The Anthropogenic Origin and Persistence of Amazonian Dark Earths

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Abstract
Patches of distinctively fertile and dark soils containing cultural artifacts occur throughout Amazonia and have been used to support numerous theories concerning preEuropean settlement patterns, population densities and cultural development. Field and laboratory analyses of these dark earths from various settings near Santarem, Brazil support an anthropogenic origin, but material accretion appears not to be the key factor in their formation. Furthermore, we identify two types of dark earths and argue that only a small proportion of these were developed at long-term habitation sites, with the more widespread type produced through soil management practices in associated agricultural zones. Heightened biotic activity and nutrient retaining capacity brought about by deposition of ash and organic material appear to be principally responsible for both soils remarkable persistence long after cultural manipulation has ceased. Our findings suggest that it may be possible to make long lasting improvements to notoriously infertile tropical soils by "innoculating" them with micro-organisms, organic material and ash.

From the footslopes of the Andes to Marajó Island at the Atlantic Ocean, "Indian black earth," or *terra preta do índio* (TP), occurs in a variety of landscape and soil contexts, in patches ranging in size from less than a hectare to many square kilometers. The color of this "black" soil in fact ranges from dark brown to black, so to avoid confusion we hereafter refer to it as "dark earth." Early theorists proposed that these soils developed from ancient deposits of volcanic ash or organic material accumulated in former lake or pond bottoms, and that the artifacts now present there were left by Amerindians attracted to their higher natural fertility (Cunha Franco 1962; Falesi 1972; Gourou 1949). Currently, most researchers believe that the dark earths are in fact cultural deposits created through the accretion of waste around habitation areas (Rodrigues 1993; Smith 1980; Sombroek 1966; Woods 1995). They cite the following characteristics in support of this "midden" model of soil formation: **[end p. 7]**

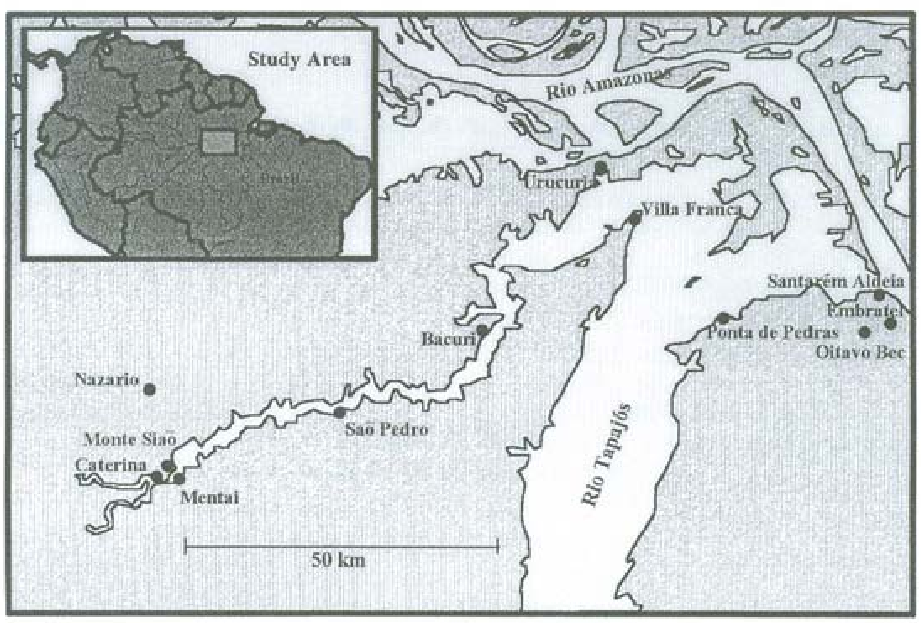
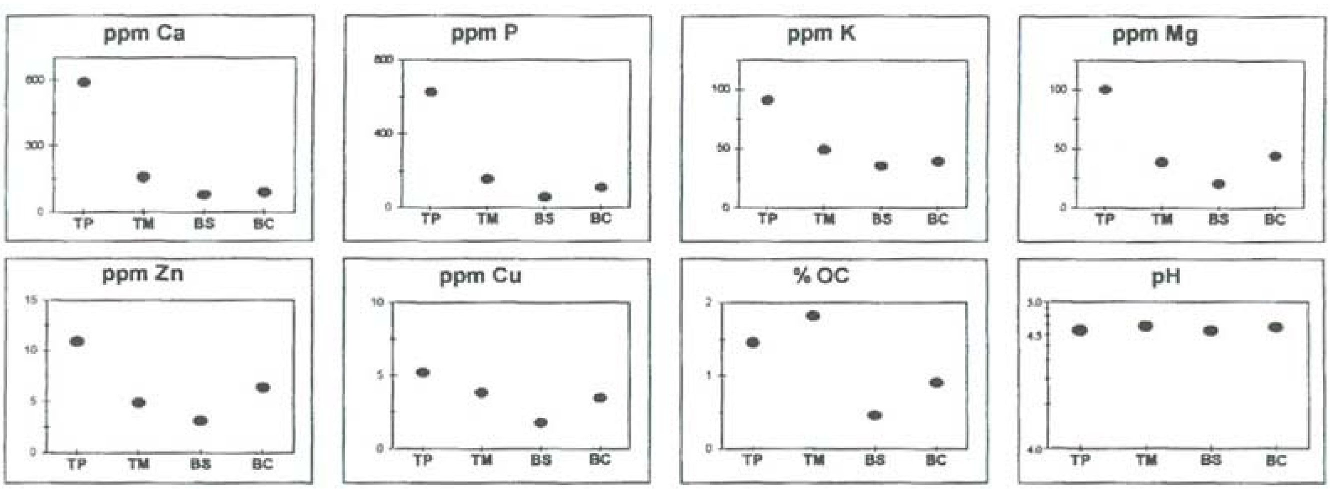


