Terra preta

Left - a nutrient-poor oxisol; right - an oxisol transformed into fertile terra preta

Terra preta (Portuguese pronunciation: [ˈtɛʁɐ ˈpɾetɐ], locally Portuguese pronunciation: [ˈtɛhɐ ˈpɾetɐ], literally "black earth" in Portuguese) is a type of very dark, fertile anthropogenic soil found in the Amazon Basin. Terra preta owes its name to its very high charcoal content, and was made by adding a mixture of charcoal, bone, and manure to the otherwise relatively infertile Amazonian soil. It is very stable and remains in the soil for thousands of years.[1][2] It is also known as **"Amazonian dark earth"** or **"Indian black earth"**. In Portuguese its full name is *terra preta do índio* or **terra preta de índio** ("black earth of the Indian", "Indians' black earth"). *Terra mulata* ("mulatto earth") is lighter or brownish in color.[3]

Terra preta is characterized by the presence of low-temperature charcoal in high concentrations; of high quantities of pottery sherds; of organic matter such as plant residues, animal feces, fish and animal bones and other material; and of nutrients such as nitrogen (N), phosphorus (P), calcium (Ca), zinc (Zn), manganese (Mn).[4] It also shows high levels of microorganic activities and other specific characteristics within its particular ecosystem. It is less prone to nutrient leaching, which is a major problem in most rain forests. Terra preta zones are generally surrounded by *terra comum* (Portuguese pronunciation: [ˈtɛhɐ koˈmũ] or Portuguese pronunciation: [ˈtɛhɐ kuˈmũ]), or "common soil"; these are infertile soils, mainly acrisols,[4] but also ferralsols and arenosols.[5]

Terra preta soils are of pre-Columbian nature and were created by humans between 450 BC and AD 950.[6][7] The soil's depth can reach 2 meters (6.6 ft). Thousands of years after its creation it has been reported to regenerate itself at the rate of 1 centimeter (0.39 in) per year[8] by the local farmers and caboclos in Brazil's Amazonian basin, who seek it for use and for sale as valuable compost.

History

Early theories

The origins of the Amazonian dark earths were not immediately clear. One idea was that they resulted from ashfall from volcanoes in the Andes, since they occur more frequently on the brows of higher terraces. Another theory considered its formation as a result of sedimentation in tertiary lakes or in recent ponds.

Anthropogenic roots

Because of their elevated charcoal content and the common presence of pottery remains, it is now widely accepted that these soils accreted near living quarters as residues from food preparation, cooking fires, animal and fish bones, broken pottery, etc., accumulated. The intentionality of the formation of terra preta has not been demonstrated, rather it is believed to have formed under kitchen middens. Areas used for growing crops around living areas are referred to as terra mulata. Terra mulata soils are more fertile than surrounding soils but less fertile than terra preta, and were most likely intentionally improved using charcoal.

This type of soil appeared between 450 BC and AD 950 at sites throughout the Amazon Basin.[7]

Pre-Columbian Amazonia

The Spanish explorer Francisco de Orellana, the 16th century explorer who was the first European to traverse the Amazon River, reported densely populated regions running hundreds of kilometers along the river, suggesting population levels exceeding even those of today. These populations left no lasting monuments, possibly because they used local wood as their construction material, which would have rotted in the humid climate (stone was unavailable). While it is possible Orellana may have exaggerated the level of development among the Amazonians, their semi-nomadic descendants have the odd distinction among tribal indigenous societies of a hereditary, yet landless, aristocracy, a historical anomaly for a society without a sedentary, agrarian culture. This suggests they once were more settled and agrarian but became nomadic after the demographic collapse of the 16th and 17th century, due to European-introduced diseases, while still maintaining certain traditions. Moreover, many indigenous people adapted to a more mobile lifestyle in order to escape colonialism. This might have made the benefits of *terra preta*, such as its self-renewing capacity, less attractive—farmers would not have been able to employ the renewed soil as they migrated for safety. Slash-and-char might have been an adaptation to these conditions.

The BBC's *Unnatural Histories* presents evidence that Orellana, rather than exaggerating his claims as previously thought, was correct in his observations that an advanced civilization was flourishing along the Amazon in the 1540s. It is believed that the civilization was later devastated by the spread of diseases from Europe, such as smallpox.[9] The evidence to support this claim comes from the discovery of numerous geoglyphs dating between 0–1250 AD and terra preta.[10]

For 350 years after the European arrival by Vicente Yáñez Pinzón, the Portuguese portion of the basin remained an untended former food gathering and planned agricultural landscape occupied by those who survived the epidemics. There is ample evidence for complex large-scale, pre-Columbian social formations, including chiefdoms, in many areas of Amazonia (particularly the inter-fluvial regions) and even large towns and cities.[11] For instance the pre-Columbian culture on the island of Marajó may have developed social stratification and supported a population of 100,000 people.[12] Amazonians may have used terra preta to make the land suitable for the large scale agriculture needed to support large populations and complex social formations such as chiefdoms.[12]

