Biochar for Climate Change Mitigation: Fact or Fiction?

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INTRODUCTION

Logs cut from Amazon rainforest to be turned into charcoal near Ulianopolis, Brazil (www.thewe.cc/weplanet/news/ forests/ amazon_destruction_speeds_up.htm)

Soils are extremely diverse and dynamic, playing a fundamental role in supporting communities of plants, detritivores (which break down organic matter) and microbial communities, interacting with the atmosphere, regulating water cycles and much more. As we face the catastrophic impacts of climate change, efforts to "engineer" the climate are proliferating. Among these is a proposal to use soils as a medium for addressing climate change by scaling up the use of biochar. Unfortunately, like other such schemes to engineer biological systems, it is based on a dangerously reductionist view of the natural world, which fails to recognize and accommodate ecological complexity and variation.

Research on biochar is clearly indicating that there simply is no "one-size-fits-all" biochar solution, that many critically important issues remain poorly understood, and that there are likely to be serious and unpredictable negative impacts if this technology is adopted on a large scale. Yet proponents still do not hesitate to make unsubstantiated claims and to lobby for very significant supports to scale up their technology.

Thus far there has been little public awareness or debate over the large-scale application of biochar. The speed with which lobbying efforts are moving forward at national and international levels is alarmingly similar to the situation observed with agrofuels several years ago; poorly considered, based on unsubstantiated claims and accompanied by an effective "greenwash", the industry grew very rapidly and secured policy and financial support measures which even the UN's Food and Agriculture Organization has proclaimed a mistake. It is imperative that we do not repeat the errors by embracing yet another technology that is poorly understood, inherently risky and will likely encourage further land conversion and expansion of industrial monocultures.

WHAT IS BIOCHAR AND HOW IS IT PRODUCED?

The term "***biochar***" was invented by Peter Read (one of the most outspoken lobbyists for vast 'biochar' plantations) to describe charcoal used as a soil amendment for agriculture. Some companies use the word 'biochar' to describe any use of charcoal, even for fuel or industry, because the word 'biochar' sounds more 'clean and green' than charcoal.

Charcoal is made by burning organic matter like wood, grasses, manure or residues from sugar cane or palm oil production under conditions of low oxygen. Low oxygen burning is referred to as ***pyrolysis.*** A number of different pyrolysis techniques are possible, depending on speed, temperature and oxygen delivery. In addition to the charcoal byproduct, this form of pyrolysis also produces "bio-oil" and "syngas", both of which can be further refined into road transport or, potentially, aviation fuels. Pyrolysis can be used to generate electricity, fuel ships, boilers, aluminum smelters and cooking stoves.

"MAGICAL CHARCOAL"?
The biochar lobby's blueprint for solving the climate, food and energy crises

Charcoal Production in Brazil (FAO/ R.Faidutti, www.fao.org/docrep/008/y5918e/y5918e13.htm)

Companies like Eprida, Dynamotive, Best Energies, Heartland Bioenergy, Shell, Brazil's Embrapa, JP Morgan Chase, Biochar Engineering, the executive director of the Indonesian palm oil association (GAPKI) and the Bolivian Agribusiness company Desarollos Agricolas, among others, claim that 'biochar' production is "carbon negative:" Firstly, carbon emitted during pyrolysis is supposedly offset by the carbon absorbed by new plant growth, and therefore "carbon-neutral," the same (false) claim made for other plant-based energy technologies. But in addition, during pyrolysis, a portion of the plant carbon is retained in the charcoal. If the carbon-rich charcoal is then tilled into soils, that portion, it is claimed, can be sequestered away, thus reducing carbon dioxide concentrations in the atmosphere. Unfortunately, this accounting completely ignores the numerous ecological and social impacts from land use changes that occur when massive demands for plant biomass are created, and is not supported by current scientific understanding of the fate of charcoal in soils.

Proponents claim that charcoal can not only sequester carbon, on a globally significant scale, but also improve soil fertility, and thereby reduce demand for synthetic fertilizers and emissions of the powerful greenhouse gas nitrous oxide (N_2O) , and can conserve and purify water, prevent runoff of chemicals from farm lands, reduce emissions of nitrogen oxide (NOx) and sulfur oxide (SOx) from coal burning power plants, reduce emissions of black carbon from biomass cooking fires, reduce methane emissions from decomposing organic waste piles and more. Sound too good to be true?