Figure 1. *Study Area Lower Tapajós and Arapiuns Rivers, Santarem, Para, Brazil.*
Depicted are the twelve black earth locations that yielded the array of samples for this analysis.
It should be noted that hundreds of dark earth expanses exist in the local region.

(1) similarity in texture between TP and the immediately surrounding soils; (2) similarity between subsoil underlying TP and that of surrounding soil; (3) occurrence of TP in a variety of physical landscape settings; (4) co-occurrence with ceramic and lithic debris; and, (5) a chemical signature commonly associated with human habitation (e.g., Cook and Heizer 1965; Woods 1984). Given this close association with human activity, dark earths have been used to support numerous theories concerning pre-European settlement patterns, population densities, and cultural development (Denevan 1996; Eden, et al. 1984; Heckenberger 1996; Kern and Kampf 1989; Meggers 1971; Pabst 1991; Roosevelt 1987; Smith 1980).

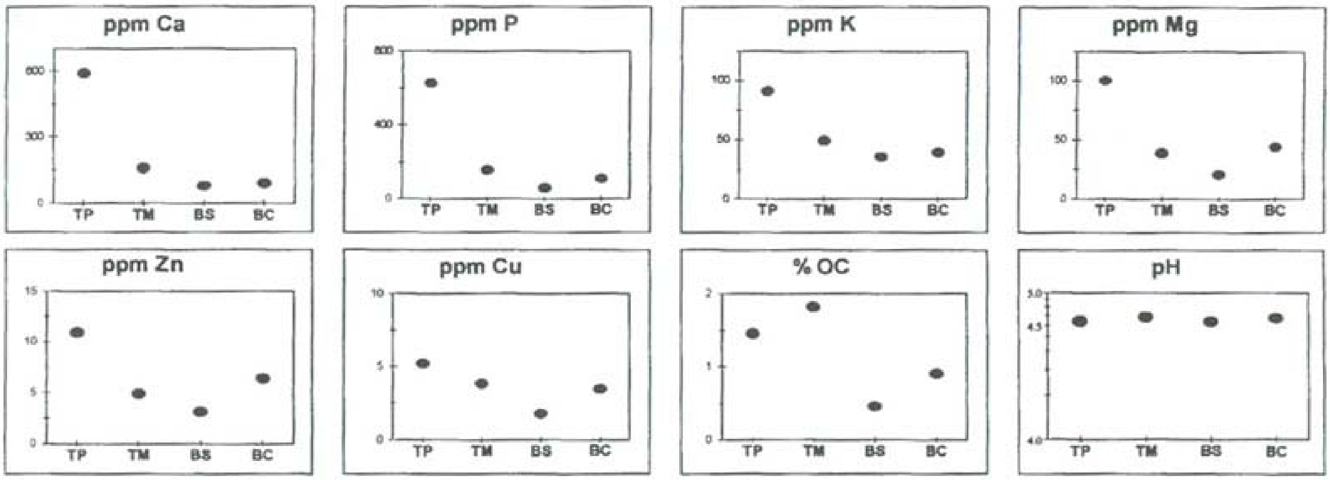
We investigated dark earth sites in the Lower Tapajós River region near Santarem, Brazil (Figure 1), the center of the prominent pre-European Santarem culture (Carvajal 1934; Guapindaia 1993; Nimuendaju 1952; Palmatary 1960). Our findings are based on field inspections in both dry and wet periods as well as on physical and chemical laboratory soil analyzes. With the intention of acquiring dark earth samples from every context in which it occurs in the region, we sampled locations along rivers, in the upland interior, on bluffs, on beaches, on plateau outliers, near water and not, and with sandy and clayey soil matrixes. The size of the sites ranged from just over 0.5 hectare to more than 120 hectares. The dry season's low water levels enabled us to inspect many kilometers of dark earth and non-dark earth profiles exposed in river cut banks. Surface examination of upland interior dark earth locations was supplemented by soil test pits, coring, and opportunistic mapping of exposed profiles in clay pits, wells, and other exposures. This report, while representative of the diversity of contexts present, considers only a small proportion of the dark earth sites found in the region. Few areas have been previously identified in the scientific literature though most, if not all, are known to local *caboclo* residents, who value their high