea behind biochar is to reduce the amount of carbon that is naturally being recycled by plants and soils and instead to 'stabilize' it by turning wood, grasses, crop residues and other biomass into charcoal. A proportion of the carbon in plants would be turned into 'additional' carbon in soils and new crops, trees and other plants would then further capture more carbon dioxide (CO2) from the atmosphere before once again being removed and charred. Over time, this is supposed to reduce the amount of CO2 that would otherwise have been in the atmosphere and thus reduce global warming. An additional benefit would come from using the energy released during charring (pyrolysis) to replace some fossil fuels that would otherwise have been burnt.

As the UK Biochar Research Centre admits, this would need to be done successfully on a very large scale to make any difference to the climate: "*On a scale of millions of tonnes needs to occur, preferably hundreds of millions of tonnes*"; elsewhere they and others have spoken of billions of tonnes.

The rationale behind biochar for climate change mitigation is thus fundamentally about geo-engineering: It is about manipulating the carbon cycle to 'improve' it by 'stabilizing' large amounts of plant carbon in soils rather than allowing them to be naturally recycled.

For this scheme to work, three conditions would need to be fulfilled:

First, one would need to be sure that a large proportion of the carbon contained in biochar will in fact be stable over long periods.

Second, adding biochar to soils would need to lead to an overall increase in soil carbon. This means it must not cause other soil carbon to be emitted as CO2, at least not a significant proportion of it.

Finally, hundreds of millions (or billions) or tonnes of biomass would need to be charred without this, either directly or indirectly, resulting in more carbon emissions than those 'saved' through biochar. Not only would there have to be a way of avoiding deforestation, wetland or grassland destruction for biochar, but even if residues were used, the carbon 'gains' from turning them into biochar would have to be greater than those from leaving them in the soil would have been.

Even if the biochar 'carbon balance' was indeed positive, one would still have to consider other climate impacts, such as biochar's likely effects on the earth's reflectivity or 'albedo', which also plays an important role in climate change (discussed below).

To further investigate these assumptions, we must first return to the question "what is biochar?" According to Kurt Spokas, a soil scientist with the US Department of Agriculture[12] biochar, though produced mainly for the purpose of carbon sequestration, "*covers the range of black carbon forms*".

Hence, in order to understand how biochar affects soils, including soil carbon and soil fertility, we need to understand what black carbon is - or rather what the 'range of black carbon forms' is.

What is black carbon and how do different forms of black carbon vary?

Black carbon is generally defined as 'the product of incomplete combustion'. When wood or other biomass is exposed to high temperatures, whether in a wildfire or a charcoal kiln, etc., it undergoes various and complex chemical transformations, starting with hydrogen and oxygen and other volatile compounds being released. If the biomass does not burn completely to ash during a fire, or if the process is controlled and oxygen is limited, then char or charcoal will remain at the end. Furthermore, particularly during an open fire, some of the carbon particles, rather than all turning into carbon dioxide, will instead be released as soot. All of the carbon-rich compounds, ranging from slightly charred logs to charcoal to soot are called black carbon. Yet chemically, they are extremely different. For example, partially charred wood will have a chemical structure similar to the original wood and its particles will be fairly large, at least initially. At the other extreme, soot particles do not resemble the original biomass (or fossil fuels) which they came from in any way - they are virtually identical no matter what source of biochar they are derived from, and very tiny. Many soil scientists speak of a 'black carbon continuum', ranging from partially charred biomass to soot[13]. In between the two extremes, one can find a whole range of different forms of black carbon, with different chemical properties and components and different molecule structures. Differences include how resistant they are to high temperatures and acids and how well they can to adsorb (see footnote[b]) nutrients, water or microbes.

This background is essential for understanding the debates about biochar because it explains why, as Kurt Spokas has illustrated, "*biochar is not a description of a material with one distinct structure of chemical compositions*". Even if one was to only look at studies about biochar produced through modern pyrolysis - which would mean ignoring the vast majority of studies on which claims about biochar are based - one would still be looking at very diverse materials. In modern pyrolysis, temperatures can range from 400°C or even less to as high as 1000°C (more commonly up to 800°C), and biomass can be exposed to high temperatures for half a second to 30 minutes[14]. The type of biomass and the way the biochar is cooled down and stored will also make a significant difference to its properties.

This immediately raises questions about any claims about 'universal' impacts of biochar, for example on soil fertility or soil carbon. If there is a wide range of very different biochars then one would expect their impacts on soils to also vary. The evidence for this will be discussed further below.

And this is just one of the problems with predicting impacts of different biochars. A recent soil science review by 14 scientists from 12 research institutes published in *Nature*[15], shows that it is impossible to predict the long-term fate of different types of carbon in soils simply by looking at molecular structures and properties. Instead, the fate and ultimate 'stability' of soil carbon depends on its interaction with different soil environments: "*Persistence of soil organic carbon is primarily...an ecosystem property.*" This is why some types of soil carbon which are highly 'unstable' in laboratory conditions have been found to remain in some soils for long periods of time whereas black carbon, which under laboratory conditions appears particularly stable, has been found under some circumstances to decompose quicker than other types of carbon. The authors therefore warn: "*Sequestration strategies based on adding recalcitrant material to soils, whether through plant selection for recalcitrant tissues or through biochar amendments must be re-evaluated.*" The chair of the IBI, Johannes Lehmann, and an IBI Advisory Board member are amongst the authors of that study.

How stable is biochar carbon?

According to Johannes Lehmann, soil scientist and Chair of the International Biochar Initiative (IBI), 1-20% of the carbon in biochar will react with oxygen and turn into CO2 relatively early on,

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[b] Adsorption means that particles, such as minerals, nutrients or water adhere or stick to the surface, in this case the surface of biochar particles.

while the remainder will be stable for several thousands of years – a claim which conflicts with the findings of the recent science review published in *Nature* to which he contributed[16].

Such claims by Lehmann and other biochar advocates rely largely on three different sources of evidence:

- Laboratory incubation studies, whereby samples of soil with black carbon, or biochar mixed with solutions of microbes are kept at steady and usually warm temperatures for periods of time and then analysed;
- Studies of older black carbon found in soils, commonly black carbon from former wildfires, but also 'terra preta' (see box);
- Field studies in which losses of black carbon are being measured.

There are many problems with each type of evidence.

The UK Biochar Research Centre pointed out in their 2010 biochar review: "*As yet, there is no agreed-upon methodology for calculating the long-term stability of biochar.* " Different studies, including different laboratory incubation studies, rely on different methodologies and their results therefore are often difficult to compare.

Virtually all ***laboratory incubation studies*** have found that some black carbon is turned into CO2 but that most of this 'loss' happens early on and that the rate at which it happens decreases over time. Lehmann and others have argued that this is because a small proportion of the biochar carbon is unstable or 'labile' and will quite quickly be turned into CO2, whereas the remainder of the carbon will be far more stable. Observations of the chemical structures of biochar appear to support the hypothesis that some biochar carbon particles are inherently less stable than others, although a 'two-types-of-biochar-carbon' model is rather simplistic[17]. Yet the soil recent soil science review referred to above shows that while the initial rate of carbon loss in a laboratory environment correlates with the molecular structures and chemical properties of the carbon, this does not predict the long-term fate of that carbon in soil. What actually happens to it in soils will depend on a range of environmental factors: Those may include how acidic the soil is, where in the soil the carbon ends up, how easily it can be accessed by enzymes, or even the effects of still unidentified compounds.

Different studies have shown that there are soil microbes and fungi which can turn black carbon into CO2[18]. Soil incubation studies will at best contain a small sample of the microbes, and often none of the fungi that are found in the soils which are studied. What is more, the microbes in the laboratory incubation studies tend to diminish over time for many different reasons, hence biochar losses due to microbes would also automatically diminish[19]. In short, laboratory studies cannot predict how stable different biochars will be in different soils and soil conditions.

Studies of older black carbon in soils have been undertaken to estimate how long some black carbon can remain in soils. The basic idea is to compare the amount of black carbon found in soils with the amount estimated to have been produced by fires in the past, in order to extrapolate how much would have been lost compared to how much remained stable. There are major problems with this approach, too: Firstly, when the carbon is dated, the date generally relates to when the original tree or other vegetation grew, not the date it burned down and got partly charred. Secondly, the assumptions about how much black carbon would have been produced by fires in the past rely to a large part on how much biomass carbon is converted to black carbon during fires, yet this conversion rate varies greatly, quite apart from the fact that past fire regimes are very difficult to reconstruct. There is no doubt that the rate of black carbon left behind after wildfires will vary according to the intensity and duration of fires, the type and amount of vegetation burned, etc. A scientific commentary article by Rowena Ball cites literature estimates ranging from 3-40% of original biomass carbon being turned into black carbon during wildfires[20]. A scientific review by Johannes Lehmann et al suggests that on average only 3% of biomass carbon is turned into black carbon during fires[21]. An experimental burning trial in Germany, on the other hand, found 8.1% of the original carbon being turned into black carbon in a wildfire which mimicked what is known about Neolithic swidden agriculture[22]. The maximum 40% biomass carbon to black carbon

conversion figure[23] is far higher than what more recent studies have found and indeed a later study co-written by one of the co-authors of the former study suggests a much lower figure (4% of overall biomass carbon and 14% of burned biomass carbon turning into black carbon)[24]. However, the 3% figure suggested by Lehmann et al is at the lowest end of estimates and far below what was measured in the German trial. The differences between estimates are important: If the amount of charcoal historically produced during fires is underestimated then it will appear that a lot more of it has remained stable over long periods than was actually the case. If the original amount of charcoal was 2-3 times higher than estimated by some authors, then only between half and a third as much black carbon will have remained stable in soils compared to the authors' estimates.

Regardless of the methodological problems, studies illustrate a great variety in the average length of time that black carbon remains in different soils in different climate zones. For example, a study by Lehmann et al in Australia suggested that black carbon remained stable in soils on average for 1,300-2,600 years, although that study relied on modelling based on assumptions about past fire patterns which are impossible to verify [25]. A study of Russian steppe soil showed black carbon remaining in soil for a period between 212 and 541 years[26]. On the other hand, a study by Nguyen et al based in Western Kenya found that, on land understood to have burnt eight times over the past century, 70% of the black carbon was lost over the first 30 years[27]. Another study compared two dry tropical forest soils in Costa Rica, only one of which had been exposed to regular fires and thus black carbon formation in the past. Although the soil which had been exposed to regular fires had a higher black carbon content, the "mean values were not significantly different" and, furthermore, the authors highlighted the difficulties in identifying and quantifying black carbon and the lack of an agreed method to do so [28]. The (common) methods which they used had uncertainties of 40-50% and, given those uncertainties, it could not be shown whether or not centuries of regular fires at one site had actually led to the soil having any more black carbon than the other soil where vegetation had not been burned regularly. The studies in Western Kenya and Costa Rica only looked at carbon found in the top 10 cm, so they would have missed counting any black carbon that had moved deeper down in the soil, as could be expected from other studies. A study in Zimbabwe compared black carbon contents of two soils, one protected from fire which had not been exposed to burning for the past 50 years, the other regularly burned during that time. The authors calculated from the differences in black carbon content that the average period for which black carbon remained in the top 5 cm of soil was less than a century[29]. Yet another study, looked at black carbon concentrations in soils underneath a Scots pine forest in Siberia which had been regularly exposed to fire[30]. The authors found low levels of black carbon which they could only partly explain through the fact that less biomass would have been turned into black carbon during forest fires compared to fires in tropical forests. They suggested that black carbon loss through erosion or downwards movements, deeper into the soil, were both unlikely reasons and that, instead, black carbon in the study had "low stability against degradation". The results of studies that look at black carbon naturally found in soils, including due to wildfires, are thus very mixed, suggesting residence times of a few decades to millennia, probably depending on different types of black carbon, climate zones, vegetation etc. – and also on different methods used by researchers. The reasons for black carbon losses in different cases are not known. They may include erosion and downward movement of black carbon,both of which could mean the carbon was still stable, just elsewhere. However, in the Siberian study the authors felt this was not likely. In sum: it is quite possible that most of the black carbon lost in other studies may have been turned into CO2, and there is no way to estimate how much was lost over time without knowing how much was generated in the first place. Or, as the authors of the soil science review published in Nature state: "*Fire-derived carbon" is not inert, but its decomposition pathways remain a mystery.*"

Field study indications about the stability of black carbon: Because laboratory studies using sterile soils and controlled conditions have limited applicability, field studies are essential for understanding the impacts of different biochars in different soil conditions. Unfortunately, the number of peer-reviewed field studies is small. We have found 13 peer-reviewed studies based on 11 different field trials. One of those looked at soil underneath charcoal kilns, i.e. at soil which had itself been pyrolysed.[31] Overall carbon levels were reduced in those soils – but pyrolysing soil is rather different from most people's idea of biochar, where pyrolysed biomass is added to soils which have not been burned themselves. Of the remaining field trials, only five considered the

impact of biochar – or rather of crushed traditional charcoal – on soil carbon and in all but one of those studies, the results did not distinguish between black carbon and soil organic carbon previously found in the soil or newly accumulated. The studies, which will be discussed below, thus say far more about the overall impacts of biochar on soil carbon – which is also most relevant to the question whether or not biochar can sequester carbon and theoretically (ignoring land use change), mitigate climate change.

Conclusions about the stability of black carbon

What is certain is that, on average, black carbon does not react with oxygen as easily as other forms of carbon found in soils. After all, some of the tests used to identify black carbon involve exposing carbon to high temperatures of 375°C and/or to acids, on the assumption that all of the carbon that remains after such conditions must be black carbon. It is also clear that some black carbon in certain circumstances will remain in soils for thousands of years – although on the other hand, some soil carbon which is not black carbon and which has is found in deeper soil levels is also several thousand years old[32]. What the evidence does not support is the claim that the great majority of all black carbon will remain stable for long periods. One scientific literature review[33] suggests that six different factors control the storage and stability of black carbon in soils: Fire frequency (with more frequent fires turning more biomass carbon into black carbon, but also turning more black carbon into CO2), the type of original biomass and the conditions under which it was burned, soil turbation (i.e. disturbance and mixing of different soil layers), the presence of different minerals such as calcium and phosphorous in soils, different communities of microbes, whose ability to degrade black carbon will vary, and land use practices. The more recent soil science review cited above shows that an even greater range and variation of environmental conditions will influence the fate of all types of soil carbon, including that of biochar. All this evidence makes claims such as the International Biochar Initiative's assertion that "scientists have shown that the mean residence time of this stable fraction is estimated to range from several hundred to a few thousand years"[34] appear very questionable.

