

J. LEHMANN



Drop of the black stuff: terra preta contrasts strongly with normal soil in colour (left) and produces much more vigorous crops (below).

Black is the new green

In 1879, the explorer Herbert Smith regaled the readers of *Scribner's Monthly* with tales of the Amazon, covering everything from the tastiness of tapirs to the extraordinary fecundity of the sugar plantations. "The cane-field itself," he wrote of one rum-making operation, "is a splendid sight; the stalks ten feet high in many places, and as big as one's wrist." The secret, he went on, was "the rich terra preta, 'black land', the best on the Amazon. It is a fine, dark loam, a foot, and often two feet thick."

Last month, the heirs to Smith's enthusiasm met in a hotel room in Philadelphia, Pennsylvania, during the World Congress of Soil Science. Their agenda was to take terra preta from the annals of history and the backwaters

of the Amazon into the twenty-first century world of carbon sequestration and biofuels.

They want to follow what the green revolution did for the developing world's plants with a black revolution for the world's soils. They are aware that this is a tough sell, not least because hardly anyone outside the room has heard of their product. But that does not dissuade them: more than one eye in the room had a distinctly evangelical gleam.

The soil scientists, archaeologists, geographers, agronomists, and anthropologists who study terra preta now agree that the Amazon's dark earths, terra preta do índio, were made by the river basin's original human residents, who were much more numerous than formerly supposed. The darkest patches correspond to the

middens of settlements and are cluttered with crescents of broken pottery. The larger patches were once agricultural areas that the farmers enriched with charred trash of all sorts. Some soils are thought to be 7,000 years old. Compared with the surrounding soil, terra preta can contain three times as much phosphorus and nitrogen. And as its colour indicates, it contains far more carbon. In samples taken in Brazil by William Woods, an expert in abandoned settlements at the University of Kansas in Lawrence, the terra preta was up to 9% carbon, compared with 0.5% for plain soil from places nearby¹.

From Smith's time onwards, the sparse scholarly discussion of terra preta was focused mainly on the question of whether 'savages' could have been so clever as to enhance their land's fertility. But Woods' comprehensive bibliography on the subject now doubles in size every decade. About 40% of the papers it contains were published in the past six years.

Loam ranger

The main stimulus for this interest was the work of Wim Sombroek, who died in 2003 and is still mourned in the field. Sombroek was born in the Netherlands in 1934 and lived through the Dutch famine of 1944 — the *Hongerwinter*. His family kept body and soul together with the help of a small plot of land made rich and dark by generations of laborious fertilization. Sombroek's father improved the land in part by strewing it with the ash and cinders from their home. When, in the 50s, Sombroek came across terra preta in the Amazon, it reminded him of that life-giving 'plaggen' soil, and he more or less fell in love. His 1966 book *Amazon Soils* began the scientific study of terra preta.

Since then trial after trial with crop after crop has shown how remarkably fertile the terra preta



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is. Bruno Glaser, of the University of Bayreuth, Germany, a sometime collaborator of Sombroek's, estimates that productivity of crops in *terra preta* is twice that of crops grown in nearby soils². But it is easier to measure the effect than explain it through detailed analysis.

Everyone agrees that the explanation lies in large part with the char (or biochar) that gives the soil its darkness. This char is made when organic matter smoulders in an oxygen-poor environment, rather than burns. The particles of char produced this way are somehow able to gather up nutrients and water that might otherwise be washed down below the reach of roots. They become homes for populations of microorganisms that turn the soil into that spongy, fragrant, dark material that gardeners everywhere love to plunge their hands into. The char is not the only good stuff in *terra preta* — additions such as excrement and bone probably play a role too — but it is the most important factor.

Leaving aside the subtleties of how char particles improve fertility, the sheer amount of carbon they can stash away is phenomenal. In 1992, Sombroek published his first work on the potential of *terra preta* as a tool for carbon sequestration³. According to Glaser's research, a hectare of metre-deep *terra preta* can contain 250 tonnes of carbon, as opposed to 100 tonnes in unimproved soils from similar parent material. The extra carbon is not just in the char — it's also in the organic carbon and enhanced bacterial biomass that the char sustains.

