Excavations in the Amazon region expose fertile black soil.

FINDING OUT HOW BIOCHAR WORKS

The ancient secrets of black soil

An ancient method used by Amazon Indians Americans to improve the quality of soils using charcoal is coming in for renewed interest. Claims are made that the black soil could solve the climate problem and save the rainforest. Research findings suggest it is not quite as simple as that.

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All is quiet in the World Soil Museum's almost completed new home on the Wageningen campus. The museum is only due to be opened officially at the beginning of April, but if you knock at the door now you can already get access to the soil profiles on display. Among them *terra preta de índio*: Indian black soil from the Amazon.

Most soils in the Amazon are old and very weathered, and no longer contain many nutrients. Terra preta is the exception. Ever since the mid-19th century, Americans were lured to Brazil by the prospect of being able to farm this fertile black soil. Charcoal particles – probably from trees burnt when clearing ground – give the soil its sometimes coal-black colour.

The profile in the museum looks much like any other soil sample at first glance: a grey-black upper layer which gradually gives way in the first metre to a yellow underlying layer. There are some fragments of pottery sticking out in a few places, remnants of the Indians who created this soil. For centuries they enriched their fields with charcoal, fishbone, bones (often of tortoises) and other household waste. Together with the humus acids and the products of decomposition of waste, the charcoal retains the nutrients in the soil, in the face of one tropical downpour after another.

ANCIENT CIVILIZATIONS

'The question for a long time was: is that combination of fertile soil with remnants of human habitation evidence that old civilizations settled on fertile ground to farm, or that fertile ground was actually created by those people?' explains Thom Kuyper, soil biologist, fungus expert and professor at Wageningen University, part of Wageningen UR. 'Ever since the early 20th century, archaeologists have been convinced that these soils were formed by human beings, but that idea had not penetrated into the soil science literature.' Since then, radiocarbon dating on organic material has suggested that these soils were developed by the ancestors of today's Indian tribes, living roughly between 2000 BCE to 1500 CE.

According to one recent inventory, about 4 percent of the land surface of the Amazon consists of terra preta – an area the size of Germany. It is almost unimaginable that Indian tribes in the sparsely populated rainforest had such a big impact on soil formation in the region. But until Columbus set off for the New World, there were probably about 10 million Indians living in the Amazon basin, in villages of up to 10,000 inhabitants. The influx of European fortune-hunters put an end to that: the Indians had no resistance to new diseases such as smallpox and the measles.

FELLING RAINFOREST

Soil scientist Wim Sombroek (1934-2003) drew terra preta to the attention of the soil science community in the mid-1960s with his dissertation at the then Agricultural College in Wageningen. Later, as director of soil science institute ISRIC, where the Soil Museum is housed, he campaigned all his life for research on this soil type.

Kuyper has adopted Sombroek's baby, and is currently coordinating a research project on terra preta in which nine Wageningen research groups are participating. The project is funded by INREF (Interdisciplinary Research and Education Fund), a Wageningen University fund for stimulating interdisciplinary work in research and education, with an emphasis on knowledge transfer to developing countries.

Within the project eight PhD students have been working in South America over the last few years to subject terra preta to closer scrutiny: which physical and biochemical processes occur in the soil? The PhD researchers also consider socio-economic aspects, and not just out of academic curiosity.

In 2003, Sombroek proposed that new terra preta soils should be developed by putting charcoal in the ground. The assumption was that in tropical countries this could lead to a more sustainable, intensive form of agriculture for which the farmers would no longer have to fell a new tract of rainforest after every harvest. The approach would also put the brakes on the greenhouse effect; the CO_2 that is stored by trees is not released but stays in the ground for a very long time in the form of charcoal. In just over 10 years, this idea has grown into a worldwide hype. Even some Dutch farmers have been heard talking about ploughing charcoal – now rechristened 'biochar' – into the land. In future it might be possible to make money from the process, by selling carbon credits obtained for carbon storage to companies seeking to compensate for their CO_2 emissions. Biochar fans also see opportunities not only for using charcoal, but also other substances such as chicken manure or sludge from purification plants, after they have been carbonized by pyrolysis (burning without oxygen).

NATURAL BIOCHAR

Tess van de Voorde, at the Nature Management and Plant Ecology chair group, shows me a pot of biochar: sour-smelling, black flakes, the end-product of pyrolized hay. She is using this biochar on the Veluwe moorlands in the Netherlands. Not to improve the agricultural value of the soil, but as a nature management measure.

