Biochar: the need for precaution?

Dr Charles Merfield

The case for the use of biochar has seen much discussion over the last five years, with some in the organic movement and beyond making the case for its benefits enthusiastically. This is no surprise given the concept promises to add fertility and life to soil while simultaneously locking up carbon that would otherwise be emitted into the atmosphere. However, others are more cautious, and point to the many unanswered questions in relation to biochar that are worthy of further study before they can be answered with any certainty. In this piece the author argues that the organic movement would do well to heed the precautionary principle in relation to biochar before we jump in 'boots and all'. Dr Charles Merfield is head of Science and Extension at the Biological Husbandry Unit Organic Trust: see www.bhu.co.nz for details. His personal website is www.merfield.com

Five years ago biochar was almost unheard of, even in the scientific literature, while today it appears in the mainstream press. The reason for this dramatic rise in awareness is that biochar is presented as a solution to two of the biggest issues facing humanity: climate change and agricultural production. Biochar achieves the apparently impossible by being both carbon negative (it removes carbon dioxide from the atmosphere) and boosting crop yields. In a world with too much carbon in the atmosphere, too little in the soil and in many places sub-optimum crop yields, it sounds miraculous. At first blush it also appears compatible with organic philosophy and increasing numbers of people in organic agriculture are suggesting that we start using it. However, I'm not so sure that this is such a great idea. Let me explain.

This is not the first time that an apparently amazing agricultural technology has been promoted with a big heap of hubris and gung-ho attitudes. For example, Haber-Bosch nitrogen and pesticides were considered miraculous in their day, yet are now increasingly being found to be double edged swords. A key antidote to such gung-ho hubris is the 'precautionary principle'. The organic movement was founded on a precautionary warning that purified mineral fertilisers (as promoted by Justus von Liebig *et al*) may not be as beneficial as claimed (Sir Albert Howard leading the riposte in *An Agricultural Testament*). The movement found its second wind in the 1960s by rejecting xenobiotic pesticides, again on precautionary grounds among others. With the adoption of the IFOAM 'Principles of Organic Agriculture' in 2005 the organic movement has now explicitly incorporated the precautionary principle as part of its fundamental world view. Precaution is therefore a key component of organic philosophy.

Therefore, my humble recommendation is that the organic movement should be viewing biochar through the lens of the precautionary principle, and the other IFOAM principles, and giving it considerable and deep thought before it decides if it is compatible with organic/ecological/sustainable agriculture, or whether it is more of a curse in disguise that needs restricting or prohibiting in its use. To be totally clear, I am not saying we should permanently ban biochar right away, as I do not claim to know all the answers: that is the problem, no one knows the answers yet, because there is insufficient information, and in many cases very little information indeed. However, from what is known, I believe there is sufficient cause to procede with precaution, and not rush in boots and all. The following is therefore a handful of points and questions for further discussion and scientific research; there are many, many more (see further reading). Only when we have good sound information, clothing a strong theoretical skeleton can wise decisions be made on whether to allow biochar or not.

Terra Preta

First a very quick recap on what biochar is. Biochar was 'discovered' by scientists looking at Amazon forest soils called *Terra Preta do Indio* (Amazonian dark earths). These soils were created thousands of years ago when neolithic farmers used a technique called 'slash and smoulder' where, instead of slashing and burning the rainforest, the 'slash' was put into piles while still fresh and moist and burnt slowly to produce charcoal/biochar. The biochar was then added to soils where crops were grown to create *Terra Preta* soils. Even after the passing of many millennia these soils still retain much of the original biochar; it has not decomposed back to the atmosphere, and the soils are more fertile, often considerably so, than similar soils that have not had biochar additions. So biochar locks atmospheric carbon into soils for thousands of years that would otherwise of had a much shorter return time back to the atmosphere (where it helps warm the planet) while boosting crop yields. A pretty stunning result you would have to say. The excitement is that if (a big if) this result can be replicated in current agricultural systems we could make big in-roads into climate change and food production. However, not everything appears to stack up with biochar: it not only seems miraculous, it appears to need real some 'real' miracles to square the circle.

