Ancient Amazonians left behind widespread deposits of rich, dark soil, say archaeologists. Reviving their techniques could help today's rainforest farmers better manage their land

The Real Dirt on Rainforest Fertility

IRANDUBA, AMAZÔNAS STATE, BRAZIL— Above a pit dug by a team of archaeologists here is a papaya orchard filled with unusually vigorous trees bearing great clusters of plump green fruit. Below the surface lies a different sort of bounty: hundreds, perhaps thousands, of burial urns and millions of pieces of broken ceramics, all from an almost unknown people who flourished here before the conquistadors. But surprisingly, what might be most important about this central Amazonian site is not the vibrant orchard or the extraordinary outpouring of ceramics but the dirt under the trees and around the ceramics. A rich, black soil known locally as *terra preta do Indio* (Indian dark earth), it sustained large settlements on these lands for 2 millennia, according to the Brazilian-American archaeological team working here (see sidebar).

Fruits of labor. Soils enhanced centuries ago underlie a flourishing papaya orchard near Iranduba, Brazil.

Throughout Amazonia, farmers prize terra preta for its great productivity—some farmers have worked it for years with minimal fertilization. Such long-lasting fertility is an anomaly in the tropics. Despite the exuberant growth of rainforests, their red and yellow soils are notoriously poor: weathered, highly acidic, and low in organic matter and essential nutrients. In these oxisols, as they are known, most carbon and nutrients are stored not in the soil, as in temperate regions, but in the vegetation that covers it. When loggers, ranchers, or farmers clear the vegetation, the intense sun and rain quickly decompose the remaining organic matter in the soil, making the land almost incapable of sustaining life—one reason ecologists frequently refer to the tropical forest as a "wet desert."

Because terra preta is subject to the same punishing conditions as the surrounding oxisols, "its existence is very surprising," says Bruno Glaser, a chemist at the Institute of Soil Science and Soil Geography at the University of Bayreuth, Germany. "If you read the textbooks, it shouldn't be there." Yet according to William I. Woods, a geographer at Southern Illinois University, Edwardsville, terra preta might cover as much as 10% of Amazonia, an area the size of France. More remarkable still, terra preta appears to be the product of intensive habitation by precontact Amerindian populations. "They practiced agriculture here for centuries," Glaser says. "But instead of destroying the soil, they improved it—and that is something we don't know how to do today."

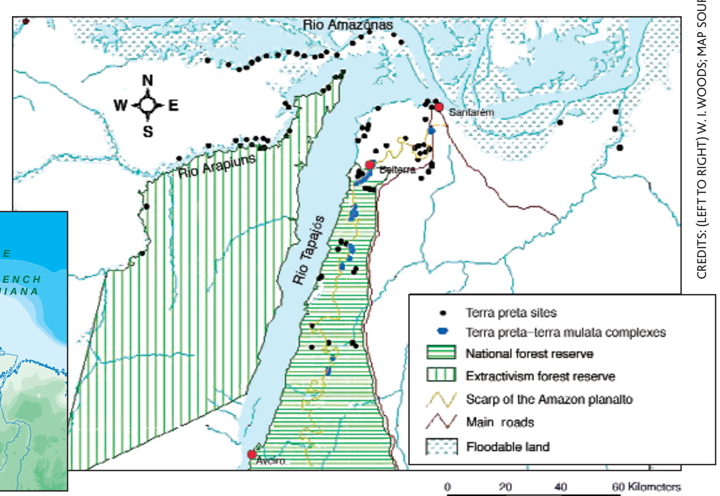
In the past few years, a small but growing group of rsearchers—geographers, archaeologists, soil scientists, ecologists, and anthropologists—has been investigating this "gift from the past," as terra preta is called by one member of the Iranduba team, James B. Petersen of the University of Vermont, Burlington. By understanding how indigenous groups created Amazonian dark earths, these researchers hope, today's scientists might be able to transform some of the region's oxisols into new terra preta. Indeed, experimental programs to produce "terra preta nova" have already begun.

The research is still in an early stage, but last month attendees at the first large-scale scientific congress* devoted to terra preta argued that its consequences could be enormous, both for Amazonia and for the world's hot regions in general. Population pressure and government policies are causing rapid deforestation in the tropics, and poor tropical soils make much of the clearing as economically nonviable in the long run as it is ecologically damaging. The existence of terra preta, says Wim Sombroek, former director of the International Soil Reference and Information Center in Wageningen, the Netherlands, suggests "that some kind of sustainable, intensive agriculture is possible in the Amazon, after all. If we can learn the principles behind it, we may be able to make a substantial contribution to human welfare and the environment."