Van de Voorde is a postdoc working on an interdisciplinary study – a collaboration between Wageningen UR and the NIOO-KNAW – of the use of biochar in the conversion of former farmland to a nature reserve. She hopes to kill several birds with one stone. 'This land has been ploughed and fertilized year in year out. In order to make it more bare and therefore more suitable for

Right: Production of biochar in Mexico.

interesting wild plants, it must be mown regularly to remove nutrients. The mown grass used to be sold as horse feed, but that is no longer possible because of the way the poisonous St James ragwort is spreading.'
Van de Voorde considers the question of whether the hay could be profitable in the form of biochar. 'If you mix it into the soil, it might provide a new source of income through carbon credits.' She hopes that the biochar will increase the soil fertility, so that the vegetation will flourish and the removal of nutrients – through the annual mowing – will go faster. And biodiversity might benefit as well.
Van de Voorde got her PhD for a study of the interaction between soil organisms and wild plants. She is working within the biochar project with postdoc Simon Jeffrey of the soil quality department at Wageningen University. Jeffrey's task is to study the abiotic and soil-physics aspects of the topic.

'The effect of biochar was not noticeable a year later'

PLOUGHED INTO THE SOIL

At Planken Wambuis, a nature area near Arnhem belonging to national nature conservation organization Natuurmonumenten, the researchers have marked out a trial field with 24 plots of 4 by 4 metres. Two years ago, on half of the plots, two types of biochar (made from hay from the area carbonized at different temperatures) were ploughed into the soil to a depth of 15 centimetres. By way of comparison, on six plots the soil was only ploughed over, while on six other plots the hay was ploughed into it. On all the trial plots a mix of 18 wild plant species was then sown.
'In the first year we could pick out the plots with biochar right away: red clover was >

PHOTO BOSQUE VILLAGE

TERRA PRETA AND BIOCHAR

Terra preta

Terra preta was developed by Indian tribes in the Amazon region between 2000 and 1500 years CE.

For centuries Amazon Indians enriched their fields with:

Charcoal

Fishbone

Bones

Organic waste

Potsherds

Biochar

Since 2003, new terra preta soils have been developed all around the world by putting charcoal into the ground. That charcoal, which now goes by the name of 'biochar', is made by carbonizing biomass.

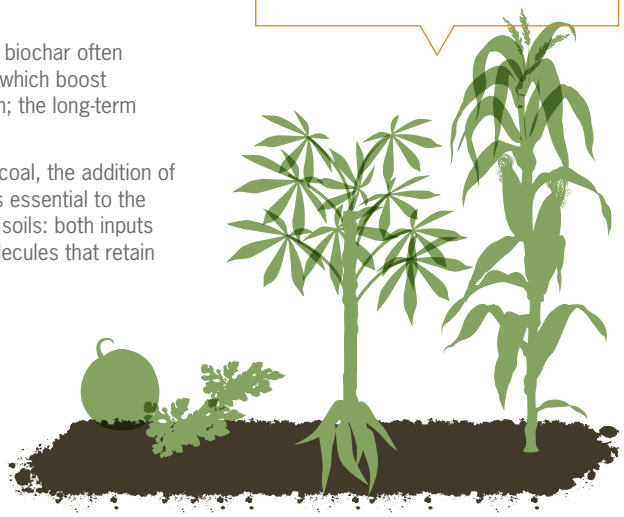
Biochar was expected to help create a more sustainable, intensive form of agriculture in tropical countries, so that farmers would not have to fell a new tract of rainforest after every harvest. It was also expected to slow down the greenhouse effect: the CO_2 absorbed by the trees is not released but stays in the ground in the form of charcoal.

Biochar

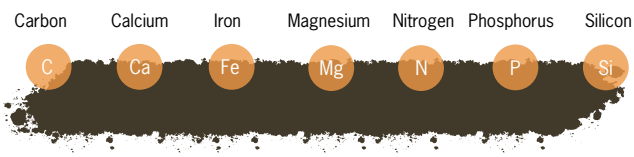
Research

Research has revealed that biochar often contains ash with nutrients which boost production in the short term; the long-term effects are not yet clear.

It is likely that besides charcoal, the addition of fishbone and other bones is essential to the development of terra preta soils: both inputs are needed to form the molecules that retain the nutrients.



