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Historical contingencies in the coevolution of environment and livelihood: contributions to the debate on Amazonian Black Earth

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Abstract

This article applies findings from agronomic and ethnographic research among small-scale Amazonian farmers to the ongoing debate over the origins of Black Earth (an anthrosol associated with native American settlements) and the intentionality of anthropic soil formation processes. Quantitative and qualitative data from semi-structured interviews, structured questionnaires and botanical plots highlight the constraints and opportunities associated with the use of Black Earth and Latosols among contemporary farmers. By identifying the strongest incentives for Black Earth cultivation today, and how many of these derive from relatively recent technological, political-economic and ecological influences, it is possible to demonstrate how perception and use of these anthrosols are likely to have changed throughout history. Data indicate that important historical contingencies underlie the relative benefits derived from the cultivation of Black Earth through time, and are likely to have structured both pedological and cultural trajectories in site evolution. They also point to the conditions under which Black Earth is likely to have become an important economic resource. By demonstrating the historical specificity of human motives, it is possible to obtain a more complex picture of the conditions under which anthropogenic environments may have expanded or restricted the range of viable economic activities in the region, influencing site evolution.

Keywords: Indian Black Earth (*Terra Preta do Índio*); Amazonia; Anthrosol; Historical ecology

1. Introduction

The formation of dark, nutrient-rich anthrosols (Black Earth) in environments known for their highly weathered soils has forced a new generation of Amazonianists to question

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outmoded models of culture and environment in the region. Yet the failure of some individuals and groups with use rights to cultivate Black Earth suggests that certain conditions are necessary for these soils to be perceived as an important resource. The objective of this article is to identify the factors that make Black Earth cultivation a preferred economic activity where it is practiced, and to demonstrate how changing historical circumstances are likely to have influenced incentives for Black Earth cultivation and labor-intensive soil modification in the past.

I utilize data from 2 years of ethnographic, pedological and agronomic research among traditional[1] farmers of the Central Amazon region of Brazil to explore these changing incentives and the circumstances surrounding Black Earth formation and utilization. Through a comparative study of cultivation strategies on anthropogenic Black Earth and non-anthropogenic soils (primarily Latosols[2]), I identify the most important incentives to Black Earth cultivation among contemporary farmers. By demonstrating the changing role of these incentives throughout time, I suggest specific factors conditioning (1) the emergence of Black Earth as an important economic resource in Amazonia and (2) the viability of labor-intensive soil enhancement. The emergence of important incentives to Black Earth cultivation through diffusion, for example, demonstrates how important influences from outside the region influenced human agency on the terra firme, perhaps providing incentives for ecosystem modification itself. This research provides insight into the ways in which diverse factors mediate human agency in localized environments, and the conditions under which site evolution (soil modification, agricultural intensification and population growth) is likely to have occurred.

2. Background

2.1. Human ecology of Amazonia

For many decades, Amazonian scholars have debated over the role of the environment in conditioning human adaptive strategies and guiding the course of cultural development in the region. Early on, the environment was viewed in terms of absolute constraints it posed to human societies and cultural evolution. This environmental determinism in Amazonian scholarship was perhaps first put forth in a succinct manner in the *Handbook of South American Indians* (Steward, 1948), where direct linkages were suggested between population density and natural resources. The most determinist stance, however, was that proposed in the early 1970s by Meggers (1996 [1971]), who identified specific environmental factors that set absolute limits on livelihood and cultural development. To Meggers, it was the amount and quality of cultivable land that determined the patterns of settlement

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[1] By "traditional" I am referring both to cultural history and to patterns of land-use that are indicative of this history, including direct (albeit distant) genealogical ties to native Amerindian groups and/or prolonged periods of adaptation to local environments during which aspects of native land-use were assimilated.