Does biochar lead to an overall increase in soil carbon?

There are different reasons why biochar might fail to lead to an overall increase in soil carbon, which do not relate to the stability of the black carbon in the biochar:

One possible reason can be ***erosion, either by water or wind***. If biochar erodes then its carbon will not automatically turn into CO2 but might still remain stable, albeit somewhere else. However, given the different factors which influence its stability discussed above, it will be even more difficult to make any prediction if the biochar ends up in an unknown place under unknown conditions. Some black carbon which ends up washed into in ocean sediments may remain there for longer periods than it would have done in soil[35], for example, whereas some may be transported to sites where it will be exposed to conditions making it less likely to remain stable.

One study, which looked at the fate of black carbon from swidden agriculture on steep slopes in Northern Laos, found that it was significantly more prone to water erosion than other soil carbon, due partly to its low density and weight[36]. The same properties also make black carbon, especially smaller particles, prone to wind erosion[37]. Wind erosion of black carbon raises particularly concerns with regards to global warming impact, which are discussed below.

Another reason why biochar might not lead to an overall increase in soil carbon is called ***'priming', i.e. biochar additions causing the loss of other, per-existing soil carbon.*** When carbon-containing matter – whether biochar or any type of organic carbon – is added to soil, it can stimulate microbes to degrade not just newly added carbon but also soil carbon which had previously been relatively stable. [c]Whether or to what extent such priming happens depends on various and still poorly understood factors. According to the soil research institute SIMBIOS Centre, "*to make progress in this area, it would be necessary to first understand why some*

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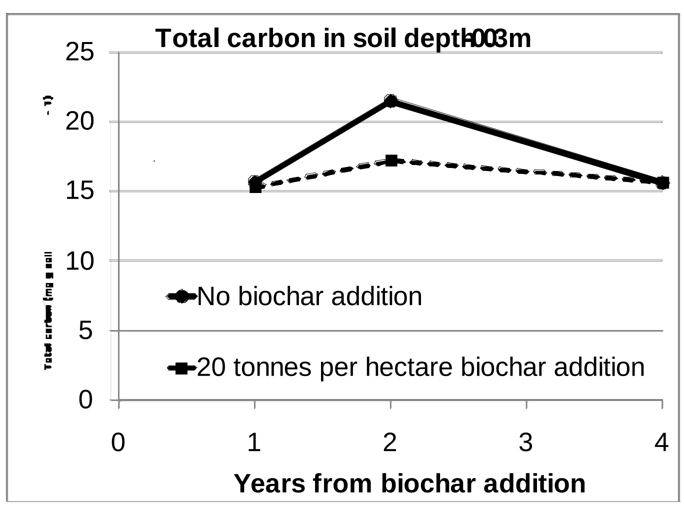
[c] For the purpose of this report, we are using the term 'priming' only to refer to biochar stimulating soil microbes to degrade other carbon in soil and residues. Elsewhere, however, it is also used to refer to the loss of biochar carbon through microbes, stimulated by other soil carbon, an issue discussed separately above.

fractions of the organic matter present in a soil are not degraded under normal conditions (in the absence of priming)"[38] Given the general gaps in knowledge of this priming effect it seems highly unlikely that any one study could 'prove' whether or not biochar will always cause priming and thus the loss of existing soil carbon, or how serious this effect will be. After all, priming depends on the responses of different soil microbes, yet scientists have so far only been able to culture and thus closely observe 1% of soil bacteria species and none of the multitude of varieties of soil fungi [39]. A widely reported Swedish study involved placing mesh bags containing charcoal or humus or a 50:50 mix of charcoal and humus into boreal forest soil for a period of 10 years. At the end of the trial, the amount of carbon in the mesh bags with the charcoal and humus mix was significantly less than could have been expected from the carbon contained in either the charcoal or the humus bags [40]. A comment by Johannes Lehmann and Saran Sohi argued that the results may reflect the loss of carbon in charcoal and that 'priming' might be less likely because most of the carbon loss occurred during the first year of the trial [41]. In response, the authors pointed to the fact that very little carbon was lost from the charcoal-only bags and that most 'priming', by its nature, occurs early on [42]. Different biochar studies, most of them laboratory ones, have had very different results: some demonstrated biochar can cause microbes to turn existing soil carbon into CO2, others demonstrated that it may have no effect on losses of existing soil carbon and that, in some circumstances, it can even reduce losses (an effect called 'negative priming'). One laboratory study looked at the impact of 19 different biochars on five different soils, in each case using a very high rate of biochar application, equivalent to 90 tonnes per hectare [43]. Initially, biochar additions increased the rate at which pre-existing non-black soil carbon was lost in most of the biochar- plus-soil combinations. Later on in the trial, a variety of outcomes were evident: in cases some, the rate of soil carbon loss continued to be higher with than without biochar (though the rate of carbon loss slowed compared to what it had been early on in the experiment), in others, there difference disappeared and in yet others, soil carbon losses were slowed down in the presence of biochar. One problem with that study however is that all soil and biochar samples were inoculated with soil microbes taken from a forest floor, not from the actual soils being tested, which means that the microbes which degraded some of the carbon were not the ones which would have been present had this been a field rather than a laboratory trial. Priming has also been observed in other laboratory studies. For example in one of the trials switchgrass residue was added to soils with biochar, the biochar increased carbon losses from that residue[44]. The other problem is that, as discussed above, laboratory studies are inherently a poor predictor to what happens to biochar and other soil carbon in varied, living soils. In sum: biochar can cause a proportion of other carbon in soils to be turned into CO2, but this effect depends on the particular type of biochar, as well as on the specific, highly variable soil environment, and on any organic residue added to soil. It is thus very difficult if not impossible to predict, particularly since relatively few studies have been published which look at this possibility.

Field study results



The five peer-reviewed field studies which look at biochar impacts on soil carbon do not clearly identify what exactly happened to which type of carbon in soil. Nonetheless, they provide the best 'real-life test' of the claim that biochar, at least at the field level, can be relied on to sequester carbon. So far, only two biochar field trials have been published which have lasted for more than two years, both of them four-year long trials. Longer- or more medium-term field studies would show more clearly how different biochars impact carbon in different soils. What those published so far show, however, is that biochar impacts on soil carbon are variable, unpredictable and by no means always positive.

Field trial on savannah soil under a maize and soya rotation, Colombia[45]

This was a four-year field study, in which biochar at the rate of 0, 8 and 20 tonnes per hectare was applied (together with the same fertilisers) to relatively carbon-poor soil from which savannah vegetation had just been cleared. Maize and soybean were grown in rotation. Total soil carbon was tested after one, two and four years although on the plots with 8 tonnes/hectare of biochar, it was only measured once, after four years.

In the first, third and fourth year, there was no statistically significant difference between amounts of carbon in different plots. Even a high biochar rate of 20 tonnes per hectare had not increased soil carbon. In the second year, the plots which had been amended with biochar held significantly less carbon than those without. It is not known how much of this was due to the loss of biochar or other organic carbon, although biochar had effects on crop yields and soil properties through the trial, so at least some of it must have remained in the soil, making the loss of other soil carbon ("priming") more likely. In the third and fourth year, carbon levels recovered on the plots with biochar, though they did not exceed the control plots and this is understood to be due to higher crop yields. Greater crop growth and yields will, temporarily, lead to crops depositing more carbon in the soil.

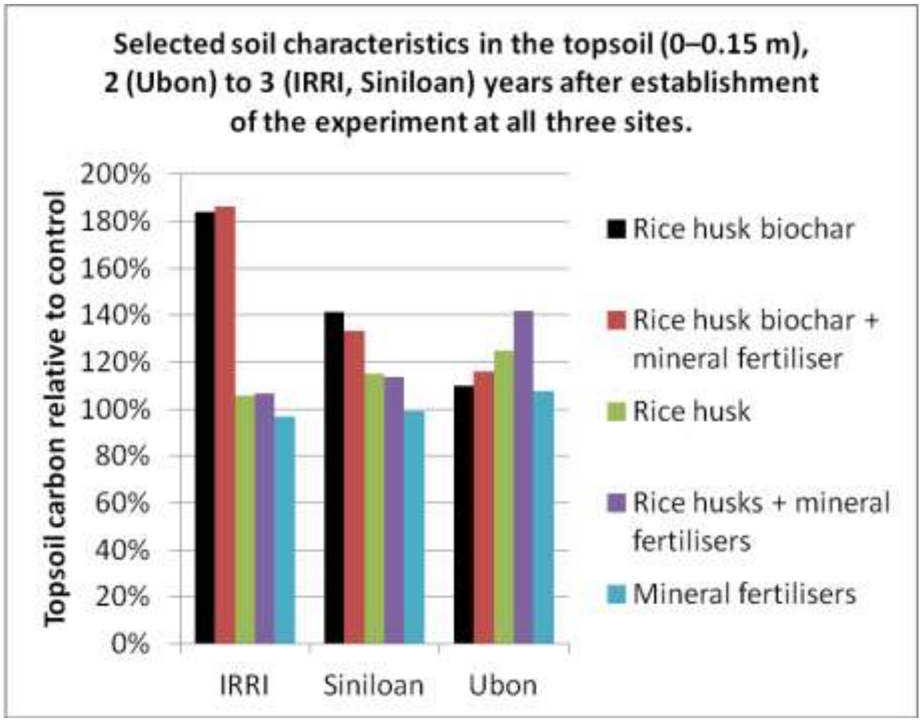
Field trial on savannah soil under regrowing native savannah vegetation, Colombia[46]

This was a two-year trial in the same region as the four-year one discussed above. Native savannah vegetation was removed before biochar application but then allowed to regrow. Biochar was applied at the rates of 0, 11.6, 23.2 and 116.1 tonnes per hectare. ***After two years, there was no statistically significant difference in the amount of carbon found in the top 30cm of soil between the plots with no biochar and those with 11.6 or 23.2 tonnes of biochar per hectare.*** Only a very large amount of biochar addition - 116.1 tonnes per hectare resulted in significantly higher carbon levels, than control plots. It is uncertain what happened to the 'missing carbon'. The authors of the study measured the amount of black carbon and other carbon emitted as CO2 from the soil ('soil respiration') and found that only 2.2% of the biochar carbon was lost that way. Other soil carbon was lost at a higher rate from plots with biochar, than from those without biochar – 40% higher in the first and 6% higher in the second year, but that was not enough to account for the missing carbon. There may have been problems with those measurements in that they were supposed to have been done on small 'rings' kept free from vegetation, but the authors suggest that the readings might have been influenced by plant growth, which indicates that the rings might have got overgrown, which would have distorted the results. According to the lead author water erosion may have played an important role [47]. However, erosion was not measured and it appears surprising in that the ground was relatively flat and savannah vegetation would have grown back very quickly, which should have minimised or stopped water erosion. In sum: the results indicate that very large amounts of carbon simply disappeared and are unaccounted for.

Field trial in Central Amazonia, Brazil, under rice and sorghum cultivation[48]

Results from two years of a field trial in Central Amazonia have been published. This took place on the same type of highly-weathered soil from which Terra Preta is understood to have been created. Secondary forest was cleared for the trial and different plots were amended with different combinations of mineral fertiliser, charcoal, chicken manure, burned and unburned leaf litter and compost. They were then cultivated first with rice and then with sorghum. ***After five months, soil carbon was measured. Total soil carbon was not significantly higher when charcoal or most of the combinations including charcoal were used, compared to controls.*** They were only significantly higher for a combination of charcoal plus mineral fertiliser plus compost. After the second harvest, soil carbon was only measured on control plots, those with mineral fertilisers only and those with combinations of compost and charcoal. Plots with either compost and charcoal plus mineral fertilisers had higher total carbon than those with compost only or mineral fertilisers only (those with charcoal only were not tested for soil carbon at that time). No carbon measurements were done for the two later harvests.

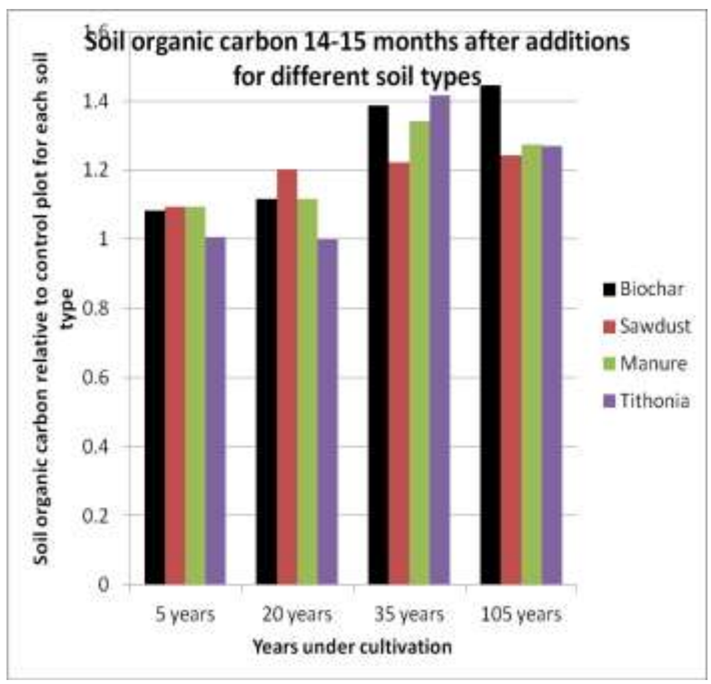
Field trial in the Philippines, under rice cultivation[49]



This was a four-year field trial on three different soils under rice cultivation in the Philippines. Different plots were amended with 1) biochar made from rice husks (at a rate of 16.4 tonnes/hectare) or 2) uncharred rice husks, with or without mineral fertilisers, or 3) left unamended or 4) with mineral fertilisers only.

After 2-3 years, soil carbon levels were higher on plots with biochar (with or without fertilisers), compared to both control plots and those with uncharred rice husks on two types of soil. On the third soil, total carbon was higher on the plots with biochar compared to the control plots or those with fertiliser only, but they were highest on plots amended with uncharred rice husks.