The key reason we need to think and look very hard for possible pitfalls and procede with precaution is that the use of biochar is irreversible. Once it has been applied to soil it is going to remain in the soil for a very, very long time (thousand of years). If it is discovered, a few years, decades, or even centuries, after it has been applied that there are serious negative effects of adding biochar, then there is no known way to remove it, and they there be nothing that can be done to mitigate the undesirable effects. As a comparison, think DDT and its persistence in soil, and multiply that by a hundred or a thousand.

What could possibly go wrong with biochar? Well, we simply don't know because we have not been looking hard or long enough. Like artificial nitrogen and pesticides, if you don't look for problems you wont find, them, or to put it logically, absence of evidence is not evidence of absence.

Potential pitfalls?

So, based on the knowledge we do have, what are a few of the issues that the organic movement needs to be aware of in its deliberations over biochar? First up the *Terra Preta* are not representative of modern agricultural soils and ecosystems so extrapolating from them is speculative at best, probably foolhardy at worst. We have very little knowledge of the actual practices that made these soils. However, it's a fair assumption that neolithic farming systems were probably closed cycles for nutrients, as they were most likely consuming all the food they produced, and they did not have flush toilets. There are good indications that biochar was not the only material going onto the treated plots. The biochar plots were mostly close to the settlements and it is likely that there were significant nutrient flows from the surrounding forest into these plots, both directly (with the biochar) and indirectly (via human and livestock manure). To put it 'scientifically' biochar is not the only variable/factor in this experiment. If large amounts of nutrients were also imported into the biochar treated plots, it is little wonder that they are more fertile and the biochar may have nothing to do with it. The soils have also been under tropical forest for thousands of years since they were created. Tropical forests and their soils behave very different from farmed soils, especially those under temperate climates, so assuming what happens in a tropical forest soil will happen in a temperate farmed soil is a bad assumption.

It is commonly believed that biochar is just carbon, however, that is not the case. All the lithospheric (non-atmospheric) nutrients (P, K, Mg, etc.,) contained in the source material can't escape during production (it's a closed system) so they remain in the char and co-products. Some biochars have nutrient levels similar to existing permitted organic fertilisers, for example 7.3% P, 5.8% K (elemental w/w). Therefore, a significant amount of the yield boost from biochar may well be due to the nutrients it contains rather than it physical properties. Clearly the amount of nutrients in the char is finite so their amounts will decrease with time and therefore so will any yield increase they create. There is a rule-of-thumb for experiments looking at changes in soil function: a minimum of five years data is required as it takes at least that long for a soil to change from one state to another. Ten years is a better timescale to ensure you are approaching the soil's new steady-state. Most experiments looking at the yield effect of biochar are pot experiments, of a few months duration, or plot experiments of one or a few years at best. In short, I would not trust the results of short term biochar crop yield experiments to inform the long term effects on soil and crop yields, one iota.

Another couple of issues should be considered. Biochar does not always increase yields, sometimes it decreases them. That is clearly a pretty undesirable effect so it's essential that the cause is understood. Where biochar is increasing yields beyond that expected from its nutrient content what is causing that increase in yield and can it be sustained? There are plenty of techniques; for example cultivation/tillage, soluble nitrogen fertilisers, or herbicide strips under perennial crops; that can cause a short term (1-10 years) increase in yield from the decomposition of existing soil organic matter, but in the long term cause yield losses as organic matter levels bottom out at low levels so no more can be mineralised to provide crop nutrients and soil function grinds to a halt. Can we be certain that adding biochar to soils is not enhancing microbial activity which in turn is depleting 'normal' soil organic matter creating short term yield boosts at the expense of long term yield declines and impoverished soils? The answer is no, we can not even make an educated guess.