[2] Latosols are a soil order of the Brazilian soil classification system (Salgado Vieira, 1988) and are the most abundant soil class in the Amazon Basin, corresponding roughly to Oxisol and Ultisol orders of the USDA system.

and livelihood among native peoples of Amazonia. The highly leached soil substrate and rapid decomposition of organic matter in the tropical climate were said to set direct limits on crop productivity and soil improvement. These factors, she stated, are strong determinants of the shifting cultivation system prevalent among upland horticulturalists in recent times, and by inference, throughout the region's cultural past.

Recent scholarship has refuted this position, bringing to light the myriad of ways in which native populations buffer themselves socially (regional trade, kinship ties), technologically (food storage, resource procurement) and ecologically (settlement in proximity to multiple ecological zones) from potential environmental constraints (Denevan, 1996; Erickson, 2000; Posey, 1983; Ribeiro, 1995). Even more striking is evidence for the modification of what were once assumed to be "inherent" environmental attributes by native populations, leading to the creation of novel resources and demonstrating a greater degree of human agency with the environment (Balée, 1989; Clay, 1988; Denevan, 1992a; Stocks, 1983). Finally, archaeological investigations published in 1999 demonstrate the existence of large, fully sedentary populations in a broad range of ecological settings in pre-contact Amazonia (Heckenberger et al., 1999), further discrediting environmental determinants of cultural evolution.

Contributions of recent historical ecological literature indicate that rather than being constrained or limited by their environments, Amazonian peoples have actively modified the environments in which they live (Balée, 1989, 1998; Posey, 1985, 1998). While most of this literature refutes the concept of human adaptation to environment, approaches differ in the importance given to environment in this human–environmental dialectic. Whitehead (1998) takes perhaps the strongest stance against environmental determinism, proposing a fully "historical" ecology. Whitehead's approach makes human decision-making the independent variable in the analysis of environmental dynamics, thereby maximizing the role of human agency in structuring the environment and uses of it. Whitehead calls the latter "ecological praxis", which includes "the persistent features in the sociocultural repertoire of human physical and mental behavior that is overtly oriented to...structure usages of the environment" (Whitehead, 1998, p. 30).

Yet human agency is not absolute. Localized behaviors are in part structured by context, both cultural and ecological. Broader cultural processes occurring beyond localized settings, environmental impacts of past cultural activity, and the "uncultured" environment itself as it influences the costs and benefits of diverse environmental uses are each reflected in the actions of individuals. Wight (1998) and Wilmott (1977) address the first of these for social structure, emphasizing the interplay between agency and structure. The importance of political-economic influences in structuring human–environmental interaction (Anderson, 1995; Rudel and Horowitz, 1993) is another example, demonstrating how large-scale cultural processes limit or expand human agency in localized environments. Secondly, the creation of artifactual resources, landscape degradation and other anthropogenic impacts on the environment affect the resources available to future occupants. Third, within any given historical context, environmental properties interact with cultural process to influence the range of viable productive options. The greater effort required to enhance extremely oligotrophic soils, for example, will influence the costs and benefits of ecosystem modification and restrict ecological praxis accordingly. There may be additional ecological limits to anthrosol formation, such as the restriction of economic options across the landscape when the rate at which nutrients are harvested and concentrated in localized areas surpasses the rate at which these may be restored by natural processes.

A stance that assumes humans to be above the constraining forces of the environment is therefore dangerous, as indicated by negative repercussions of economic activity on human health and ecosystem productivity (global warming, pesticide/antibiotic resistance, biological amplification of environmental toxins, etc.). This would suggest that the debate on historical vs. environmental determinism is not yet over, that the environment, broader cultural and historical processes, and the ecological praxis of local actors together influence human uses of the environment through space and time.

2.2. Terra Preta do Índio: unbridled ecological praxis?

Terra Preta do Índio, or Indian Black Earth, is an anthrosol distributed throughout the Amazonian terra firme (non-inundated upland environments) in small pockets of 1 to 6 ha, although sites of up to 350 ha and in a broader range of environments may be found (Smith, 1980, 1999). The *World Reference Base for Soil Resources* defines anthrosols as "soils that have been so transformed by anthropedogenic processes that the original soil is no longer recognizable or survives only as a buried soil" (Spaargaren, 1994). The absence of Black Earth deposits in contemporary Amerindian and mestizo settlements (Heckenberger et al., 1999) would suggest that itinerancy, low-density settlement and swidden agriculture are apparently not the patterns of settlement and land-use that led to these lasting soil modifications. Black Earth has therefore caught the eye of anthropologists and historians alike, in recognition of the broader story told by these soils about Amazonian cultural history (Rival, 1998; Whitehead, 1998).

