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Article

The Amazonian Formative: Crop Domestication and Anthropogenic Soils

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Abstract: The emergence of sedentism and agriculture in Amazonia continues to sit uncomfortably within accounts of South American pre-Columbian history. This is partially because deep-seated models were formulated when only ceramic evidence was known, partly because newer data continue to defy simple explanations, and partially because many discussions continue to ignore evidence of pre-Columbian anthropogenic landscape transformations. This paper presents the results of recent geoarchaeological research on Amazonian anthropogenic soils. It advances the argument that properties of two different types of soils, *terras pretas* and *terras mulatas*, support their interpretation as correlates of, respectively, past settlement areas and fields where spatially-intensive, organic amendment-reliant cultivation took place. This assessment identifies anthropogenic soil formation as a hallmark of the Amazonian Formative and prompts questions about when similar forms of enrichment first appear in the Amazon basin. The paper reviews evidence for embryonic anthrosol formation to highlight its significance for understanding the domestication of a key Amazonian crop: manioc (*Manihot esculenta* ssp. *esculenta*). A model for manioc domestication that incorporates anthropogenic soils outlines some scenarios which link the distribution of its two broader varieties—sweet and bitter manioc—with the widespread appearance of Amazonian anthropogenic dark earths during the first millennium AD.

Keywords: Amazonia; Formative; anthropogenic dark earths; *terras pretas*; *terras mulatas*; manioc; plant domestication; landscape domestication; geoarchaeology, soil micromorphology; anthropogenic landscape transformations; Historical Ecology

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1. Introduction

In the archaeology of the Americas, the period known as the Formative is synonymous with a historical process in which groups specialized in hunting, fishing and gathering began to increasingly depend on foodstuffs which were available or were storable during a substantial portion of the annual cycle. As the conventional account goes, this dependence was accompanied by a progressive decrease in residential mobility, which, over time, led to the adoption of more sedentary lifestyles [1-3]. Instances have been identified in which sedentism became possible through harvesting and stocking of aquatic resources [4,5], but in many regions the latter were unavailable, insufficiently productive, or altogether unpredictable. Thus, at a continental scale, the most widely-observed pathway towards sedentism—indeed, its fundamental engine—is widely regarded to have been an increasing emphasis on the consumption of plant foodstuffs. Through selection of their attractive characteristics and modification of their habitats, this emphasis prompted founder events of different domesticated species, which in turn fuelled agri-cultural diffusion of crops to non-agrarian populations and/or the expansion of agricultural populations. Eventually, intensification of agricultural production resulted in population growth and prompted the evolution of more complex social arrangements [6-8].

Amazonia sits uncomfortably within this American account of the Neolithic Revolution [cf. 6,9-18]. Looking back at fifty years of Amazonian scholarship, one observes the deep-seated influence of old archaeological models [19-21], which, until three decades ago, discussed the emergence of sedentism based on the spatial distribution and age of ceramic remains. Interpreting the latter as an expansion of horticulturists from beyond the region, the 'immigrant scenario' argued that challenging environmental limitations had consistently impeded population growth and the development of social complexity [11,22-26]. Construing ceramic remains as indicative of the development of horticulture within the Amazon basin, the 'indigenist scenario' proposed that subsequent agricultural intensification had enabled societies to grow into the large riverside villages recorded by early European observers [6,9,27,28].

This panorama was ostensibly transformed by subsequent archaeological investigations. Studies in the lower Amazon [29-33] and upper Madeira [34-37] demonstrated the existence of late Pleistocene and early-mid Holocene occupations, including ceramic remains associated with shell middens [29,31]. These findings prompted suggestions of a protracted antiquity for pottery making in the Americas and, more to the point, provided potentially time-deep ascendants for late Holocene ceramic occupations in Amazonia. In parallel, archaeobotanical investigations of preceramic sites in the Colombian Amazon documented early Holocene microfossils and charred seeds of edible fruits (mainly palm trees) and allochthonous cultivars (*Calathea allouia*, *Cucurbita sp.*, and *Lagenaria siceraria*), as well as mid Holocene phytoliths of *Zea mays* and pollen of *Zea mays* and *Manihot* spp. [7,38]. This research demonstrated that arboriculturalist or horticulturalist groups had inhabited the region millennia before the appearance of late Holocene ceramists and thus cast doubt on suggestions that the latter had introduced crop cultivation to the region.

Amazonia's uncomfortable position is not only epitomised by plant cultivation evidence that is much older than late Holocene ceramic archaeological sites but controversy has also existed regarding whether the latter indicate permanent occupations: Evans and Meggers [39] initially proposed that ceramic remains at large riverside sites constituted evidence for a temporary agglutination of populations resulting in syncretised ceramic traditions [see also 40], an idea which evolved into the suggestion by Meggers [11,41,42] that these sites represent a superimposition of short occupations by small groups. Working from southwestern Amazonia, Miller [35-37] emphasised short- to mid-term sedentism associated with concentrations of aquatic resources, whilst in the vicinity of Manaus, Neves *et al.* [43-45] argued that these sites resulted from successions of intense sedentary occupations. The latter accounts converge with suggestions of continued occupations advanced by Roosevelt, Herrera, Heckenberger, and their respective colleagues [46-50]. Although data on the agricultural base of these societies is still fragmentary, recent archaeobotanical studies do show the presence of pollen, phytoliths and/or starch grains of *Zea mays*, *Cucurbita* sp., *Manihot* spp., *Ipomoea batata*, and *Bactris gasipaes*, among others [7,46,51-53]. This crop repertoire is similar to that recorded in ethnographic studies of sedentary Amazonian societies.

A far more complicated question is whether the origins of these ceramist societies can be traced back to early-mid Holocene shell-fisher ceramists. In the lower Amazon region and Marajó Island, 4th-3rd millennium BP pottery associated with *terra firme* occupations cannot be easily derived from older shell-midden pottery but instead recalls complexes associated with the Colombian Barlovento and Macaví periods [54,55]. In western Amazonia, protracted debate about relations between 4th and 3rd millennium BP ceramists of the Peruvian Amazon and Andean populations [e.g., 56-60] has been superseded by evidence of ceramists in the Ecuadorian *Montaña* [61]. Significantly, both sets of occupations are approximately coeval with surprisingly ancient evidence of *Zea mays* pollen in palaeoecological records from each region [62-66], in effect supporting more strongly an ‘immigrant’ account of the emergence of Amazonian sedentism.

In this paper I will discuss contrasting accounts of the Amazonian Formative through the prism of anthropogenic landscape transformations. I will first outline why I believe anthropogenic soils known as Amazonian dark earths constitute key evidence to argue that sedentism and agricultural intensification took place in pre-Columbian Amazonia. Next I will discuss extant evidence of similar forms of landscape modification that identify suggestive links between these anthrosols and processes of crop domestication, husbandry and intensification. By offering a series of archaeological hypotheses that can be explored by future research, I will outline a perspective on Amazonian pre-Columbian history that underscores the role of cumulative anthropogenic landscape transformations in the emergence of sedentism.

2. Sedentism and Amazonian Anthropogenic Soils

It is no exaggeration to state that anthropogenic landscape transformations have become a crucial dimension in discussions about the origins of sedentism in Amazonia. This is best exemplified by research on anthropogenic soils known as Amazonian dark earths. The latter are soil expanses ranging from <1–80 ha in which the topsoil shows a higher degree of melanisation, a thicker A horizon, and a more enhanced agricultural aptitude than the vast majority of soils in the Amazon basin [67]. Before a recent surge in scientific interest [68-70], Hartt [71], Nimuendajú [72,73], and Sombroek [67], among others, had defended an anthropogenic origin for these soils by suggesting they were an outcome of pre-Columbian settlement-related activities. This assessment is correct: most well-documented exemplars are located in landscape positions [e.g., high bluffs alongside rivers, by lakes associated with abandoned river channels, in interfluvial areas distant from large water courses, see 40,49,74-81] that overrule a common natural origin. The vast majority of reported cases show large quantities of pre-Columbian ceramic shards on their surfaces.