fertility, planting on them the most nutrient-demanding crops, including corn, beans, squash, sweet potatoes, melons, and tobacco. They also recognize a distinctive vegetation structure (lower canopy, more closed understory) and species composition, exploiting a unique and abundant assemblage of useful wild and semi-domesticated plant species occurring on them. Among the dark earth indicator**[end p. 8]** species are many palms, Brazil nut (*Bertholletia excelsa*), papaya (*Carica papaya*), cacao (*Theobroma cacao*), cupuayu (*Theobroma grandiflorum*), and the giant Ceiba pentandra. Additional sites not reported here are the focus of our ongoing pedological and historical-ecological research.

In light of the prevailing "midden model," we were surprised to find that only small portions of most dark earth expanses showed clear evidence of long-term human habitation. Even where we observed the chemical signature and dense ceramic concentrations diagnostic of settlements, accretion through cultural deposition was probably not a significant factor in soil formation. We believe that the main human contribution toward the darkening of these soils was not through primary deposition, but rather was the indirect result of chemical changes that stimulated soil biota activity and "growth" downward through the incorporation of their organic byproducts, i.e., the soil formation process of melanization. Furthermore, our field observations suggest that there is no general relationship between the depth of the dark zone and duration of occupation. Rather, we found geomorphic context and soil texture to be the key variables determining depth. The deepest dark zones were found at sandy riverine sites, which had sustained significant nonanthropogenic alluvial and aeolian accretion. In comparison, material deposition by humans was insignificant, though the byproducts of waste disposal and burning were evident at depths of up to 2 m and more, these having been incorporated into the aggrading matrix over the duration of habitation. Though the denser clay-rich dark earths were never found to exceed 70 cm in depth, they may represent an occupation of equal or even longer duration than at the thicker sites. It is no wonder that estimates of formation rates vary so widely: 0.015cm/yr (Rodrigues 1993), 0.lcm/yr (Smith 1980), or even 1.0 cm/yr (Evans 1964).