Nutrients in terra preta



'It sounds too good to be true: the climate problem solved, waste recycled, soil fertility improved and the rainforest saved'

dominant on them,' says Van de Voorde. 'In the lab we discovered that this was an effect of a bit more potassium in the biochar. That effect was no longer noticeable the next year.' There is no question of extra biomass production to date, says the researcher. So it does not seem to be a faster way to deliberately degrade land. Even the nematodes, springtails and earthworms in the soil and the insects above it seem to take no notice of the biochar after two years.

Van de Voorde still plans to look at whether the interactions between plants and the soil fauna are affected by the added charcoal. 'You mix a kind of activated carbon into the soil. How will that affect the chemical substances with which plants communicate with fungi and bacteria? Can a symbiotic fungus still locate the plant root then? That is what we are working on.'

PREDICTING CONSEQUENCES

The researcher warns against the random application of biochar. 'Once you have put it in the ground, it doesn't get out again. We work with a simple, natural base material and even then it is not predictable quite what will happen. Let alone being able to predict the consequences of using pyrolized household waste, for instance.

This is a warning Thom Kuyper fully endorses. 'Most biochar researchers claim successes in the form of higher yields, for example in maize cultivation in Zambia, but these are usually studies lasting one or two years,' he warns. 'Biochar often contains ash, with nutrients which boost production in the short term. That is an easy result to book but we don't have any sense of the long-term effects yet.'

And then there remains the question of whether this kind of approach to soil improvement will catch on among farmers in tropical regions. In spite of the great fertility, it is not a foregone conclusion, thinks PhD student and ethnobotanist André Braga Junqueira from Brazil. In the Wageningen terra preta project, he is studying the use of terra preta by farmers along the Madeira river, a major tributary of the Amazon, near Manaus in northern Brazil.

'My impression is that we scientists have a higher estimation of the value of these soils than the farmers do,' says Junqueira. His conclusion from 200 interviews is: 'They do see that terra preta gives them more scope, because they can grow both water melons and maize, for instance. They can't do that elsewhere. But there is a flip side to it: weeds flourish in the fertile soil too, so that it is labour-intensive to farm. Many farmers are wary of it, therefore, and even avoid terra preta locations.'

BITTER CASSAVA

The users of these soils also try to shorten the growing season in order to stay one step ahead of the weeds. Normally a key crop such as bitter cassava takes one to even two years to grow, but on terra preta the farmers opt for varieties which are productive after only six months, Junqueira explains. Because this cassava does not keep as long, like water melon, it is only a viable crop if a big city market is easily accessible.

Whether terra preta can play a role in the transition from shifting cultivation to more intensive agriculture, thereby sparing the rainforest, is far from certain, says the PhD researcher. 'It depends on local conditions. Terra preta gives the farmers more scope to adapt because they can start growing other crops. It increases their chances of making use of new development such as the creation of new road connections, but the farmer does need to be able either to buy pesticides or to put in a lot of labour.'

Kuyper hopes that the PhD students´ broad research on terra preta will generate new insights and lead to the biochar discussion being informed with facts. 'To be honest I think a simplistic approach based only on carbonized material doesn´t work.'

At the beginning of 2014 he and his colleagues published a critical article to this effect in the journal GCB Bioenergy. 'The biochar hype makes use of the terra preta argument that goes: 'we are just copying what the Indians did centuries ago.' We dispute that: we think the input of both charcoal and fishbone and other bones was crucial to the development of these soils. Both are necessary for forming the right molecules for retaining nutrients.'

Kuyper is afraid this warning will fall on deaf ears. 'It will take time to convince everyone that there is more to it than just adding biochar. It does sound too good to be true, anyway. Adding carbonized pig manure to the soil was going to solve the climate problem, recycle our waste, improve soil fertility and save the rainforest. A win-win-win-win situation. That's never the way it works in the real world.' ■

www.wageningenur.nl/en/terrapreta

TERRA PRETA ELSEWHERE

Soil types comparable with terra preta have been found in Sierra Leone and in Liberia, as well as on Kalimantan, albeit on a small scale. The fact that 'black soil' is mainly found in the Amazon is assumed to be related to differences in the technology available to the populations. Almost all rainforest cultures practise slash-and-burn agriculture, but the Indians of South America were the only population that did not have access to iron for making machetes. It is difficult to chop down a tree with stone tools, which made it more important here than in other parts of the world to find sustainable ways of exploiting a field that has been cleared.