Greenwire

1. CLIMATE: Once-lowly charcoal emerges as 'major tool' for curbing carbon

(09/07/2010)

Paul Voosen, E&E reporter

Charcoal is taking root on the farm.

Simmered out of eucalyptus, charcoal is being hoed into the degraded soils of former forests in western Kenya. Roasted out of chicken manure, it is spurring the growth of malting barley in Australia. And in Iowa, researchers are plowing charcoal into corn rows, hoping to limit the tons of fertilizer that saturate the state's fields each year.

At these farms and more, scientists are probing the limits of how high-grade charcoal, dubbed biochar, can be formed from plant and animal waste to squirrel away the atmosphere's carbon for centuries, or even millennia. Inspired by ancient Amazonian soils, researchers have found that buried charcoal resists bacteria's attempts to break it down. And thanks to its porous geometry, it has a knack for improving land in ways still being revealed.

"Once we get serious about climate change, this information is available now," said James Amonette, an environmental geochemist at the Energy Department's Pacific Northwest National Laboratory. "[Biochar] is one of the major tools we can use to fight climate change, if we decide to do so."

Charcoal's status may be comparable to the start of the world's head-over-heels embrace of synthetic fertilizer a century ago, scientists say. As piling evidence shows, converting organic matter -- be it corn scraps, human sewage or chicken litter -- to charcoal can, in effect, increase the carbon cycle's latency by hundreds of years, buying humanity just a bit more time to solve its fossil fuel fix.

While it has roots in decades-old research, the biochar movement took life only recently, as soil scientists realized the scope of charcoal's climate implications. The field, rich in unanswered questions, has exploded in the past five years, leading several hundred scientists to gather this month in Brazil for the world's third annual biochar conference.

Biochar has caused vigorous crop growth in some degraded soils, such as these banana roots, supplemented with rice-derived charcoal, in Tamil Nadu, India. Courtesy of Rob Bryant, Swansea University.

"Biochar is certainly not a fringe science anymore," said Lukas van Zweiten, an Australian researcher running one of the world's largest biochar field trials. "[It's] a big change from five years ago, when we were still trying to convince the scientific community of its worth."

Even Washington is digging into biochar. Last year, Senate Majority Leader Harry Reid (D-Nev.) introduced a bill supporting biochar research, and provisions tucked into the stalled climate measure sponsored by Sens. John Kerry (D-Mass.) and Joe Lieberman (I-Conn.) direct the Agriculture Department to provide grants to up to 60 research projects. It is funding that is sorely needed -- currently, there is not enough biochar being produced to meet even scientific demand.

In Brazil, scientists will complain about lack of funding, of course, but they will also detail recent progress made in understanding why biochar can be so beneficial for degraded soils. They will discuss how variable biochar can be, depending on its source. (Forest and chicken waste, it turns out, are not created equal.) And they will tamp down some of the rapturous rhetoric that can accompany charcoal's agricultural potential.

"Biochar is not a fix for all problems," be it soil quality or climate change, said Johannes Lehmann, a scientist at Cornell University and perhaps the leading biochar researcher. It will only improve soil that can be improved, he said. "Whether it's a viable global strategy? Nobody can say at this point."

Biochar may not sequester all of society's excess carbon, but it can play a tangible role in limiting emissions. Projections recently released by Amonette have found that biochar could trap the equivalent of 12 percent of the world's greenhouse gas emissions a year, in sustainable scenarios. Such a plunge, however, would carry steep economic costs and would likely only be spurred by putting a price on CO_2 emissions.

In effect, these researchers believe that biochar will allow society to generate energy from plant waste and nonfood crops -- a combustible oil is the major byproduct of charcoal production -- while also ticking down CO_2 emissions. Plants naturally absorb atmospheric CO_2 to build themselves up and by delaying the escape of that carbon once crops die a thumb is placed on the carbon-cycle scale, mitigating emissions.