So dark earth soils are generally not middens. Perhaps even more surprising is that most of the areas covered by dark earths are probably not even directly associated with habitation; Ca and P levels are not significantly higher (Figure 2), cultural artifacts are rare, and the soil is typically not black but rather dark brown. To distinguish it from *terra preta*, we call this brown soil *terra mulata*

(TM), following Sombroek's (1966) use of the term to describe expanses of slightly lighter soils devoid of ceramics encircling darker TP sites in the Tapajós region. He believed that the dark brown color of TM was the result of long lasting Amerindian gardening. A few other researchers have also suggested an association between darker soils and traditional agricultural activities in other areas of Amazonia (Mora C., et al. 1991; Prance and Schubart 1977). Current residents **[end p. 9]** in our study area have



recognized during their lifetimes a gradual darkening of soil resulting from the burning and mulching of permanent gardens or short fallow fields. Furthermore, TM does not appear to form under conditions of natural burning frequencies, or under the long fallow shifting cultivation and forest fallow agroforestry currently practiced in Amazonia. The occurrence of TM in the midst of such a large variety of landscape contexts and its typical close association with TP make it highly unlikely that natural phenomena are primary agents of its formation.

We suggest that some combination of long-term mulching and frequent burning produces the heightened organic content and dark color of the TM expanses. Though perhaps temporarily reducing near surface soil biota, fire more importantly contributes charcoal and ash, which increase soil pH and thereby suppress Al activity toxic to soil biota. This brief increase in pH is enough to provide the impetus for growth, and the consequent increase in microbiological activity adds colloidal-sized organic decomposition products to the soil matrix. These, along with the byproducts of incomplete combustion, provide charged surfaces largely absent from both the highly weathered clays and sands in the local soils and increase nutrient retention capacity. It is these organic complexes that coat soil particles and give the dark earths their distinctive coloration.

The Kayapó, whose agricultural technologies have remained relatively intact, employ a sophisticated array of soil management techniques including composting, mulching, burning, and direct application of fertilizers in the form of specially formulated ashes, organic material from offsite and ant and termite mounds. They cultivate their swiddens intensively for five years, and less intensively for an additional six. It is clear that the Kayapó modify soil characteristics in the short- and long-term (Hecht and Posey 1989).

Figure 2 provides a summary of total elemental concentrations and levels of organic carbon and pH for four groups of soil samples. The TP samples are high in organic carbon, and thus organic matter content, and showed greatly elevated concentrations of those elements (e.g,. Ca, P) strongly associated with human habitation. These characteristics, and the abundance of cultural materials, attest to the importance of household waste deposition (e.g., food processing, bones, blood, feces, urine, broken pottery) in the formation of TP. In contrast, while Ca and P concentrations of the TM samples are not significantly greater than the background clays and sands, organic matter content is most concentrated in TM, more so even than in TP. Now, where did all this organic matter come from? The consistently high organic concentrations in TM samples, regardless of texture, parent material, or geomorphic context, strongly suggest an anthropogenic origin. However, in situ habitation waste deposition is clearly not a likely source, considering TM's lack of chemical enrichment and paucity of cultural materials. The most plausible explanation is that organic content was elevated through long-term soil management practices (especially mulching and burning) under intensive agriculture (Figure 3).

The spatial associations of dark earths, whereby TP patches typically occur nearby or embedded within larger TM expanses, support this hypothesis and bring into focus a pre-European landscape of long-term settlements and associated fields. Indeed, the slightly lower organic content of the TP samples might be expected in a settlement situation where plazas and open areas around houses are regularly swept. Some of this debris and other household organic wastes might also have been collected as mulch for the nearby fields, resulting in a net transfer of organic matter from the TP habitation zone to the TM agricultural zone.

But why is TP darker than TM, despite slightly lower organic content? The key lies in the TP's very high concentrations of Ca, K, and Mg ions available for organic combination. Greater decomposition allows a more complete coating of soil particulates and produces a darker color.