The claims on behalf of 'biochar' are based in large part from the observation of "Terra Preta". Thousands of years ago, indigenous peoples in Central Amazonia developed methods for creating highly fertile and carbon rich soil by mixing charcoal from a variety of biomass sources with other diverse organic materials and using those in their gardens and fields. Amazonian rainforest soils normally lack nutrients and contain little organic matter. But the soils tended and enriched by these peoples still to this day retain much of the original carbon-rich charcoal and are much more fertile than surrounding soils. The question is: can we replicate their success using industrial production?

WHAT THE INDUSTRY AND LOBBYISTS WANT

Modern day applications and proposals for 'biochar' range in size and scope: small-scale operations are promoted as providing people living on forest frontiers with a means of maintaining soil fertility and hence reducing deforestation. Charcoal-making cooking stoves are promoted as a means for reducing the problems of black soot, and respiratory illness created by open cooking fires. Large scale use of pyrolysis, which produces charcoal as a byproduct, aims to contribute significantly to addressing the energy demands in industrialized countries. Finally, scientists such as James Hansen, Johannes Lehmann, Peter Read, Tim Flannery advocate climate geoengineering, using "carbon negative" bioenergy technologies including 'biochar' from hundreds of millions of hectares of "energy crops" and trees.

Tree plantation, Brazil, photo: World Rainforest Movement

Prior to any genuine and open public debate, well-connected lobbyists are hard at work promoting 'biochar': Their main international forum, the International Biochar Initiative, was present at the recent United Nations Framework Convention on Climate Change (UNFCCC) climate conference in Poznan. There the UN Convention to Combat Desertification, (UNCCD), and the government of Micronesia succeeded in getting biochar included in the draft agenda for the Copenhagen climate negotiations in 2009. UNCCD is calling for the inclusion of biochar into the "dialogue for the post 2012 climate regime", alongside "afforestation and reforestation". They also seek revision of CDM guidelines, (claiming that additionality can be directly and accurately measured for 'biochar'), and the abolition of the 1% limit for credit that currently applies to "afforestation and reforestation". A recommendation could be made to the Subsidiary Body on Scientific and Technological Advice (SBSTA) in June 2009, followed by endorsement in Copenhagen UNFCCC, December 2009.

At a recent high level conference by IES, GLOBE-EU, GLOBE-EUROPE, the European Economic and Social Committee and EurActiv considered requests not just for 'biochar' CDM credits, but double CDM credits. Biochar Europe, which includes Shell, JP Morgan, a carbon offsetting company, and the Centre for Rural Innovations (organisers of the First International Conference on Sharing Innovative Agribusiness Solutions), is strongly lobbying for the inclusion of 'biochar' into the EU Emission Trading Scheme, and also for establishment of a Biochar Technology Platform. In the US, the 'biochar' lobby is well connected with the new administration. The new secretary of the Interior, Salazar, previously submitted an amendment to the Farm Bill to support 'biochar' research and development. One of the main US groups behind 'biochar' is Renew the Earth, which is very well connected nationally and internationally. In Australia, the opposition Liberal Party supports large-scale charcoal use as a soil amendment, in New Zealand the Forestry Ministry has voiced its support, Embrapa in Brazil is represented in the International Biochar Initiative. 'Biochar' lobby forums have been set up elsewhere, for example in Canada and in Mongolia.

PROMISES VERSUS EVIDENCE

Before national and international financial supports are put in place, and before we scale up production of charcoal for use as a soil amendment, shouldn't we make sure the proclaimed benefits are in fact valid? While it is true that Terra Preta was incredibly successful, the indigenous peoples in pre-colonial Amazonia developed their technique over a long period based on small-scale, biodiverse farming techniques and a knowledge base that is now largely lost. Charcoal was only part of their technique. Modern techniques, based on industrial monocultures and seeking instantaneous economic rewards are quite different. How do the claims hold up?

DOES BIOCHAR INCREASE SOIL FERTILITY? A CLOSE LOOK AT THE EVIDENCE

The farmers who created Terra Preta added diverse types of biomass to the soil, thus building up humus as well as charcoal. 'Biochar' advocates, on the other hand, promote stripping the land of 'agricultural and forestry residues', which would greatly reduce humus. Done on a large scale, this would to replace at least some humus with biologically 'dead' charcoal, an untested but potentially very dangerous strategy.