Field trial in Western Kenya under maize cultivation [50]



An 18 month study was conducted on four different soils, which differed according to how long they had previously been under continuous cultivation – 5, 20, 35 and 105 years. The longer the soils had been under cultivation, the less carbon they contained. For each soil, plots were amended with biochar, manure, sawdust, fresh Tithonia leaves (commonly used as green manure) or left as controls. At the end of the trial, biochar-amended plots had the highest carbon concentrations on only one of the four soils – the one which had been cultivated the longest. On another soil, biochar, manure and Tithonia all raised carbon levels compared to controls, with no significant difference between them; on a third, sawdust resulted in the highest carbon levels and on another, there was no significant difference in soil carbon between any of the plots, including controls. Thus, although biochar increased soil carbon compared to plots without any amendments, it did not perform any better in that respect than other organic residues.

Summary results from field studies

The five relevant field studies involved 11 different soils/vegetation. If we look at those as 11 separate 'samples' then we find that there was no carbon sequestration compared to unamended

control soils in five of those samples (excluding the unrealistically high rate of 116.1 tonnes/hectare in one such trial) and a temporary net carbon loss linked to biochar on one of those. In three samples, biochar resulted in higher total carbon compared to largely unamended soils, but not when compared to common alternative soil amendments. And in three samples, biochar did result in more carbon sequestration than the alternatives tested, though a different range of alternatives was used in different studies. The basic proposition of most carbon sequestration offset projects – an increase in soil carbon compared to what would have happened in the absence of the project (i.e. common farming practices in an area) – would thus have been met in only three out of eleven cases, at least over the short duration of the trials.

Part 2: Climate impacts of airborne biochar

When black carbon becomes airborne, it absorbs solar energy rather than reflecting it back into space and thus contributes to global warming. The effect is worsened when black carbon particles, which can travel for thousands of miles, are deposited on snow or ice and accelerate melting[51]. The warming effect of black carbon is short-lived but so powerful that NASA scientists suggest that, evened out over a century, airborne black carbon particles have 500-800 times the warming effect of a similar volume of CO_2[52]. Airborne black carbon has been mainly discussed in the context of soot, since soot particles are particularly small, i.e. in the submicron range. However, some fresh biochar particles are in the same size range as soot which would make them as liable to becoming airborne, as dust particles which can also become airborne. For example, in a non-peer-reviewed field trial study in Quebec "an estimated 30% of the material was wind-blown and lost during handling, transport to the field, soil application and incorporation"[53]. The particle size of the biochar produced by the company which supplied that trial was analysed by the Flax Farm Foundation, who found that it "approaches a low of 5 μm in size"[54]. This is smaller than the size of many (airborne) soot particles. Furthermore, according to a report published by Australia's Commonwealth Scientific and Industrial Research Organisation (CSIRO), "the size of biochar particles is relatively rapidly decreased, concentrating in size fractions <5μm diameter"[55]. In other words, over time, larger biochar particles are likely to also break down to the size of black soot particles. Given that wind erosion of black carbon is well documented[56], it seems surprising that no scientific literature has been published about the potential warming effects of airborne small biochar particles. Concerns about the lack of research into biochar impacts on albedo has been increasingly acknowledged by scientists, including ones advocating for biochar deployment[57]. The magnitude of the warming effect of black carbon in the atmosphere is such that, if even a small proportion of biochar particles was to become airborne, this is likely to reverse any of the proposed 'climate benefits' of biochar (themselves unproven).

Part 3: Biochar impact on nitrous oxide emissions from soils

Nitrous oxide is the third most important greenhouse gas involved in global warming, after carbon dioxide (CO_2) and methane. Its warming effect is about 300 times as strong as that of the same volume of CO_2. Nitrous oxide is produced by soil bacteria as a natural part of the nitrogen cycle, but the amount produced that way has been greatly increased by the use of nitrogen fertilisers as well as fertilisation with large quantities of manure.

The International Biochar Initiative's prediction about the amount of greenhouse gas emissions that could be 'offset' by biochar relies partly on the assumption that biochar will reduce the amount of nitrous oxide emitted from soils[58]. However, only one peer-reviewed field trial has looked at the effect of biochar on nitrous oxide emissions. That trial, which took place on pasture in New Zealand, compared the impacts of 15 and 30 tonnes of biochar per hectare compared to none when added to patches of cow urine[59]. The higher amount of biochar reduced N_2O emissions from the cow urine by 70%, but the lower amount had no statistically significant impact. According to the UK Biochar Research Centre review, only one peer-reviewed (short-term) laboratory study exists which found reduced nitrous oxide emissions with biochar use. A greenhouse gas trial in Colombia reported to have shown a 50% reduction in nitrous oxide emissions from soybean production with biochar, was never published[60]. Three laboratory studies with conflicting results also remain unpublished. There thus appears to be far too little evidence for drawing any conclusions about biochar impacts on nitrous oxide emissions.

Part 4: Biochar and crop yields

According to the International Biochar Initiative, biochar can boost food security, discourage deforestation and preserve cropland diversity...Biochar can improve almost any soil. Areas with low rainfall or nutrient-poor soils will most likely see the largest impact from addition of biochar"[61]. This claim suggests that biochar will usually improve crop yields.

The large variations between different biochars as well as different soils suggest that impacts on crops are likely to differ, too. The UK Biochar Research Centre review identifies the different ways in which biochar can affect crop yields, which are discussed below. The additional comments and explanations about each effect are the authors', i.e. not taken from the UKBRC report.

a) As discussed above, a proportion of ***biochar carbon*** is easily degradable and ***provides food for soil microorganisms***. Those microorganisms will then build up stores of nutrients in soils which are needed by plants. However, this can also be a negative short-term effect: Compared to plant residues, compost or manure, biochar contains a high proportion of carbon relative to nitrogen. If a soil is already nitrogen limited, then microbes, stimulated by the carbon which they digest, can proliferate and out-compete plants – using up the accessible nitrogen. This can suppress plant growth and thus crop yields temporarily, during the first harvest or year.

b) Fresh biochar contains different proportions of ***ash, which is rich in minerals*** and benefits plant growth. This is a temporary positive effect, allowing biochars rich in ash to serve as a fertiliser early on, until the minerals have been depleted. That fertiliser effect may be delayed and extended if minerals adsorb to the pores in the biochar and thus become available to plants only more gradually.

c) Most, though not all, biochars are alkaline. Adding anything alkaline – including ***alkaline biochar - to acidic soils*** can boost plant growth. This is because acidic soils make it less possible for plants to absorb key soil nutrients, such as nitrogen, phosphorous, potassium, calcium and magnesium. Furthermore, acidic soils have increased concentrations of some trace metals, such as aluminium, which are toxic to plants in larger quantities. Biochars can only make soils more alkaline for a limited period of time, possibly a few years.

d) One important measurement of soil fertility is called the ***Cation Exchange Capacity (CEC)***. The CEC measures the ability of soils to hold and to release to plants various different elements and compounds, including soil nutrients such as calcium, magnesium, potassium and sodium. It is important for the ability of soils to retain nutrients and to protect groundwater from some forms of contamination. Highly-weathered tropical soils tend to have a low CEC, whereas the CEC is high in Terra Preta. The high CEC of Terra Preta, appears to be linked to the black carbon content, and so improving CEC has been cited repeatedly as a likely 'benefit' of biochar, including by companies[62] There are two problems with that claim: First, soil scientists distinguish between the 'potential CEC'

Terra Preta

Terra preta soils, found in Central Amazonia, are frequently cited as 'evidence' for the beneficial properties of biochar in soils. The soils, which are highly fertile and rich in carbon, including black carbon, are found mostly in patches of, on average, 20 hectares , though in some cases up to 350 hectares, mostly, though not exclusively, along the Amazon and its tributaries. Terra preta soils are associated with past farming practices by indigenous communities around 500 to over 2,500 years ago. According to the Food and Agriculture Organisation, "the knowledge systems and culture linked to the Terra Preta management are unique but have unfortunately been lost"; what is, however, known is that it the farming methods involved "diverse organic nutrient sources...such as fish residues, turtle shells, weeds and sediment from the rivers, manures, and kitchen waste other than fish" . Furthermore, Terra preta is characterised by an abundance of pottery shards and minerals left behind from ceramics Sediments from seasonal river flooding played a role in at least some places and evidence that perennial trees and shrubs as well as long-crop cycles all played a role in those pre-colonial farming methods. Charcoal was thus only on component in a complex biodiverse farming system and soils amended with biochar, unsurprisingly, have different properties from Terra preta.

and the 'effective CEC' and the latter is thought to be linked most closely with soil fertility, yet that is not particularly high in Terra preta, which means that different properties may be responsible for the high fertility of those soils [63]. Secondly, it is thought that the charcoal remains in Terra preta would only have gained a high CEC over time, as a result of slow changes to black carbon in soils over a long period of time[64]. According to a laboratory study in which samples of biochar was incubated for a year at different warm and high temperatures, it was concluded that it would take around 130 years for biochar particles to have undergone the changes found in black carbon particles in Terra preta which are responsible for Terra preta's high CEC[65]. Although some increase in CEC could be expected sooner, especially in a warm climate, it is still a very slow process, except in the case of certain biochars such as those made from cow manure[66] or some biochars produced at relatively low temperature, around 350°C[67].

e) Other changes to soil properties: All biochars are porous. Depending on their pore sizes and distribution (which vary greatly), they can hold water and adsorb various chemicals, including nutrients, pesticides, etc. It is also thought that the porous and light nature of biochar can help to improve the structure of compacted soils and improve soil aggregation[d]. Again, the effects which different biochars of different ages have on different soils vary greatly. For example, the impact of biochars on the water holding capacity of soils varies with different biochars and different soil types and the 'positive' impact can be reduced or negated by the fact that fresh biochar particles can be water-repellent. For example, in a laboratory trial, biochar produced through fast pyrolysis increased the water holding capacity of a sandy loam soil by nearly one third, but biochar produced through slow pyrolysis had a very small impact on water retention, apparently too small to be statistically significant[68]. And in a laboratory study which looked at the impact of two different biochars on three soil types from Ghana, the water holding capacity was increased, but it was higher when biochar was applied at a relatively low rate of 5 tonnes per hectare compared to a higher rate of 15 tonnes/hectare[69].

f) Providing a habitat for micro-organisms: At least some biochars have pores large enough to provide shelter for various soil microbes as well as the hyphae[e] of beneficial fungi, and helping microbes and fungi to access nutrients. Of particular interest is the link between black carbon and mycorrhizal fungi, small, diverse fungi which enter into a usually symbiotic relationship with plant roots, helping plants to access various mineral nutrients and receiving sugars in return. Terra preta appears to provide a rich habitat for mycorrhizal fungi. There are several different ways in which black carbon could support such fungi, as well as other microorganisms, although biochar's high ratio of carbon to nitrogen could, in the short term, have a negative impact on microorganisms as described previously[70].

What do field studies show?

The lack of longer-term field studies makes it impossible to predict what the long-term effects of different biochars on soil fertility and soil properties will be. Long-term effects are particularly important because of the relatively large quantities of biomass required to produce biochar. Most trials have involved applying biochar at a rate of at least 10 tonnes per hectare, which would require at least 40 tonnes but more likely 50-60 tonnes of biomass to produce. If biochar could be relied upon to raise crop yields or, more likely, to reduce the use of mineral and/or organic fertilisers over long periods, this would increase the likelihood of it becoming economically viable without subsidies or carbon offsets, at least for large farmers, agribusiness and other plantation companies who can afford upfront payments and investments. For example, interim results of a Cornell University Life Cycle Assessment suggest that several decades of expected higher yields with lower fertiliser use greatly increases the economic potential of biochar[71].

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[d] Well aggregated soils are ones in which soil particles are hold together well, for example by organic matter, moist clay, fungi, etc. and which are more stable and less prone to erosion. Pores within and between 'clumps' of soil particles allow air, water, microbes, nutrients and organic matter to be stored.

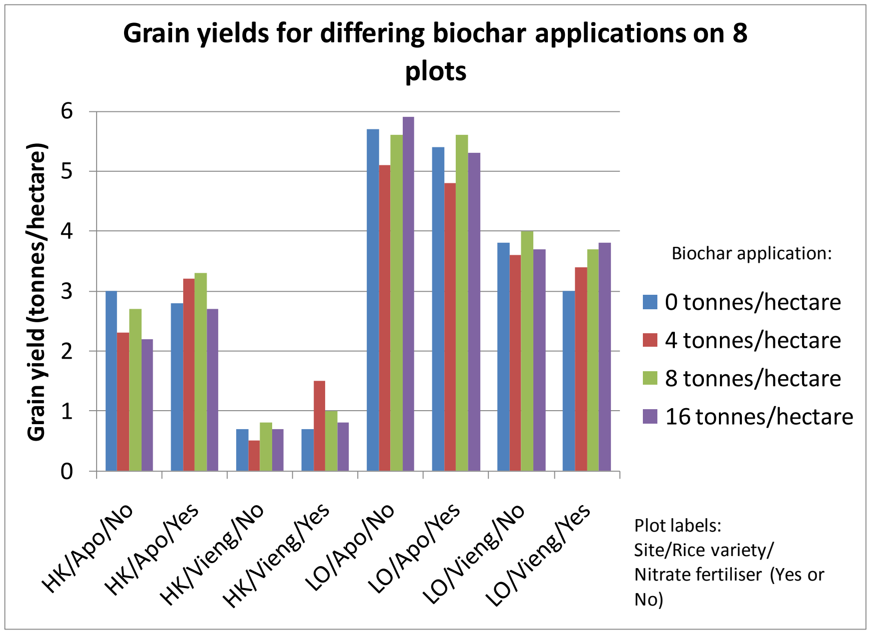
[e] Hyphae are the long, branching structures which most fungi have and on which they rely to access nutrients.

So, does biochar application reduce fertilizer demand and increase crop yields? What is the evidence? Eight of the peer-reviewed field trials which we have found look at biochar impacts on soil fertility. Those include the trial involving 'charred soil' rather than biochar, leaving us with seven relevant field trials.

Field trial involving biochar for rice production in Northern Laos[72]

This was a six-month trial which involved three different field experiments, involving traditional charcoal applied at rates of 0, 4, 8 and 16 tonnes/hectare, with and without mineral fertilisers, with two different rice varieties grown. Impacts on crop yields varied greatly, from negative to neutral to positive.

