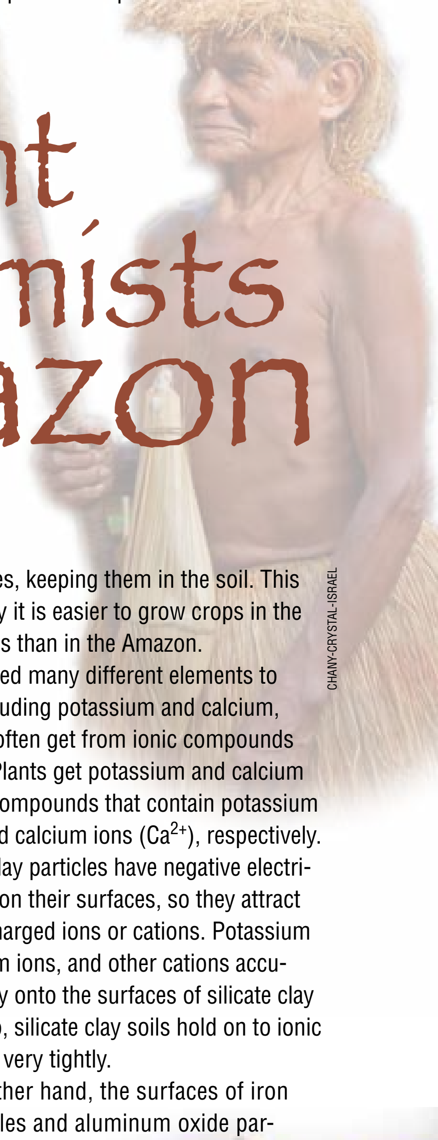
Ancient Soil Chemists of the Amazon

By Mark Michalovic


RHETT BUTLER, WWW.MONGABAY.COM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The Amazon rainforest is a wild place, seemingly untouched by human hands. Surprisingly, native people may have built a great civilization in the jungles of South America long before Christopher Columbus crossed the Atlantic Ocean. This civilization thrived from about 2,500 years ago to about 500 years ago.

"The Amazon probably had native populations reaching over 6 million in 1491," says Clark Erickson, an anthropologist at the University of Pennsylvania. "To feed that many people, the Amazonians transformed the environment into a landscape of cultivated and tended trees interspersed with gardens, fields, and settlements."

During the past two decades, archaeologists have gathered evidence that this lost civilization developed intensive agriculture thanks to a fertile soil they called *terra preta*. The use of *terra preta* spread over thousands of square kilometers—an area as big as Virginia—and fostered the development of an advanced society.

Unlike current soil fertilization techniques, the use of *terra preta* allows the soil to remain fertile year after year. Scientists are trying to understand what makes this soil persist for hundreds if not thousands of years and are finding ways to use it to boost agricultural productivity, while reducing the use of fertilizers. Also, scientists have found that *terra preta* collects large quantities of carbon dioxide, one of the greenhouse gases contributing to global warming.

The Amazon soil problem

Scientists had previously shown that most of the Amazon's soil does not contain the nutrients that are needed to support crops. They had tried to introduce chemicals to fertilize this soil, but without sustained success. As a result, scientists had dismissed the idea that indigenous people could have survived in large numbers, assuming instead that these people probably lived in semi-nomadic groups.

So it came as a surprise when landscape archaeologist Clark Erickson discovered pottery vessels in Bolivia's Mojos Plains that seemed too big for wandering nomads. Erickson and other scientists also noticed that the area contained a network of causeways connecting villages together along with canals. Erickson now believes that this canal network was used to irrigate cultivated crops, allowing indigenous people to prosper and build villages.

"These people must have known how to grow food that modern people don't know, because farming in the Amazon is really hard to do," Erickson says. "Most Amazonian soil is orange or yellow and is made mostly of iron oxide and aluminum oxide. This soil doesn't contain many of the nutrients that plants need to survive."

The Amazonian soil is not easy to cultivate because trees in the Amazon rainforest receive their nutrients from dead plants on the forest floor, not from the soil. So when farmers chop down trees to make farmland, the organic matter is decomposed rapidly, the carbon is transformed into carbon dioxide that goes in the air, and what is left of the organic matter is washed away by the rain. As a result, the field cannot be used for growing crops anymore. Even artificial fertilizers do not help much, because they wash away just like organic matter does.

