The promise
(and uncertainties)
of Biochar

by Nancy Maddox

amendment now available at Whole Foods Market—has been known to man for thousands of years. Today, it is discussed as a possible means to reduce dependence on nonrenewable energy reserves, enhance agricultural productivity, reduce environmental pollution, and simultaneously reverse climate change.

Sound too good to be true? Read on.

Basically, biochar is an end product of pyrolysis. It is what you get when you take organic matter—anything from wood chips to corn stover to poultry litter—and heat it at a relatively low temperature under relatively oxygen-starved conditions. The original biomass, termed feedstock in the trade, releases heat and gases during its conversion into liquids (bio-oils) and various solid black carbon products, such as charcoal or ash.

According to ASA and SSSA member Kurt Spokas, a USDA-ARS soil scientist based in St. Paul, MN, that black carbon residue can be called biochar when it is created specifically for carbon sequestration. However, some other researchers define the term to include only black carbons created for soil application.

Semantics aside, the scientists who work in this field seem to agree on two things. First, biochar does indeed have potential to store carbon, boost soil fertility, generate energy, and mitigate pollution. But, second, there are a hundred caveats and unanswered questions. Biochar technology, it turns out, is both incredibly simple and, as yet, somewhat enigmatic.

In the end, says ASA and SSSA member Johannes Lehmann, a Cornell University soil scientist, biochar may not “save the world.” But he says, “That’s okay . . . even if it turns out that it’s appropriate only for a certain segment of farmers, it still justifies the effort that we are putting in.”

Amazing Attributes

The promise of biochar comes from a confluence of amazing attributes. With the right feedstock and optimal pyrolysis, biochar retains half or more of the carbon in the original biomass. And, in the soil, that carbon is remarkably stable.

Lehmann was among the first modern researchers to rediscover ancient biochar deposits. Working in the Brazilian rainforest in the 1990s, he saw swaths of ebony soil—termed terra preta or “black earth”—standing out against the surrounding brown dirt and red clay soils. Terra preta, he says, “turned out to be full of this char material and that char material turned out to be responsible for the enduring high fertility of these soils over several hundred or several thousands of years.” According to radiocarbon dating, the biochar was at least 1,500 years old and up to 8,000 years old.

In addition to long-term carbon sequestration—and associated reduction of carbon dioxide emissions—Spokas says biochar has demonstrated “marvelous suppression” of other greenhouse gas emissions from soil, especially nitrous oxide.

Moreover, Lehmann calculates that the initial pyrolysis used to create biochar produces at least two to four times more energy than is used to make it, including the energy costs associated with biomass production, transport to the manufacturing site, the pyrolysis itself, and subsequent biochar soil application.

And there is more good news.

Biochar can have an unusually high cation exchange capacity, but also appears able to adsorb phosphate, an anion (no one knows why). As Lehmann writes in *Frontiers in Ecology and the Environment*, “These properties make biochar a unique substance, retaining exchangeable and therefore plant-available nutrients in the soil.
and offering the possibility of improving crop yields while decreasing environmental pollution by nutrients.”

Like all organic matter, biochar also increases the soil’s water-holding capacity, sometimes dramatically so.

And, last, but not least, biochar alters the dynamics of soil microbial communities. For example, volatile organic compounds released by the material (or sorbed from the environment into the biochar) may stimulate microbial breakdown of soil minerals or alter plant–microbial interactions. And the physical structure of biochar, with millions of micropores, makes it excellent habitat for soil inoculants and for beneficial organisms already in the soil. Paul Wever, one of a handful of commercial biochar manufacturers, calls the substance “a hotel for microbes.”

Not a Miracle Cure

With so much to commend it, biochar may seem like a miracle cure for some of the serious problems plaguing the environment and challenging farmers. But, says Lehmann, “There is no one-stop shop.”

The demythification of biochar begins with terra preta. Although pottery shards mixed with the char material in Amazonia are evidence of human intervention, Spokas says, “We do not know what the soils were like when the biochar was added. A very romantic image has grown up around terra preta as an intentional cultivation management practice. We don’t know truly what the purpose was. There is no documentation, and there are a lot of other hypotheses you can come up with to explain how these soils could have been formed.”

Lehmann adds that it is “too simplistic to say you could just add biochar to create terra preta.” Nor, he says “is it essential to recreate the exact conditions found in terra preta; not that you could because one terra preta site is completely different from another terra preta site.”

Biochar itself also turns out to be not one material, but a seemingly infinite variety, whose exact properties vary depending on the feedstock, pyrolysis conditions, and postproduction handling. Wood-based biochar, for example, has a lot of carbon, but not much nitrogen, phosphorus, potassium, or calcium, while manure-based char has less carbon and more nutrients.