Biochar appeared to increase the water holding capacity of soils, but to reduce the availability of nitrogen to plants, particularly if used in larger quantities.

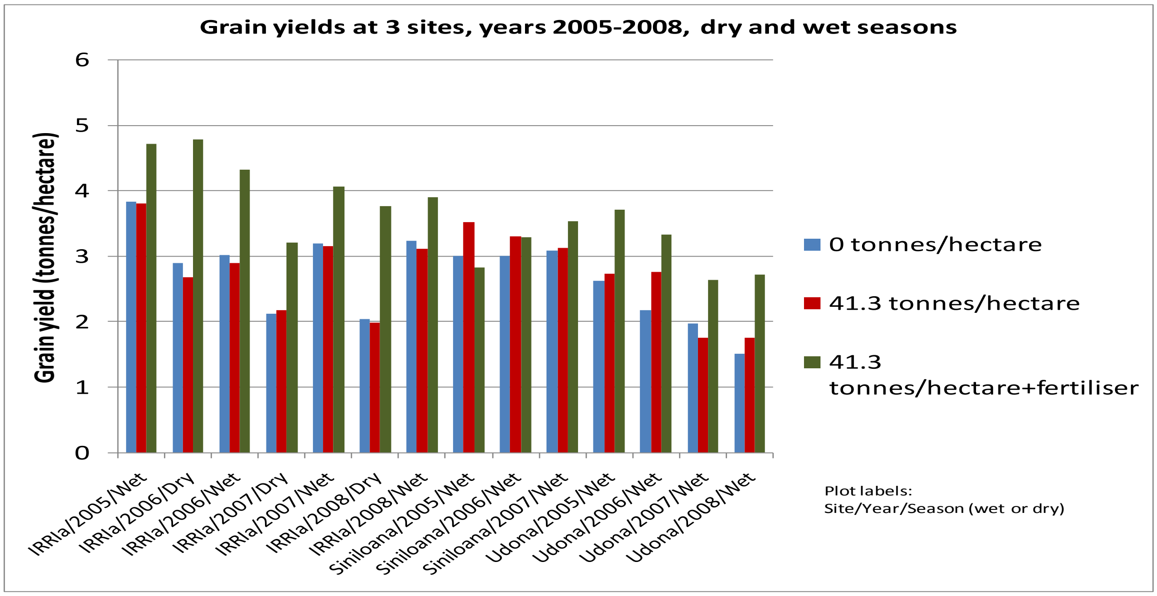


Field trial looking at the impacts of pine chip and peanut hull biochars on soil cultivated with maize in the SE US[73]

This was an 18 month trial using biochars made from either pine chips or peanut hulls at rates of 0, 11 and 22 tonnes per hectare, with and without nitrogen fertilisers. The maize was irrigated, though not enough to prevent drought stress in the second year.

Field trial in the Philippines, under rice cultivation[74]

This trial has been described above in relation to soil carbon impacts. At one site, the effect of biochar on grain yield was generally negative, possibly due to the high proportion of carbon in relation to nitrogen, which may have suppressed nitrogen take-up by plants. At the second site, different treatments with fertilisers and/or biochar made little difference overall. At the third site, combinations involving biochar mixed with mineral fertilisers and/or rice husks achieved the highest yields during three of four harvests, but biochar on its own had no effect.

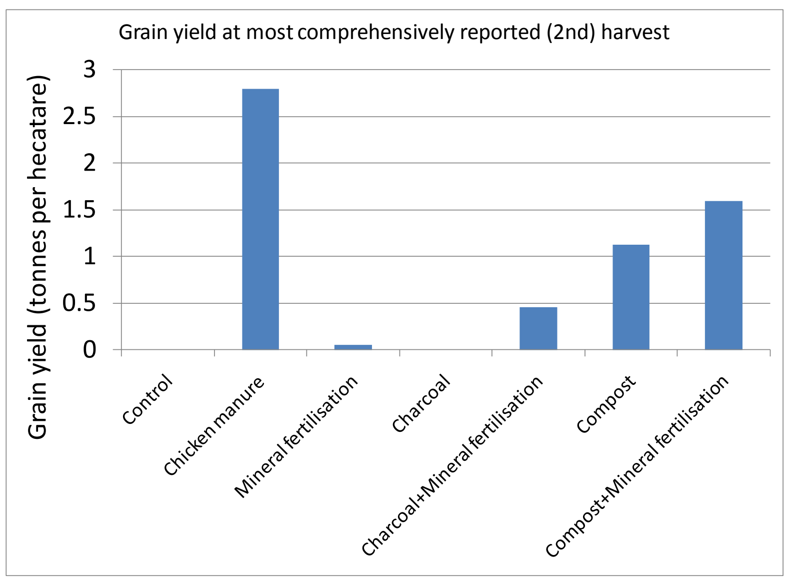


Field trial on savannah soil under a maize and soya rotation, Colombia[75]

This trial has been described above in relation to soil carbon impacts. Maize yields were measured annually for four years, soybean yields during the fourth year only. During the first year, biochar had no statistically significant impact on crop yields. During subsequent years, it raised maize yields, applying 20 tonnes per hectare of biochar raised maize yields more than 8 tonnes per hectare. In the fourth year, all maize yields declined sharply, although yields on plots with biochar were significantly higher than those on control plots, on which only mineral fertiliser had been used. Soybean yields were not affected by biochar.

Field trial in Central Amazonia, Brazil, under rice and sorghum cultivation[76]

This trial has been described above in relation to soil carbon impacts. Both overall biomass and grain yields were highest when chicken manure was applied, followed by a combination of compost and mineral fertilisers. Applications of biochar on its own were associated with the lowest yields other than those for control plots and in the second year, soil amended with nothing but charcoal did not support any growth of crops at all.



Field trial in South Sumatra, under maize, cowpea and peanut cultivation[77]

This was a short, three month trial, with three different sites. The experiments at two sites took place a year earlier than those at the third. Traditional charcoal was produced from Acacia wood waste from pulp and paper production and applied to fields on which maize, cowpea and peanut were grown. Three different locations were selected: One was located in the garden of a farmhouse, a second in a garden reclaimed from a chicken farm, and a third on former grassland which had recently been turned into farmland. The two treatments compared at the first site were mineral fertiliser alone and mineral fertiliser combined with charcoal, with control plots being unfertilised and unamended. At the first site, yields of maize and peanut were significantly greater when charcoal and fertilisers were combined than when fertiliser alone was used, whereas charcoal had no significant impact on cowpea yields. Maize yields doubled when charcoal was added to

fertilisers. At the second site, there was no statistically significant difference between the two treatments, both of which raised yields compared to the unfertilised control plots. At the third site, overall maize yield increased significantly when charcoal was added to fertilisers and resulted in similar yield increases when it was applied on its own, compared to plots amended with mineral fertilisers only.

This is the only field trial described here which did not use the "randomised block design with replicates" method which has been described as good practice in the International Biochar Initiatives guide to biochar field trials. This makes the results of this study less reliable than others.

Field trial in Western Australia under wheat cultivation[78]

This was a short, 3-4 months field trial on acidic sandy clay loam in Western Australia. Charcoal was made from oil mallee (Eucalyptus oleosa) after extraction of the oil. Different combinations of charcoal, at rates of 0, 1.5, 3 and 6 tonnes per hectare and either water-soluble mineral fertilisers or slow-release mineral fertilisers inoculated with mycorrhizal fungi were tested, with nitrogen and phosphorous fertilisers applied to all plots. When soluble fertilisers were used, only one biochar combination out of six (6 tonnes per hectare of biochar and 30 kg/hectare of fertiliser) significantly improved yields. Biochar raised yields in combination with the inoculated mineral fertilisers.

Summary findings from field studies

Field trials illustrate the variable and as yet unpredictable impact which biochar has on crop yields, which can be positive, negative or neutral, depending on different types of biochar, soils and even crop varieties, and on combinations with different organic and mineral fertilisers. Although biochar researchers are looking at the possibility of producing 'designer biochars' for different conditions, the large variation in impacts compared to the small amount of field data – as well as the large variation in soil conditions - make it difficult to see how this would be possible or practical, at least in the foreseeable future. Given how inconsistent biochar impacts on yields are and how little is known about their longer-term impacts, farmers who are to use biochar on their fields are taking considerable risks, even more so if they have to invest in producing or purchasing the biochar, rather than taking part in a trial in which biochar was supplied for free.

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Chapter 4: Biochar – The Policy Context

The push for commercial scale biochar production focuses largely on securing funding – whether through carbon markets, public subsidies or loan guarantees, philanthropist funding or other finance streams. The main lobbying force is the International Biochar Initiative (IBI), which has been effective in promoting biochar at international, regional and national levels worldwide. The IBI is complemented by a number of regional biochar initiatives, including in Australia and New Zealand, Canada, China, Europe, India, Japan, Mongolia, Thailand and the US. Some of these are rather small, but others more active and growing. These initiatives are comprised largely of academic researchers, business entrepreneurs (including those developing biochar- producing stoves) start-up companies, bioenergy companies with interest in pyrolysis and gasification and carbon offset and other consultancy firms. A small number of NGO groups, including the French NGO Pro-Natura and the US-based Clean Air Task Force are also instrumental. The low-profile but influential US bioenergy lobby group Renew the Earth describes the International Agrichar Initiative (the previous name of the IBI) as their project. Two leading IBI members are on Renew the Earth's Board of Directors. Renew the Earth is part of the Energy and Security Group, a US organisation which promotes renewable energy and energy efficiency and lists amongst their clients and partners various US government agencies, the US Army and US Army Corps of Engineers, private sector companies (including military ones), the World Bank and different UN organisations as well as some NGOs/Foundations - they are thus very "well connected."

Biochar and the IBI have also attracted interest from industrial agriculture and tree plantation industries. The former executive director of the Indonesian Palm Oil Association (GAPKI), Didiek Goenadi presented at the IBI's 2008 Conference and Malaysian researchers are looking at biochar production from oil palm plantation residues. In Indonesia, at least three pulp and paper companies, PT Musi Hutan Persada and PT Tanujngenim Lestari Pulp and Paper have taken part in studies looking at the potential of biochar for carbon offset.[79] The managing director of the Norwegian company Green Resources, investing in monoculture tree plantations for 'carbon offsets' in East Africa, has publicly supported biochar.[80] Finally, there is interest and involvement from bioenergy producers who increasingly view the potential to profit from char, previously considered a less desirable by-product of their processes – and from tar sands and coal companies looking at biochar to offset some of their emissions or possibly help with land reclamation. Examples of such links are discussed at the end of this chapter.

How much biochar for what purpose?

Biochar advocates seem to embrace a philosophy that biochar is good for just about everything, and hence seek supports through diverse means for diverse, often overlapping and not necessarily mutually exclusive applications. Most advocate for biochar as a means of sequestering carbon in order to reduce atmospheric CO2 levels. Others focus instead (or in addition) on the claimed yield increases and soil "improvement." Others encourage use of biochar for reducing nitrous oxide emissions from soils and livestock manures. It has even been suggested that feeding biochar to livestock can reduce methane emissions.[81] Some promote use of biochar producing cook stoves. Some encourage use of biochar for urinals.[82] When Japan's Fukushima Daichi nuclear power plant went into core meltdown, some biochar advocates suggested biochar should be used for remediation and clean up.[83] Applications for soil decontamination and mine reclamation are increasingly common. For some, biochar is primarily a by-product of processes for bioenergy production, for which "beneficial use" and profits are sought. In at least one case, the "hype" around biochar was used to support a ponzi scheme (see text box)

Biochar Fraud Investigations

2011 saw fraud charges being upheld against two US companies that had claimed to produce biochar.

The first and larger of those cases had been brought against Mantria Industries LLC, a subsidiary of Mantria Corporation. They claimed in 2009 that they had opened the world's first commercial-scale

biochar production facility and they advertised 'EternaGreen' biochar for sale. Mantria Corporation was set up as a partnership with Speed of Wealth LLC and Mantria Industries claimed to invest in the BioRefinery industry and specifically in biofuels and biochar, focussed around carbon credits. There is no evidence that they ever sold or even produced biochar. In August 2011, a US District Court described Mantria Corp. as a Ponzi scheme with "*sociopathic greed*", responsible for $54.5 million of fraud, through "*misrepresentations, omissions and blatant lies*."[84] The investigation had been brought by the Securities and Exchange Commission in 2009. At the time, the IBI published a statement claiming that their knowledge about Mantria's biochar activities was limited to what was in the media, that they had not supported their projects and received no funding from them. Yet previous, uncontested, media articles had described the IBI as a supporter of Mantria's biochar activities and the IBI website hosted a full 'project page' for Mantria. There are no reasons to believe that the IBI would have had any idea about the apparently fraudulent nature of the business. However this example shows the ease with which a fraudulent company could take advantage of the positive image created around biochar and even be promoted by the IBI, without any checks on the nature of their business.

This is confirmed by the second fraud conviction against New Earth Renewable Energy, who were found guilty and fined [85]. New Earth had attracted investment into a large industrial plant to produce "E-coal and E-oil" made from biomass as well as biochar, to build on what was claimed to be their successful 25,000 ton per year plant in Canada. That plant however was neither operational nor did it belong to New Earth[86].

With so many different "uses", the possibilities for funding for biochar are similarly varied. The IBI and others are leaving "no stone unturned" in their mission to gain finance. Much effort has gone into securing finance through carbon markets, viewed as especially promising (but, as detailed below, so far unsuccessful). Different pyrolysis or gasification technologies can produce biochar at different scales, ranging from biochar-making cookstoves to, potentially, very large gasification and pyrolysis plants. All biochar projects so far are small-scale ones and many involve cheap, backyard technologies, due to limitations to funding and investment. Yet the claimed successes of such projects are being used to advocate for major scaling up production. The overall vision of most of those advocating for biochar for climate change mitigation – including the IBI - is one of very large-scale global use.