Figure 1. Some of the sites studied by the Central Amazon Project [43]. Note the diversity of geographical emplacements, which includes river bluffs near black and white water rivers, areas with flooded forest, and *terra firme* areas.

Students recognise two broad types of Amazonian dark earths—*terras pretas* and *terras mulatas*—and argue that they reflect soils modified by human practices associated with, respectively, old settlements and farming [67,82,83]. Research on *terras pretas* shows that their better nutrient status and higher organic matter retention [67] are enhanced by the presence of significant quantities of black carbon, the latter deriving from charcoal produced during pre-Columbian occupations [74,84-86]. The spatial variability of elemental concentrations at the intra-site level appears to reflect the overall layout and superimposition of houses, middens, and other activity areas associated with old villages [87-90], an inference that fits actualistic and ethnoarchaeological insights about the formation of these soils [91-95]. *Terras mulatas*, which have been less intensively studied, minimally record areas of clearance surrounding former settlements [67,82,83].

The chronology of formation of Amazonian dark earths can be derived from archaeological studies [17,35-38,40,49,75,77-79,96,97]. In general the vast majority of occupations associated with their formation begin around or after 0 AD. This holds true for numerous excavations produced by the Central Amazon Project in the vicinity of Manaus, Brazil [45,55,80,81,90,98]. These excavations show that archaeological remains embedded in dark earths are stratified in the same way as would be expected from an up-building deposit [99-101], such that thick A horizons often indicate two or more overlapping occupations (Figure 1 and Figure 2). Coherent dates on samples of different materials (macroscopic and microscopic charcoal, diagnostic pottery shards), including here coeval samples collected at a horizontal distance exceeding 200 m at one site [102], overrule suggestions of short (decadal) occupations; rather, they consistently suggest that inhabitation-related soil enrichment took place during long (centennial) time scales [43-55].

Figure 2. Top: Chronological synthesis of ceramic occupations of sites studied by the Central Amazon Project (current to 2006). Rectangles are calibrated age ranges (IntCal04.14c). Bottom: Excavations at the Hatahara site. Ceramic vessels left *in situ* are different-period funerary urns. Note features filled with darker sediments originating higher in the deposit. Dotted lines show sampling for geoarchaeological analyses.

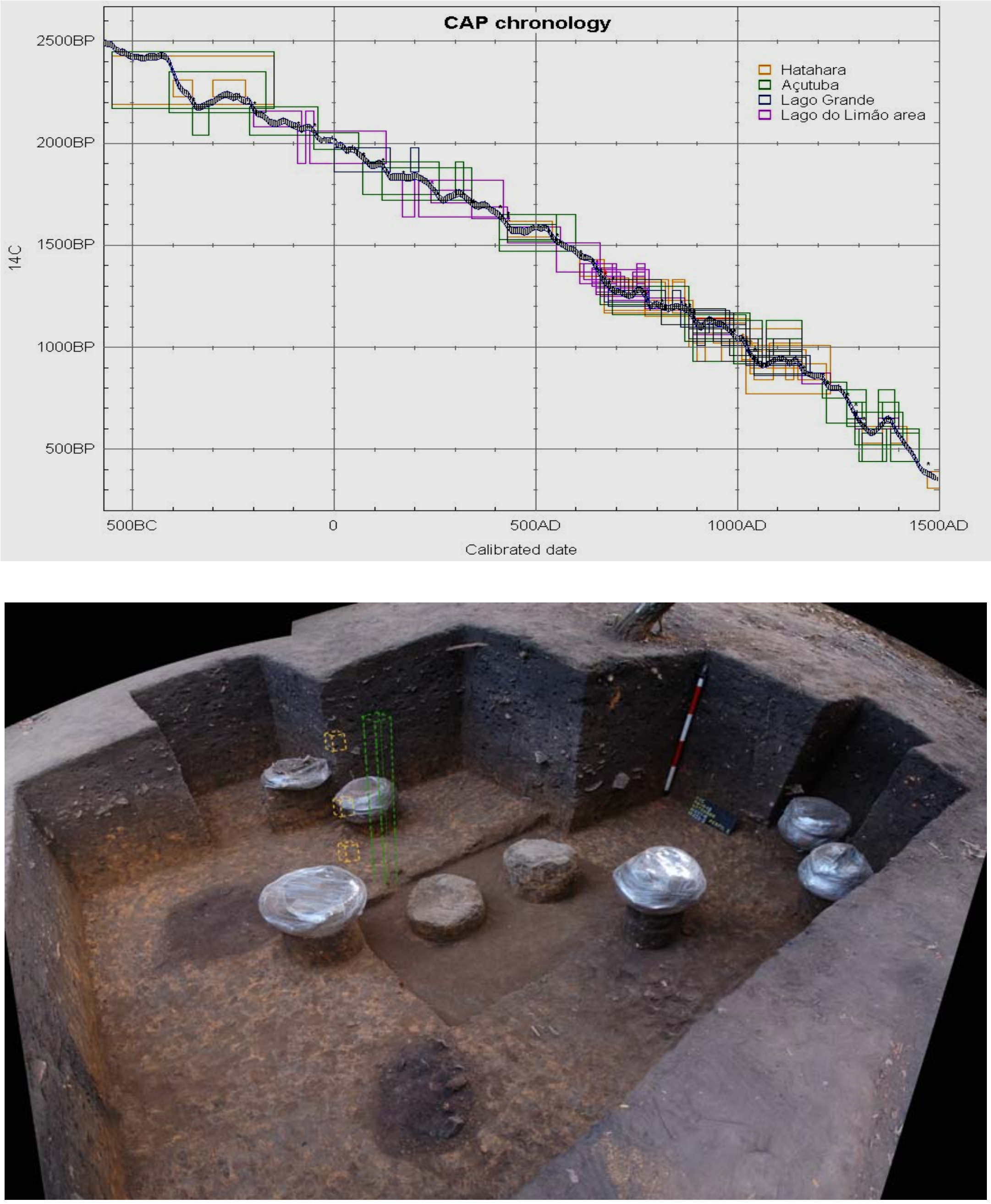
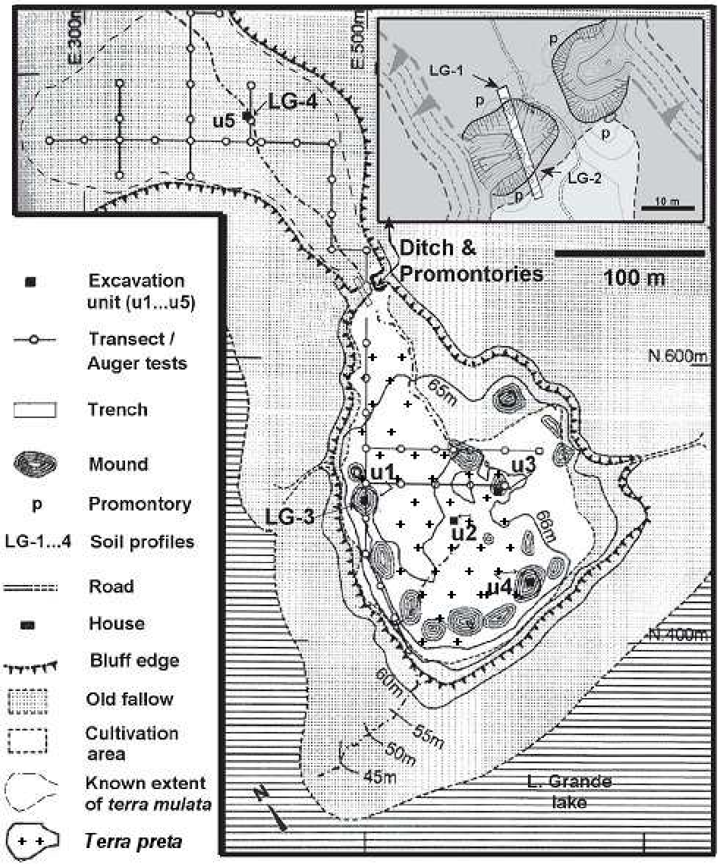
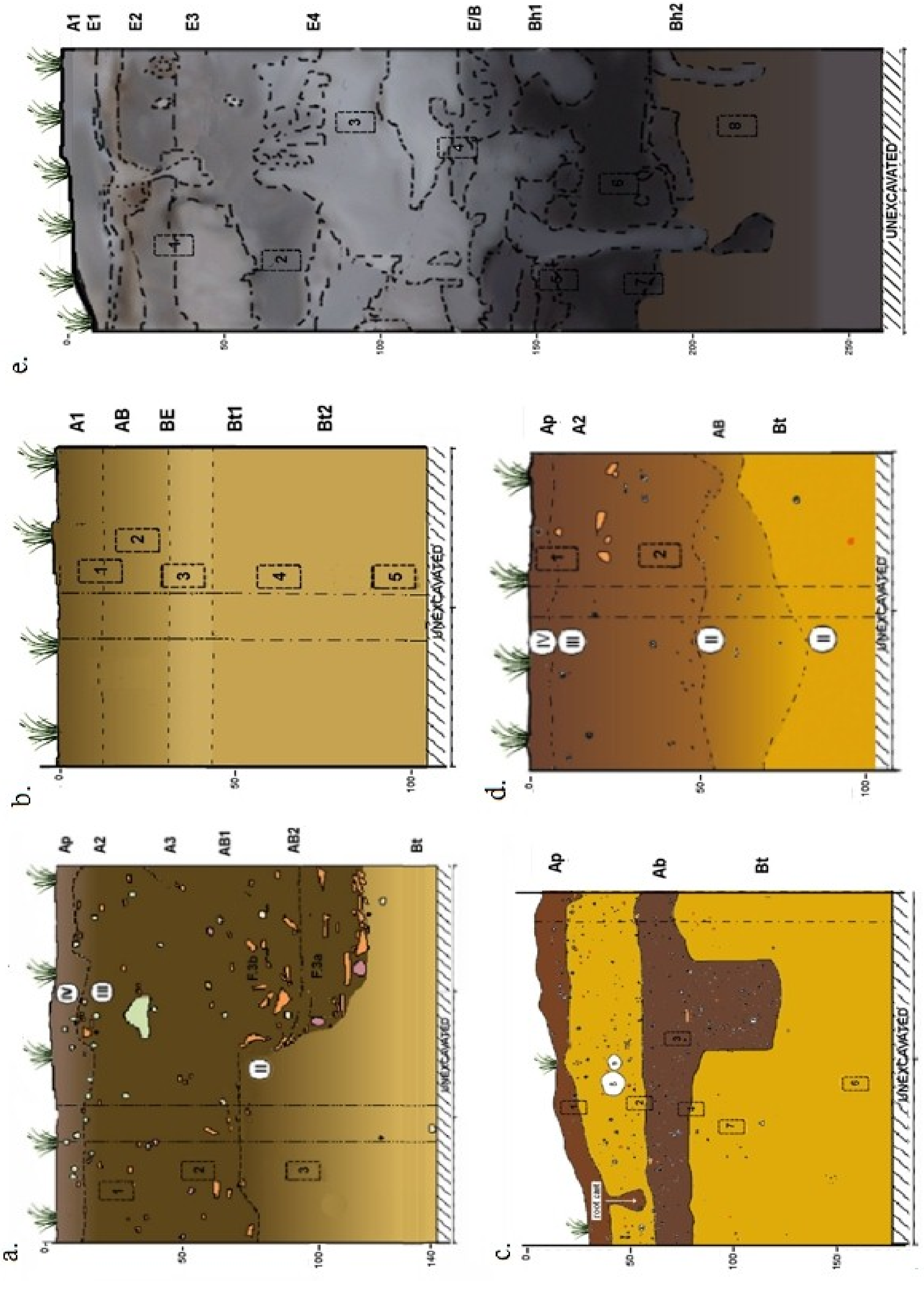