Removal of 'forest residues' for bioenergy in Germany: (Peter Wohlleben)

As farmers practicing swidden agriculture have long known, adding some charcoal to the soil can help to make some soils temporarily more fertile, not least because 'fresh' charcoal retains nutrients essential for plant growth. This is different from the long-term fertile Terra Preta. Studies have shown that soil recently amended with charcoal has been shown to have quite different properties from Terra Preta[1]. Soil scientist Bruno Glaser has suggested that it may take 50-100 years for interactions between soil microbes and

[1] Nutrient availability and leaching in an archaeological Anthrosol and a Ferralsol of the Central Amazon basin: fertilizer, manure and charcoal amendments, J Lehmann et al, Plant and Soil 249**:** 343–357, 2003

charcoal to create soils resembling Terra Preta[2]. A recent field study near Manaus, Brazil (one of the few published in peer reviewed journals) found that charcoal mixed with synthetic fertilizer enhanced yields more than synthetic fertilizer alone, but the highest reported yields were obtained using solely chicken manure instead. Charcoal alone, actually suppressed plant growth completely after two harvests![3] Other studies have shown that charcoal amendments can, in the short term, either increase or decrease plant yields, depending amongst other things on the quantities of charcoal added, soil type and crop tested.[4] There are no longer-term field studies and so it is not known whether the increased plant growth sometimes observed with the addition of charcoal would be sustained over the longer term. The much touted fertility effect of biochar is thus dangerously unfounded.

In fact much of the industry and research focus is on producing fertilizer made from a combination of charcoal and synthetic nitrogen fertilizer (ammonium bicarbonate). This technology was pioneered by US company Eprida. They use pyrolysis to produce hydrogen and charcoal which is then used as a medium for scrubbing the flue-gases from coal burning facilities. NOx, SOx and CO_2, adhere to the charcoal. For every kg of carbon thus 'captured' from a coal power plant, 33 kg of dry biomass would need to be burned. Little is known about the fate of this flue-gas carbon in soils, even less than is known about the fate of charcoal carbon. Nonetheless, Eprida claim that this could allow coal power plants "to reach target [CO2] reductions without reducing plant efficiencies".[5]This "enriched" biochar is then used as a slow-release fertilizer. An innovative means for using biomass to create fertilizer, perhaps, but the underlying result is a so-called carbon capture and sequestration technology which will perpetuate the use of coal and dangerously places absolute faith in the retention of carbon in soils.

Moreover, nitrogen fertilizers lead to emissions of nitrous oxide, which is about 300 times more potent than carbon dioxide as a greenhouse gas. Proponents claim that adding charcoal to fertilizers could reduce nitrous oxide emissions from soil and reduce the quantity of nitrogen fertilizers used, if such fertilizers become more efficient as a result of charcoal amendments. However, soil scientist and chair of the International Biochar Initiative Johannes Lehmann has stated that it is not yet known whether charcoal reduces nitrous oxide emissions and, that overall the impact of charcoal on soil nitrogen is poorly understood.[6]

CAN WE RELY ON 'BIOCHAR' TO SEQUESTER CARBON?

There is no question that the carbon in biochar will eventually end up back in the atmosphere at some point in the future. It is biological carbon: free to circulate between the atmosphere, soils, plants, oceans etc. and thus capable of contributing to climate

[2] Special Report: Inspired by Ancient Amazonians, a Plan to Convert Trash into Environmental Treasure, Anne Casselman, Scientific American, 15th May 2007

[3] Long term effects of manure, charcoal and mineral fertilization on crop production and fertility on a highly weathered Central Amazonian upland soil, Christoph Steiner et al, Plant Soil (2007) 291:275–290

[4] Effect of charcoal, coal and peat on the yield of moong, soybean and pea, Iswaran V et al, 1980. Soil Biol. Biochem.12, 191–192 and Charcoal as a soil conditioner, Kishimoto S and Sugiura G 1985, Symposium on Forest Products Research International Achievements for the Future 5: 12/23/1-12.23.15

[5] www.eprida.com/hydro/2004doc.pdf

[6] Bio-energy in the black, Johannes Lehmann, Front Ecol Environ 2007; 5(7): 381–387

change. Fossil carbon, on the other hand, is permanently and safely sequestered within the earth's crust. The problem of climate change is caused by the dual impacts of both extracting fossil carbon and dumping it into the above ground biological pool, and at the same time, damaging ecosystems so severely that their capacity to store carbon is compromised. 'Biochar', like other bio-sequestration technologies does nothing to stem the flow of fossil carbon into the biosphere. Instead, it seeks to address the problem by manipulating "sink capacity" of the biosphere. Worse yet, the close link between the coal industry and biochar production models of companies such as Eprida and Carbon Crucible suggests that 'biochar' will further perpetuate fossil fuel burning. This would also be the case if biochar is included in carbon trading mechanisms where it would be used to "offset" and legitimize further fossil fuel burning.