The good earth

Terra preta is scattered throughout Amazonia, but it is most frequently found on low hills overlooking rivers—the kind of terrain on

* First International Workshop on Anthropogenic Terra Preta Soils, Manaus, Brazil, 13–19 July.



CREDITS: (LEFT TO RIGHT) W. I. WOODS; MAP SOURCE: ADAPTED FROM NIMUENDAJU, ROOSEVELT, MEGGERS, SOMBROEK, FALESI, IMAFLORA, WOODS, AND MCCANN which indigenous groups preferred to live. According to Eduardo Neves, an archaeologist at the University of São Paulo who is part of the Iranduba team, the oldest deposits date back more than 2000 years and occur in the lower and central Amazon; terra preta then appeared to spread to cultures upriver. By A.D. 500 to 1000, he says, "it appeared in almost every part of the Amazon Basin."

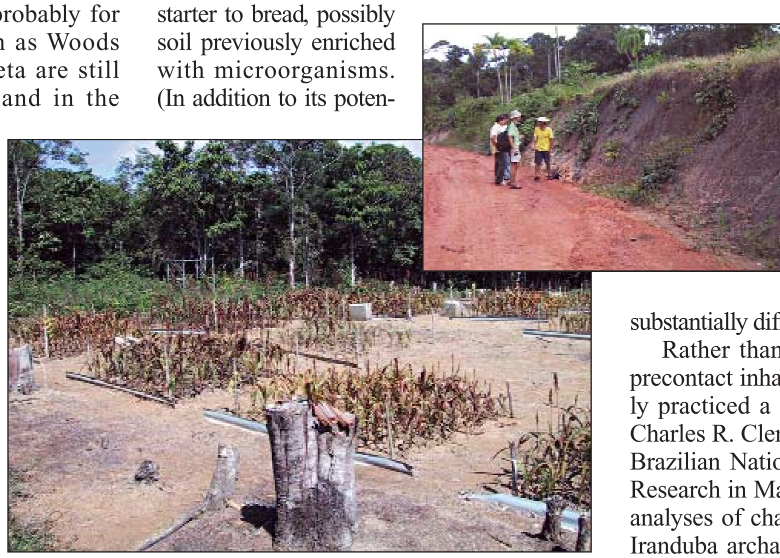
Typically, black-soil regions cover 1 to 5 ha, but some encompass 300 ha or more. The black soils are generally 40 to 60 cm deep but can reach more than 2 m. Almost always they are full of broken ceramics. Although they were created centuries ago—probably for agriculture, researchers such as Woods believe—patches of terra preta are still among the most desirable land in the Amazon. Indeed, terra preta is valuable enough that locals sell it as potting soil. To the consternation of archaeologists, long planters full of terra preta, complete with pieces of pre-Columbian pottery, greet visitors to the airport in the lower Amazon town of Santarém.

As a rule, terra preta has more "plant-available" phosphorus, calcium, sulfur, and nitrogen than surrounding oxisols; it also has much more organic matter, retains moisture and nutrients better, and is not rapidly exhausted by agricultural use when managed well.

The key to terra preta's long-term fertility, Glaser says, is charcoal: Terra preta contains up to 70 times as much as adjacent oxisols. "The charcoal prevents organic matter from being rapidly mineralized," Glaser says. "Over time, it partly oxidizes, which keeps providing sites for nutrients to bind to." But simply mixing charcoal into the ground is not enough to create terra preta. Because charcoal contains few nutrients, Glaser says, "high nutrient inputs via excrement and waste such as turtle, fish, and animal bones were necessary." Special soil microorganisms are also likely to play a role in its persistent fertility, in the view of Janice Thies, a soil ecologist who is part of a Cornell University team studying terra preta. "There are indications that microbial biomass is higher in terra preta," she says, which raises the possibility that scientists might be able to create a "package" of charcoal, nutrients, and microfauna that could be used to transform oxisols into terra preta.