As discussed in Chapter 3, the basic premise of climate change mitigation through biochar is by its nature based on a large-scale geo-engineering vision – manipulating the carbon cycle to "stabilize" large amounts of carbon in soils. Even some of those advocating biochar-making cook stoves, argue in terms of how their use will impact global carbon cycles. IBI founder Johannes Lehmann, though not necessarily referring to it as "geoengineering" has repeatedly referred to biochar potential to sequester 5.5-9.5 gigatonnes of carbon per year by 2100, more than the current annual emissions from fossil fuel combustion.[87] Some IBI members have openly spoken about using biochar for geoengineering, requiring conversion of hundreds of millions of hectares to biochar plantations. For example, IBI Advisory Committee Member and Founder of the Society of Biochar Initiatives, India describes himself as a "*geo-engineering initiator*", while former IBI Advisory Committee member, the late Peter Read, called for the conversion of up to 1 billion hectares of land to produce biochar.[88] Outside the IBI, Tim Lenton and Nem Vaughan from the University of East Anglia described biochar as the most promising geoengineering strategy in a peer-reviewed article[89] and the head of the climate unit at the European Commission's Joint Research Centre, Frank Raes, has described it as 'geo-renovating' or 'soft geoengineering'.[90]

It appears that IBI members have been increasingly reluctant to use the term geoengineering or to publicly advocate large-scale land conversion for biochar production, even if this is what they promote – likely in response to the growing criticism of such plans. The most high-profile example of this was an article about the potential for 'sustainable biochar' to mitigate climate change, published in Nature Communications in August 2010 to which the Chair and Vice-chair of IBI contributed.[91] The study was widely reported in the media as having shown that biochar from waste and residues alone could 'offset' 12% of global greenhouse gas emissions every year. BBC News reported that: "*The vision put forward is of a world where waste is burned, where some of the heat from that burning is used to transform waste to charcoal, and where the charcoal is*

ploughed into soil, increasing its capacity to support crops and locking up carbon for centuries, possibly millennia."[92] Neither the authors nor the IBI challenged or corrected this interpretation. Instead it was left to 21 civil society groups to point out that the calculations assumed conversion of hundreds of millions of hectares of land for feedstock production (556 million hectares as a co-author of the article later clarified)[f], as well as the collection and pyrolysis of a large proportion livestock and agricultural and forestry residues.[93] Many calling for very large scale deployment openly openly call for croplands to be dedicated to feedstock production. For example, IBI chair, Johannes Lehmann et. al. 2009 states "*Research in genetics and plant breeding is needed to develop new, high-yielding hybrids of cereal crops and dedicated biomass crops that optimize the quality and maximise the quantity of biomass for a pyrolysis industry*."[94] It appears that for some biochar advocates the decision to refrain from speaking about large-scale land conversion and geo-engineering in public appears to merely be a tactical decision about communication.

Biochar, with its emphasis on manipulating carbon cycles via "biosequestration", has featured in most recent reports on climate geoengineering, though in many cases it has received lukewarm ratings. The 2009 Royal Society report on geoengineering states: "T*echniques that sequester carbon but have land-use implications (such as biochar and soil based enhanced weathering) may be useful contributors on a small-scale although the circumstances under which they are economically viable and socially and ecologically sustainable remain to be determined.*"[95] The report rates the effectiveness, affordability and timeliness of biochar as "low" and warns about the potential for land use conflicts and point out that the long term effects of biochar on soils remain unknown. The US recent Government Accountability Office Technology Assessment report on geoengineering gives biochar a low "Technology Readiness Level" (2 out of 9), based on "substantial uncertainties about capacity to reduce net emissions of CO2", as well concerns about land use trade-offs, uncertain effects on soils and health and safety concerns.[96] Nonetheless, biochar continues to be featured in discussions and debates – for example, it was on the agenda of the 2010 Asilomar Conference on Climate Geoengineering[97] and it was also mentioned among other Carbon Dioxide Removal technologies at a recent Intergovernmental Panel on Climate Change Meeting of Experts, and has been discussed in the context of the Convention on Biological Diversity liaison group on climate-related geoengineering. Some IBI members are very active on climate geoengineering listserves and blogs. A 2010 report by the Center for Energy and Environmental Security and the US Biochar Initiative states: "*Geoengineering discussions are taking on increasing importance for Biochar and vice-versa. Most of geoengineering's controversy has been about Solar Radiation Management (SRM), not the less well-studied CDR [Carbon Dioxide Removal] into which Biochar fits. A better umbrella might be the term 'Biosequestration' or 'Biomimicry-driven carbon reduction.'*[98] And during the Royal Society Consultation on their 2009 geo-engineering report, the UK Biochar Research Centre made a detailed submission in which they referred a future global biochar potential of 1-9 billion tonnes of carbon sequestration annually.[99]

Given the growing desperation to address rapidly escalating global warming, funding for research on geoengineering techniques is expanding and biochar advocates view this as a promising avenue. Both the Gates Foundation and Richard Branson, who set up the Carbon War Room, have been very supportive of both biochar and geoengineering in general.

Biochar for poverty alleviation?

Much biochar advocacy is focused on promoting biochar as a means of addressing poverty and/or reducing deforestation. For example, according to the French NGO Pro Natura, biochar could lead the way towards a 'Third Green Revolution': "*The Green Revolution...was instrumental in greatly increasing the agricultural output of the lucky minority of farmers throughout the world who had enough money to buy seeds, fertilisers, and access to water for irrigation. Hence the importance of the second wave 'Evergreen Revolution'...directed at the needs of the masses of small farmers...With biochar we now find ourselves on the threshold of a third wave, even more universal*

[f] Note: the figures for land conversion were not published in the article or in supplementary materials, but could only be deduced from references. Personal communication with James Ammonette following the above press release confirmed a total of 556 million hectares, even higher than our initial estimate.

in its application."[100] In chapter 3, we show that claims about long-term reliably higher yields with biochar production are not backed by the existing science. What is of interest here is the policy context and the assumption made by IBI member Pro-Natura. Behind the claim that biochar can reduce malnutrition and hunger are two assumption: First, that biochar will reliably increase crop yields – even though, as discussed in chapter 3, this is not borne out by scientific field trial results. The second assumption is that current practices by small farmers are commonly associated with low crop yields and soil depletion and that this is a significant cause of malnutrition/hunger. This assumption ignores the political, social and economic context behind large-scale and increasing hunger and malnutrition as well as soil depletion and other environmental degradation – as well as the fact that in many cases small-scale peasant farming can achieve high levels of productivity whilst maintaining or even enhancing soil fertility. It runs counter to the realities expressed by La Via Campesina: "*The contemporary food crisis is not really a crisis of our ability to produce. It is more due to factors like the food speculation and hoarding that transnational food corporations and investment funds engage in, the global injustices that mean some eat too much while many others don't have money to buy adequate food, and/or lack land on which to grow it, and misguided policies like the promotion agrofuels that devote farm land to feeding cars instead of feeding people."*[101]

Interestingly, the policy context defined by Pro-Natura is not simply one in which international trade and the role of transnational food corporations and agribusiness are ignored: By linking their vision of a biochar 'Third Green Revolution' to the so-called 'Evergreen Revolution'[102], they are linking it to policies which involve more trade liberalisation and more agricultural policies which seek to replace traditional knowledge and practices by small farmers (including, by implication, agro-biodiversity) with agricultural 'techno-fixes', including GMOs[103], to be transferred by Governments such as the US, academic 'experts', many of them trained at or supported by US universities, and undoubtedly, agribusiness. The association with the 'Evergreen Revolution' concept chosen by Pro-Natura is particularly noteworthy because of the crucial role played by Cornell University both in biochar advocacy and the Green Revolution. Not only did Cornell University provide much of the training and 'expertise' for the original Green Revolution in South Asia, but they have been given a key role in training for and implementing A Green Revolution for Africa (AGRA), with the new Chair of the Alliance for a Green Revolution for Africa, Kofi Annan, linking this to the "Evergreen Revolution" blueprint.[104] Cornell University are, at the same time, a leading centre for biochar research and development, with the Chair of the IBI, Johannes Lehmann an Associate Professor at Cornell's Department of Crop and Soil Science, and they have been awarded funds for deployment-oriented biochar work for example by the Gates Foundation[105], also major funders of AGRA. Over the past year, the terms 'evergreen revolution' and 'evergreen agriculture' have been increasingly subsumed into the concept and term 'Climate-Smart Agriculture', discussed below.

Biochar trials and projects in southern countries

A large number of pilot projects or 'trials' are supported by northern biochar interests, and implemented in southern countries. Many of these cite poverty alleviation as one of their main aims. Those projects differ from scientific field trials such as those discussed in Chapter 3. Though often called trials, they tend to be pilot projects for testing the deployment of biochar amongst different communities and for demonstrating the 'feasibility' of future biochar carbon offset projects, the latter a goal which is mentioned in many of the project descriptions. Even if scientific data about yields is collected, it is commonly not submitted for peer-review. Such pilot projects have been initiated by biochar and other companies and by some NGOs. In some cases, studies by research institutes have been funded which, although they are expected to result in peer-reviewed articles, focus entirely on the feasibility of biochar deployment rather than on biochar impacts on soils, soil carbon or crops. An example of the latter is a Cornell University 'biochar stoves' project funded by the Gates Foundation.[106]

Biochar "trials" include several projects in Latin America, three of which have been supported by the IBI as part of their "9 country projects".[107] One of them, a biochar "feasibility" project involving Carbon Gold and the Toledo Cacao Growers Association in Belize is said to have had initial support from the Cadbury Foundation. Also a project in Costa Rica, with support from the IBI, is using a

small pyrolysis facility to produce biochar from timber and oil palm plantations with the hopes of a "possibility of eventual carbon credits."[108] Seattle based "Seachar" recently obtained a significant grant from National Geographic Society for biochar producing gasification stove project in Costa Rica as well. Embrapa, the state-owned Brazilian Agricultural Research Corporation (affiliated with the Brazilian Ministry of Agriculture), is represented on the IBI science advisory board, and has supported trials through a biochar research program, a "terra preta" conference in 2002, and, as partner with IBI, hosted the 2010 International Biochar conference in Rio de Janeiro.

By the end of 2010, at least 28 projects and project plans in 13 African countries had been announced.[109] From information published by the project developers, it would appear that the largest ones are projects initiated by the (Belgian) Biochar Fund in Cameroon and DR Congo as well as another project by the (French) Centre for Rural innovations in Cote D'Ivoire. Many others are projects initiated by foreign biochar interests, some with connections to the IBI.

The questions which must be asked are: Do these projects actually benefit the small-scale farmers who who are enrolled to participate in the trials? Might their land and labor diverted, taking an overall toll on their productivity? Do they receive any form of remuneration or compensation for their efforts? Are they properly instructed in how to safely handle biochar to avoid breathing dust or otherwise avoid being exposed to risks? Are they fully informed not only about the claimed benefits but also about the potential risks and unknowns? Or are they told biochar "will" improve crop yields and "will" provide income from carbon credits? As discussed in chapter 3, the results of field tests suggest it is very unlikely that all or most farmers participating in trials would have seen consistently higher yields as a result of a biochar use. And as discussed below, carbon credits for biochar, let alone ones that would generate income for farmers, still appear a distant prospect.

In several cases, images portraying smiling farmers with healthy robust crops are offered with optimistic claims about project successes. But no independent assessments have so far been available. In many cases, trials are started but then no updated information has been published, putting into question whether the projects were abandoned. In one case, an NGO has announced that their initial biochar project in southern Ghana resulted in failure, despite technical support from three universities, but states that a second trial, in northern Ghana, has been successful and they are optimistic that a larger trial will succeed based on "chemical soil analysis."[110] However, no data from either of those trials has been published. The 'lessons' learned from these and other trials can thus be neither evaluated nor transferred and it is not clear how farmers were affected by those projects.

Biofuelwatch, together with Cameroonian researcher Benoit Ndameu, published an assessment of one of the supposedly largest African trials, those undertaken by the Biochar Fund in southwest Cameroon.[111] This project was meant to establish the feasibility of replacing slash and burn "swidden" agriculture with "slash and char" by maintaining long term high yields with biochar, thus avoiding the need to periodically move to new land and cut down trees and other vegetation repeated in the process. It was followed by a second project in DR Congo, financed by the Congo Basin Forest Fund. The 'slash-and-char' concept was first expressed in a 2006 article by soil scientist and IBI chair, Johannes Lehmann, who claimed: "*Existing slash-and-burn systems cause significant degradation of soil and release of greenhouse gases...Our global analysis revealed that up to 12% of the total anthropogenic C emissions by land use change (0.21 Pg C) can be off-set annually in soil, if slash-and-burn is replaced by slash-and-char*." Yet, to date there are no scientific studies which compare slash and char with traditional swidden cultivation.

Biochar Fund's trials were considered an important effort to address the issue of "slash and char". It was claimed that 1500 farmers had been involved, however, as the assessment revealed, in fact the trials had been set up to only involve 50 farmers many of whom did not complete the trials. While data collection (including soil analyses) from a second harvests had been promised in the media and the project had been publicly portrayed as a long-term one, only preliminary data from the first harvest were ever made public. Farmers who participated had been led to believe that they would in future benefit financially from the sale of carbon credits for biochar use, even though no such credits are currently traded on any carbon markets and the price at which voluntary carbon offsets have been traded is way below what Biochar Fund had claimed would be viable. Instead,

farmers gave up considerable amounts of their time without any rewards and in some cases even rented the plots of land for the trials. Some farmers were still anticipating such benefits even though we could find no evidence to suggest that Biochar Fund had ever actively looked at finance for a continuation of the Cameroon project – in fact, during the first half of 2011, the Biochar Fund's website disappeared. While many participants appeared enthusiastic about the impact of biochar on maize yields – and all of them had been promised higher yields with biochar - they were not provided with any training or facility to carry the project forward on their own. The design of the trials, the small amount of data collected and the lack of any peer-reviewed study arising from the trials, made any credible evaluation of results impossible. Nonetheless, Biochar Fund succeeded in using exaggerated claims about the success of these trials to secure further support from the Congo Basin Forest Fund to undertake another biochar project in DR Congo, as well as yet another non-biochar project in the same region. The proposals submitted to Congo Basin Forest Fund also indicate potential carbon finance as well as renewable energy generation as benefits to participants. The technology applied by Biochar Fund in both projects, like the technology used in most biochar field studies so far, does not allow any energy to be captured and used.