Slow pyrolysis at temperatures between 400 and 700°C maximizes solid biochar yield and produces a highly recalcitrant, decay-resistant product—a good choice if the primary goal is long-term soil carbon sequestration. However, there may be a reason to choose other thermal conversion processes. For example, microwave-assisted pyrolysis can handle wetter feedstocks, even though it yields more gas and less solid material.

The problem is that similar manufacturing methods can still produce a variable product. Spokas compares biochar production to baking; cakes made by two cooks following the same recipe may not have the exact same taste and texture.
Spokas and colleagues reviewed more than four dozen biochar and black carbon studies dating from 1850 to 2011 to assess “agronomic impact beyond carbon sequestration.” Findings were inconclusive. Half of the studies reported positive effects on yield, 20% no effect, and 30% negative effects. The overall impact on yield ranged anywhere from +200% to −87%.

Standardization and Certification

However, without standardized ways to characterize biochar and full reporting of manufacturing processes (including postproduction handling and storage), Spokas says researchers are comparing “apples to oranges.”

Lehmann is not surprised at the findings. “We could probably do a study and irrigate soils everywhere across the world and find that, in half the cases, the irrigation had no effect while 25% had a positive effect and 25% had a negative effect,” he says. “Where water is not limiting, additional water will not improve growth. Clearly we would not conclude that water is bad or that there is no role for irrigation.”

Lehmann says the conclusion from the meta-analysis “is not (a) that we have no clue what’s going on—partly true, but we’re getting there—or (b) that we won’t be able to optimize the biochar method to address certain constraints effectively.”

Alread the International Biochar Initiative (IBI)—a member-based organization promoting the development of sustainable biochar systems—has published a product definition and testing guidelines for biochar intended for use as a soil amendment. The organization has also begun a voluntary program to certify that biochar products meet quality standards.

IBI-certified biochar must include a label reporting feedstock composition and the results of all required tests, covering everything from moisture and ash content to mineral composition to pH to the presence of toxicants, such as polycyclic aromatic hydrocarbons. Lehmann, who chairs the IBI board, says the guidelines result from a rigorous, multi-step process and are akin to similar standards for fertilizers or compost, which must meet state-of-the-art regulatory thresholds.

Yet, given the many uncertainties surrounding biochar, Spokas says certification standards may be premature. “They’re ahead of where the science is,” he says. “We’re not just amending soil, we’re potentially changing its future development, and that’s the big unknown.”

One of the big hopes for biochar has been large-scale, agricultural carbon sequestration and soil greenhouse gas suppression to mitigate—or reverse—global climate change. Even here there are hurdles.

“A big challenge is understanding how and why these greenhouse gas suppressions are occurring and how long they will last,” Spokas says.

Lehmann notes that making biochar does not automatically result in net carbon sequestration. As an example, he says, taking down a forest that would otherwise stand to put biochar in the soil would not constitute net carbon sequestration. However, making biochar from trees killed by pine bark beetles—trees that would otherwise be burned—“would indeed net sequester them.”

“The take-home message,” Lehmann says, “is that one can find plenty of opportunities and types of interventions that would dramatically decrease emissions. The question is whether this is cost-effective compared with doing nothing or compared with doing something else, such as afforestation, no-till [farming], or solar power generation.”

Can Even the Best Char Salesman Sell Carbon to a Farmer?

Large-scale biochar application would also require a compelling economic incentive for farmers. Currently, there is none.

“All the way back to the 1700s, there is literature saying that biochar would not produce the yield benefits to pay for itself,” says Spokas. “That’s a big problem.”

Jonah Levine, a self-described char salesman with Colorado-based Biochar Solutions and Biochar Now, recalled a conversation with a friend who grows peaches in the Virginia piedmont. “Jonah,” the friend said, “you’re never gonna sell a farmer carbon. Farmers grow their own carbon. You’re wasting your time.”
If farmers are leery of the “biochar revolution,” what’s a char salesman to do?

The answer, Levine says, is to find “functional niches” where biochar produces a predictable, cost-effective benefit. “No one is just going to simply plow tons and tons of charcoal per acre into a corn field and find that that’s logistically or financially feasible. You need to use it to coat a seed for higher germination or as a carrier for water and nutrients.”

A ponderosa pine, for example, will die if it gets less than 7% soil moisture. Levine has planted thousands of pine trees and had great success maintaining soil moisture at 10% with a 4–5% biochar soil amendment.

Similarly, an almond tree has a root ball that goes into the ground for 20 years. Levine believes mixing 5% biochar into that root ball can increase water efficiency by 20% over the life of the tree.

The trick, he says, is targeting high-value crops with a long-term payback, like fruits and nuts. He also uses low-cost feedstock that might otherwise go to waste, mainly Rocky Mountain lodgepole pines that have succumbed to the pine beetle.