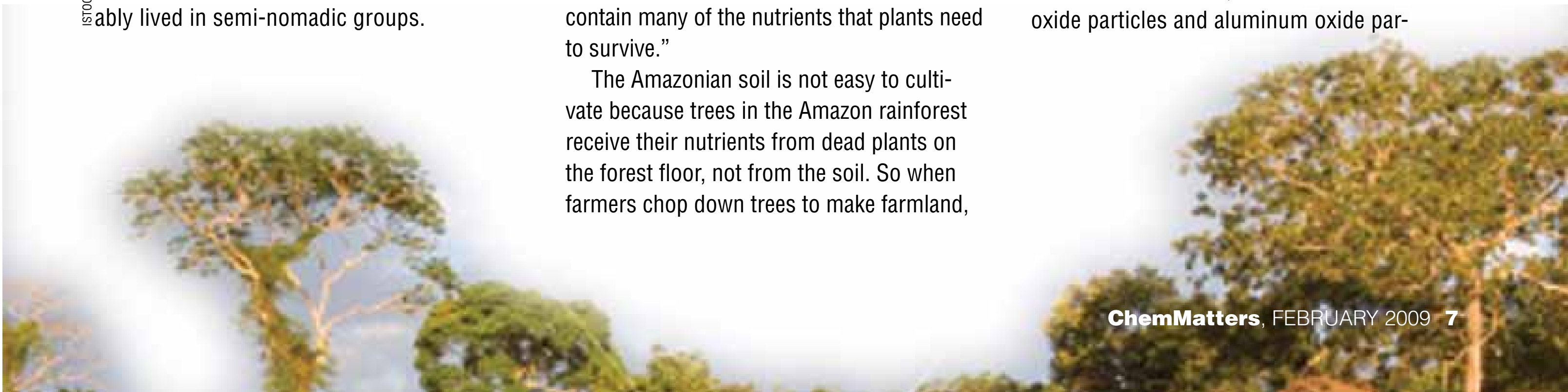
Ions and surfaces

Unlike the Amazon soil, soil in many parts of the United States is made of silicate clays, which contain aluminum, oxygen, and silicon. Silicate clay particles trap certain nutrients on their surfaces, keeping them in the soil. This explains why it is easier to grow crops in the United States than in the Amazon.

Plants need many different elements to survive, including potassium and calcium, which they often get from ionic compounds in the soil. Plants get potassium and calcium from ionic compounds that contain potassium ions (K^+) and calcium ions (Ca^{2+}), respectively.

Silicate clay particles have negative electrical charges on their surfaces, so they attract positively charged ions or cations. Potassium ions, calcium ions, and other cations accumulate easily onto the surfaces of silicate clay particles. So, silicate clay soils hold on to ionic compounds very tightly.

On the other hand, the surfaces of iron oxide particles and aluminum oxide par-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JULIE GROSSMAN

U.S. and Brazilian scientists examine changes in the color of *terra preta*.

CLARK ERICKSON

A patchwork of ancient raised fields.

ticles, which are present in the Amazonian soil, do not have negative electrical charges, so they cannot attract cations, which easily wash away.

Dark secrets

Instead of growing acres and acres of maize, ancient Amazonians mostly farmed by letting forest fruit and nut trees grow, while culling other types of trees. This gave them food but preserved the forest and wildlife habitat.

"Entire forests were transformed to serve humans," Erickson says. "But maize and manioc were critical because of their use in everyday life to feast and to brew native beers for social life."

Corn draws more nutrients from the soil than any other Amazonian crop and thus needs better soils. So, without good natural soils, the ancient Amazonians made their own.

In many places where archaeologists have found signs of ancient Amazonian towns, they have also found a very dark soil, different than the surrounding soils, which are typically yellowish white. This soil is called *terra preta*, which means "black earth" in Portuguese. "Plants grow well in this soil, and, in some cases, you can produce several times the regular yield of maize in *terra preta* as in Amazonian soil," says soil scientist Johannes Lehmann of Cornell University, Ithaca, N.Y.

There are rich black soils in other places on Earth, but *terra preta* is different. Most black soil is naturally rich because it contains rotting plant matter. But the black color of *terra preta* is a result of unusually high contents of biochar or charcoal. "It was mixed into the *terra preta* by human hands," Lehmann says. "I find *terra preta* a very exciting detective story: What did the populations do to 'make' *terra preta*?"

Biochar is made mostly of carbon, and it helps *terra preta* hold nutrients. Lehmann found that the surface of biochar has an unusually high density of negatively charged groups of carbon and oxygen atoms called carboxylate groups. Cations would then be strongly attracted to these carboxylate groups.