Location

Terra preta soils are found mainly in Brazilian Amazonia, where Sombroek *et al.*[13] estimate that they cover at least 0.1 to 0.3%, or 6300 to 18900 square kilometres (2,400 to 7,300 sq mi) of low forested Amazonia[3]); but others estimate this surface at 10.0% or more (twice the area of Great Britain).[8][14]

Plots of terra preta exist in small plots averaging 20 hectares (49 acres), but areas of almost 900 acres (360 ha) have also been reported. They are found among various climatic, geological, and topographical situations.[3] Their distributions either follow main water courses, from East Amazonia to the central basin,[15] or are located on interfluvial sites (mainly of circular or lenticular shape and of a smaller size averaging some 1.4 hectares (3.5 acres), see also distribution map of terra preta sites in Amazon basin.[16] The spreads of tropical forest between the savannas could be mainly anthropogenic — a notion with dramatic implications worldwide for agriculture and conservation.[17]

Terra preta sites are also known in Ecuador, Peru, French Guiana,[18] in Benin, Liberia, and on the South African savannas.[4] Similar dark earth was found in late Roman Britain.

Pedology

Terra preta is defined as a type of latosol, having a carbon content ranging from high to very high (more than 13–14% organic matter) in its A horizon, but without hydromorphic characteristics.[19] Terra preta presents important variants. For instance, gardens close to dwellings received more nutrients than fields farther away.[20] The variations in Amazonian dark earths prevent clearly determining whether all of them were intentionally created for soil improvement or whether the lightest variants are a by-product of habitation. The varied features of the dark earths throughout the Amazon Basin suggest the existence of an extensive ancient native civilization dating back 500 to 2500 years.

Terra preta's capacity to increase its own volume—thus to sequester more carbon—was first documented by pedologist William I. Woods of the University of Kansas.[8] This remains the central mystery of terra preta.

The processes responsible for the formation of terra preta soils are:[5]

1. Incorporation of wood charcoal
2. Incorporation of organic matter and of nutrients
3. Role of micro-organisms and animals in the soil

Wood charcoal

The transformation of biomass into charcoal produces a series of charcoal derivatives known as pyrogenic or black carbon, the composition of which varies from lightly charred organic matter, to soot particles rich in graphite formed by recomposition of free radicals.[21] Here, all types of charbonated materials are called charcoal. By convention, charcoal is considered to be any natural organic matter transformed thermally or by a dehydration reaction with an Oxygen/Carbon (O/C) percentage less than 60[21] (smaller values have been suggested[22]). Because of possible interactions with minerals and organic matter from the soil, it is almost impossible to identify charcoal with any certainty by determining only the proportion of O/C. The Hydrogen/Carbon percentage[23] or molecular markers such as benzenepolycarboxylic acid,[24] are therefore used as a second level of identification.[5]

Early farmers added charcoal to poor soils, in the form of wood charcoal processed at low temperature and with a limited supply of oxygen (e.g., with smothered fires). Up to 9% black carbon has been measured in some terra preta (against 0.5% in surrounding soils).[25] Other measurements found carbon levels 70 times greater than in surrounding Ferralsols,[5] with approximative average values of 50 mg/ha/m.[26]

The chemical structure of charcoal in terra preta soils is characterized with poly-condensed aromatic groups, providing prolonged biological and chemical stability that sustains the fight against microbial degradation; it also provides, after partial oxidation, the highest nutrient retention.[5][26] Wood charcoal (but not that from grasses or high cellulose materials made at low temperature) thus has an internal layer of biological petroleum condensates that the bacteria consume, and that is similar to cellulose in its effects on microbial growth.[27] Charring at high temperature loses that layer and brings little increase in soil fertility.[8] The formation of condensed aromatic structures depends on the method of manufacture of charcoal.[24][28][29] The slow oxidation of charcoal creates carboxylic groups; these increase the cations' exchange capacity in the soil.[30][31] The nucleus of black carbon particles produced by the biomass highly remains aromatic even after thousands of years in the soil and presents the spectral characteristics of fresh charcoal. Around that nucleus and on the surface of the black carbon particles, there were higher proportions of forms of carboxylic and phenolic Cs spatially and structurally distinct from the particle's nucleus. Analysis of the groups of molecules provides evidences both for the oxidation of the black carbon particle itself, as well as for the adsorption of non-black carbon.[32]

This charcoal is thus decisive for the sustainability of terra preta.[30][33] Soil amendment of Ferrasol with wood charcoal greatly increases productivity.[15] Note that agricultural lands have lost in average 50% of their carbon due to intensive cultivation and other damage of human origin.[8]

Fresh charcoal must first be "charged" before it can function as a biotope.[34] Several experiments demonstrate that uncharged charcoal can bring a provisional depletion of available nutrients when first put into the soil - until its pores fill with nutrients. This is overcome by soaking the charcoal for 2 to 4 weeks in any liquid nutrient (urine, plant tea, etc.).

