Rethinking biochar

Imagine a simple agricultural soil amendment with the ability to double or triple plant yields while at the same time reducing the need for fertilizer. In addition to decreasing nutrient-laden runoff, what if this amazing ingredient could also cut greenhouse gases on a vast scale? This revolutionary substance exists, and it isn't high-tech, or even novel—its use can be traced back to pre-Columbian South America.

The ingredient is charcoal, in this context called biochar or agrichar, and if a growing number of scientists, entrepreneurs, farmers, and policy makers prevail, this persistent form of carbon will be finding its way into soils around the world. "Biochar has enormous potential," says John Mathews at Macquarie University in Australia. "When scaled up, it can take out gigatons of carbon from the atmosphere," he adds.

Agrichar's benefits flow from two properties, says Cornell University soil scientist Johannes Lehmann. It makes plants grow well and is extremely stable, persisting for hundreds if not thousands of years. "Biochar can be used to address some of the most urgent environmental problems of our time—soil degradation, food insecurity, water pollution from agrichemicals, and climate change," he says.

But fulfilling the promise is going to take more research. "We need to get reliable data on the agronomic and carbon sequestration potential of biochar," says Robert Brown, director of the Office of Biorenewables Programs at Iowa State University. "The effects are real, but these are hard to quantify at present."

Momentum appears to be building—this year has seen the first international conference on biochar, more research funding, and the scaling up of projects from the greenhouse to the field.

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Experiments at Cornell University's Musgrave Experimental Farm show that biochar reduces nitrous oxide and methane, both greenhouse gases.

Think negative

The notion that charcoal, traditionally produced in smoky kilns, might reduce emissions of greenhouse gases may seem counterintuitive, but technology for pyrolyzing biomass makes biochar production relatively clean. And the process is unique because it takes more carbon out of the atmosphere than it releases. In the jargon of carbon accounting, the process goes beyond carbon neutral to carbon negative.

Here's how it works: first, plant biomass takes up CO_2 from the atmosphere as it grows. A small amount of this carbon is released back into the air during pyrolysis and the rest is sequestered, or locked up for long periods, as biochar. Because atmospheric carbon has been pulled from the air to make biochar, the net process is carbon negative.

Biochar pioneer Makoto Ogawa at the Osaka Institute of Technology (Japan) and colleagues calculated in the journal *Mitigation and Adaptation Strategies for Global Change* (**2006**, *11*, 429–444) that, even allowing for the carbon emissions during processing, making biochar from waste biomass could sequester 20–50% of the total carbon originally present in the biomass.

Pyrolysis, a technologically advanced form of smoldering, involves burning biomass under controlled, low-oxygen conditions. Small- and large-scale facilities work in various ways and yield a variety of energy products, including bio-oils and gases, with biochar as a byproduct.

For the most part, pyrolysis methods are currently being developed not to make biochar but with the goal of maximizing the quality and quantity of the energy product, say biochar advocates. Figuring out how to optimize biochar properties using pyrolysis has not been a priority, but such research is taking shape.

In May, Dynamotive USA (a subsidiary of Dynamotive Energy Systems Corp.) and Heartland BioEnergy started testing biochar's effects in the Iowa corn belt with 12.7 metric tons (t) of biochar and three strips of cornfield. Dynamotive USA's Canadian parent company has developed a fast pyrolysis process to make a high-quality bio-oil.

"Not only has biochar the potential to raise high yield rates of corn another 20%, but we believe there is a real possibility the char trial could also result in evidence that could point the way to dramatic improvements in water quality, which could have far-reaching beneficial consequences," says farmer and agricultural consultant Lon Crosby of Heartland BioEnergy. He anticipates that farmers using biochar will use less fertilizer and hence will produce less nitrogen- and phosphorus-rich runoff from fields.

Madison, Wisconsin-based BEST Energies has developed a slow pyrolysis process. The company received more than $225,000 in June from the Australian state of New South Wales to continue research on biochar's role in terrestrial carbon sequestration and agricultural greenhouse-gas mitigation. The company's

Australian subsidiary already produces small amounts of biochar for field trials at New South Wales's Wollongbar Agricultural Institute.

A further $100 million in U.S. research funding is also in the pipeline. U.S. Sen. Ken Salazar (D-CO), a member of the Agriculture Committee, is sponsoring a Farm Bill amendment to fund research into bringing biochar to market.