Similarities in buried horizons support the classification of anthrosols as sub-classes of the predominant background soils. This holds for Black Earth, which has been classified as a Humic Anthropogenic Yellow Latosol among Brazilian soil scientists (Salgado Vieira, 1988). While logical from a pedological standpoint, this classification obscures pedogenic processes and the highly distinctive chemical and physical differences between Black Earth and Latosols.

Black Earth generally has three highly distinct horizons: (1) a deep, dark and nutrient-rich epipedon with a sandy texture and an abundance of potsherds, (2) a transitional horizon with a mottled appearance and an abundance of organic ped coatings and root linings, and (3) a sub-adjacent horizon that is lighter in color, has few thin organic ped coatings and a more clayey texture. Latosols, on the other hand, tend to be brownish red or yellow in color, have a thin organic epipedon and less distinctive sub-adjacent horizons that are clayey and nutrient-poor. Composite samples collected from Latosols and Black Earth swiddens along the Negro and Urubú Rivers (Map 1) and analyzed according to the official analytical procedures of EMBRAPA (see Area description and methods), a federal agricultural research institute with a regional office in Manaus, confirm the higher fertility of Black Earth (Table 1). Results, averaged by horizon for each soil class,[3] show Black

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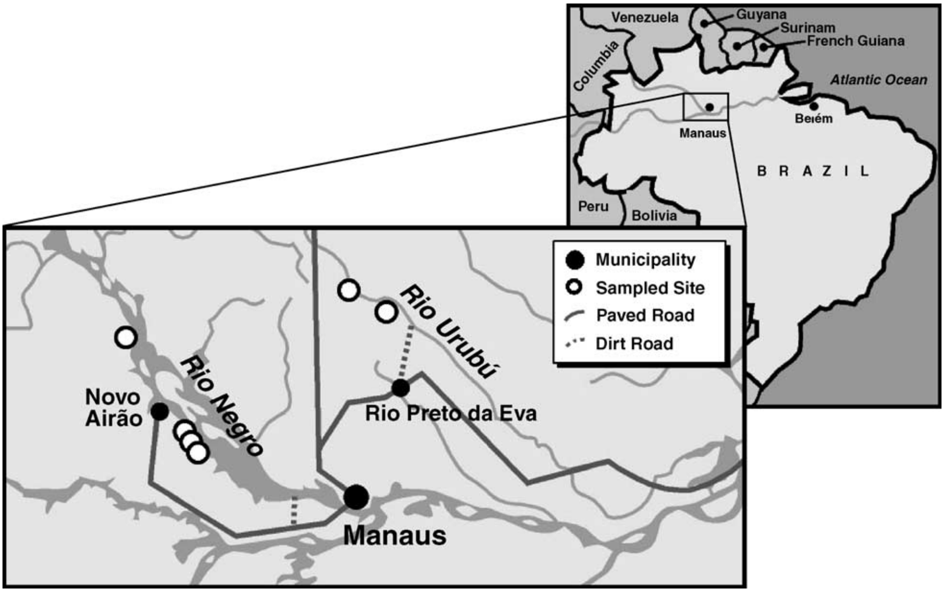
[3] While the averaging of soil horizons may be questioned due to variation in horizon depth, these data are useful for demonstrating broad trends in the properties of each soil class.



Map 1. Research sites on lower Negro and middle Urubú rivers.

Earth to have higher soil nutrient stocks, more favorable indices of soil fertility (cation exchange, pH, levels of toxic Al) and extremely high amounts of soil phosphorous, a known limiting nutrient in Amazonian ecosystems (Jordan, 1985, 1989).