A key plank of current organic farming, at least as far as standards are concerned, is the prohibition of using xenobiotic materials in the production and processing of agricultural products. Biochar seems to pass this hurdle. The source material for biochar is eobiotic: plant and, in a few cases, animal remains such as bones. The production process is also one that occurs naturally, for example in forest fires, therefore biochar appears to be eobiotic (commonly but imprecisely referred to as 'natural') and therefore permissible under organic standards. However, the situation is not so cut and dried. If you wanted a quick and easy recipe for making some pretty harmful compounds you would do well to start with a rag-bag mix of unknown biological/'organic' compounds and heat them up with varying levels of oxygen; exactly how biochar is made. Biochar is not 100% carbon and not all the other chemicals are harmless. Volatile organic compounds (VOCs) and polycyclic aromatic hydrocarbons (PAHs) are also produced: taking the lid off a container of 'fresh' biochar and sticking your nose in will quickly confirm this, even without lots of complex laboratory tests. How little of a bad thing is little enough not to be harmful? The VOCs and PAHs in biochar are present in small quantities but their highly active nature and often considerable bio-persistence means that a little could be enough to cause significant harm. There is also an issue of heavy metal contamination:

just the same as sewerage sludge and slurry from intensive animal production systems, heavy metals in the source material become concentrated in the biochar and may also have their chemical forms altered in the process. The assumption that because at first blush biochar is eobiotic, does not mean that is necessarily 'natural' or safe.

An additional caveat is that not all biochar is equal. We have no comparison with neolithic and modern biochar. Even modern biochar is very variable, with many factors altering its properties, particularly the source material and production temperature. Even when precise standardisation is attempted a minimum 5% variation is expected. Therefore, the empirical results from one batch of biochar cannot be directly extrapolated to others. So, where there are concerns about harmful materials in the char and or its effects on soil, each batch may have to be tested and analysed separately.

Opportunity cost

Returning to the nutrients in biochar. The main nutrients that are 'lost' from the source material during biochar during production (and that end up in the liquid and gas co-products) are the atmospheric nutrients oxygen, hydrogen, carbon and some nitrogen, plus a lot of energy. These co-products are another reason given in support of biochar, in that they are mostly hydrocarbons (liquid and gas) of various forms and can be used as fuel. The energy released during biochar production can also be captured and used, typically directly for heating as it is 'low-grade' heat. All well and good, but, to use an economic concept, what are the opportunity costs? In other words, what are the alternatives to creating biochar?

The starting material for biochar are biological compounds, mostly plant materials. These are often called 'agricultural wastes'. There can be few things that more clearly demonstrate an ignorance of soil than the term 'agricultural wastes'. There are no wastes in agriculture, just as there is no waste in nature, everything is food for something else. 'Agricultural wastes' are in fact one of the most valuable resources on the planet: they are soil 'food'. Soil is the most complex ecosystem on the planet and it needs a constant supply of food (energy and nutrients) to function properly, and that food is plant (crop) residues. As far as we know biochar is not soil food, and if it is, it's a poor comparison with the crop residues from which it is made as much of the C, O, H and a big chunk of energy have been removed. Biochar is likely to be a zero sum game, if biological materials, especially crop residues ('agricultural wastes'), are used to create biochar, that same material can not be used as soil food, the same as when crop residues, are used to make biofuels. This is not however an all or nothing situation, more a matter of balance. While biofuels create an ongoing loss of soil food, biochar application is mostly proposed as a one-off activity; the biochar is applied once to an area of soil and then no more should need to be added, because biochar remains in the soil for a very long time.