It is interesting to note that our field observations and laboratory results (Figure 2 and additional data not included) are consistent with the local farmers' own soil classifications and fertility rankings: Terra preta is perceived as the most fertile, followed by clayey soils (*barro*), and lastly, sandy soils (*areiio*). Some of these "para-taxonomists" are "splitters," recognizing superior (*legitima*) and inferior(*ifraca*) terra preta varieties. These appear to correspond to our TP and TM, respectively. The "lumpers" refer to all dark earths as simply terra preta. **[end p. 10]**

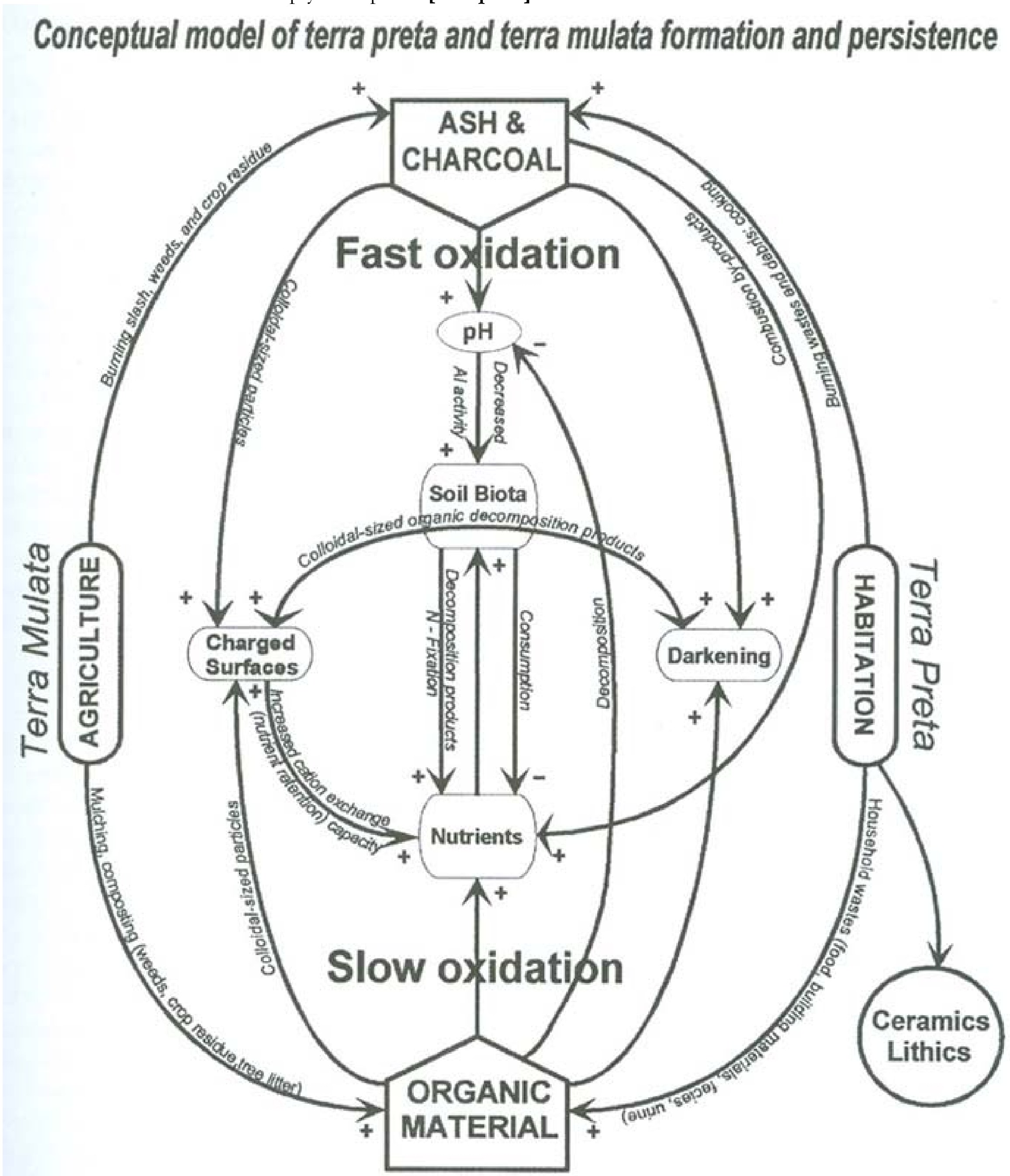


Figure 3. *Conceptual model of terra preta and terra mulata formation and persistence. Deposition by settled agriculturalists of ash/charcoal and organic matter, and resultant stimulation of soil biological activity, are key processes in Amazonian dark earth formation and persistence. Concentration of household wastes (ash, food remains, building material, feces, urine, pottery, tools etc.) in and around habitation areas forms TP, darker, richer in P, Ca, and cultural material; while TM is created in zones of intensive agro-forest and crop production and associated soil management.* **[end p. 11]**

If human activities are indeed primarily responsible for the development of dark earths, one might expect that cessation of these activities would result in reductions in fertility and organic matter content, and an eventual reversion to yellow latosol or whatever soil type makes up the surrounding context. However, this appears not to be the case. The unique properties of both TM and TP are remarkably persistent. Local farmers report that the "strongest" TP areas maintain their high fertility even after many years of cultivation. One particularly rich patch of TP within a large dark earth complex in the interior uplands north of the Arapiuns River is reputed to be in continuous cultivation for the last 50 years or more, with extremely productive harvests of the most demanding crops, including corn and beans. Indeed, it is often the excessive weed growth on the rich dark earths, not declining fertility, that results in field abandonment. Of course, any soil may exhibit declining fertility over time under certain circumstances, and dark earths, especially TM, are no exception. But the locals have learned that on those occasions when dark earths do become "tired," they recover their fertility more readily under fallowing than do the other soils in the region.