Can charcoal act as a reliable carbon sink?

Tree plantation, Ecuador, photo World Rainforest Movement

Amazonian indigenous peoples succeeded in designing a method which has maintained soil carbon for thousands of years. Elsewhere, some charcoal remains in soil have been dated as far back as 23,000 years ago. According to Lehmann et al., modern large scale charcoal application could sequester as much as 9.5 billion tons of carbon per year, which would necessitate over 500 millions of hectares of dedicated plantations. Even if we could duplicate the success of Terra Preta on a small scale, the climate impacts of converting large parts of the planet to 'charcoal plantations' would be devastating and involve large-scale deforestation and other ecosystem destruction. The carbon contained in the charcoal might be sequestered for a while, but how long is "a while"? What if we fail? What if modern charcoal remained in soils for a hundred years or even less, but then suddenly released its' carbon back into the atmosphere? Proponents are confident enough that they argue 'biochar' should be classed as a "permanent" carbon sink, at least permanent enough to be included in a post 2012 climate agreement. So far the results from small scale soil-science studies paint a very different picture.

In order for 'biochar' to be properly deemed a 'carbon sink', two conditions must be fulfilled: First, we must be sure that the carbon in the charcoal will not end up being broken down and emitted to the atmosphere as carbon dioxide. Second, we must also be sure that adding charcoal does not cause large quantities of the pre-existing carbon in the soil to degrade and release CO2. Neither can be guaranteed at present.

Can 'biochar' become a carbon source?

The success of Terra Preta proves that under certain environmental conditions, some black carbon (the type of carbon found in charcoal) can remain in the soil for very long periods. But there is equally clear evidence that black carbon can be, and frequently is, lost from soil. Worldwide, far more black carbon is produced by wildfires every year than remains in soils or, through erosion, ends up in the oceans. A recent peer-reviewed study of black carbon remains from swidden agriculture in Western Kenya revealed that 72% of the carbon was lost in the first 20-30 years.[7]

The processes through which black carbon is lost are not well understood. Johannes Lehmann of Cornell University, chair of the IBI, has confirmed that very little is known about how long charcoal will remain in the soil and that this will depend on various factors, including soil type and climate, type of biomass used and temperature at which it is charred.[8] It is not certain that all of the black carbon lost from soil ends up in the atmosphere as carbon dioxide, but there is worrying evidence that at least a significant proportion of it does.

Wildfires may play a role in the loss of soil carbon from charcoal, and an ongoing study is underway to examine whether fires can cause the carbon in charcoal to be degraded and released into the atmosphere.[9] Meanwhile there is good evidence that soil microbes can and do metabolize black carbon, which results in the carbon being emitted into the atmosphere.[10] In fact, one concern is that the large scale application of charcoal could create an expanded ecological niche for black-carbon degrading microbes.[11] There is also strong evidence that charcoal can increase soil microbial activity which degrades pre-existing (non charcoal) soil organic carbon into carbon dioxide. A 2008 peer-reviewed study suggests that placing charcoal into boreal forest soil led to the loss of substantial amounts of soil organic carbon over ten years.[12] Initial result of a study in Colombia show 60% increases in soil carbon losses during two years of 'biochar' use, compared to control plots. Although the final conclusions have not yet been published, this may well be in line with other studies suggesting increased microbial activity and increased loss of original soil carbon through charcoal.[13]

In sum, there is little basis for confidence that charcoal will retain carbon in soils. The charcoal itself can be degraded, and charcoal encourages microbial activity that in some cases degrades either the charcoal carbon or other soil organic carbon or both. In other words, charcoal in soil has the potential to become a carbon *source*, rather than a carbon sink. This is especially true if the carbon emissions associated with large scale land conversion, discussed below, are included in the equation.