The pedological properties of Black Earth are anomalous for terra firme environments, in which the combination of relatively stable landforms and tropical climate has favored the formation of highly weathered soils (Salgado Vieira, 1988; Sombroek, 1966).

Table 1
Pedological comparison between Latosols and Indian Black Earth, Negro and Urubú Rivers[1]

Soil	Hor.	Depth[a] (cm)	Particle size distribution				pH (H_2O)	P_2O_5 (ppm)	Exchange Complex (meq/100g)					Total C (%)	Total N (%)	BS (%)	ECEC (meq/100 g)
			CS (%)	FS (%)	S (%)	CL (%)			Ca^{2+}	Mg^{2+}	K^+	Na^+	Al^{3+}				
Latosol	A	16	28	10	18	43	4.3	3.6	0.11	0.10	0.04	0.02	2.34	4.5	0.1	10	2.61
	AB	45	22	9	20	50	4.3	1.7	0.03	0.03	0.02	0.01	1.72	1.9	0.1	5	1.81
	B_1	88	21	13	13	53	4.3	2.1	0.05	0.06	0.02	0.01	1.62	1.1	0.1	8	1.76
	B_2	110	8	2	19	71	4.5	0.7	0.01	0.01	0.01	0.01	0.93	n/a	n/a	4	0.97
Black Earth	A	30	45	14	15	21	5.6	68.6	5.41	0.66	0.04	0.04	0.47	3.2	0.1	93	6.62
	AB	58	39	13	12	37	5.2	37.4	1.63	0.22	0.01	0.01	0.72	1.5	0.1	72	2.59
	B_1	96	33	11	11	45	5.0	41.9	0.70	0.13	0.01	0.01	0.61	0.6	0.0	58	1.46
	B_2	114	27	8	14	50	4.8	39.2	0.45	0.07	0.01	0.00	0.83	n/a	n/a	39	1.36

CS = Coarse Sand; FS = Fine Sand; S = Silt; CL = Clay; BS = Base Saturation; ECEC = Effective Cation Exchange Complex.

[a] Values are averaged by horizon. A total of 8 Latosol and 8 Black Earth soils were sampled.

These anomalies are perhaps what first stimulated great interest in the origins and cultural function of these soils. While early scholars supported theories on natural origins (Smith, 1980), it is now unquestioned that Black Earth is a human artifact (Heckenberger et al., 1999; Woods, 1995; Woods and McCann, 1999). Evidence includes high levels of calcium and phosphorous (Eidt, 1977), spatial distribution (typically on high landforms where depositional processes could only be cultural), the presence of artifacts throughout the modified horizon, and the occurrence of Black Earth over buried horizons typical of the region's Latosols. Research published by Zech et al. (1990) and supported by later scholars (McCann et al., 2001; Woods and McCann, 1999) suggests that Black Earth forms through chemical and biological processes that commence once a threshold level of pH, nutrient retention capacity and biological activity is reached as a result of cultural activity (burning, deposition, etc.).

Despite this emerging consensus, there is new evidence to suggest that Black Earth is heterogeneous and may be formed by distinctive cultural processes. In a recent publication, Woods and McCann (1999) identify two distinct classes of Black Earth. The first they call *Terra Preta*, which corresponds to a darker and spatially restricted anthrosol resulting from high-density or lasting settlement (i.e., middens). Soils surrounding these darker anthrosols have values of Ca and P that are only slightly higher than background soils, despite comparable levels of soil organic matter. Woods and McCann (1999) call this soil *Terra Mulata* following Sombroek (1966), and use soil chemistry (high SOM, low Ca and P) to deduce that these soils were formed through intensive agriculture. These authors propose the term "Amazonian dark earths" for Black Earth to stress diversity in these soils and in related pedogenic processes.