Slash-and-char

Surprisingly, terra preta seems not to have been created by the "slash-and-burn" agriculture famously practiced in the tropics. In slash-and-burn, farmers clear and then burn their fields, using the ash to flush enough nutrients into the soil to support crops for a few years; when productivity declines, they move on to the next patch of forest. But Glaser, Woods, and other researchers believe that the long-ago Amazonians created terra preta by a process that Christoph Steiner, a University of Bayreuth soil scientist, has dubbed "slash-and-char." Instead of completely burning organic matter to ash, in this view, ancient farmers burned it only incompletely, creating charcoal, then stirred the charcoal directly into the soil. Later they added nutrients and, in a process analogous to adding sourdough starter to bread, possibly soil previously enriched with microorganisms. (In addition to its potential benefits to the soil, slash-and-char releases much less carbon into the air than slash-and-burn, which has potential implications for climate change.)



Gaining ground. Soil enhanced with charcoal and fertilizer did best in tests (*above*). Rich, dark terra preta contrasts with poor red soil (*inset*).

In a preliminary test run at creating terra preta, Steiner, Wenceslau Teixeira of the Brazilian Agricultural Research Enterprise, and Wolfang Zech of the University of Bayreuth applied a variety of treatments involving charcoal and fertilizers to test plots of highly weathered soil at a site outside the central Amazonian city of Manaus. They then planted rice and sorghum in each plot for 3 years. In the first year, there was little difference among the treatments (except for the control plots, in which almost nothing grew). But by the second year, Steiner says, "the charcoal was really making a difference." Plots with charcoal alone grew little, but those treated with a combination of charcoal and fertilizer yielded as much as 880% more than plots with fertilizer alone.

The "Bambi syndrome"

Researchers believe the best use of the newly revived technique will be in a kind of updated version of precontact indigenous agriculture, which used methods very different from slash-and-burn. According to a pathbreaking 1992 analysis by William Denevan, a geographer emeritus at the University of Wisconsin, Madison, the slash-and-burn agriculture practiced until recently by most Amazonian cultures is probably a recent invention. In contemporary slash-and-burn, farmers shift from plot to plot every 2 to 4 years. But field experiments by archaeologists in Amazonia indicated that clearing the forest with stone tools was so difficult that rapid movement among areas would have been impractical, if not impossible. "What they found was that for a single moderate to big hardwood tree it can take more than 30 times longer to cut down that tree with a stone ax than with a steel ax," Denevan says. "I argued that this meant that Indians had to stay with a piece of land in precontact times for much longer than they do now and had substantially different agricultural regimes."

Rather than planting annual crops, the precontact inhabitants of the Amazon mostly practiced a type of agroforestry, argues Charles R. Clement, a plant geneticist at the Brazilian National Institute for Amazonian Research in Manaus. Initial paleoecological analyses of charred plant remains from the Iranduba archaeological site show, in addition to annual crops such as manioc and maize, the wood from at least 30 species of useful trees. "They put down annuals until the orchards grew," suggests Clement. "We'll have to find some modern equivalent to Indian agroforestry. Otherwise creating new terra preta"—if scientists learn how to do it—"will simply lead to the same kind of clearing we have now, except the land will last longer." Indeed, research in Amazonia by Laura German of the International Center for Research in Agroforestry in Nairobi, Kenya, has shown that over time the nutrients in terra preta, when poorly managed, can decline to near-oxisol levels.

New terra preta farms, researchers acknowledge, will be subject to novel problems, especially weeds. In small central Amazon plots, German says, weeds grow so fiercely on terra preta that they overwhelm crops—they are a principal reason that farmers on ancient terra preta sites move their fields. New techniques to control tropical weeds will have to be developed, says Cornell weed scientist Antonio DiTommaso, much as scientists have created methods to manage temperate-zone weeds.

Some researchers hope that the more intensive agroforestry possible on terra preta would allow landowners to spare more tropical forest, especially near cities like Manaus,

CREDITS: W. I. WOODS

where the organic waste now overflowing dumps could be burned to provide charcoal. It might even be possible to reclaim cleared land. But because the benefit of increased yields depends on quickly transporting produce and fruit to large markets, the increased costs of terra preta may not be economically viable in remote parts of Amazonia. In addition, Clement argues that any success with terra preta will simply lure more people to work with it and that those people will end up clearing forest in the process. "Terra preta is about making the current process of development more rational and sustainable, not about conservation," he says. "It's about creating the conditions for the forest to return more quickly after it's cleared, not about preserving it from development."