Unlike the geological CO_2 sequestration proposed for coal-fired power plants, biochar can operate on small scales. It can be produced in massive factories but also in small stoves tagged for distribution in the world's poorest regions, which often also have impoverished soil, an option that has drawn interest from the Bill & Melinda Gates Foundation. Such stoves, though they might not produce ideal charcoal, possess a rare trait in the development world: poverty relief that also reduces CO2 emissions.

For many scientists, biochar is about much more than climate change. It is a chance to rewire agriculture. For too long, farmers have neglected soil health, instead dousing their fields with escalating amounts of synthetic fertilizer, heavy in nutrients, to boost plant growth, said David Laird, a soil scientist at Iowa State University.

"Soil quality has not been the focus of a lot of research or industry over the years," Laird said, with attention instead locked on fertilizer and irrigation. "Char is a paradigm shift. It puts the emphasis on building the soil resource base itself. That's the opportunity."

'Many different chars'

It is appropriate that this month's biochar conference is meeting just south of the Amazon.

It was there, decades ago, scientists found an unusually productive dark soil called *terra preta* that was rich in charcoal, among other ingredients. Seeds planted in the soil grew with unusual vigor and to surprising heights. The charcoal was ancient, its radiocarbon dating stretching back thousands of years. It had lingered, resisting degradation, for all that time.

Many believe that lost Amazonian cultures intentionally created the charcoal, though that is far from a settled fact, said Lehmann, who lived and worked in the central Amazon in the late 1990s. At first, Lehmann was not working directly on *terra preta*, but the draw was unavoidable. "You can't help but be interested in it," he said. The soil was so rich in nutrients and had just the right acidic balance.

"The sheer fact there were soils that were undoubtedly generated thousands of years ago and maintained a higher carbon content ... that was really kind of astounding in that environment," he said.

Whether the charcoal was created artificially or naturally -- some Australian soils are also rich in charcoal, the impromptu briquets caused by the continent's legendary wildfires -- it formed by a technique known as pyrolysis. Believed to be one of mankind's oldest energy technologies, pyrolysis is a simple process: Carbon-rich organic compounds are baked under moderate temperatures, around 500 degrees Celsius, in nearly oxygen-free conditions.

Biochar can be cooked out of a variety of organic waste, like this charcoal prepared from pelletized manure. Courtesy of Hal Collins, USDA-ARS.

The world is a different place without oxygen, and that holds true for pyrolysis. With oxygen, organic material -- called, in shorthand, biomass -- bursts into flame, releasing nearly all of its energy and carbon into the atmosphere, with piles of ash left behind. Without oxygen, the biomass resists ignition, instead separating into flammable oil and charcoal, a porous solid composed of disordered, stable stacks of ring-like carbon molecules, along with ash.

These carbon rings helped keep the *terra preta* stable through the centuries, resisting the bacteria that normally break down other supplements, like compost or manure, as it is slowly driven deeper into the soil by earthworms. Manure falls apart quickly, especially in tropical heat, while charcoal can last up to 100 times longer in the soil, recent research has shown -- hundreds of years, or even thousands.

Biochar's stability tends to vary with the climate, just like normal biomass. If a leaf falls in Nigeria, for example, it will degrade in a week, but if the same leaf falls in the depths of Siberia, it will last much longer. The point is that against normal biomass, biochar lasts many multiples longer. At least, the right kind of biochar, Lehmann said.

"We need to recognize that there are many different chars that have many different effects on soil," he said. The process for creating the charcoal varies, as do feedstocks. "A biochar from poultry litter is less stable than one from oak wood," Lehmann said. "But poultry is also less stable than oak wood."

According to Amonette, biochar's stability provides half of its greenhouse gas benefit; another third derives from replaced fossil fuel energy, and one-fifth to avoided emissions of methane and nitrous oxide, both powerful greenhouse gases. (The degree that biochar limits nitrous oxide emissions remains a matter of debate.) For nearly every farming region, it will be better to produce biochar for energy, rather than simply burning waste, Amonette's study found, except for areas with already fertile soil that depend on coal-fired power plants.