Figure 3. A plan of the Lago Grande site [adapted from 103] showing the distribution of *terras pretas* and *terras mulatas*, as well as sampling points discussed in the text.



Detailed geoarchaeological study of a *terra preta* profile (Figure 4a) exposed during excavations by the Central Amazon Project [55,104] overrules suggestions that these soils have been enriched by additions of floodplain sediments. Soil micromorphological analyses instead reveal that the sand- and silt-sized fractions of the A horizon are bulked up by large quantities of microscopic inclusions of anthropic origin. These include fragments of microscopic bone and charcoal (Figure 5, top left and middle left and right) that are well reflected in high concentrations of phosphorous, calcium and carbon measured in bulk samples (Figure 6, row 1). They also include microscopic fragments of ceramic vessels and baked clay (Figure 5, top right) that are well reflected in higher magnetic susceptibility values (Figure 6, row 4, graphs 1 and 2). Levels of enhancement/enrichment compared to non-ADE soils from the same landform eloquently show that differences in some in these parameters are as large as an order of magnitude. These observations confirm and amplify the conclusions of previous and parallel research [86,105,106]. They suggest that *in situ* burning associated with cooking, smoking, pottery manufacture, and/or waste management produces ash and charcoal, the former mineralising nutrients in the plant matter and raising soil pH, the latter contributing to organic matter retention. Melanisation of these soils takes shape as charcoal and organic matter are thoroughly mixed by soil fauna [107], with a possible contribution of manganese oxides (Figure 5, middle row).

Figure 4. Profiles discussed in the text. (a) Hatahara site (see also Figure 2, bottom). (b) Control profile with sub-recent burning, same landform as Hatahara. (c) and (d) Lago Grande site: buried and exposed *terra mulata* profiles. (e) Dona Stella site.



Profiles exposed during excavations and surveys around sites studied by the Central Amazon Project [45,55,80,108] have shown unusually thick A horizons compared to those generally observed in the region (Figure 4d). The characteristics of these horizons are coherent with those described by Sombroek [67] and Andrade [82,109] in *terra mulata* soils. At the Lago Grande site (Figure 3), micromorphological observations of *terra mulata* horizons (Figure 5, bottom left) show these soils have important quantities of microscopic charcoal yet lack the microscopic fragments of bone, pottery, or burnt clay observed in settlement-related *terras pretas* [101]. This contrast suggests that *terras mulatas* are not reworked or redeposited *terras pretas*, yet underscores that they are soils significantly-modified by human practices. Plots by depth of elemental concentrations in a buried *terra mulata* A horizon (Figure 6, row 3) shows higher levels of enrichment compared to background soils (Figure 6, row 2). Micromorphological analysis of this horizon reveals that microscopic illuvial clays of the B horizon are truncated (Figure 5, bottom right), a feature which suggests deliberate scraping, raking, and/or churning of the organic-rich soil mantle until exposure of the B horizon. Ubiquitous microscopic charcoal fragments, lack of burnt clay inclusions, and significant magnetic susceptibility enhancement from fairly deep within the profile (Figure 6, row 4, graphs 3 and 4) points to continuous *in situ* burning [110] as the profile accretes. These inferences are consistent with a scenario of continued near-surface burning during pre-Columbian times and overrule implicit suggestions that charcoal was ‘spread on the fields’ [111]. Together, they provide tangible evidence to support the hypotheses advanced by Sombroek [67], Andrade [109], Woods [83] and Denevan [112] that *terras mulatas* are an outcome of spatially-intensive agricultural activities involving organic amendments and low-temperature near-surface fires.