Promises of carbon finance are especially troubling. Even if there were established trade in biochar credits, farmers would not necessarily be the beneficiaries. The Institute for Agriculture Trade Policy (IATP) reports that a pilot "Kenya Agriculture Carbon Project" - the World Bank's first ever soil carbon offset project, supported through their BioCarbon Fund - will see most of the credits generated going into project development and transaction costs, with very little – possibly less than one dollar per year - actually going into the hands of participating farmers. They further point out the risks inherent to putting agriculture at the whims of market forces given volatility and potential for fraud, and uncertainties with accurate accounting for carbon flows. They question the entire exercise as a wasteful diversion, stating: "*The World Bank's need to demonstrate a successful pilot project should not outweigh the imperative to assess the tradeoffs of diverting scarce resources to creating an asset, the soil carbon credit, for which the market demand is very weak, even by the World Bank's own account*."[112]

Another form of biochar promotion to "benefit the poor" involves biochar cookstoves (see box).

Biochar cook stoves

The development of clean, efficient cook stoves to replace open fires and other inefficient, polluting ways of cooking with biomass has recently attracted greater support and prominence. In September 2010, Hilary Clinton announced the Global Alliance for Clean Cook stoves (GACC), a public-private partnership. The US Government has pledged to invest $53.32 million into the new GACC initiative. The initiative aims to build upon the work of the Partnership for Clean Indoor Air (PICA) which was set up in 2002 and has over 310 members, including non-profit organizations, private sector companies and consultants, governments, multilateral agencies and research institutes. One of the aims is to reduce illness and death from indoor air pollution, which is responsible for 1.5 million premature deaths a year and for about 2.6% of the global disease burden according to the World Health Organisation.[113] .The other aims are to reduce the amount of fuel which women and children have to collect for cooking and with it reduce pressures on forests, to develop alternatives to fuel wood use (e.g. use of agricultural residues) and to reduce atmospheric black carbon emissions.

One group of modern stoves are 'micro-gasifiers', also called 'wood gas stoves'. Micro-gasifiers expose biomass in various forms (depending on design), to very high temperatures to release gases that are then burned in a separate part of the stove for cooking. Most micro-gasifiers currently gasify all of the biomass except for the ash that is left behind. These are also called 'char-gasifiers' because the char is combusted to provide more heat for cooking. Some micro-gasifiers have been designed so that the char can be retained rather than gasified. Those are promoted as biochar-producing stoves.

Peer-reviewed data about the performance of different modern stoves, including biochar-making ones, is scant. The US Environmental Protection Agency (EPA) has started work on a comprehensive stoves testing programme, looking at efficiencies and emissions of different stove types and models. In 2009, two of their researchers published the results of their first round of

tests that looked at 14 different combinations of stoves and fuels.[114] No biochar-making stove was included but the authors confirm and emphasise the lack of existing peer-reviewed evidence on stoves performance: "*Better stoves have been developed to reduce emissions and improve fuel efficiency, but test results have not previously been reported in the peer reviewed scientific literature.*" A second round of testing has since been completed but results are still to be published. An interim summary, however, was presented at a Webinar in June 2011.[115] This time, 20 different stoves were tested. Several of those were micro-gasifier and some of them could have been operated in 'char-retaining' mode, although it is not clear from the presentation whether this actually happened. The study showed that stoves efficiency varied greatly according to the type of fuel (wet or dry) used. It found that most, though not all, were more efficient than open 3-stone fires, with which all stoves were compared. The stove with the highest thermal efficiency tested when operated with dry biomass – which also had one of the lowest particulate emissions – was a particular type of micro-gasifier. One of the authors confirmed to us that the stove in question had achieved 52% thermal efficiency, without any char being retained. He suggested that, if the same stove had been operated so as to retain char, then around 36% rather than 52% of the energy would have been available for cooking.[116] Though much more efficient than 3-stone fires and more efficient than several other stoves, the char retention, unsurprisingly, meant that significantly less of the energy was available for cooking compared to all the biomass being gasified. The study also showed major differences between the performances of micro-gasifiers. Those results are in line with what had been indicated for example by a recent German report which reviewed and summarised manufacturers claims about 'micro-gasifers' and which was prepared in collaboration with the IBI. While all are promoted as clean and efficient, the data published (largely from stove developers) suggested that char-gasifying stoves provide more heat for cooking from the same volume of biomass compared to stoves that retain biochar. This is logical because the more charcoal is retained, the less of the biomass is converted to usable energy and vice versa.

The same has also been confirmed in a recent study published by the UK Biochar Research Centre. They state: "*More biomass ends up being used where biochar is produced and this additional collection costs time and removes more biomass. In order to counter these very real disadvantages, the benefits of applying biochar to soil would need to be very evident to the stove user and her household*". The UKBRC research included pot trials using biochar from stoves the results of which are described as '*somewhat mixed*'. In some, though not all, cases crop yields improved during the short trial duration when such biochar was applied at a rate of 20 tonnes per hectare. But producing this amount of biochar, not for a pot but for a one hectare field, would require a family to save up biochar from a stove over many decades (by which time, of course, it would no longer be fresh and might not have the same impacts on crops).

Efficiency is not the only concern. As the UK Biochar Research Centre's study confirms, there are also questions whether different micro-gasifiers meet practical needs for cooking. For example, once a gasifier stove has been lit, the cooking temperature cannot generally be turned up or down and it is difficult or impossible to add more biomass or to switch the stove off early, making cooking more difficult and inflexible. Char removal can also be problematic in some designs, which require that it be either removed hot, risking accidental fires or burns, or that the user quench the stove with water, which causes the metal to corrode. Stoves also vary in the form of biomass they can handle. Some, for example, can only burn pelletized biomass, which may not be readily available.

Slash and char

The friendly sounding rhetoric surrounding small-scale, supposedly farmer-friendly and poverty-alleviating biochar projects - even when these projects often fail to deliver promised benefits - is used to lend support to advocacy for the much larger scale forms of implementation (i.e. it works wonders for these farmers and therefore will work on a very large scale to address climate change. This leap of faith is made without any independent audits or investigations to assess whether the claims about different projects and acceptance amongst farmers are justified. The strategy of using small scale projects in developing countries to make biochar more 'politically acceptable' is quite explicit in some cases. For example, biochar marketing company Genesis Industries used to describe a "guerilla marketing" strategy with a focus on small farmers as a key marketing slogan

for helping owners of pyrolysis units to market their products. Although they have removed this controversial reference from their website, their close links to the film industry together with a 'farmer-friendly' web image suggest that they continue pursuing this strategy. Several biochar projects involving or aiming to involve farmers cite the development of carbon offset projects and methodologies as an aim. Will villagers enrolled in a biochar stove project in Western Kenya, for example, have been told that the project and their participation are to be used for "*application for the project to be recognised for carbon trading under the Clean Development Mechanism or other schemes including the voluntary market*" as the IBI website description states?[117]

For the most part, it appears unlikely that small scale farmers are aware that biochar is being promoted on a very large scale and especially that their own participation in trials is being used to promote something much larger and far less innocuous – the scaling up of commercial biochar production, the inclusion of soils into carbon markets and global deployment under the guise of climate geoengineering.

Commercial and policy setbacks: biochar carbon finance looks unlikely

In spite of efforts at all levels to promote biochar, so far visions for scaling up production of biochar have not been fulfilled. Biochar deployment has so far attracted little private or public finance and has not yet been included into any carbon market.

Carbon Offsets

Carbon offsetting allows polluting companies in the North to emit more greenhouse gases as long as they pay for projects which 'save' equivalent amounts' of emissions, usually in the South. The 'emissions savings' from such projects are compared not just to current emissions but also to assumptions about what might have happened in the absence of a project. Carbon offsets are thus at best a 'zero sum game'. In reality, however, carbon offset projects tend to benefit those who can afford the specialist carbon consultants and navigate the system, and those who can offer projects large enough to offer 'economies of scale'. That generally means larger companies, including polluting industries, industrial livestock and plantation companies.

In 2008, the IBI had a realistic hope that biochar support would be written into a UN climate agreement. They succeeded in getting a supportive submission to the UNFCCC from the Secretariat of the UN Convention to Combat Desertification (UNCCD), who were being advised by a consultant with close IBI links.[118] In addition they succeeded in getting submissions from several national delegations. Had they succeeded at the UNFCCC level, this would have virtually guaranteed inclusion into the Clean Development Mechanism (CDM) and likely other financial and policy supports. Today, such a prospect appears remote, although, as discussed below, biochar could still be boosted if soil carbon in general was included into existing and future carbon markets – although there are currently more doubts about the future of carbon markets in general than there had been in recent years. Outside UNFCCC as well, the IBI has faced major setbacks in their efforts towards including biochar in any carbon trading mechanisms or larger voluntary offset schemes. This is confirmed by a word search on the Ecosystem Marketplace website, one of the biggest web portals about carbon trading and Payments for Environmental Services, which yields 23 mentions of biochar since 2008, but not a single one dated 2011.[119] So far not a single biochar methodology has been adopted or is close to adoption by any of the regional carbon trading mechanisms or standards for voluntary carbon offsets. This is true even for smaller schemes, which support other soil carbon methodologies and projects.

Some significant investors in biochar have gone into receivership or had to downsize their operations, such as Best Energies Inc. in the U.S. (now in receivership, although their biochar and pyrolysis business has been taken over by Pacific Pyrolysis in Australia),[120] Dynamotive in Canada and Carbon Gold in the UK both have had to downsize significantly; some biochar firms are increasingly looking for non-biochar markets and uses of char, as in the case of Carbonscape in New Zealand who are now looking at the 'activated carbon' market in the chemical industry.[121] ConocoPhillips remains the only multi-national corporation to have endorsed biochar and offer support (except for some very limited research funding for example from Shell). Many biochar advocates are now hoping to develop small niche markets rather than envisioning exponential global growth of biochar production and use. For example, in a recent article entitled "Getting The

Biochar Industry Up to Speed: What Can We Learn From the Pellet Business", (illustrating the synergies with bioenergy in general), the author poses the question: "*…Given this background and an abundance of good press, why is so little biochar being produced, sold and used*?" The advice offered: serve niche markets, requiring "designer" biochars, and develop "*small scale affordable pyrolysis units*".[122] Another niche market eyed by biochar companies and their supporters is land-reclamation following industrial pollution, mining or even tar sands developments, discussed further below.

Very little commercial production of biochar is currently underway. According to a 2011 survey by the Irish consultancy firm C.A.R.E., 20 companies worldwide claim to be commercially producing biochar but only 10 would actually provide a quote.[123] The fact that most biochar research, including field studies, has so far relied on traditional charcoal, not modern pyrolysis biochar, indicates how difficult it is even for researchers to obtain modern biochar for trials. There are multiple reasons for this, including the fact that experimentation has not verified claims made about biochar, and that biochar thus has no proven benefit, including to farmers - (although clearly this lack of support has not stopped many from continuing to advocate based on these same claims). Another factor that has kept biochar marginal is that the pyrolysis equipment required to produce biochars with consistent qualities has proven costly and difficult to design and maintain. According to the C.A.R.E. survey, prices for biochar currently range from £100.- £16,000 per tonne. Even the lowest figure is considerably more than what farmers would expect to pay for organic fertilisers, including manure or compost – and far more than the price at which a tonne of carbon is being traded on carbon markets.

Biochar has won over many "converts", but it has also been met with considerable scepticism. This is in part due to growing awareness of the disastrous consequences of biofuels policies. As evidence has mounted demonstrating that biofuels (ethanol and biodiesel) are driving increased demand for crops, water, soil and land, contributing to rising food prices and hunger, and all the while failing to actually reduce emissions, public opinion has soured. Further initiatives such as biochar, requiring large amounts of plant biomass are increasingly viewed with suspicious reserve. In March 2009, over 147 groups worldwide signed a declaration urging caution against large-scale biochar use and opposing the inclusion of biochar and soils in general into carbon trading.[124] Some of those organizations have continued to actively oppose the IBI's efforts and claims and some have published critical analyses.[125] La Via Campesina, the global peasant farmers movement lists biochar as a "false solution" to climate change that will "further marginalize small farmers" and has repeatedly warned against large-scale biochar deployment.[126]

Expanding horizons? The 'landscape' approach to incorporating soils and agriculture into markets

The IBI continues to push for the inclusion of biochar into different carbon markets, including the CDM and the World Bank, while the UN Food and Agriculture Organisation (FAO) and agribusiness lobby group continue to push for soil carbon in general to be included into existing and new carbon markets. A plethora of proposed new 'landscape approaches', would potentially include soil carbon, forests, tree and crop plantations of all types, agricultural practices, biodiversity etc. in carbon markets. At the international and regional levels, market-based landscape approaches are being promoted through a variety of channels, with obscure acronyms, such as REDD-plus-plus, LULUCF (Land Use, Land Use Change and Forestry) carbon markets, AFOLU (Agriculture, Forestry and Land Use) or REALU (Reducing Emissions from ALL Land Uses). Hiding within these acronyms is a debate and policy drive that is hardly transparent even to UN delegates, let alone to civil society. While opportunities for biochar to gain supports lie within these various mechanisms, given the increasing uncertainties about the future of global carbon markets, the prospect of creating any significant and over-arching global market-based framework for landscapes seems remote.

Far from expanding, the volume of carbon offsets traded through the CDM has fallen for the third year running, by nearly 50% since 2009.[127] A global mandatory cap on Annex I countries' emissions, i.e. a continuation of the Kyoto Protocol, seems increasingly unlikely beyond 2012. Annex I countries are calling for the CDM to be retained nonetheless, however without such a cap,

it is difficult to see where the demand for CDM credits would come from. This seems the main reason for the recent decline in the volume and value of CDM carbon credits.

The EU Emissions Trading Scheme (EU-ETS) accounts for 84% of the global carbon market value and the World Bank estimates that, if 'secondary CDM credits', i.e. the purchase of CDM credits through third parties is included, the EU cap-and-trade scheme accounts for 97% of the global carbon market.[128] There appears to be no realistic prospect that it will be opened up to include more land-based carbon credits, at least through the fourth commitment period, 2013-2020. Indeed, the future of EU-ETS seems in doubt, too, with a Swiss investment bank warning: "We expect the recent carbon price decline to escalate into a 'crash' as carbon market supply should double over the coming months."[129]

The ***World Bank***, expecting an end to the Kyoto Protocol, is already phasing out its existing 'Kyoto Carbon Funds'.[130] At the same time, they are supporting the development of voluntary and new regional carbon markets. At the Durban UN Climate Conference in November/December, they intend to launch a $130 Carbon Initiative for Development Fund for Least Developed Countries and a $75 million New Generation BioCarbon Fund which will include a tranche of $20 million for developing soil carbon projects for the voluntary markets – funded through World Bank upfront finance, private investors and government credit purchase schemes.