However, biochar application rates can be quite substantial. While 20-40 tonnes per hectare ($t\ ha^{-1}$) are typical, rates of up to a 1,000 $t\ ha^{-1}$ have been used (with the aim of locking up as much carbon as possible). In comparison an application of 20-30 $t\ ha^{-1}$ of compost is a substantial amount that will last several years. However, an application of 20-30 $t\ h^{-1}$ of biochar is equivalent of 60-120 $t\ ha^{-1}$ of dry weight of plant residues as biochar has a typical conversion factor of 25-35%. In a best case scenario, say growing a strawy cereal, the amount of crop residues left to covert to biochar could reach 5 $t\ ha^{-1}$ ('wet' weight). So to create a typical application of biochar would require the residues from at least 12 to 25 years of crop residues (though in practice it could be up to half a century's worth, because only few crops would produce a couple of tonnes of high carbon residue per hectare let alone five). Depriving soil of its main food source for that long is without doubt going to cause serious problems. The usual alternative suggested is to use non-agricultural crop wastes from forestry. However, taking crop residues from forests just deprives the forest soils of their food. Transferring any form of biologically derived soil amendments, be it compost, biochar, manure or whatever from one soil or farm to another, is a case of robbing Peter to pay Paul. The only source of biological soil amendments is agriculture (in the broad meaning) so importing it onto one farm is robbing another farm's soils of their rightful soil food.

This issue of the source of the feed stock for biochar and its alternative uses is a classic illustration of the need for holistic/system thinking and using well thought out life cycle assessments (LCA). This is something the organic movement has been very good at and it is essential that it continues to maintain this perspective (it has been slipping lately) with regards to biochar. Much of the rest of the agricultural world still have their reductionist blinkers firmly on.

The need for caution

The above are a small fraction of the many issues surrounding biochar. Only a handful of the issues are understood in any detail, most issues are known unknowns, and there are quite likely to be quite a few unknowns unknowns, just as there are new issues being found today for mineral fertilisers and pesticides, even a century after their discovery. If all of these issues with biochar are resolved and none turn out to have harmful effects it will be great, as we desperately need less carbon dioxide in the atmosphere and more organic matter in our soils. However, it would also be pretty amazing – the shear number of issues surrounding biochar mean the likelihood of all being without problems is pretty low.

The questions then must be how bad are these problems likely to be, especially considering biochar application is irreversible as far as we know? Are they serious enough that we should urge caution in the adoption of these technologies, or should we carry on regardless due to the potential benefits biochar seems to promise? Well, in my view any technique with the ability to alter the biogeochemical cycles is clearly pretty powerful. So, just as putting carbon dioxide and other green house gasses into the atmosphere raised no concerns for a very long time, if biochar has large unknown negative effects that take many decades or longer to reveal themselves then humanity could be creating a bigger problem that the ones we are trying to fix. Hubris, as the saying goes, is inevitability and inexorably followed by nemesis.

Further reading and information sources.
Caveat emptor! Finding good information on biochar is not simple, even for scientists, and especially for the layperson. The general media is rarely a source of accurate scientific information, even the quality press. The general internet is even more unreliable. The primary scientific literature is a murky place at the best of times and particularly so for a new and emerging ideas, where advocates outnumber the sceptics many-fold (no, scientists are not always impartial and objective). The best sources are mostly reviews commissioned by governments and large independent (research) organisations, they are (mostly) high quality, impartial, thorough, written for a non-technical audience (ie policy makers) and are available for free. The following are recommended and were used as source material for this article along with a range of other research articles.

Biochar application to soils: A critical scientific review of effects on soil properties, processes and functions. 2010. F. Verheijen, S. Jeffery, A.C. Bastos, M. van der Velde, I. Diafas. http://eusoils.jrc.ec.europa.eu/esdb_archive/eusoils_docs/other/EUR24099.pdf
Biochar, climate change and soil: A review to guide future research. 2009. S. Sohi, E. Lopez-Capel, E. Krull, R. Bol. http://www.csiro.au/files/files/poei.pdf
An assessment of the benefits and issues associated with the application of biochar to soil. 2010. S. Shackley, S. Sohi (editors). www.geos.ed.ac.uk/homes/sshackle/SP0576_final_report.pdf

“I am not saying we should permanently ban biochar right away, as I do not claim to know all the answers: that is the problem, no one knows the answers yet”

CHARLES MERFIELD