Scientists are now trying to use biochar to make soil more productive. For example,

MIKE CIESIELSKI

Unlike clay soil (left) and garden soil (right) found in the United States, *terra preta* allows soil to remain fertile for years.

Georgia is known for its poor red soil, which is mostly ferric oxide. Eprida, Inc., a Georgia-based company, is now trying to use biochar-soil mixtures similar to *terra preta*. "In 110 days, we took red clay and turned it into brown topsoil, 16 centimeters deep," says Danny Day, the founder of Eprida, Inc. "We can actually grow corn here now." Day

JOHANNES LEHMANN

***Terra preta* near Iranduba, Central Amazon, Brazil.**

hopes that biochar will be used to grow food in the poor soils of tropical countries, where people are often poor and food shortages are common.

Ancient soil, future fuel

Biochar is made by heating wood or other plant matter, but not by burning it. Wood consists mostly of two compounds called cellulose and lignin, which are both made of carbon, hydrogen, and oxygen. When wood burns, these compounds react with oxygen to form carbon dioxide and water, along with smoke, ash, and other gases.

But sometimes the fire doesn't get enough oxygen for combustion. Instead of burning, the cellulose and lignin break down. The hydrogen and oxygen atoms form water molecules, while the carbon atoms are left behind. The leftover carbon is biochar. This process is called pyrolysis. You may have seen biochar leftover after a campfire is extinguished. Ancient Amazonians probably made most of their biochar by heating wood in slow, smoldering, fires, specifically for making *terra preta*. "The size of most *terra preta* sites is huge, and this implies something special and intentional," Erickson says.

PHOTO BY RHETT BUTLER, WWW.MONGABAY.COM

Clear-cutting in the Amazon rainforest as viewed from an airplane.

CLARK ERICKSON

Clark Erickson's team, agronomy students, and local farmers studied how past farming was done by constructing their own raised fields.

Day hopes to use pyrolysis to make clean fuel while making biochar. During normal pyrolysis, the hydrogen atoms and oxygen atoms in cellulose and lignin join to form water molecules. But under the right conditions, the hydrogen atoms can form hydrogen gas (H_2) instead of joining with oxygen. Day hopes to make hydrogen fuel this way.

Since the entire process of growing plants and pyrolyzing them does not produce carbon dioxide, it does not worsen global warming. But inexpensive and eco-friendly ways to make hydrogen have been difficult to find. "Hydrogen, as a form of fuel, is something that is easy to do with biomass," Day says.

When pyrolysis is carried out in just the right temperature range, it generates energy, minimizing the amount of fuel needed to produce hydrogen in the first place. According to Day, the pyrolysis methods can also be tweaked to make it produce biodiesel fuels, a process called hydrocarbon reforming.

Day hopes that his clean fuels and biochar soil additives will be a one-two punch in the fight against global warming. When a plant grows, it takes carbon dioxide out of the air and converts it into the materials that make up the plant—like cellulose and lignin. When the plant dies, the carbon in the plant turns back into carbon dioxide. Other times, the plant might be burned as fuel or to get rid of it. This also turns the plant's carbon back into carbon dioxide. But if you turn this carbon into biochar, that carbon does not turn back into carbon dioxide. Large-scale production of biochar for farming could cut the levels of carbon dioxide in the atmosphere, which could help reduce global warming.

Over 1,000 years ago, people in the Amazon rainforest learned how poor soil can be transformed to give good crops. They did so by using chemistry that we don't entirely understand yet. A lot of research needs to be done to figure out what they did so long ago. As we try to solve the puzzles of *terra preta*, those ancient people give us clues about the distant past while leading us to new technologies for the future.

SELECTED REFERENCES

Glaser, B.; Woods, W. I. *Amazonian Dark Earths: Explorations in Space and Time*; Springer: New York, 2004.

Lehmann, J. Bio-energy in the Black. *Front. Ecol. Environ.,* **2007***,* 5, pp 381–387.

Mann, C. *1491*: *New Revelations of the Americas Before Columbus*; Vintage, 2006.

Marris, E. Black Is the New Green. *Nature*, August 2006, 442, pp 624–626.

Renner, R. Rethinking Biochar. *Environ. Sci. Tech.*, Sept. 1, 2007, 41, pp 5932–5933.

Wallace, S. Last of the Amazon. *Natl. Geogr.*, January 2007, *211* (1), pp 40–71.

Mark Michalovic teaches at Bucks County Community College, Newtown, Pa. His most recent *ChemMatters* article, "Beyond Hydrogen: The New Chemistry of Fuel Cells," appeared in the December 2007 issue.