Biochar

Biochar is low temperature charcoal produced from a biomass of wood and leafy plant materials. Amending soil with biochar has been observed to increase the activity of arbuscular mycorrhizal fungi. Tests of high porosity materials such as zeolite, activated carbon and charcoal show that microbial growth substantially improves with charcoal. It may be that small pieces of charcoal migrate within the soil, providing a habitat for bacteria that decompose the biomass in the surface ground cover.[35] This process may have an essential role in terra preta's self-propagation; a virtuous cycle develops as the fungus spreads from the charcoal, fixing additional carbon, stabilizing the soil with glomalin, and increasing nutrient availability for nearby plants.[36][37] Many other agents contribute, from earthworms to humans as well as the charring process.

If biochar becomes widely used for soil improvement, it will involve globally significant amounts of carbon sequestration, helping remediate global warming. "Bio-char soil management systems can deliver tradable C emissions reduction, and C sequestered is easily accountable, and verifiable."[38]

Organic matter and nutrients

Charcoal's porosity brings better retention of organic matter, of water and of dissolved nutrients,[30] as well as of pollutants such as pesticides and aromatic poly-cyclic hydrocarbons.[39]

Organic matter

Charcoal's high absorption potential of organic molecules (and of water) is due to its porous structure.[5] Terra preta's great quantity of charcoal supports a high concentration of organic matter (on average three times more than in the surrounding poor soils[5][26][31][40]), up to 150 g/kg.[15] Organic matter can be found at 1 to 2 metres (3 ft 3 in to 6 ft 7 in) deep.[19]

Gerhard Bechtold proposes to use terra preta for soils that show, at 50 centimeters (20 in) depth, a minimum proportion of organic matter over 2.0-2.5%. The accumulation of organic matter in moist tropical soils is a paradox, because of optimum conditions for degradation.[26] It is remarkable that anthrosols regenerate in spite of these tropical conditions' prevalence and their fast mineralisation rates.[15] The stability of organic matter is mainly due to the biomass being only partially consumed.[26]

Nutrients

Terra preta soils also show higher quantities of nutrients, and a better retention of these nutrients, than the surrounding infertile soils.[26] The proportion of P reaches 200–400 mg/kg.[41] The quantity of N is also higher in anthrosol, but that nutrient is immobilized because of the high proportion of C over N in the soil.[15]

The anthrosol's availability of P, Ca, Mn, and Zn is clearly higher than the neighbouring Ferrasol. The absorption of P, K, Ca, Zn, and Cu by the plants increases when the quantity of available charcoal increases. The production of biomass for two crops (rice and Vigna unguiculata (L.) Walp.) increased by 38–45% without fertilization ($P < 0.05$), compared to crops on fertilized Ferrasol.[15]

Amending with pieces of charcoal approximately 20 millimeters (0.79 in) in diameter, instead of ground charcoal, did not change the results except for manganese (Mn), for which absorption considerably increased.[15]

Nutrient drainage is minimal in this anthrosol, despite their abundant availability, resulting in high fertility. When inorganic nutrients are applied to the soil, however, the nutrients' drainage in anthrosol exceeds that in fertilized Ferralsol.[15]

As potential sources of nutrients, only C (via photosynthesis) and N (from biological fixation) can be produced *in situ*. All the other elements (P, K, Ca, Mg, etc.) must be present in the soil. In Amazonia the approvisionning in nutrients from composting *in situ* is excluded for natural soils heavily washed-out (ferralsols, acrisols, lixisols, arenosols, uxisols, etc.) that do not contain these elements in high concentration. In the case of terra preta, the only possible nutrient sources are primary and secondary. The following components have been found:[26]

1. Human and animal excrements (rich in P and N);
2. Kitchen refuse, such as animal bones and tortoise shells (rich in P and Ca);
3. Ash residue from incomplete combustion (rich in Ca, Mg, K, P and charcoal);
4. Biomass of terrestrial plants (e.g. compost); and
5. Biomass of aquatic plants (e.g. algae).

Saturation in pH and in base is more important than in the surrounding soils.[41][42]

Microorganisms and animals

Bacteria and fungi (myco-organisms) live and die within the porous media, thus increasing its carbon content.

A significant biological production of black carbon has recently been identified, especially under moist tropical conditions. It is possible that the fungus *Aspergillus niger* is mainly responsible.[35]

The peregrine earthworm *Pontoscolex corethrurus* (*Oligochaeta: Glossoscolecidae*) ingests pieces of charcoal and mixes them in a finely ground form with the mineral soil. *P. corethrurus* is widespread in all Amazonia and notably in clearings after burning processes thanks to its tolerance of a low content of organic matter in the soil.[43] This as an essential element in the generation of terra preta, associated with agronomic knowledge involving layering the charcoal in thin regular layers favourable to its burying by *P. corethrurus*.

Some ants are repelled from fresh terra preta, their density of appearance is found to be low after about 10 days as compared to control soils.[44]

Modern research on creating terra preta

Average poor tropic soils are easily enrichable to terra preta nova by the addition of crumbled charcoal and condensed smoke.[45] Efforts to recreate these soils are being undertaken by multiple companies.[46] Academic research efforts continue.[47] Embrapa and other organizations in Brazil are working with terra preta.[48]

Notes

[1] Terra preta as mixture of charcoal, bone and manure (http://www.nature.com/climate/2009/0906/full/climate.2009.48.html)

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