OTHER GLOBAL WARMING IMPACTS OF 'BIOCHAR'

Airborne black carbon, or soot, is the second greatest contributor to global warming after carbon dioxide, according to James Hansen. It is emitted from fossil fuel and biomass

[7] Long-term black carbon dynamics in cultivated soil, Binh Tanh Nguyen et al, Biogeochemistry, Volume 89, Number 3 / July, 2008

[8] Bio-energy in the black, J Lehmann, Frontiers in Ecology and the Environment: Vol. 5, No. 7, pp. 381-387.

[9] USGS Soil Carbon Research, M Waldrop, US Geological Survey

[10] Interactive priming of black carbon and glucose mineralisation, Ute Hamer et al, Organic Geochemistry 35, no. 7 (July:823-830).

[11] Biochar as a soil amendment: A review of the environmental implications, Dominic Woolf, January 2008

[12] Fire-Derived Charcoal Causes Loss of Forest Humus, David A. Wardle et al, Science 2 May 2008: Vol. 320. no. 5876, p. 629; also see Comment by J Lehmannan and Sohi, 10.1126/science.1160005 and authors' response. 10.1126/science.1160750

[13] Fate of biochar applied to a Colombian savannah Oxisol during the first and second years, Julie Major et al, 2007 International Agrichar Conference

burning. 'Biochar' proponents claim that charcoal-making stoves can play a major role in reducing black soot emissions which is also true for many different types of 'clean' biomass stoves. A review by Dominic Woolf warns that, if the charcoal is not transported, stored and added to the soil with care, the black carbon content could become airborne and thus contribute to global warming. [14] This raises the question of how biochar is to be integrated into soils. Images from an Australian biochar trial suggest Best Energies, for example, simply lays the biochar on top of soil and vegetation without incorporating it. [15] But to avoid the problem of airborne black carbon, it will likely be essential that biochar be tilled deep into soils, a disruptive process which results in carbon emissions from soil.

CLAIMS ABOUT SOIL WATER RETENTION AND NUTRIENT LEACHING

Biochar proponents argue that biochar can increase the water retention of soils, reducing the need for irrigation, resulting in greater plant growth, decreasing water run-off and thereby reducing soil erosion and leaching of agricultural nutrients (a major cause of freshwater and marine pollution).

There is evidence that biochar does indeed increase the water retention of soils – as in the case of Terra Preta. But this has been shown most clearly for sandy soils, and does not appear to hold true for loamy or clayey soils. In loamy soil, it does not change water retention while in clayey soil it actually reduces it. Additionally, there is some concern that charcoal has properties which over time and particularly after a fire could result in soils actually becoming water-repellent.[16]

The evidence regarding biochar and nutrient leaching is, once again, far from uniform, with Johannes Lehmann confirming that far more research is needed. One study found that when synthetic fertilizers are used on Terra Preta, nutrient leaching increases dramatically, well beyond what happens when synthetic fertilizers are added to lower carbon soils. In the same experiment, modern charcoal as well as synthetic fertilizers were applied to soil and this resulted in lower nutrient leaching compared to using synthetic fertilizers alone. This study again shows that soils with modern charcoal behave differently from Terra Preta and that serious uncertainties remain. Although in that particular experiment, modern charcoal did reduce nutrient leaching caused by synthetic fertilizers, the results cannot be extrapolated to all different soil types.[17]

"GOOD FOR THE POOR"?

Some biochar initiatives are presented as "pro-poor" strategies to improve livelihoods, charcoal-making stoves, for example. Indeed, finding efficient and cleaner alternatives to open fire cooking is critical. Emissions of black soot from open cooking fires contribute to global warming while particulate matter is a major cause of respiratory disease. Collecting fuel wood for cooking fires is often time-consuming and a major energy drain, especially for women and children.