Field observations at Oitavo Bec, an interior plateau site where the TM with embedded zones of TP covers over 120 hectares, suggest this regenerative quality. This extensive zone of clay-rich, 60 cm deep dark earth is quarried for use as potting soil in the city of Santarem. After the vegetation is cleared and burned, the soil is typically removed by hoe and shovel. The bottom third (20 cm) of the dark zone is intentionally left intact. Dorival Lucas de Castro, who has worked the site for over 30 years, explains that this practice is necessary for the soil to "grow." According to him, in approximately 20 years, the dark zone will reestablish its original 60 cm depth, primarily through the downward darkening process explained above. Apparently, at some threshold level of biotic activity and soil nutrient retention status, dark earth attains the capacity to perpetuate - even regenerate itself - thus behaving more like a living "super" organism than an inert mineral. If the dark layer is entirely stripped, however, regeneration does not occur because the biotic innoculate is lacking. In two adjacent areas quarried six months prior to our visit, we noted that the one which had been scraped by machine to the underlying yellow latosol was nearly devoid of vegetation. In contrast, the area mined by hand, which had retained its 20 cm of dark earth, was covered with thick regrowth.

At Catarina, on another dark earth site (TM) overlooking the Arapiuns River, a series of leaf cutter ant mounds which had been abandoned sequentially over a 25 year period also demonstrated the regenerative properties of these soils. The young mounds were composed of orange, highly weathered material brought up by the ants from the subsoil. Without any organic inputs applied by people, the progressive melanization of the mound matrices was apparent. Within 20 years the color had become indistinguishable from the surrounding TM.

Based on the patterns we have observed in the Lower Tapajós region, where small areas of TP tend to be associated with, and are often imbedded within, more extensive areas of TM, we propose a model of long-standing habitation, sustained by surrounding permanent gardens and fields. Intensive permanent cultivation is consistent with the stone axe technology in use before Europeans introduced iron and steel cutting implements. Stone tools are inefficient in felling large trees and opening clearings, and provide a strong disincentive for the frequent and repeated clearing of secondary growth forest that shifting cultivation and settlement mobility require (Denevan 1992). However, once fields are established, the effort required to maintain them through weeding, mulching, burning of crop residues, and other soil enhancement activities would compare favorably to the more arduous task of making new openings.