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Traditional charcoal making in Lempira, Honduras, has changed little over the years. A modern pyrolysis plant could produce energy as well as biochar more cleanly.

Black gold

The agricultural grail that motivates this research is the Amazon region's "terra preta de indio", rich black earths whose fertility produces high crop yields even though the surrounding soils are poor. Carbon dating shows that this biochar has lasted for thousands of years. Researchers believe that the area's original inhabitants cleared forests for fields by slashing down trees and allowing the remains to smolder, forming biochar.

Using charcoal as a soil amendment has a long history in Japan, and recent agricultural experiments also demonstrate biochar's beneficial properties, with increased yields reported for many crops, including corn and sugarcane. These experiments mainly focus on poor soils in Indonesia, the Philippines, Australia, South America, and Asia.

Adding biochar to soil generally raises pH, increases total nitrogen and total phosphorus, encourages greater root development, hosts more beneficial fungi and microbes, improves cation exchange capacity, and reduces available aluminum. This track record is promising, but scientists currently do not know how to produce high-quality, consistent biochar in large quantities.

Several types of biochar have been tested, but more systematic investigations are needed to determine the effect of specific biochar characteristics. In many instances, scientists may not know the exact composition of the feedstock or the temperature and oxygen content used during smoldering. "These values may not have been measured or reported, and sometimes they can't be assessed. For example, the temperature in traditional kilns varies with time and position in the kiln," says Lehmann.

"We need a research effort comparable to the development of fertilizers over the past century to provide the underlying scientific information for the development of biochar in this century," Lehmann adds.

Greenhouse-gas reducer

Some of the most intriguing research needs surround what appears to be biochar's ability to decrease emissions of nitrous oxide and methane, two potent greenhouse gases.

Nitrous oxide is several hundred times more potent than CO_2 as a greenhouse gas. The agricultural application of nitrogen fertilizers is a major source of the gas and has been difficult to control.

Preliminary results indicate that biochar amendments to soil appear to decrease emissions of nitrous oxide as well as methane, which is a greenhouse gas 23 times more potent than CO_2. In greenhouse and field experiments in Colombia, nitrous oxide emissions were reduced by 80% and methane emissions were completely suppressed with biochar additions to a forage grass stand, Marco Rondon of the International Development Research Centre and colleagues told participants at the U.S. Department of Agriculture Symposium on Greenhouse Gases and Carbon Sequestration in 2005. Lukas Van Zwieten and colleagues at Wollongbar Agricultural Institute are seeing similar preliminary results, and Lehmann's group also has greenhouse and field data showing the same effect. Possible explanations, Lehmann says, include biochar's influence on water-filled pore space, nitrification rates, and the microbial community structure.

Chasing carbon credits

Biochar advocates believe that the economic key to unlocking the substance's potential lies in making it eligible for carbon credits or other incentives for greenhouse-gas mitigation. "That is not to say that other benefits of using biochar are less important," says Brown, "but in terms of driving implementation, it is greenhouse-gas policies."

Compared with tree planting projects, the earth's capacity to store biochar is almost endless—theoretically, arable lands could hold all the carbon in the 200 million t of anthropogenic CO_2 in the atmosphere today, according to eco-entrepreneur Mike Mason of U.K. biomass company BioJoule. Forest-stored CO_2 can also go up in smoke with a fire, he adds, and geological storage can leak.

But currently, the soil cycle is not considered a viable sequestration mechanism under the Kyoto Protocol. John Gaunt of GY Associates, a consulting company specializing in sustainable development, has been working with Lehmann and colleagues to delineate how carbon-trading schemes could foster and account for biochar. At the Power-Gen Renewable Energy and Fuels meeting in Las Vegas this past spring, they presented calculations showing that biochar sequestration could be economically attractive when the value of CO_2 emissions, currently trading at $4/t on the Chicago Climate Exchange, reaches $37/t.

Mathews keeps a bag of biochar on his desk, because he sees it as key to the earth's future. He contends that the time is right for individual countries to promote pyrolysis and biochar. Kyoto's cap-and-trade approach "can never get CO_2 levels down fast enough or far enough. The biochar approach can solve global warming by biosequestration of carbon direct from the atmosphere using the power of photosynthesis."

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