Even if Clement's view is correct, examining terra preta is still worthwhile, according to Susanna Hecht, a geographer at the University of California, Los Angeles. "We have to get over this Bambi syndrome of seeing all development in the tropics as necessarily catastrophic," she says. "People have been farming there—farming hard—for thousands of years. We just have to learn how to do it as well as they did."

–CHARLES C. MANN

STEM CELL LINES

'Show Us the Cells,' U.S. Researchers Say

One year after President Bush announced that some 60 human embryonic stem cell lines were available, U.S. scientists have their hands on just four

Ali Hemmati-Brivanlou, a molecular embryologist at Rockefeller University in New York City, has been trying since last September to obtain samples of all the cells listed on the National Institutes of Health's (NIH's) registry of "available" human embryonic stem cell lines—which at the beginning of this month numbered 71. The results: two viable lines, one from WiCell in Madison, Wisconsin, and one from ES Cell International (ESI) in Melbourne, Australia. (ESI sent him two lines, but the other one won't grow, he says.) "Everybody has their own reasons why they should not be sending things out," says Brivanlou.

One year has passed since President George W. Bush announced, after much deliberation, that he would allow federally funded researchers to work with human embryonic stem (hES) cell lines—as long as the cells had been derived before he began his speech at 9:00 p.m. on 9 August 2001. The cell lines, which can in theory develop into any type of cell in the body and thus might someday be useful for treating disease, are controversial because their derivation requires the destruction of week-old embryos. In his speech, Bush also announced that "more than 60" such cell lines were available, taking the research community by surprise. Until then, most researchers suspected that perhaps a dozen hES cell lines had been derived. But a worldwide survey by NIH had turned up at least 64 cell lines on four continents, NIH officials said.

A year later, the scientists' conservative estimate still seems closer to the mark. Although the NIH list has grown to include 71 "eligible" cell lines—derived in accordance with certain ethical standards before the specified date—practical and legal hurdles have kept most of the lines in the labs where they were derived. And because relatively few have been fully characterized, it's not clear that all of them are in fact bona fide hES cells. So far, just 16 cell lines are currently available for distribution, according to their proprietors. Of these, at most four are actually in the hands of U.S. researchers who aren't collaborating with the labs that derived the cells; another seven or so lines are expected to be available to the scientific public in the next few months.

"The whole thing is going pretty slowly," says a scientist who asked not to be identified—and who would like to use up to 10 cell lines in various experiments. He blames the delay on extensive negotiations over rights to the cells and layers of NIH bureaucracy. Even so, much of the community seems to agree with George Daley of the Massachusetts Institute of Technology's Whitehead Institute that, despite the slow progress, "NIH has been doing the best it can."

Cell waiting. Brivanlou, shown here before images of *Xenopus* ova and embryos, so far has received only two cell lines.

CREDIT: YANIK WAGNER

In an attempt to speed access to the cell lines, NIH has crafted a model materials transfer agreement (MTA) and funded a half-dozen groups that have derived cell lines so they can ramp up production. The agency has also procured cells for six intramural labs and given supplementary funds to close to 20 researchers so they can add hES cells to their ongoing research.

But none of these efforts can ensure the quality of the cell lines, many of which are not ready for prime time. A San Diego company called CyThera, for example, is listed as having nine lines, but none is available yet. "We first have to find out whether the derivations will result in bona fide human embryonic stem cells," says the company's president Lutz Giebel. Of the 19 lines listed at the University of Göteborg in Sweden, only three will be available in the near future, says neuroscientist Peter Eriksson; 10 others are on hold until the Swedish researchers develop new protocols for growing them more easily. And at Stockholm's Karolinska Institute, all six NIH-approved lines are frozen while work focuses on newer lines. "It is an open question if the 'NIH' lines can be successfully thawed," says researcher Michael Andäng.

Brivanlou points out that both commercial and academic cell providers have little or no incentive to supply cells to competing groups—particularly at the modest going rate of $5000 per sample. Many of the labs holding the cells "are not at the outset thinking of supplying the scientific community," Wendy Baldwin, NIH's deputy director for extramural research, admitted to the president's bioethics council in early July. Some plan to supply only collaborators, she said.

Right now, four groups are emerging as the main suppliers of hES cells to U.S. researchers: WiCell; ESI; the University of California, San Francisco (UCSF); and the Athens, Georgia, branch of the Australian company BresaGen. WiCell and ESI are al-