This practical, entrepreneurial approach coincides with the view from academia. Lehmann says biochar should be considered “a tool in the farm toolbox,” alongside composts, fertilizers, crop residues, and mulches. “Biochar has gained, for better or worse, some silver bullet attribute,” he says. “There is no silver bullet. There is a portfolio of options.”

One of the exciting things about biochar, Lehmann says, is the range of possibilities it gives farmers who are more or less locked into the organic matter they have at hand.

“Say you have an alfalfa green manure. It will release nitrogen very quickly. You might decide to compost that and thereby change its qualities. With biochar, you can dramatically alter its properties, and that opens up a completely new perspective on residue management.” An alfalfa-based biochar, for example, could reduce nitrogen release, while still boosting soil moisture retention much longer than the compost could.

One way biochar could help to mitigate climate change is as a replacement for peat, a nonrenewable resource that generates greenhouse gas in its worst form and whose extraction destroys landscapes. “If we were to only substitute biochar for peat, I think that would still be a great thing,” says Lehmann.

ASA and SSSA member Jim Ippolito, a USDA-ARS soil scientist based in Kimberly, ID, thinks water may be the next biochar frontier. “I’m kind of envisioning 50 years down the road, where we know how to mix woody-based biochar and crop stubble or woody-based biochar and manure to produce the same crop yield with less applied water. If you could add biochar and reduce irrigation by X% because of greater water use efficiency, that would be an important impact. Wow!”

USDA-ARS soil scientist Jim Ippolito analyzes essential plant elements from biochar-amended soils. Photo by Peggy Greb (USDA-ARS).
Ippolito says biochar technology potentially could be a tremendous asset for farmers facing drought conditions; they could increase soil water-holding capacity for, say, a 10-year period and also reap extra plant benefits.

“Here in Kimberly,” Ippolito says, we have some evidence biochar can create positive conditions for plant germination and growth. It looks like there’s a correlation between increased water-holding capacity and increased germination. For areas in the world that experience drastic and sudden droughts or have limited irrigation, the big research question is Can we quantify whether biochar can lessen the impact of drought stress, whether permanent or temporary? That’s a question that really needs attention.”

Looking for Uses beyond Production Agriculture

In the meantime, however, Ippolito concedes that biochar is a hard sell for farmers: “Production agriculture is not where biochar gives the most bang for the buck, at least currently.”

He says, “We don’t have carbon credits in the U.S., and who knows if they will ever be in place [to incentivize farmers]. So, in addition to carbon sequestration, we need to think about what else we can get out of biochar.”

Ippolito and colleagues have shown that the material can adsorb up to 42,300 parts per million copper in water. They have also mixed several different biochar blends into mine tailings and documented significant decreases in levels of bioavailable heavy metals. “In the end, you still have a product that may require disposal,” Ippolito says, “but the biochar is now concentrated with metals and thus presents potential for metal recovery.”

Lehmann has seen biochar applied to drainage ditches on dairy farms to reduce E. coli and phosphate runoff. It is not a big leap to envision its use to reduce herbicide leaching into waterways. But Lehmann cautions, “It works both ways; the efficacy of herbicides can be reduced by biochar applications.”

At the moment, most of Levine’s Biochar Solutions customers are interested in land reclamation: oil and gas producers, hard rock mining companies, and landfill owners. His second largest buying sector is the landscape services industry, and the third is split between water filtration and other industrial uses.

As someone on the leading edge of an emerging industry, Levine talks about “designer biochars,” with specific utility and is keen to explore new markets, such as the compost industry. “If we can put char in at some percentage and that char can retain nutrients and water and reduce smells, it can add value to that product.” Already, he provides the biochar for Maxfields soil conditioner, a product with about 10% biochar sold at over a hundred Colorado Front Range locations, including a number of Whole Foods Market outlets.

Paul Wever’s Illinois-based company, Chip Energy, sells largely to researchers. His one commercial customer is a Chicago landscape company that uses biochar in its green roof installations—an ideal application for a lightweight carbon product that retains moisture and nutrients.

To create a sustainable business plan, Wever says, “You have to have a purpose for the thermal energy you produce in the production of biochar.” He calls his biochar business “an expensive hobby” at present, and only manufacturers char in cold weather, when he uses the thermal energy to heat his primary business building furnaces.

Wever considers Chip Energy a model for “biomass recycling,” more than anything else. “In the state of Illinois, we bury five million pounds of biomass every day. We can convert that material based on market needs,” he says. “It could be biochar, could be heat, could be ash.... That is what Chip Energy is trying to do—create a place for biomass to be recycled.”

In the final analysis, biochar may not be the ultimate solution for any one problem. But it seems certain to be at least part of the solution for many different problems, including climate change reversal.

“Biochar showed that we are not at the end of our ideas,” Lehmann says. I’m quite certain it will have its place somewhere. It would be a pity to not investigate it. I don’t think we have the luxury to overlook promising interventions.”

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