Several authors are now favoring models of Black Earth formation based on intensive agricultural practices and intentional soil modification (Denevan, in press; McCann et al., 2001). The emerging view stresses the ecological praxis of native Amazonians, or stated more simply, "soils were a constraint, but people overcame them" (Mann, 2000, p. 788). The ability to enrich localized environments to suit changing cultural demands would indicate that human agency is almost limitless, and often the sole determinant of cultural and ecological process. This raises a number of questions. First, were these anthrosols modified intentionally to expand livelihood opportunities in previously impoverished landscapes, as suggested by Herrera et al. (1992) and Mora et al. (1991), or are they by-products of independent changes in settlement and livelihood? Second, if intentionally modified, was this ecological praxis absolute? If not, what were the conditions that made labor-intensive soil modification desirable or feasible?

As cultural acts, settlements are "intentional," as are agricultural practices, waste treatment and other activities carried out within settlements. Yet even though the many processes that have been claimed to contribute to Black Earth formation are each intentional cultural acts, does this mean that Black Earth as an *outcome* of these processes is also intentional? In this article, I include as intentional ecosystem modifications only those cultural behaviors through which soils are modified to achieve higher fertility, improved performance of culturally important crops, or other outcomes directly related to soil quality. I employ this more restrictive usage for heuristic purposes: to discriminate soil modification that was both purposeful and useful in achieving some culturally defined goal, from that resulting from independent goal-oriented behaviors.

To assess intentionality and the degree of human ecological praxis in Black Earth formation, it is important first to identify benefits derived from these soils once formed. Despite widespread acceptance of anthropogenic origins and soil enrichment (Kern, 1988; Woods, 1995; Woods and McCann, 1999), evidence for the importance of these soils in traditional agriculture has been mostly anecdotal. Furthermore, historical factors that played a role in defining the cultural importance of Black Earth through time, leading to its treatment as an important resource, have yet to be addressed. McCann et al. (2001) discuss indigenous practices of soil inoculation with ash, organic material and microorganisms, and the implications of these practices for tropical soil management. Yet linkages between intentional agricultural intensification and Black Earth formation, and between Black Earth and an increase in human carrying capacity, have been insufficiently established. Furthermore, while the presence of Black Earth continues to provide evidence of relatively permanent settlement in Amazonia prior to European arrival (Denevan, 1996; Smith, 1980), the suggestion that these richer pockets of soil made possible this transition to a more sedentary lifestyle is as yet untenable.

In the following pages, ethnographic data among contemporary farmers point to the advantages and disadvantages of Black Earth cultivation. Evidence for how these influences have changed throughout time paints a complex picture of the origins and cultural function of these sites, and highlights important gaps in our knowledge about Black Earth site transformation—both pedological and cultural.

3. Area description and methods

Research was carried out along two blackwater rivers of the Central Amazon, the Rio Negro and the Rio Urubú (Map 1), where comparative research on the cultivation strategies of resident *caboclo* families on Black Earth and adjacent Latosols was carried out.

Caboclos are contemporary inhabitants of Amazonia whose complex genealogy reflects indigenous, Portuguese, Afro-Brazilian and even Japanese ancestry. While assimilating many aspects of indigenous land-use practices, the caboclo economy has been strongly shaped by integration into the market economy. Caboclo families generally share a history of mobility due to changing economic opportunities and the influx of groups from outside the region throughout the 20th century, contributing to the complexity of their cultural history. While the individuals participating in this study grew up in the region (along the Branco, Solimões, Tapajós and Negro Rivers), they are children of either first-generation immigrants or of a union between a recent immigrant and a resident *caboclo* or native American. They therefore have limited ethnic ties to pre-Columbian Arawak and Carib groups inhabiting the region (Leonardi, 1996; Porro, 1992).

Three preliminary criteria were utilized to select sites of in-depth research: the presence of Black Earth, the importance of this soil to family sustenance, and non-use of chemical fertilizers. The last of these was necessary because chemical fertilizers would obscure the influence of anthropogenic soil modification on agricultural practices. Research participants (collaborators, informants) were then selected to participate in in-depth ethnographic, pedological and agronomic research. This selection process was carried out not to obtain an equal number of collaborators, but an equal number of Latosol and Black Earth cultivation systems[4] for comparative analysis. Final participation rested on the full consent of participants.