The preceding observations, as well as research conducted over the last decade [68-70], together underscore a rapid development of knowledge about Amazonian dark earths. These soils are not only unanimously considered as anthropogenic but also increasingly regarded as important pre-Columbian agricultural legacies: studies documenting ubiquitous fruit-bearing trees established on known expanses highlight their importance as niches for the conservation of agrobiodiversity [113-115]. Other research emphasises their role as present-day agricultural infrastructures and records higher yields of crop varieties which do not grow well on low-nutrient, low pH *terra firme* soils [116-120]. These and other lessons from the study of Amazonian dark earths provide important insights for reconstructions of pre-Columbian history: not only do *terras pretas* and *terra mulatas* represent some of the most striking indicators of sedentary occupations in Amazonia, but the positive feedback loop at the core of their formation:

$$\text{sedentism} \leftrightarrow \text{soil fertility}$$

elicits two important and interrelated questions which are key to expand our knowledge about the Amazonian Formative [55]. First, when did anthropogenic landscape modifications that augment the agricultural aptitude of Amazonian soils truly begin? Second, what role—if any—did they play in the development of sedentary lifestyles?

Figure 5. Microphotographs of selected features in *terras pretas* (row 1 and 2) and *terras mulatas* (row 3). Top left: microscopic fragment of fish bone, the fluorescent colour indicates high retention of phosphorus. Top right: microscopic fragments of pottery and rubified clay, the latter probably originating in clay ovens. Middle row: microscopic fragments of charcoal. Note that fragments can be resolved optically: the darker colours on the right-hand side microphotograph are likely to reflect the formation of manganese oxides. Bottom left: important quantities of microscopic charcoal but absence of bone or pottery fragments in the A horizon of *terra mulata*. Bottom right: truncated illuvial clays show lack of mixing between the *terra mulata* A horizon and the charcoal-devoid limpid clays of the B horizon.

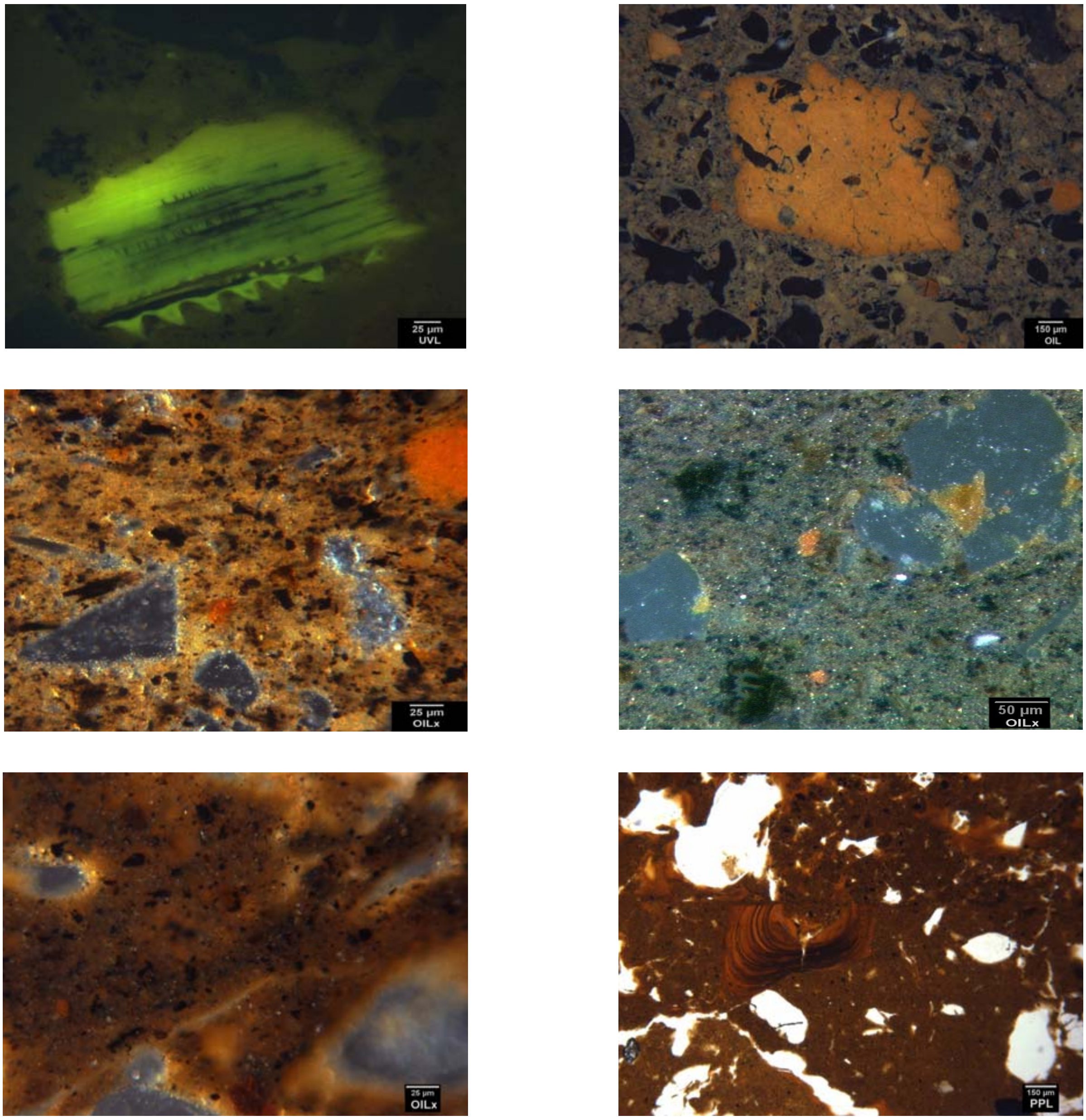
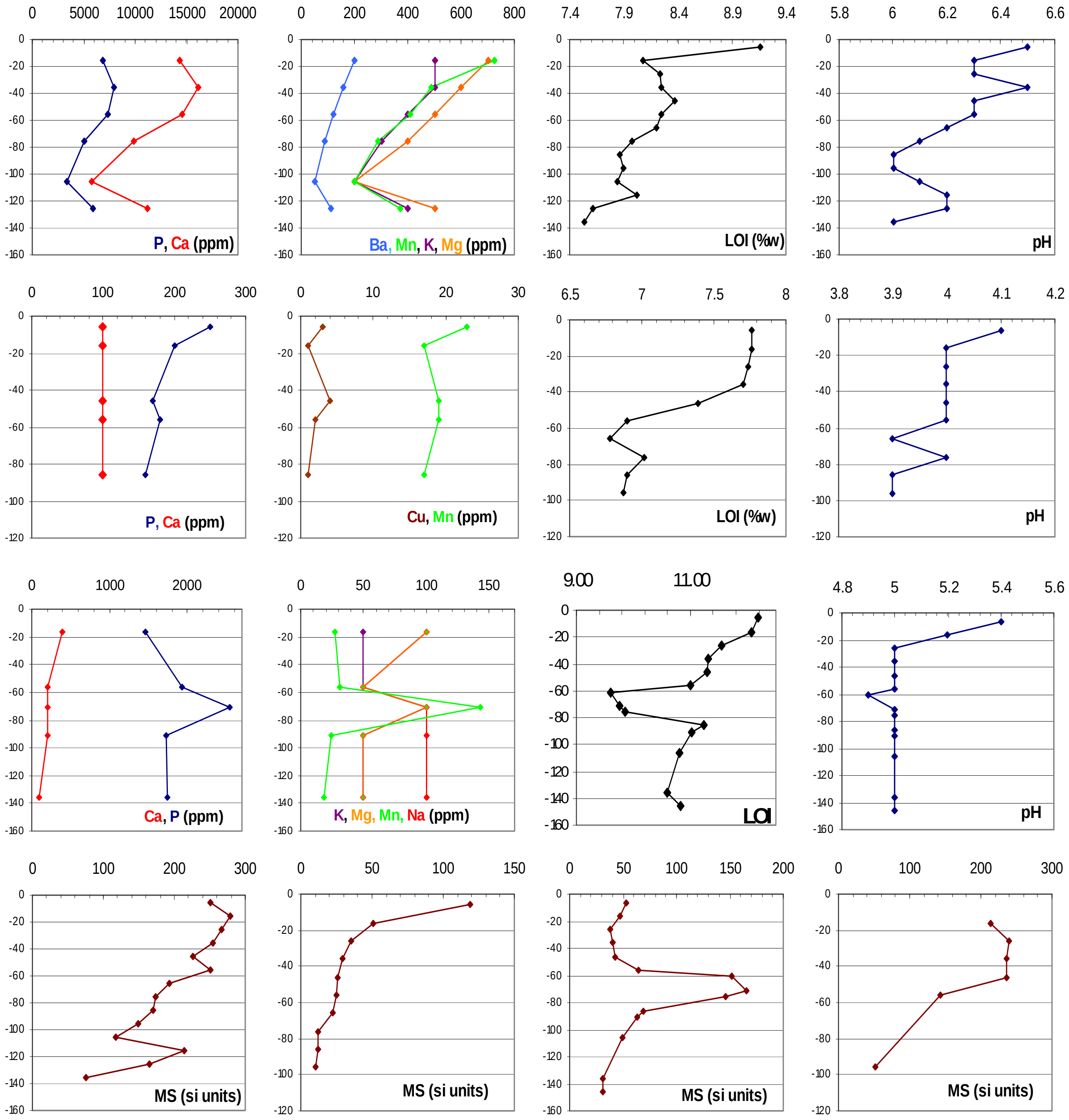