Unfortunately, while charcoal producing cooking stoves reduce soot and particulate emissions, they are considerably less efficient than other 'clean' biomass stoves in that a portion of the biomass collected and burned is retained as charcoal, hence unavailable as

[14] see Ref 10

[15] http://uk.youtube.com/watch?v=nzmpWR6JUZQ

[16] see Ref 10

[17] See reference 1

cooking energy. This means that a family will need to collect 20-30% more wood or 'residues' for cooking than they would need for a more efficient stove that does not produce charcoal. Proponents of charcoal-making stoves justify the added demand on the basis that the charcoal can be used as a soil amendment, improving yields and reducing the expense of purchasing fertilizer a claim which, as we have been above, is highly questionable. The IBI is supporting charcoal-making stove projects in a number of countries, including India and Mongolia. It is however not clear whether local people are presented with a choice between charcoal-making stoves and other more efficient ones.[18]

Another "pro-poor" initiative encourages charcoal production as a means of maintaining soil fertility for farmers on the "forest frontier" where soils are weak and generally cannot support farming for more than a few years at best. Proponents, such as the company Biochar Fund, claim that "slash and char" will enable the enrichment of soils and hence reduce the need for farmers to clear new land. Promoting biochar to small farmers means using them to test a technique that is far from proven. If it fails, farmers will be left with crop failures and debt. Meanwhile, the more promising ammonium bicarbonate fertilizer will be patented and thus will benefit companies rather than poor farmers.

The inclusion of biochar in carbon trade schemes will further reduce benefits to the poor. As Larry Lohmann has shown: "The CDM's market structure biases it against small community-based projects, which tend not to be able to afford the high transaction costs necessary for each scheme."[19] In the case of biochar, concerns over air pollutants created during pyrolysis, and introduction of toxic polycyclic aromatic hydrocarbons (PAHs) to soils will likely indicate mandatory testing before credits are granted, further pricing farmers out of carbon markets.

INDUSTRIAL 'BIOCHAR' FOR GEO-ENGINEERING?

Charred forest remains

Any technology that increases demand for plant biomass must be very carefully scrutinized in light of 1) greenhouse gas emissions resulting from the conversion of land, and 2) the already unsustainable demand for agricultural and forest products, soil, freshwater and biodiversity. 3) impacts on people's access to land. Some 'biochar' advocates focus on the use of "wastes and residues" and crops grown on "marginal and idle" lands. The same claims have been made for other bioenergy technologies, but the reality is that there are no large quantities of wastes and residues lying around unclaimed; not on a scale that can supply facilities *over time* and substantially contribute to energy demands. Furthermore,

[18] Reference for details on efficiency and pollution: A Study on improved institutional biomass stoves, S.C. Bhattacharya, www.retsasia.ait.ac.th/Publications/An%20Improved%20Gasifier%20Stove%20for%20Institutional%20Cooking.pdf

[19] Carbon Trading: A critical conversation on climate change, privatisation and power, Larry Lohmann, 2006, p. 257

removing residues and dead wood dangerously depletes soil nutrients, makes land more vulnerable to drought and reduces biodiversity. Nor are there vast expanses of “marginal and idle” lands. Such terminology dangerously excludes land uses that are not formally recognized as contributing to global markets. Traditional uses, where formal title is unclear, are considered “marginal”, even when they are critical to the livelihoods of rural smallholder farmers, pastoralists and others. This is already resulting in unprecedented displacement, often violent, as countries, corporations and private investors increasingly seek access to land for food, energy and secure, profitable investments.[20]

When large scale energy crops are required, as would certainly be the case if biochar is adopted as a strategy to reduce atmospheric greenhouse gas levels, emissions from land use change become very concerning. Clearing of forests or grasslands to make way for energy crop monoculture results in large quantities of emissions, reduces future sink capacity and causes further collapse of ecosystems and the biodiversity on which we depend for climate regulation. As widespread freshwater shortages are predicted, the regulation of rainfall by healthy forests and soils becomes increasingly critical, and the allotment of water for irrigation of energy crops increasingly unsustainable.

For a more detailed discussion about the impact of large-scale bioenergy production for geo-engineering and for the experience with first generation agrofuels, see www.globalforestcoalition.org/img/userpics/File/publications/Therealcostofagrofuels.pdf, www.biofuelwatch.org.uk/docs/cnbe/cnbe.html and www.econexus.info/pdf/Agrofuels.pdf.

CONCLUSION

Lobbying is underway for a massive scaling up of biochar production, and yet there is little to substantiate the many proclaimed benefits. It is critical that we address this issue with caution, especially given the many dire consequences associated with any technology that involves large biomass demand and manipulation of poorly understood soil ecosystems!

[20] Agrofuels and the Myth of the Marginal Lands, Joint briefing published by Gaia Foundation, September 2008, www.gaiafoundation.org/documents/Agrofuels&MarginalMyth.pdf