Quantitative and qualitative data on farmer perceptions of soil performance, actual cropping behavior and soil properties were collected for each household. Semi-structured interviews were first carried out to identify factors that most differentiate cultivation on Terra Preta from that on adjacent Latosols. Structured questionnaires documented (1) advantages and disadvantages to cultivation on each soil class, and (2) local perceptions of the performance of common crops on the two soil classes.[5] In addition to crop performance ratings, a list of crop-specific incentives was generated from semi-structured interviews. This time, farmers were asked to rate biophysical (soil quality), political-economic and other culturally important advantages associated with the cultivation of each crop.

To contrast farmer perceptions with actual swidden management practices and underlying biophysical parameters exerting an influence on human behavior, cropping practices, swidden dynamics and soil fertility were determined. Botanical quadrants were established in 68 Black Earth and Latosol plots (swiddens[6]) to research cropping practices. Three quadrants of 5 × 5 m each were marked in each swidden, and monitored for a period of 1 year. At the end of each 3-month period, the crops present in each quadrant were documented, and individuals counted to determine the presence and abundance of each species. Swidden dynamics were monitored through the documentation of fallow clearing times, the age of cleared vegetation, time in production, and swidden age upon abandonment. Unlike some systems in which the forest fallow is managed, “abandonment” was easy to determine on Black Earth and Latosols due to the absence of practices aimed at managing successional processes and the tendency to harvest all crops when management ceases.[7] Finally, composite samples were taken in each swidden to assess soil fertility.

Laboratory methods included a variation of Mehlich I (0.025 N H_2SO_4 and 0.05 N HCl extractants) to assess plant-available phosphorus and exchangeable potassium and sodium, which involved standard colorimetric and photometric determinations. Exchangeable magnesium, calcium and aluminum were determined using a 1 N KCl extractant. Readings for magnesium and calcium were taken on an atomic absorption spectrophotometer. Aluminum was assumed to represent all exchangeable acidity and was estimated by titration using 0.025 NaOH.[8] Total carbon and nitrogen determinations were made using a

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[4] For those families farming both Black Earth and Latosols, the two cultivation systems were contrasted accordingly. In all other cases, the comparative research framework was upheld by matching cultivation systems *between* families.

[5] Crops with high yields in each soil class were given a rating of two, those with low yields a rating of one, and those with negligible yields a zero.

[6] Shifting agriculture is practiced on both Black Earth and Latosols. I therefore use the term “swidden” to refer to the agricultural plots established on each soil.

[7] There are a few exceptions to this general rule. Individuals may return to Latosol swiddens to harvest banana, yam or manioc (from cuttings that have spontaneously sprouted in abandoned swiddens). I nevertheless treat abandonment as absolute, given that the relative contribution of these practices to overall production is negligible.

[8] Accuracy for this procedure is controlled through periodic testing of samples at other EMBRAPA laboratories where procedures for direct determination of Al^{3+} are used.

LECO analyzer, and pH by electrode determination in water at a 1:2.5 soil-to-solution ratio.

4. Historical contingencies to site transformation: identifying motives for the intentional modification and cultivation of Black Earth in prehistory[9]

Despite evidence for heightened soil fertility and for the broader range of crops that may be grown on these anthrosols (German, 2001; Smith, 1980; Woods and McCann, 1999), field observations suggest that certain conditions must be met for Black Earth cultivation to be incorporated into regional livelihood strategies (German, 2001). While some farmers have substantially increased household income and food security through the cultivation of Black Earth, not all Black Earth sites are cultivated. This is due to the market orientation of Black Earth cultivation practices, and to the greater susceptibility to pests and disease of those crops for which there is high market demand. Furthermore, beyond a certain distance from market, most Black Earth sites are left uncultivated as marketing costs exceed benefits derived from the sale of Black Earth produce.