Figure 6. Rows 1-3: total elemental concentrations (measured by ICP-AES), carbon estimates (LOI, 550C), and pH (1:2 solution) plotted by depth. Row 1: Hatahara *terra preta* (Figure 4a). Inflection in lower part of the profile is at the same depth as an early 1st millennium AD occupation. Row 2: Yellow Latosol profile (Figure 4b) with sub-recent burning, same landform as Hatahara *terra preta* profile. Row 3: *Terra mulata* buried horizon at Lago Grande (Figure 4c). Row 4: Magnetic susceptibility values (Low frequency Tesla units, measured with a dual frequency Bartington MS2/MS2B sensor). From left to right: each of the previous three profiles and (bottom right) exposed *terra mulata* at the Lago Grande site (Figure 4d).

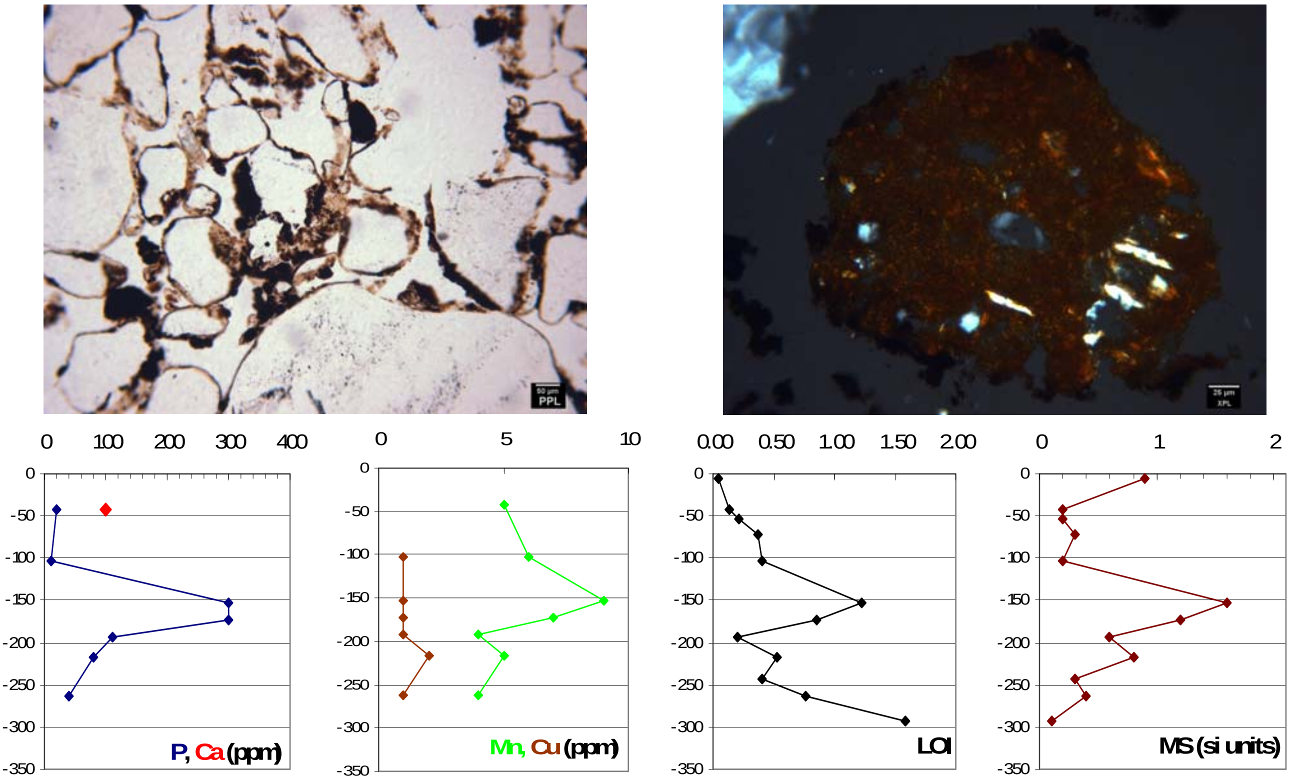


3. Domestication in the Landscape

In order to attempt partial answers to the preceding questions I wish to focus our attention on the other classic case of anthropogenic modification of Amazonian rainforest landscapes: the formation of anthropogenic concentrations of fruit trees. Balée [113,121] emphasised a model of agricultural regression when he suggested that these concentrations, sometimes found associated with *terras pretas*, were a result of the abandonment of gardens and settlements dating from pre-Columbian times. However, Politis [122,123] subsequently presented ethno-archaeological observations that show how the discard of seeds from edible fruits by nomadic groups can significantly increase the potential for the formation of fruit tree concentrations. These positions are evidently not contradictory: there exist relatively mobile groups inhabiting regions whose biota was modified by past sedentary peoples and there exist nomadic groups who, as a result of their own practices, are capable of significantly altering alpha diversity [124]. Charles Clement [125,126] discussed the role of practices of edible fruit collecting for domestication processes of different arboreal taxa in Amazonia. Previously mentioned data from the Colombian Amazon and other sites of the 'intermediate area' [127-132] leave few doubts about the antiquity of similar practices in the early Holocene. This evidence, on the other hand, does not resolve whether early Holocene occupations reflect sedentary lifestyles [133,134]: it is unlikely that arboriculture alone could have supported year-long sedentism [125,126] and the provocative evidence for early cultivation of allochthonous crops identifies a narrow repertoire [7] that hardly suggests high starch production or year-long cropping.