Like biofuels, biochar has the potential, if widely used, to see forests sacrificed to farming, or food crops used instead for fuel. Well aware of these problems, Amonette's projections relied only on the use of agricultural and human waste, along with dedicated energy crops that would only be grown on abandoned, degraded soil, he said. Estimates for biochar's offset potential could have run higher, but not without untold indirect consequences.

There are other possible indirect consequences, Amonette added. Darkening soil with finely ground charcoal could cause more sunlight to be absorbed. And should too much charcoal escape into the air, it could become the equivalent of black carbon, blowing into arctic regions and glaciers, its darkness causing increased heat absorption. Watering down charcoal before use will limit those concerns, though, Iowa's Laird said.

For some crops, biochar is a no-brainer, particularly rice, Amonette said. Water lies stagnant in paddies for weeks or months at a time. Bacteria feed off the rice waste and suck oxygen out of the water, creating space, once the oxygen is gone, for microbes that emit methane. ("Take any soil, put it in a beaker, and in a few weeks you'd be producing methane," Amonette said.) Steps to eliminate such methane emissions with biochar, including production from manure and yard waste, make immediate sense, he said.

In other environments, biochar could prove an ineffective carbon sink, scientists warned. Seeding forests does not seem particularly promising, especially in colder climates. And there needs to be more study of the overall influence charcoal has on soil, Iowa's Laird added. Does it bump the growth of carbon-chewing microbes? Does it encourage more carbon to settle?

"We actually have data that say both," Laird said.

The Swedish biologist David Wardle has been one of the most prominent researchers calling for calm in the charcoal rush. He conducted a 10-year study of charcoal's interaction with forest tundra and found that the charcoal accelerated the loss of carbon. (Wardle's methodology may have been flawed, however, as it did not account for new charcoal-caused carbon deposits, Lehmann said.) It is one data set for one region, but the upshot is that a more holistic accounting needs to take place, Wardle said.

"A more realistic vision is a more nuanced vision," he said. "If you have [charcoal] in the soil, there will be long-term consequences on microbial activity. It's not as simplistic as it initially seems."

Improving soil

While biochar's carbon storage grabs headlines, what gets soil scientists exercised is its potential to improve soil in the United States and, especially, in the tropics, where so many currently suffer from food insecurity. For too long, farmers have focused on improving yield with fertilizers derived from natural gas, Amonette said. The soil itself has been neglected.

Cornell's Lehmann has been at the forefront of testing how African soils could take to charcoal, running trials in western Kenya's highlands for six years. Over the past century, the highland forests have been slowly razed for agriculture, resulting in a gradient of soil richness, from the lush dirt of recently deforested land to plots that have been farmed, year after year, for a century -- a perfect experimental site.

In these trials, Lehmann found that, after several years, the amount of corn grown per plot doubled in older soils supplemented with biochar. The yield gains were not unprecedented: By spreading dead sunflowers across the soil, scientists made similar improvements. But unlike the mulch, which will erode unless reapplied, the biochar's benefits will linger, Lehmann said.

Similar studies have paralleled Lehmann's work across multiple continents -- China is building a large biochar research cohort -- over the past five years, to varying results. In the United States, biochar has potential for the southeast United States, where soil is nearly as poor as the tropics. Fruit and vegetables grown in California's Central Valley, too, are promising targets, Amonette said.

Such empirical trials are necessary, the grist of science. But as they have gone forward, soil scientists have grappled with a more fundamental question: Why does dumping a poor man's version of graphite, which holds little of the mineral nutrients found in fertilizer, send corn stalks soaring? The answers, provisional and halting, are beginning to come, Lehmann said.

"We're starting to be able to put our finger on the process by which biochar improves soils, or in some cases doesn't," he said. "Up to now a lot of that research was empirical."