The voluntary carbon offset sector remains very small – less than 0.1% of the global carbon market last year.[131] Here, protocols and methodologies for including soil carbon sequestration as well as many other land-based activities are being rapidly developed, although in 2010, agriculture accounted for just 2% of all voluntary carbon credits. No specific biochar methodologies or projects have been seriously considered by any voluntary offset standard as yet.[g]

Regional carbon trading schemes, other than EU-ETS, have so far remained very small, with several plans and initiatives having been abandoned and others still in the early and uncertain development stages.

A US-wide cap-and-trade scheme was proposed but rejected in 2010. Across ***North America***, three regional cap-and-trade schemes are currently operating or approved:[h] Separate emissions trading schemes in the north-eastern US (Regional Greenhouse Gas Initiative, established) and in California (recently approved) currently exclude soil carbon offsets. Plans to extend carbon markets across the Western US have had a major setback, with six seven out of ten members of the Western Climate Initiative (set up to facilitate regional carbon trading) just having announced their resignation from the scheme.[132] The Alberta Offset System is a relatively small scheme linked to a cap on 'greenhouse gas intensity', i.e. not overall emissions but only to 'emissions intensity'. It is primarily an offset scheme for the tar sands industry. A significant number of land-based methodologies exist or are being consulted on, though no biochar method as yet.

In ***Australia***, a new carbon offset scheme for the agriculture and forestry sectors only has been approved, called the Carbon Farming Initiative (CFI). Under the CFI, the development of methodologies for soil carbon and specifically for biochar is foreseen, although no such methodology has been published for consultation as yet. The CFI on its own is merely a voluntary government-administered offset scheme, however it has been linked to a newly approved future emissions trading scheme, part of a wider legislative package called the Carbon Pollution Reduction Scheme. 'Linkage' means companies being able to count CFI credits towards future obligations to either reduce their emissions or purchase carbon credits. Demand for CFI carbon offsets will depend on such linkage. Under current rules, however, only those CFI carbon credits which are compatible with the UN's Clean Development Mechanism can be used that way (hence little availability of "sinks"). This means that, while biochar and other soil carbon methodologies might be developed, there would be little or no demand for them.

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[g] Note: CarbonGold proposed a biochar methodology to the Voluntary(now Verified) Carbon Standards Agency in 2009, however this was not progressed.

[h] Some other very small schemes are also in operation, limited to only a small proportion of overall emissions or sectors, which make no significant contribution to the carbon markets.

In ***New Zealand***, a regional emissions trading scheme has been introduced and agriculture (though at least initially not soil carbon-related activities) was to have been included into cap-and-trade from 2015. Recently, however, the Government has indicated that they are no longer committed to this but will hold another review in 2014.[133]

In ***East and South-east Asia***, Japan is developing bilateral carbon offsetting, South Korea is developing a government-administered voluntary carbon offset programme and debating a possible future Emissions Trading Scheme, and the Chinese government has announced a series of local and regional pilot emissions trading schemes. There is no indication so far that agriculture will play a role in any of those schemes.

In the near future, significant carbon credits for biochar and other soil and cropland management practices thus appear highly unlikely. This might change should the World Bank's vision for the future of carbon markets succeed. Their vision can be summed up as a vision of a large range of interlinked new emissions trading schemes, including in developing countries in which land-based, including soil carbon offsets would play a major role.

The World Bank has long been a 'pioneer' of carbon trading. In November 2010, they announced their first ever soil carbon offset project, mentioned above - a long-standing project in Western Kenya which now forms part of the BioCarbon Fund. At the UNFCCC COP 16 in Cancun, World Bank President Robert Zoellick announced a multi-million dollar fund to help emerging market countries set up their own carbon markets, called 'Partnership for Market Readiness' and he included a strong statement for the inclusion of agricultural mitigation activities, including soil carbon sequestration, within these markets. They have committed themselves to "*expand carbon finance in areas such as soil conservation and to work on standardized baselines*"[134] Recently the World Bank has partnered with the IBI and Cornell University (where IBI Chair Johannes Lehmann is based) to conduct a survey of biochar projects in developing countries, and a detailed "lifecycle assessment" of their potential for greenhouse gas mitigation.[135]

"Climate Smart" Agriculture: a new framework courtesy of WB and FAO

Extending carbon markets to cover far more land-based projects and practices, including soil-carbon, has been a major focus for the World Bank, the UN Food and Agriculture Organisation (FAO) and some governments for several years. A major reasoning for this has been the recognition that Africa, in particular, has not received much investment from Kyoto CDM projects. The World Bank in particular has been working to convince African delegates that this is at least partly due to the fact that carbon credits from land "sinks" are limited under CDM (and EU ETS) – only Afforestation/Reforestation (generally tree plantation projects) are eligible, and those projects are capped to 1% of the CDM. As a joint report published by the African Biodiversity Network and Gaia Foundation shows: "*There is increasing pressure for Africa to initiate more CDM projects. This is based on a widespread assumption that Africa's large unpopulated territories make it ideal for CDM projects that use extensive areas of land.*"[136]

It is increasingly recognized that Africa is bearing enormous consequences of climate change – including water shortages and crop failures and policymakers are increasingly calling for investment in African (and other) agriculture. However, the experience with carbon markets in India and China has been one of a small number of polluting companies (ranging from coal companies, to companies using outdated and polluting methods for manufacturing fridges, to palm oil companies cashing in on carbon credits for biogas or use of residues for bioenergy) profiting at the expense of communities.[137] Furthermore, as discussed above, the very future of the carbon markets looks doubtful.

Although FAO still supports carbon markets and the inclusion of soil carbon within them, they have acknowledged the limitations to relying on carbon finance and particularly the CDM for substantial near-term investments: "*CDM's project based and offset approaches may be inadequate to generate the breadth and scale of incentives required for agricultural mitigation.CDM incentives appear too weak to stimulate transformation in the economy and have not enabled developing countries to move towards low emission development pathways that do not threaten economic growth. CDM projects also tend to have high transaction costs for many developing countries, long approval periods and a narrow geographic spread.*"[138] They have therefore developed a more

comprehensive 'package' of policy and financing proposals for the agricultural sector: Climate-Smart Agriculture. While embracing carbon finance, Climate-Smart Agriculture calls for a range of different public and private financing options. The FAO defines it as a "transformation of agriculture [which] *sustainably increases productivity, resilience (adaptation), reduces/removes greenhouse gases (mitigation) while enhancing the achievement of national food security and development goals".*[139] The FAO key report about Climate-Smart Agriculture discusses the remit of different practices and approaches, key principles, the political framework and finance mechanisms.[140] See text box for a brief summary of what is proposed and some concerns about it.

"Climate Smart Agriculture": What is proposed?

- A significant transformation of both commercial and "smallholder" agriculture in developing countries. Although "smallholder" farming is central to this concept, the emphasis is on "transforming" rather than strengthening and supporting it. Also, the term "smallholder" is understood by many civil society groups to exclude millions of peasant farmers who have no personal land titles, only customary and collective land rights not always fully recgnised by governments.
- Large-scale 'landscape' approaches for agricultural policies, planning and finance, rather than a focus on individual projects;
- Integrating policies that focus on food security (not sovereignty) with climate change policies that focus on quantifiable emissions reduction and carbon sequestration. This carries a significant risk of the discourse about agriculture being increasingly reduced to a discourse about units of CO2. This is problematic since the goal of reducing and/or accounting for carbon emissions may fail to serve other goals such as producing food, supporting farmers' livelihoods, encouraging good agroecological practices, preserving diverse varieties and techniques, protecting biodiversity, protecting soils and waters, etc. Furthermore, a very high level of scientific uncertainty remains about measurement, reliability and verifiability of soil carbon sequestration and of many types of 'emissions reductions' from agriculture proposed.
- Interestingly, the FAO's report does not contain a single reference to the key 2008 International Assessment of Agricultural Knowledge, Science and Technology for Development (IAASTD), to which over 400 scientists had contributed in a process involving a range of different UN organizations (including FAO).[141]The IAASTD report, while fully acknowledging the important role which agriculture plays in relation to climate change and '*the uptake and release of carbon*', strongly emphasizes the '*multifunctional role of agriculture*', the role of biodiversity, including agro biodiversity, in maximizing resilience to the effects of climate change, and the importance of supporting, involving and empowering peasant farmers and especially women farmers. Yet this report has been ignored in the FAO Climate-Smart Agriculture report.
- A range of practices are being described as 'climate-smart', including both agro-ecological and industrial agriculture including intensification of livestock farming, aquaculture and the use of no-till agriculture which commonly mains mechanized production of GM monocultures, mainly of soy and maize.[i]
- A near-exclusive focus on increasing the efficiency and productivity of agriculture. 'Commercial' (i.e. industrial) agriculture is to become more 'efficient' and adopt technologies that reduce greenhouse gas emissions, while peasant farming is to become more productive, with the assumption that higher per-hectare yields will reduce pressures on forests and other ecosystems. Yet the IAASTD report, amongst many others, shows that an emphasis on yields and productivity has often had very negative and often unforeseen environmental consequences.

[i] Monsanto, purveyors of GMO soya seed and Roundup herbicide have long advocated conservation tillage. (see: Harbinson R. (2001): Conservation tillage and climate change. Biotechnology and Development Monitor 46: 12- 17.

- Over-consumption and excessive demand for agricultural products and wood from Northern countries are not even mentioned as drivers of deforestation and other ecosystem destruction and thus accelerators of climate change. The current land-grabbing trend, driven by speculative and other investment in land spurred by expanding demand for food, fuel and fiber, has not been acknowledged either. The bias in agricultural and trade policies in favour of corporate agribusiness at the expense of peasant farmers is not addressed, nor is the importance of food sovereignty (as differentiated from "security") acknowledged.
- Strengthening institutional capacity to disseminate climate-smart agriculture over large areas. This could result in diverting existing policies and public funding for agriculture (inadequate and under-resourced as this is) towards a climate-change mitigation focused "*transformation of agriculture*".
- Combining public and private finance, including Overseas Development Aid, as well as innovative finance mechanisms, such as various Payments for Environmental Services, including carbon offsets, insurance, public-private partnerships, possible carbon taxes, issuing bonds, etc.
- The World Bank, which has strongly endorsed the concept of Climate-Smart Agriculture puts greater emphasis on the role of carbon finance, although it also calls very broadly for a major upscaling of all forms of finance for this concept. Their report states that it will "*require a package of interventions and be country- and locality specific in their application.*"[142]
- The World Bank report also makes it clear that 'reforestation and afforestation', commonly associated with industrial tree plantations, is expected to play a major role in Climate Smart Agriculture, even though it is also promoted under REDD (Reducing Emissions from Deforestation and Degradation).

Biochar has not so far been prominent in proposals for Climate-Smart Agriculture and it is not mentioned in the two key reports, by FAO and the World Bank, discussed above. However, biochar advocates can be expected to lobby strongly for its inclusion in this concept. The World Bank has already invested in biochar, financing a study by the IBI and Cornell University involving a survey of biochar projects in developing countries, and life-cycle greenhouse gas impacts of 3-4 such projects (mentioned above). In May 2011, the World Bank hosted a one-day biochar seminar focussing on interim results from the report with discussions about the possibility of future World Bank finance for biochar.[143] An IBI presentation about the interim results of the study suggests that the survey of existing projects has relied exclusively on unverified information/claims by the project developers.[144] Another presentation indicates that the life-cycle assessments rely on the assumption that 80% of all carbon in biochar will be securely 'sequestered', without testing what actually happens to it or to soil carbon overall following biochar use.[145] As shown in Chapter 3, those assumptions are not backed by field-trial result.

In September 2011, an FAO speaker at the Asia Pacific Biochar Conference 2011 called for more biochar research, development, demonstration and deployment projects to be implemented.[146] The FAO Working Paper about Integrated Food-energy Sectors within the context of Climate-Smart Agriculture has uncritically endorsed many scientifically dubious claims about biochar.

At the Climate Conference in Durban, supporters of the Climate-Smart Agriculture concept, led by the World Bank, will be pushing for an Agricultural Work Programme under the auspices of UNFCCC (under the Scientific Body for Scientific and Technical Advice. The IBI has consistently supported this, claiming it "*holds the most promise for establishing a clear role for biochar.*"[147] The IBI appears to be working with individuals in key institutions and organisations to have it included in publications, proposals and thus, ultimately, finance.[148]

Beyond carbon markets

The IBI and other biochar advocates have successfully lobbied to have several provisions for biochar included in the proposed American Power Act in the US in 2010.[149] They also convinced four

Senators to put forward another bill, the "Water Efficiency via Carbon Harvest and Restoration" (WECHAR) bill, solely aimed at creating incentive for biochar. Both bills were dropped however.[150]

Some support has been won from Gates Foundation (to Cornell University) and from Richard Branson's Carbon War Room. However, the only multinational corporation so far offering significant support to IBI and biochar is ConocoPhillips. As one of the largest investors in tar sands extraction, ConocoPhillips seeks inexpensive means to offset their emissions. They have therefore offered funding to develop a biochar protocol for the Alberta Offset Scheme and for the voluntary markets.

IBI Links With Tar Sands Industry

ConocoPhillips are one of the largest investors in Canadian tar sands, considered to be among the most destructive and polluting endeavours on earth. In 2010, they announced that, together with Total, they would quadruple their tar sand production by 2015.[151] In 2007, they first supported biochar research and development with $25 million in funding for bioenergy and biochar research project at Iowa State University.[152] In that same year, the Alberta government introduced a mandatory greenhouse gas reduction programme. The name is misleading in that it does not mandate actual emission reductions, but rather requires a small number of large polluters to reduce their carbon intensity, or to purchase carbon offsets through the Alberta Offset System, or to pay into a Climate Change and Emissions Management Fund, set up by the provincial government. Reducing carbon intensity means reducing emissions per 'production unit'- even if greater production may mean overall more emissions. At a meeting of climate activists in 2010, IBI advisory board member Lloyd Helferty announced "Biochar could offset Canada's tar sands industry for 14.5 years".[153] Together with Richard Branson's "Carbon War Room", ConocoPhillips Canada became one of the two main funders of the Biochar Protocol, the aim of which is to get biochar included in the Alberta Offset Scheme as well as having it accredited by the Verified Carbon Standards Agency.[j] Biochar Protocol's Keith Driver describes himself as a "key contributor and developer of Alberta's provincial offset quantification and trading scheme".[154] The other director is John Gaunt, a founding member of IBI and member of their Advisory Committee, as well as founding director of biochar consultancy Carbon Consulting LLC. Keith Driver was appointed by the IBI to draft their biochar standards/specifications, discussed below.