Ground control

That difference of 150 tonnes is greater than the amount of carbon in a hectare's worth of plants. That means turning unimproved soil into *terra preta* can store away more carbon than growing a tropical forest from scratch on the same piece of land, before you even start to make use of its enhanced fertility. Johannes Lehmann of Cornell University in Ithaca, New

York, has studied with Glaser and worked with Sombroek. He estimates that by the end of this century *terra preta* schemes, in combination with biofuel programmes, could store up to 9.5 billion tonnes of carbon a year — more than is emitted by all today's fossil-fuel use⁴.

Mud pack

The year before he died, Sombroek helped to round up like-minded colleagues into the Terra Preta Nova group, which looks at the usefulness of using char in large-scale farming and as a carbon sink. The group was well represented at the Philadelphia meeting, although Glaser was not there. Their aim is to move beyond the small projects in which many of them are involved and find ways of integrating char into agribusiness. After all, wherever there is biomass that farmers want to get rid of and that no one can eat, char is a possibility. That means there are a lot of possibilities.

One problem is that there is a new competitor for farm waste. Plant are largely made up of cellulose, indigestible material in cell walls. Recent technological advances make it likely that quite a lot of that cellulose might be turned into biofuel. At the moment, ethanol is made from corn in the United States and from sugar in Brazil; if it were made directly from cellulose, producers could work with a wider range of cheaper biomass. Given the choice of turning waste material into fuel or into charcoal, farmers might be expected to go for fuel, especially if that is the way that policy-makers are pushing them: US President George W. Bush promised \$150 million for work on cellulosic ethanol in his 2006 state of the union speech.

But Lehmann and his colleagues don't see biofuel as an alternative to char — they see the two developing hand in hand. Take the work of Danny Day, the founder of Eprida. This "for-profit social-purpose enterprise" in Athens, Georgia, builds contraptions that farmers can use to turn farm waste into biofuel while making char. Farm waste (or a crop designed for biofuel use) is smouldered — pyrolysed, in the jargon — and this process gives off volatile organic molecules, which can be used as a basis for biodiesel or turned into hydrogen with the help of steam. After the pyrolysis, half of the starting material will be used up and half will be char. That can then be put back on the fields, where it will sequester carbon and help grow the next crop.

Negative thinking

The remarkable thing about this process is that, even after the fuel has been burned, more carbon dioxide is removed from the atmosphere than is put back. Traditional biofuels claim to be 'carbon neutral', because the carbon dioxide assimilated by the growing biomass makes up for the carbon dioxide given off by the burning of the fuel. But as Lehmann points out, systems such as Day's go one step further: "They are the only way to make a fuel that is actually carbon negative".



C. STENNER

Slow burn: the idea of using charcoal to sequester carbon may take a while to catch on.

Day's pilot plant processes 10 to 25 kg of Georgia peanut hulls and pine pellets every hour. From 100 kg of biomass, the group gets 46 kg of carbon — half as char — and around 5 kg of hydrogen, enough to go 500 kilometres in a hydrogen-fuel-cell car (not that there are many around yet). Originally, Day was mostly interested in making biofuel; the char was just something he threw out, or used to make carbon filters. Then he discovered that his employees were reaping the culinary benefits of the enormous turnips that had sprung up on the piles of char lying around at the plant. Combining this char with ammonium bicarbonate, made using steam-recovered hydrogen, creates a soil additive that is now one of his process's selling points; the ammonium bicarbonate is a nitrogen-based fertilizer.

"We don't maximize for hydrogen; we don't maximize for biodiesel; we don't maximize for char," says Day. "By being a little bit inefficient with each, we approximate nature and get a completely efficient cycle." Robert Brown, an engineer at Iowa State University in Ames, has a \$1.8-million grant from the United States Department of Agriculture (USDA) to fine-tune similar technology, although being in Iowa, he uses corn stalks not peanut hulls. "We are trying an integrated approach: we are trying to evaluate the agronomic value, the sequestration value, the economic value, the engineering," he says.

