Back in Black: An Ancient Fix for Modern Agricultural Sustainability?
Sebastian Behrens explores how biochar soil amendment affects microbial nitrogen cycling.

Hidden throughout the rainforests of Brazil lie patches of unusually vital soil. Thousands of years ago, Amazonian farmers amended these humble plots of land with charcoal - a surprisingly effective soil management strategy. Today, rich and black against the tawny earth that surrounds them, these isolated acres of "*Terra Preta"* somehow retain their intense fertility. Consequently, biotechnologists are taking an interest in this old agricultural approach, hoping to make modern agriculture more sustainable and find "new" ways to mitigate global climate change.

Biochar, the modern equivalent of ancient farmers' charcoal, is simply organic matter that has been "pyrolyzed" by being heated to temperatures of 400-700°C in the absence of oxygen. The term is a bit of a catch-all for many different compounds with a variety of charactistics, some of which contribute to its increasing usage as a cheap, sustainable soil amendendment. However, we know very little about *why* biochar lasts so long or *how* it actually works in soil. But thanks to emerging international collaborations, including University of Minnesota researchers at the BioTechnology Institute (BTI), scientists are finally beginning to put the pieces together.

BTI's engagement in this research started back in 2015 when Sebastian Behrens joined the Univeristy of Minnesota as an Associate Professor in the Department of Civil, Environmental, and Geo-engineering. Behrens, an environmental microbiologist, became interested in biochar research when master's students of the Geoecology Graduate Program at the Univeristy of Tuebingen in Germany approached him. They were curious about biochar and how it affects microbial nitrogen cycling in arable soils.

At the time, Behrens didn't know much about biochar, but his prior work on anaerobic microbial processes in soils made him an excellent candidate to help the students pursue their curiosity, and even stoke his own. "If it hadn't been for these students, I wouldn't be working on this right now," says Behrens, who went on to study biochar-microbe interactions at the Univeristy of Minnesota together with colleagues in Switzerland, Austria, Germany, the United States, and Australia. Meanwhile, under Behrens' supervision, his former Master's students have gone on to earn PhD's for their work on this topic.

"Biochar is very similar to the charcoal you use for your barbecue," says Behrens. "It is a very porous material with a large surface area that binds many (in)organic compounds like a sponge." Biochars can increase nutrient retention and water-holding capacity in soil when it is either mixed with inorganic fertilizers or composted. This means that applying the right type of biochar to sandy, nutrient-deficient soils might help to cut down on the use of expensive inorganic fertilizers that often wash through these soils before plants can take them up. That's why these nutrients often end up in runoff waters that pollute streams, rivers and lakes.

While biochar amendment can increase crop yields, Behrens found that there might be even bigger long-term benefits. "By researching the effects of soil biochar amendment on microbial nitrogen transformation processes, we found that certain biochars can stimulate complete microbial denitrification," he says. "That would mean reduced greenhouse gas emissions."

In order to understand "denitrification", consider the nitrogen cycle. Elemental nitrogen continually cycles through the land, water, sky, and all biological organisms. However, nitrogen has many chemical forms. Some of them are generally perceived as beneficial (i.e. nitrate, used as agricultural fertilizer) or completely harmless (i.e. nitrogen gas, which comprises *most* of our atmosphere and is not a greenhouse gas), whereas others (i.e. nitrous oxide, commonly known as "laughing gas") can degrade the ozone protecting our planet and stick around for hundreds of years, contributing to global warming.

Denitrification is a metabolic process of specialized microbes that live in environments without oxygen. In a nutshell, these microbes reduce nitrate and produce nitrogen gas. That's good news for the planet. However, nitrous oxide is an intermediate product along this metabolic pathway. In many agricultural contexts, there is so much nitrate repeatedly added to soil that microbes don't get a chance to *finish* making nitrogen gas, and instead release toxic nitrous oxide into the air. That's definitely bad news for the planet. So…how might biochar help?

"When added to soil, biochar has a huge surface area, lots of pores, and huge absorption capacity," says Behrens. "Basically, biochar creates tons of anaerobic micro-bioreactors in the soil, preventing nitrous oxide from escaping into the atmosphere through gas entrapment."

Imagine a million tiny caves with billions of tiny bacterial colonies populating their walls, buried throughout farmlands. Behrens has experimentally demonstrated that gases simply get stuck within these microscopic confines, giving the microbes plenty of time to reduce nitrate and convert it fully to nitrogen gas, without losing nitrous oxide to the atmosphere.

Behrens and his collaborators, including Bruce Wilson from the Department of Bioproducts and Biosystems Engineering, have studied this process through months-long experiments, both in lab and out in the field. The researchers constructed large climate-control chambers containing wood-chip bioreactors amended with biochar. Next, they measured nitrogen inputs and outputs, temperature differences, and other factors. Unlike some other lines of research, however, these studies did not add new microbes to the soil.

“We want to understand how to manage mixed microbial communities, where and how they naturally occur,” says Behrens. “If we can just figure out what is actually going on, and where the limitations are, then we can try to optimize the performance of these treatment systems by letting nature take care of natural selection and adaptation.”

A perfect solution? Perhaps, but it’s also possible that biochar could contribute to long term retention of soil contaminants, like heavy metals or other waste products. Behrens’ current work will help to understand not only how biochar works, but also unearth new questions for future exploration.

Like ancient Amazonian farmers, we might not have perfect solutions to our problems just yet...but give it some time. Perhaps science can help us dig up the answers we need.

-C. Estelle Smith