At regional and national levels, biochar advocates have had modest success in attracting public sector funding for biochar research and development:

For example, in ***Australia***, the government has supported biochar research and development with several grants, the biggest of them an AUS$1.4 million (US$1.41 million) grant made available to the Commonwealth Scientific and Industrial Research Organisation (CSIRO).[155] More recently, in September 2011, the government of Victoria awarded a grant for AUS4.5 million (US$4.52 million) to biochar company Pacific Pyrolysis to build a pilot pyrolysis plant for organic and wood waste.[156]

In the ***EU***, pyrolysis and gasification research and development (and in some countries deployment) attract public support through the EU and member states in the context of renewable energy targets. The EU has taken on binding emissions reduction targets, which have translated to an alarming degree, into subsidies and mandates for bioenergy, including biofuels. Biochar advocates recognize that these mandates and subsidies are one of their most promising avenues for achieving supports for biochar in Europe, given that biochar is a co-product of syngas and pyrolysis oil production. In the UK, the UK Biochar Research Centre (members of the IBI) received core funding of £2 million ($3.26 million) from a government research council,[157] as well as additional funds from another UK government research council, the European Regional Development Fund, a Canadian Crown Corporation and Shell Global Solutions.[158] The EU's North Sea Region Programme includes a "Biochar: climate changing soils" project to "r*aise awareness and build confidence in black carbon as a way of capturing carbon and increasing soil quality and stability*". They also seek to establish "biochar competence centres" in countries in the region,

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[j] Formal letter of intent: carbonoffsetsolutions.climatechangecentral.com/files/microsites/OffsetProtocols/DraftProtocolsDocs/Biochar_Intent_to_Develop_Protocol_Proposal_April_2011.pdf

supporting biochar research at research institutes in seven EU member states. Furthermore, the EU's 7th Framework Programme includes funding for biochar research and some funds for biochar commercialization have been made available by member states under the European Rural Development Programme.

In the **US**, the U.S. Department for Agriculture (USDA) and the U.S. Department for Energy, as well as some state governments have been funding biochar as well as broader pyrolysis research and development through various initiatives, including through the Biomass Research and Development Initiative which, amongst other biochar funding, has provided $5 million to use beetle-damaged trees for biochar and energy production. Another example is a $2.6 million grant by USDA for research biochar use with strawberries and vegetables.[159] And in Montana, the Rocky Mountain Research Station has been awarded $5.31 million from USDA and the US Department of Energy for commercialising bioenergy and biochar production from wood in beetle-damaged forests. [160]

In ***South-east Asia***, biochar-making stoves form part of a wider bioenergy technical assistance grant for $4.6 million approved by the Asian Development Bank and funded by the Nordic Development Fund and the governments of Cambodia, Laos and Vietnam. [161]

Developing Standards

A top priority for the IBI is the development of industry standards (specifications) that they have come to recognize is a pre-requisite for commercializing biochar as well as appealing to carbon market developers and participants. The idea is, above all, to allow investors and customers to have some idea what they are buying when they purchase 'biochar', which is currently not at all clear. The IBI appointed Keith Driver, one of the architects of the Alberta Offset System (discussed below), to facilitate drafting of "Guidelines for Specifications or Biochars", intended to be voluntary, international guidelines for public use and adaptation to any national or local regulatory system. These guidelines focus on defining physical and chemical characteristics and suggesting labelling and chain of custody records.[162] A separate effort to develop certification, i.e. based on sustainability standards, is intended to follow.

The draft standard includes a 3-tiered approach. The first level tests only for basic characteristics - moisture, ash content, carbon content, pH etc. as well as testing earthworm avoidance and germination inhibition. It does not consider potential toxins and thus food safety at all. The mid level includes the above plus some basic soil toxicity testing as well as nutrient contents. Only the highest level includes testing for potential Polycyclic Aromatic Hydrocarbons, PCBs, Dioxins, Furans and several additional toxins, all of which are linked to cancer and birth-defects. Labeling and Chain of Custody guidelines are also specified.

Given the very wide range of variation in biochars, the fact that access to testing is likely to be costly, and that testing is not mandated, it is difficult to envision that these standards will be widely implemented – in particularly levels 2 and 3, which relate to toxins and thus food safety. Given the lack of knowledge about how chemical and physical characteristics of biochar relate to performance in soils, such standards may prove to have limited practical relevance – except to facilitate marketing.

Synergies with coal, mining and biofuels

Many companies involved with biochar are essentially bioenergy companies, or industrial forest/agribusiness companies, with biochar being just one facet of a broader portfolio of interests. These companies are simply looking for means to profit from char residues that might otherwise languish – or even pose a messy disposal problem. A look at some of the start-up companies that have arisen (and in some cases, subsequently failed) is revealing. Equally revealing is a look at attempts to capitalize on synergies between biochar and the coal industry. Although the IBI's definition of biochar is strictly limited to biomass sources of black carbon, various companies, including ones linked to the IBI are seeking to combine biochar with the agricultural use of coal power station residues.

Best Energies (www.bestenergies.com)

Best Energies Inc. was based in the U.S. with a subsidiary in Australia. They began as one of the primary start-ups promoting biochar, but are now in receivership. A look at their approach, claims, and portfolio of interests and marketing is illustrative however. Best Energies invested mainly in biodiesel but also in biochar and 'green charcoal', i.e. charcoal as fuel and they claimed to provide carbon offsets. Several of their directors came from Union Carbide and Dow Chemical. The Best Energies website stated: "*We are well positioned to win the current land grab in next-generation fuels.*" Their biochar and pyrolysis business has been taken over by Pacific Pyrolysis in Australia.

Alterna Biocarbon (www.alternaenergy.ca)

Based in Canada with a subsidiary in South Africa, Alterna owns and uses a technology called "Enviro Carbonizer" in a small industrial facility in South Africa and another demonstration facility in B.C., Canada. Their website claims: "*Alterna Biocarbon is a company focused on the manufacturing of biocarbon from products, such as wood, municipal and agricultural waste and tires. Biocarbon, also called biochar or charcoal, is a renewable replacement for coal manufactured for industrial markets...There are many markets for the product including biochar (agricultural applications), activated biocarbon, and energy pellets.*" The company is owned in partnership with "All Wood Fibre", which procures and markets woodchips, stating "*Our services are utilized by the major forest products, logging, lumber, pulp and paper, and bioenergy companies.*" Alterna Biocarbon has not yet produced biochar commercially, only for research purposes.

Biochar Solutions (www.biocharsolutions.com)

Biochar Solutions, based in Colorado, are advertising pyrolysis units and biochar for sale. They took over the manufacturing and sale licence from Biochar Engineering Corporation, a start-up company that went out of business earlier in 2011. Biochar Solutions focus in particular on the use of biochar for land reclamation, specifically reclamation of defunct mines. They have formed a subsidiary, Biochar Reclamations, which is working on a biochar project involving land reclamation at a former gold and silver mine. [163] Might such schemes be used to justify new mining? The founder of one regional biochar initiative in BC, Canada believes so, claiming: "*If [biochar] was incorporated in the day to day activity of the mines then there would be less negative reaction to new mining projects.*"

Full Circle Solutions Inc. (www.fcsi.biz/fcs01.htm)

According to the US companies website, their mission is: "*to serve the producers of coal combustion products. We do this by providing beneficial reuse of those products in environmentally sustainable and economically responsible ways".* In other words, it is to find markets for fly ash and other waste products from coal combustion. Their website shows a tractor spraying coal dust onto fields, which strongly resembles pictures about biochar application but otherwise nothing on their website suggests an interest in biochar. This, however, is misleading. John Gaunt from the IBI and Biochar Protocol has been appointed Executive Vice President for Biochar Product Development[164]and the company's CEO and co-founder presented about biochar at a conference in Utah about "Sustaining Forests, Woodlands and Communities through Biomass Use" in October 2011.[165]

Cool Planet Biofuels (www.coolplanetbiofuels.com)

Cool Planet are a California-based biofuel company developing biofuels from biomass fractionation (related to gasification). They state on their website: "*Imagine driving high performance cars and large family safe SUV's while actually reversing global warming*". General Electric, NRG Energy, ConocoPhillips and Google Ventures are investing in Cool Planet Biofuels. Their technical advisory board is made up of Leio Manzer (DuPont Fellow), David Austgen (formerly with Shell), Raymond Hobbs, Cliff Detz (formerly with Chevron) and Ron Sills (formerly with BP and Mobil). Cool Planet produces small amounts of biochar in their process, but they use that to argue that their fuels are "carbon negative".

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Chapter 5: Discussion and Implications

The promotion of biochar bears troubling resemblance to the history of biofuels promotion. Biofuels in general were promoted as a "green" alternative to fossil fuels, based on unsubstantiated claims. Many in civil society and elsewhere repeatedly warned that they would result in escalating competition with food production, deforestation, expanding industrial monocultures, worsening hunger, depleting water resources, more rather than less greenhouse gas emissions, human rights violations and land grabs etc. Yet subsidies and supports were put in place, above all in North America and Europe, and still remain in spite of escalating evidence of the harms.

Especially similar to the push for biochar is that underway for jatropha. Jatropha has been strongly promoted as a 'miracle crop'. As Jatenergy Ltd, a company investing in jatropha as well as coal, claims: "*Properly developed, it will not compete with land or water resources for food production. It is extremely hardy, and can survive long, dry periods in a wide range of soil conditions.*"[166] Those claims have long been disproven. In fact, jatropha plantings have largely failed even on fertile soil with regular watering. A study in Kenya, published by the World Agroforestry Centre concluded: "*Based on our findings, jatropha currently does not appear to be economically viable for smallholder farming when grown either within a monoculture or intercrop plantation model.*"[167] No commercial quantities of jatropha have been sold, several years after the first plantations should have reached maturity. Nonetheless, large and growing numbers of communities have lost their land, livelihoods and food sovereignty to jatropha and forests and other ecosystems are being destroyed as a result of this land-grab. Jatropha continues to be promoted in a growing number of countries in Asia, Africa and Latin America, regardless of the lack of evidence that it 'works', let alone that it brings any wider benefits.

Biofuels, biochar and the other "green technologies" that employ use of biomass as a substitute for fossil fuels, all share a standard blueprint for underlying assumptions upon which advocacy is based. For example, a recent Nature Communications article on the "theoretical potential" of biochar, which claimed that 12% of global greenhouse gas emissions could be offset through 'sustainable biochar'[168] embraces this blueprint. The models used for this assessment were based on a study of the global potential for 'sustainable biomass', including biofuels, according to which 386 million hectares of 'abandoned cropland' exist[169] which, it is claimed, are not forested and have not been built upon, though they include non-forest ecosystems and pasture. This study is but one of many 'biomass potential' studies[170] which are the building blocks of the bio-economy blueprint, based on the following assumptions:

a) The idea that large areas of land can be converted to biomass production without causing significant emissions from deforestation or other land-use change (lending biomass a 'positive carbon balance' or even carbon neutrality).

b) That there are hundreds of millions of hectares of "idle", "marginal" and "degraded" lands available, especially in Africa, Asia and Latin America, that could be used to grow biomass crops.

c) That 'social impacts' (except for the overall amount of food production), for example the fact that so-called 'marginal or 'degraded' land provides the livelihood and home of hundreds of millions of pastoralists, indigenous peoples and other communities can be ignored when calculating the 'theoretical' biomass potential, (on which policies are then based).[171]

d) That standards can be developed, agreed and implemented that will ensure that the conversion of large areas of land to biomass crop production does not worsen biodiversity losses or interfere with food production.

e) That there are vast quantities of "wastes and residues" available from agriculture and forestry operations that could be used.[172]

In reality, crop producers and investors will seek not the most degraded and difficult to cultivate lands, but rather the best available soils – with access to water for irrigation – that their money can buy. Peasant farmers and others without formal title to their lands increasingly find themselves

pitted against wealthy foreign investors (and often, complicit governments within their own countries). The current trend in land grabbing has been spurred on by the food and financial crises. Investors, cognizant of the growing demand for food and bioenergy crops and seeking secure investments, have brokered deals to purchase and lease tens of millions of hectares of arable lands, particularly in Africa, Latin America and South-east Asia.[173] This is in addition to already escalating conflicts over access to lands such as those happening as a result of industrial expansion of soya and palm oil. This trend is countered by, for example, the worldwide peasant farmers organization, La Via Campesina, among others, have called for a ban on land grabbing and continue to mobilize resistance.[174]

Biochar, particularly if it does succeed in gaining supports through carbon markets and/or as a climate geo-engineering strategy, could contribute further fuel to the land grab fires.[175] Concerns over the potential for biochar to contribute to the harms already underway as a result of biofuels policies, resulted in an international declaration of opposition "Biochar, a New Big Threat to People, Land and Ecosystems", signed by 147 organizations in 44 countries.[176] While biochar advocates engage in discussions couched in terms of "sustainable harvests" and "sustainability standards", there is little basis for confidence in these, which are ineffective, not least because they cannot address indirect impacts: Greater demand for crops, woods and land inevitably pushes the agricultural frontier further into forests and grasslands and no credible way of preventing this without curbing demand has ever been proposed. Furthermore, even very basic 'sustainability standards' have been shown to be unenforceable and serve more to greenwash than to ensure protections.[177]

Ironically, as with biofuels, biochar is promoted largely as a "solution" to the problems of climate change and food crisis. Yet it is poised to work directly at odds with the known, proven effective and justice-based solutions that already exist: protecting biodiversity, preserving soils and water resources, and promoting diverse, locally adapted peasant farming and organic and agro-ecological practices.[178] Reducing demand for wood and other biomass is key. Creating large new demands based on unfounded claims, faulty assumptions and hype, only makes these real solutions less likely to be achieved.

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