There is no one reason biochar improves soil, but many, researchers have found. Biochar is porous at the microscopic level, its nooks and crannies creating a massive surface area to catch bacteria and nutrients like nitrogen. Its structure seems to retain water, and depending on the feedstock, biochar can balance soil acidity. Most intriguingly, charcoal carries a negative electrical charge through its structure, attracting positively charged nutrients like calcium, potassium and magnesium that might otherwise flush away.

These are all useful mechanisms, but not useful everywhere, cautioned Australian researcher van Zweiten.

"We have examples where biochar does very little, at least in the short term, in soil, while other examples show quite stunning improvements in soil fertility and productivity," van Zweiten said. Farmers should not get ahead of themselves in expectations, he said, "that biochar is always going to do good things in the soil, because I know for a fact this is not the case."

Some of van Zweiten's earliest field trials, on subtropical pasture in Australia, saw little in the way of additional growth when one biochar variety was added, he said. Another trial, though, begun three years ago, has had large yield gains for a mix of crops, such as malting barley; the site's control plots, fed only fertilizer, are failing.

Few places have better farming soil than Iowa, where Laird tests biochar on row after row of corn. Given these conditions, biochar will only add a slight yield improvement, if any, he said. Laird's hope, instead, is that charcoal will improve soil's nutrient efficiency, dropping the vast amount of synthetic fertilizer dumped on cash crops each year, much of which then leaches into the watershed to cause seasonal "dead zones" in the Gulf of Mexico.

The nutrient efficiency questions are far from answered. "It's going to take time to put all the pieces together and be able to come up with definite answers," Laird said. But while it is not yet proven, he said, "I think we need to move ahead with testing of this at a significant scale."

Revving up production

Pushing biochar use out to a scale large enough to spur some corporate investment is one of the goals of the International Biochar Initiative (IBI), a nonprofit lobbying group founded several years ago.

The initiative, led by Debbie Reed, a former legislative director under President Clinton at the White House's Council on Environmental Quality, has been behind language supporting biochar research in the Senate's recent climate bill, as well as the 2008 farm bill.

According to Lehmann, who serves as IBI's chairman, getting biochar production up and running should be a priority for the agricultural community. Often, Lehmann gets requests from farmers interested in testing charcoal, and he has to turn them away. He barely has enough for his own trial fields, a situation shared by Iowa's Laird.

"There are not enough biochar plants around that you can generate the biochar to fulfill even the scientific community's interest," Lehmann said. "We need to catch up, dramatically. There's a little bit of urgency to meet that demand."

Increased production should be accompanied by a classification system that can easily explain different biochar varieties, an effort being led by IBI. Currently, "there are lots of people who say they are creating biochar," Reed said. But many of these products are high in ash and would never qualify as proper biochar, she said.

A grading system would also need to take account of soil differences, Laird added. For example, he said, "'Grade A' char is fantastic for acidic soils in the southeastern United States. But you would not want to put it in the Western corn belt."

All sorts of best practices need to be established, Lehmann said. The government should be concerned that some biochar feedstocks could carry heavy metal contaminants or dioxin, though regulations governing manure and composts could easily be adapted for charcoal, he said. The pyrolysis process can also eliminate many problems, Australia's van Zweiten added.

"Like these other products, what you put in is what you get out," van Zweiten said. "The key advantage over these products is that organic contaminants ... can usually be dealt with effectively during pyrolysis."

Most scientists believe that the waste-management industry will be the first to stimulate biochar production, but even then there is doubt that investment will come without a price on CO_2 emissions. Van Zweiten, however, believes biochar can be profitable even without a carbon cap, at least in soils that respond to charcoal.

In the end, it could be the powerful farm lobby that will ultimately push biochar forward. Farmers have long desired a way into the carbon markets that would be created by potential climate legislation, if it ever moves forward. And biochar could provide the greatest certainty that their biological carbon sinks cause true emission offsets, though only time will tell.

"Biochar becomes increasingly viable once we make a societal decision to deal with climate change," Amonette said. "Until we do that, it will remain a niche."