Though our findings provide support for a view of permanent settlement in pre-Columbian Amazonia, we caution that *projections of population size or density based on overall areal extent of dark earths should not be made*. Rather, the characteristics of resident populations, as with duration of occupation, can only be understood through detailed archaeological examination, especially of that portion of the dark earth related directly to the zone of habitation.

Finally, the persistence and regenerative qualities we have identified in the dark earths suggest that notoriously leached and infertile tropical soils may be "improved" with burning and organic inputs (Hecht and Posey 1989; Kamara 1986), or other direct manipulations of pH, cation exchange capacity and soil biota, perhaps even with an artificial **[end p. 12]** microbiological innoculate (Sylvia, et al. 1998:404-405). Once infused with the self-perpetuating life force of an active soil biota and an adequate nutrient retention capacity, under proper management additional inputs may not be necessary to maintain a reasonable fertility. Whether vilified or glorified, shifting cultivation has been viewed by most Western observers as a logical adaptation to soil limitations in Amazonia and throughout the tropics. Although shifting cultivation can be an environmentally friendly analog to the natural processes of disturbance and regenerative succession in tropical forests, it is unsustainable above a certain population density or frequency of clearance. As increasing human populations place ever greater pressure on forest resources, the agricultural practices of pre-contact Amerindians and their legacy of rich, "living" soils warrant further study in the search for high-yield, land intensive, yet sustainable forms of land management in the humid tropics.

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Resumen
Las parcelas de tierras distintivamente fértiles y oscuras que contienen artefactos culturales ocurren por todo lado en la Amazonia. Estas tierras oscuras han sido citado para soportar numerosas teorías acerca de los patrones demográficos y el desarrollo cultural pre-Europeo. Análisis del campo y del laboratorio de tierras oscuras de varias lugares cerca de Santarém, Brasil, soportan un origen antropológico, pero el crecimiento material no parece ser el factor clave en su formación. Además, identificamos dos tipos de tierras oscuras y podemos argumentar que solo una proporción muy pequeña fue desarrollada en bajo de lugares de vivienda de largo plazo, y que la mayor parte fue producida através de prácticas del manejo de la tierra en zonas agrícolas asociadas. Las elevadas actividades bióticas y la capacidad de retención de nutrientes a causa de los depósitos de cenizas y de material orgánico parecen ser principalmente responsables para la persistencia notable de las dos clases de tierras oscuras después de una ausencia prolongada de la manipulación cultural. Los resultados sugieren que sea posible mejorar los suelos pobres tropicales atraves da "inoculación" com micro-organismos, material orgánico, e cenizas.

Resumo
Encontra-se por toda a Amazonia extensoes de terras distintivamente fertis e escuras que con tern artefatos culturais A existencia desses solos tern sido citado em numerosas discussoes teoricas acerca das padroes de assentamento, a densidade de populacão, e o desenvolvimento cultural pre-europeu. Analises de campo e de laboratorio de terras escuras de varias lugares na região de Santarem, Brasil, suportam uma origem antropologica, mas o crescimento vertical de material cultural nao parece ser o fator chave na sua formacao. Alem disso, identificamos dois tipos distintos de terras escuras. Argumentamos que solamente uma proporção pequena foi desenvolvida sob lugares de vivendas de largo prazo, e que a maior parte foi formada atraves de práiticas de manejo de terra en zonas cultivadas associadas. A estimulada atividade biotica e elevada capicidade de retencão dos elementos nutritivos causada pel as adicoes de cinzas y de material organico parecem ser os fatores mais importantes na preservanya excepcional das duas clases de terras escuras apos uma prolongada ausencia de manipulação cultural. Os nossos resultados sugere que seja possivel melhorar os solos pobres tropicais atraves da "inoculação" com micro-organism os, material organico, e cinzas.
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