A perspective on soils as archaeological artefacts [135-137], on the other hand, is useful to examine different and important implications of these findings. In the Araracuara area, the Archaic levels of both the Peña Roja and the Abeja sites show subtle but characteristic modifications of soil chemistry associated with large numbers of carbonised plant remains [38,133,138]. This pattern of soil enrichment, which by now should be familiar to the reader, is by no means restricted to the Colombian Amazon: at Dona Stella [55,80], another site investigated by the Central Amazon Project (Figure 4e), mainly lithic archaeological remains are found within, below and above a buried organic horizon dated to 6.2–5.9 cal ky BP (Beta-178913). Whilst the macroscopic characteristics of this profile suggest podzolisation [55], micromorphological observations reveal the unexpected presence of surprising quantities of carbonised plant matter in the buried horizon (Figure 7, top left). Analyses of associated bulk samples (Figure 7, bottom) suggest nutrient enrichment and magnetic enhancement, the latter coherent with the presence of very rare microscopic fragments of burnt clay (Figure 7, top right). These observations highlight that a history of sporadic occupations during the early-mid Holocene [80,139] enduringly modified what today appear as highly leached sandy soils [55].

Figure 7. Top: Microphotographs of the buried horizon at the Dona Stella site. Left: charred plant matter embedded in the scant clay adhered to quartz grains composing the skeleton of the sediment. Right: microscopic fragment of burnt clay. The author believes it represents a microscopic fragment of ancient pottery. Very rare pottery shards are recorded at the site (Arroyo-Kalin, personal notes, 2006) but until now have been regarded as intrusive from later occupations. Bottom: total elemental concentrations (measured by ICP-AES), carbon estimates (LOI, 550C), and magnetic susceptibility values (Low frequency Tesla units, measured with a dual frequency Bartington MS2/MS2B sensor) from the Dona Stella site (Figure 4e).



The preceding examples bear witness to a dynamic of utmost importance to understand the Amazonian Formative. The analysis of ceramic anthropogenic dark earths has taught us to regard pyrogenic carbon as a potential factor in the recipe for nutrient retention. The presence of abundant charred remains and enhanced soil parameters in early-mid Holocene occupation soils suggest these could constitute embryonic forms of later-day *terras pretas*. At least in Araracuara, soil enrichment goes in hand with the presence of microfossils of extra-Amazonian cultivars [7], some of which require a higher soil pH and higher nutrient concentrations to thrive. It is possible, and in my view likely, that the cultivation of these species was enabled by soil enrichment triggered by dynamics of concentration, perhaps also of domestication, of fruit trees by preceramic populations. These dynamics – which would have undoubtedly resulted in the deposition of seeds, bone, charcoal and ash in middens – recall Anderson's [140] argument that plant domestication may have started in dump heaps. They also bring to mind the types of processes that Clement [13] has coherently described as landscape domestication. To put it succinctly: enduring soil enrichment instigated by human inhabitation appears to have started many millennia before the formation of ceramic-age *terras pretas*.

4. Anthropogenic Soils and Manioc

Soil enrichment may constitute a crucial watershed in the broader history of Amazonian anthropogenic landscape transformations because, as I will discuss in this section, it may have been instrumental for domestication processes associated with the emergence of sedentary lifestyles. It is useful to point out that among the different crops that have been identified by archaeobotanical studies in Amazonia, only maize (*Zea mays*) and manioc (*Manihot esculenta* ssp. *esculenta*) are considered starch-rich crops capable of becoming staples for sedentary lifestyles. I have previously highlighted early evidence of maize [62-66], but there are good reasons to question its centrality in the emergence of Amazonian sedentism: maize does not grow well on acid soils, its keystone significance in pre-Columbian diets is overruled by extant carbon isotope data from mid Holocene human bones [33], its cultivation among ethnographic Amazonian societies relies on intercropping with other cultivars, and its use is restricted to small populations of the western half of the basin [141-144]. If maize had been as crucial to the development of Amazonian sedentism as it was elsewhere, one would expect strong evidence of permanent settlements older than 0 AD as well as widespread use of the crop in the present. On the other hand, 16th and 17th century chroniclers mention maize and manioc gardens, as well as floodplain cultivation of manioc, among peoples living along the Solimões and Amazonas rivers [145,146].

Different scholars have argued that the cultivation of domesticated manioc played a key role in the emergence of sedentary lifestyles of the humid Neotropical lowlands. This is because this crop is well adapted to low-nutrient acid soils and possesses what has been dubbed an ‘underground storage capacity’: manioc tubers can remain in the ground for up to 2 years and thus permit management of cropping without parallel investment in storage. Ethnographic data from regions as far apart as northwestern Amazonia, the Guianas, and the upper Xingu [147-152] show it can supplement the protein source most available and predictable in the tropical lowlands, fish. Even in ecosystems regarded as the poorest in the Amazon basin, a mix of aquatic fauna, manioc and fruit, exchanged directly between farmers and foragers [153-155] or indirectly through intercommunity feasts (Figure 8), is recorded to support sedentary lifestyles [156-159].

The fossil record for the use of manioc in pre-Columbian times is difficult to interpret. First, there appears to be only partial consensus about the presence of diagnostic phytoliths for the family [cf. 51,52,160]. Second, experimental work suggests that manioc starch grains become denaturalised during cooking of the tuber, resulting in very significant evidential biases in the microfossil record [161]. Third, whilst research by geneticists shows that all varieties of domesticated manioc derive from wild populations of *Manihot esculenta* ssp. *flabellifolia* growing in southwestern Amazonia [162], the temporal fall-off curve of known fossil findings of *Manihot* appears to show the trend of an exotic species (the oldest are located north or west of the Amazon basin, the youngest within): in addition to different-age trans-Andean records of *Manihot* macro and microfossils [161,163-166], early Holocene starch grain data for *Manihot* are recorded by Piperno and Holst [167,168] in Panama, comparably early *Manihot* pollen/starch grain data are presented by Aceituno and Castillo [69,130,131] in the Colombian intermontane valleys, and *Manihot* pollen is recorded in a palaeoecological profile from the Colombian savannahs [170]. The oldest record for *Manihot* in Amazonia are mid Holocene soil pollen grains of the Abeja site [7,38] and, to the best of my knowledge, other evidence for *Manihot* in

Amazonia is associated with more recent occupations [46,51,52]. Were it not for the molecular genetic data, previously discussed evidence for mid Holocene maize and early pottery in the Ecuadorian *Montaña* [61-63] would lead one to conclude that Amazonia was colonised by maize and manioc horticulturalists during preceramic times [7]. However, a decade after the publication of Olsen and Schaal's [162] paper, analyses seem to strengthen their overall conclusion: populations of *Manihot esculenta* ssp. *flabellifolia* of French Guiana, for instance, do not appear to be as closely related to domesticated manioc as those from southwest Amazonia [171].

Figure 8. A *dabacuri* feast in the village of Matapi, at the mouth of the Tiquié River, upper Negro River. Tukano and Yuhupdu who live in this village have little access to agricultural land and rely on exchange with communities upstream to obtain manioc (Arroyo-Kalin, field notes, 2001). In the photo, however, they have the upper hand in a fluid system: the Tukano village elder has asked the neighbouring Yuhupdu community to collect Inga and Patauá and offered to supply manioc cuttings, acquired from other Tukanoan groups, in exchange.