Brown thinks a 250-hectare farm on a char-and-ammonium-nitrate system can sequester 1,900 tonnes of carbon a year. A crude calcu-





lation on that basis suggests the US corn crop could sequester 250 million tonnes of carbon a year. At the moment, no one knows how long this could go on; no one has yet found a ceiling for char addition.

Stephen Joseph of Biomass Energy Services and Technology in New South Wales has built a number of char-producing machines in Australia that work at fairly large scales (the models have grown from an original 'Piglet' through a larger 'Daisy' to a positively bullish 'El Toro'). Joseph looks for companies with a waste problem such as a paper mill with spare scraps or a dairy with old bedding and manure, and then integrates char production into the business so that the heat produced in pyrolysis is used where the firm needs it.

So far, Joseph's company is being brought in to solve waste-management problems, but he hopes the value of the char will become a selling point in itself. For that to happen, however, he needs some help. His machines can be tuned to make char of various sorts: different sized particles with different sized pores and different amounts of other elements. Which is the best? It's a question he asks in Philadelphia, and one of the things that Brown's research in Iowa aims to find out.

The right protocol

Such technical unknowns are not the only obstacles on the road to a black revolution. One problem is that the purported benefits of char do not slot easily into the framework of the Kyoto Protocol, an international agreement to reduce carbon emissions. Lehmann hopes to see the process get going under the aegis of the protocol's Clean Development Mechanism, in which rich countries sponsor green projects in poor countries and get credit for the reduced emissions. To this end, he is amassing evidence that modern char techniques can actually keep the carbon involved locked up for centuries. His Cornell colleague John Gaunt is working on ways to present the technique as the sort of 'change in practice' that could count as a tradeable carbon-emission reduction of the sort allowed under Kyoto.

Then there are your risk-averse farmers. They haven't heard of char. And they aren't going to buy it — let alone buy a strangely named machine to make it — unless they know it will make them money. It is no good pitching it to them with a mouthful of scientific caveats about not knowing the right kind of char for each type of soil or exactly how it works. You have to be able to sell specific benefits and real attractions. "A lot of farmers are environmentalists," says John Kimble, a USDA man who has just retired from the National Soil Survey Center in Lincoln, Nebraska. "But they look at the bottom line, as we all do."

After the afternoon coffee break in Philadelphia, Kimble takes the podium and the



Father of the field: Wim Sombroek championed the study of the Amazon's dark soils.

wind out of everyone's sails. He is sympathetic to the terra pretans goals — indeed he was a good friend of Sombroek's — but that doesn't stop him asking hard questions. "Can you do this in a no-till way?" is one tricky query. Kimble and many others have been pushing no-till farming, which basically means doing without ploughs, as a partial solution to erosion, pesticide run-off and fuel costs. The idea is that the less you mess with the soil, the less its components separate and wander away. But biochar is light and fine, like the black grit left in a barbecue. If you don't physically insert it into the soil, it might just blow away.

Everyone listens politely. But while watching their responses, it was hard not to worry that the same enthusiasm that has brought them together might also trap them in a cul de sac. They obviously respect economics and pragmatic requirements. But these are not people principally moved by practical politics or bottom lines; they are people moved by ideals. They start from the basis that the answer lies in the soil, more or less whatever the question is, and can't quite understand why this isn't self-evident to everyone else. Faced, for example,

with the suggestion that all corn matter be turned into ethanol, they tend simply to say "Well it could be — but we hope, of course, it will go into the soil." They know they ought to be marketing *terra preta* as a resource, or a policy instrument; but they can't stop

seeing it as a wonder.

Policy is not always, or even often, dictated by pure rationality. Perhaps *terra preta's* compelling history and rich, earthy smell will go to the heads of that diffuse band of policy-makers who hand out the cash. The enthusiasts need to be more down to earth; but the policy people might benefit from getting their hands dirty. ■

Emma Marris is a Washington correspondent for *Nature*.

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— Johannes Lehmann

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