How can the apparent contradiction between genetic evidence and what appears as a north to south trail of *Manihot* fossils be explained? One possibility is to suggest that the current location of the wild ancestor of manioc does not show where the founding event of manioc took place [172]. It is difficult to imagine, however, how populations of *Manihot esculenta* ssp. *flabellifolia* ancestral to manioc would have shifted their location from the north to the south of the basin within the time-scale of the Holocene. A more plausible alternative emerges if we remember issues of taxonomic resolution in archaeobotanical analysis: the presence of *Manihot* microfossils in and beyond Amazonia indicates that different pre-ceramic populations were experimenting with *Manihot* tubers, *not* Manioc tubers during the first half of the Holocene: neither pollen, starch-grain, or phytolith analyses can clearly discriminate between different *Manihot* species [see however 173]. Thus, the early presence of *Manihot* plant fossils beyond the region of domestication need not identify the founding lineage of domesticated manioc nor, consequently, date the timing of manioc domestication. If this interpretation is correct, it could be argued that preceramic populations throughout the tropical lowlands harvested the tuberous roots of different wild species of *Manihot* until, at a later point in time, other crops became more attractive alternatives.

The molecular genetic data does not provide an estimate of when domestication of manioc took place. However, an intriguing possibility is outlined by archaeological evidence from the overall region where ancestral populations of *Manihot esculenta* ssp. *flabellifolia* are found: preceramic occupations of the Massangana phase, recorded in the Jamari River, upper Madeira River basin, constitute the oldest known case of settlement-related *terras pretas* in the Amazon basin [35-37]. These findings are contemporary with both mid Holocene occupations of the Dona Stella site and with archaeological soils in which the oldest Amazonian *Manihot* microfossils are found [7,38]. If anthropogenic dark earths constitute signals of sedentism, manioc may be among the few crops that could have permitted this lifestyle among preceramic groups of the mid Holocene. That they occur in a region where palaeoecological studies indicate vegetation was more open during the early-mid Holocene [174-176], and which increasingly emerges as a possible pre-Columbian centre for crop domestication [17,177,178], is even more intriguing: open, dry conditions would have been ideal to domesticate a palm tree species (*Bactris gasipaes*) which subsequently would thrive mostly in areas of disturbed vegetation [126] as well as a shrubby species (*Manihot esculenta* ssp. *esculenta*) whose tubers are adapted to prolonged drought [7,179] and whose germination also appears to be disturbance-adapted [180].

Could mid-Holocene anthropogenic soils be the landscape infrastructures that permitted the domestication of manioc? This seems entirely plausible if different lines of evidence are considered. First, research by geneticists [181,182] shows that the two main varieties of manioc—bitter and sweet—derive from *Manihot esculenta* ssp. *flabellifolia* yet can be genetically discriminated such that an ancient separation between them can be inferred[1]. Second, bitter manioc grows well in acid soils with low nutrient contents, is resistant to pests, and develops large tubers with high concentrations of carbohydrates. The tubers, however, are extraordinarily poisonous: their consumption requires conducting an extensive process of detoxification that includes grating, washing, straining, fermenting and/or boiling of manioc meal. In contrast, sweet manioc tubers, which are typically planted in the proximity of houses, i.e. soils altered by inputs associated with domestic activities, may be consumed without any process of detoxification. They are, however, low starch yielders, are less resistant to pests, and are far less tolerant to soils with lower pH and nutrient contents. Ethnographically, sweet manioc tends to supplement yields of other crops, particularly maize; bitter manioc, in contrast, is the *par excellence* crop of extensive slash-and-burn cultivation in acid, low nutrient Amazonian soils [179,183 and pers. obs.].

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[1] One reviewer of this paper suggested that sequencing chloroplast non-coding areas or even specific nuclear genes (perhaps even the G3pdh already used in manioc) could allow - through coalescence analysis - estimates about when a specific lineage of the crop derived from another or from a wild ancestral population.

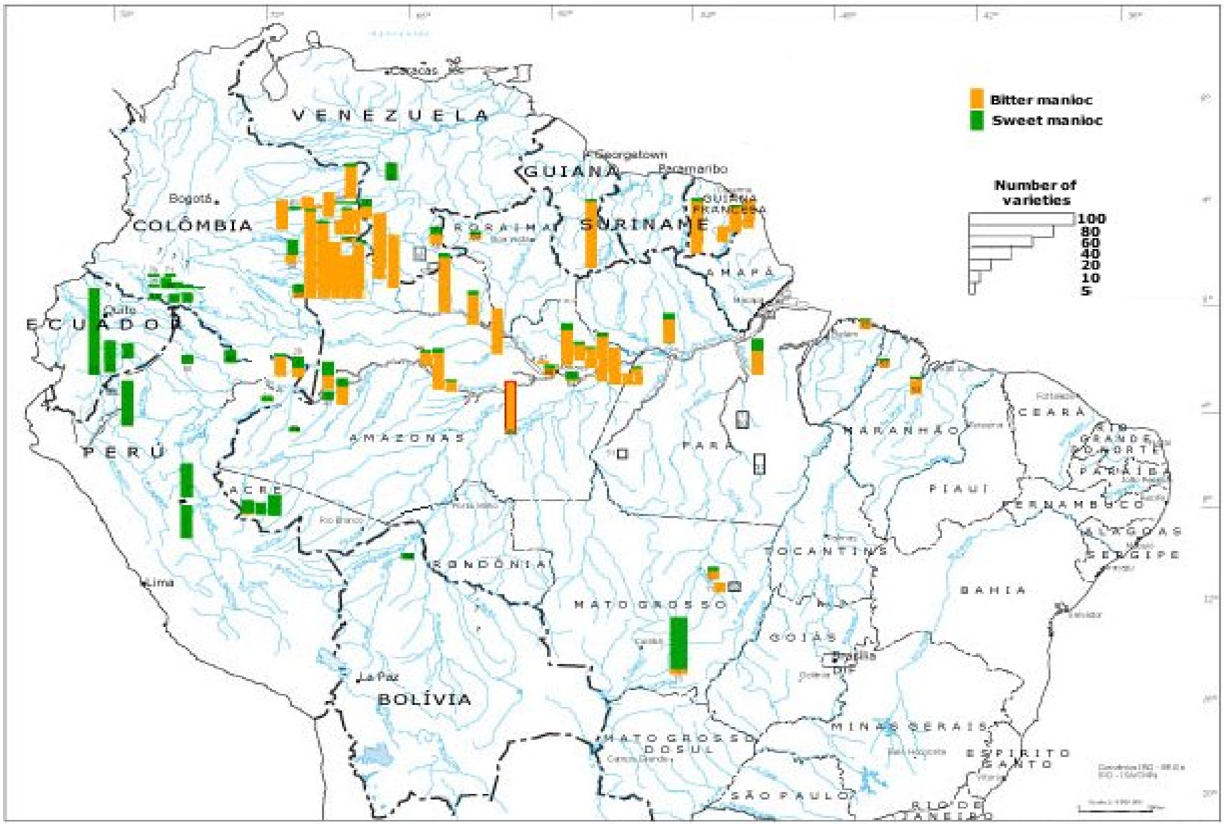
Keeping in mind how savannah foragers harvest and process wild tubers [184], I would argue that human-induced selective pressures on a species—*Manihot esculenta* ssp. *flabellifolia*—that is adapted to conditions of open vegetation and has small tuberous roots would be unlikely to have selected those individuals with high levels of toxicity [55]. Instead I would argue that transplantation of *M. esculenta* ssp. *flabellifolia* plants with low toxicity tuberous roots to patches of anthropogenically-enriched soils could have permitted domestication of a crop resembling sweet manioc in its lower toxicity, sensitivity to nutrient-enhanced soils, and overall lower resistance to pests [55]. That is, nurturing of selected individuals in anthropogenically-enhanced soil patches—areas variously resembling Anderson's [140] dump heaps or Lathrap's [27] house gardens—would have reduced chances of introgression with wild populations [185,186] at the expense of diminished resistance to pests and increasing dependence on high pH, nutrient-rich soils. What, then, to make of bitter manioc? What could drive the selective processes that enabled the evolution of a toxic high starch-yielder that is well-adapted to grow in the poorest soils and constitutes the most important source of starch in Amazonian diets? The answer may be profoundly cultural and deeply historical: the development of specific technological means—slash and burn—to fell gardens in rainforest areas, the use of organic amendments and controlled fires for intensive farming, the evolution of a complex processing technology to detoxify manioc through grating, washing, and straining, and the widespread use of ceramic vessels to extract, boil and process secondary manioc products, together may have permitted relaxation of selective pressures on lower concentrations of cyanogenic glucosides to the point where a high starch-yielder was evolved [179].

A historically-deep contrast between bitter and sweet manioc has a number of implications for understandings about the origins of sedentism in Amazonia. Sweet manioc, which is typically cultivated in the vicinity of houses, may have expanded throughout Amazonia and beyond during preceramic times. At a latter point, when people began to cultivate beyond habitation areas and consequently reduced human protection against pests, increased toxicity may have been favoured if means to process tubers could be devised and adopted. Put another way, bitter manioc may have evolved as a result of later-day agricultural intensification by pottery-making peoples who were capable of opening gardens in areas with rainforest vegetation [55,187].

5. Crop Domestication and Intensification

Figure 9 shows that among Amazonian indigenous and peasant peoples, sweet manioc is much more cultivated in the western half and southwestern portion of the Amazon basin whilst bitter manioc is far more common in eastern Amazonia, the Orinoco basin and the Guianas [143,144,151,179,183,188]. Considering what we know today about the archaeology of these regions, including the distribution of large sites with anthropogenic dark earths, it is striking how bitter manioc appears to be common in the overall region—the middle and lower Amazon, the middle and lower Negro, and the middle and lower Madeira—where a sudden explosion in occupations forming anthropogenic dark earths can be observed from the beginning of the first millennium AD. Sweet manioc dominates in a broad region that, aside from the upper basin of the Madeira River, has yet to show a widespread existence of dark earths of similar antiquity, where a number of isolated linguistic families exist, and where a widespread signal of model-incised ceramic complexes has yet to be documented.

Figure 9. Map of bitter and sweet manioc varieties compiled from ethnographic sources by Emperaire [144], modified with permission. Bar with red outline in the middle Madeira River region reflects *caboclo* dataset presented by Fraser [120].



Lathrap's [6] argument for the expansion of Barrancoid groups out of the middle and lower Amazon may be questionable [149,189] but his suggestion that larger archaeological sites with modeled-incised pottery reflect the expansion of new livelihoods and higher populations can hardly be doubted [see also 190]. Lathrap noted that ceramic remains at these larger sites included fragments of ceramic griddles similar to those recorded ethnographically for the processing of bitter manioc. He also highlighted how these were lacking in the much smaller ceramic middens of the Ucayali River. Although cautionary notes [191] and recent starch-grain analyses have cast doubt on the association between these griddles and manioc use [192,193], the widespread use of bitter manioc in eastern Amazonia, the presence of *Manihot* pollen in Colombian sites with anthropogenic dark earths [38,46], and the fact that bitter manioc processing could well decrease the preservation of *Manihot* starch grains [see 161], warrants caution with the cautionary note. Insisting that their main use was the processing of bitter manioc, on the other hand, brings to mind suggestions by Reichel-Dolmatoff [194,195], Sanoja [196] and Angulo [197], who long ago argued that model-incised ceramic complexes north of the Amazon basin reflected the cultivation of this crop variety.

As noted in the introduction, Meggers [54] has discussed continuities between Hormigoid modeled-incised complexes and 4th–3rd millennium BP pottery from the lower Amazon and Marajó Island as a north to south expansion of ceramists into the basin [14,31]. Leaving aside her assessment that these were the earliest Amazonian farmers, it is important to highlight that around the 1st millennium AD a widespread formation of anthropogenic dark earths alongside the middle and lower course of the Amazon River appears to be strongly correlated with developments in the Orinoco basin [8,9] and the Guianas [198]. Increasingly, pottery specialists suspect the formation of a demographically-dense and tightly-knit interaction zone [45,189]. Just as it is not difficult to situate Zucchi's [199,200], Heckenberger's [16,50] and Hornborg's [201] thoughts on Arawak languages and sedentism within this framework, it is possible to argue that a late Holocene population expansion associated with the intensification of bitter manioc cultivation in eastern Amazonia may have fuelled population growth and thus contributed decisively to the widespread appearance of anthropogenic dark earths. This model accommodates the presence of modeled-incised pottery in the Chambira basin [59,202] which, like Lathrap's [6] Ucayali Barrancoid wares, is found in much denser middens. It can also accommodate archaeological evidence from the Madeira basin [35-37], where sweet manioc cultivation appears to dominate in the headwaters (pers. obs.) and fast-growing bitter manioc varieties showing some similarities with sweet manioc are reported to grow well on anthropogenic dark earths and floodplain soils [120].

6. Discussion

It is possible that the appearance of loci of demographic concentration, enduring forms of landscape modification, and complex social arrangements in rainforest-clad Amazonia had to wait until a crop rich in starch, with a high storage capacity, and that could be adapted to growth in rainforest areas—bitter manioc—came to be cultivated in human-modified agricultural soils of the region. This suggestion may appear surprising to those ready to argue that an expansion of maize agriculture, parallel to that proposed by Roosevelt [203,204] for the Orinoco basin, could explain the origin of Amazonian dark earths. Whilst this is a tantalising suggestion when considered from the perspective of available palaeoecological and archaeobotanical evidence [46,53,62,63,65], it is worthwhile to reiterate that human bone isotopic data presented by Roosevelt [33,205] indicates that maize was not a staple in the lower Amazon and Marajó Island until the last centuries before European colonisation. This conclusion is corroborated by data from the Central Amazon Project [80]: carbon isotopes from human bones indisputably associated with the formation of anthropogenic dark earths [98] suggest a maize-existing but not maize-reliant diet [55]. If maize did eventually become important in the meals and not just the feasting [206] of communities inhabiting the margins of the Amazon River, it is possible that its cultivation may have relied on the agricultural reuse of *terras pretas*, the latter an outcome of population growth associated with the intensification of bitter manioc cultivation in areas of *terras mulatas*.

7. Conclusion

Developing knowledge of the Amazonian Formative not only requires identifying archaeological remains and crop evidence, but also demands reconstructing landscape modifications associated with crop domestication, cultivation, and intensification. In this respect, it can be argued that studies of anthropogenic soils are of paramount importance: the presence of horizons with anthropic signatures dating to the early part of the Holocene, the fact that dark earths appear to be contemporaneous with the earliest Amazonian evidence for *Manihot*, the positive feedback cycle between enduring habitation and fertility, and the evident association between these soils and dense human occupations, contradict any suggestion that Amazonian soils constitute an inherently limiting factor for agricultural societies. These observations instead highlight important research questions about broader process of human niche-building and help craft a new perspective on the history of lowland sedentism. This perspective renders disingenuous old arguments about whether surplus fish or surplus crops permitted the emergence of sedentary lifestyles. In Amazonia, the obvious answer is, to varying and regionally-specific degrees, both. In contrast, it highlights intriguing possibilities that demand further attention: Has the timing of domestication, husbandry and intensification of specific crops acted as a pacemaker of pre-Columbian developments? Did these processes rely on the cumulative effects of human communities on the landscape? Both of these questions invite us to intensify our efforts to reconstruct the human history of the Amazonian biome.

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