Despite these limitations to market-based agriculture on Black Earth, one would expect to see frequent use of Black Earth for the cultivation of more robust cereals and legumes[10] for household consumption. While several farmers on the Lower Negro and Urubú do produce crops for household consumption on Black Earth, this practice is by far the exception. As one moves upstream along the Rio Negro, Black Earth cultivation disappears altogether despite the high fertility of these soils and an understanding among indigenous residents of the broader array of crops that may be grown on them.

Given this differential treatment of Black Earth, what conditions lead to favorable assessments of Black Earth production potential among local farmers? What are the factors that allow individuals to derive significant benefits from Black Earth cultivation? This section summarizes results of ethnographic research to identify the most important advantages and disadvantages to Black Earth cultivation among contemporary farmers. By identifying the conditions under which Black Earth cultivation becomes feasible and/or advantageous, and determining the presence or absence of these influences through time, it is possible to make historical inferences about formation and prior uses of Black Earth. The presence or absence of important incentives to Black Earth cultivation during distinct periods in history would also influence motives for intentional, labor-intensive soil modification. The emergence of these incentives at critical periods of site transformation would support the premise that Black Earth formation was intentional, and that Black Earth played a functional role in culture change.

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[9] I use a very broad definition of “site,” defined in spatial terms and therefore encompassing the full array of human and environmental phenomena contained within: soil properties, patterns of human habitation and subsistence, etc.

[10] Crops such as maize and beans may be easily stored and provide an alternative to animal protein, for which seasonal shortages are common. If protein does, in fact, tend to be limited in regional diets, then one would expect these crops to be highly valued by local residents.

In the following pages, ethnopedological categories are utilized to organize the data. Residents of the Lower Negro and Urubú distinguish perceptually between "Terra Preta Legítima" (the darkest soils, or prototype) and "Terra Preta" (the lighter, outlying soils) when pushed to do so. Yet these sub-classes are neither recognized functionally (within management practices) nor acknowledged in everyday speech (in which all variations are grouped into one class, "Terra Preta"). This relatively homogenous treatment of spatial variability on the region's anthrosols grounds the analytical use of a single taxon, Terra Preta, to refer to the full spectrum of dark earths. It is important to note that the designation "Terra Preta" therefore reflects local cultural and agronomic realities, and does not necessarily reflect formation processes or recent pedological classifications of these soils. I use the term "Black Earth" accordingly, using the Portuguese version (Terra Preta) only when presenting ethnographic data. The corresponding ethnoscientific nomenclature for Red-Yellow Latosols includes soils that are managed similarly but nevertheless differ in texture and color: *Terra Amarela* (Yellow Soil), *Terra Vermelha* (Red Soil), *Barro Amarelo* (Yellow Clay) and *Terra Comum* (Common Soil, which encompasses each of these spatially abundant soil classes).

4.1. Technological contingencies to intentional soil modification and Black Earth cultivation

Many authors have addressed how technology influences costs and benefits of diverse resource procurement activities (Denevan, 1992b; Herrera et al., 1992). Others have discussed the relative or cultural value of soils as a function of available and economically important crops (Hecht and Posey, 1989; Johnson, 1974). In the Lower Negro and Urubú, differential crop performance on Terra Preta and Latosols is the factor that most influences the value local residents place on each soil. While crops may differ in their cultural and economic importance to local farmers, crop performance data are particularly instructive because they discriminate between crops on the basis of yields alone, emphasizing the technical feasibility of distinct cropping practices. By identifying the preferred crops for each soil among contemporary farmers and determining the presence or absence of these crops during distinct historical periods, it is possible to generate indirect evidence for the relative incentives of Black Earth cultivation through time. Motives for intentional soil modification in pre-contact Amazonia can also be deduced from these data.

Table 2 summarizes farmer ratings of crop performance on Terra Preta and adjacent, naturally forming Latosols from the Central Amazon region. Given that swidden agriculture is the predominant use of Black Earth,[11] the elicitation of crop performance ratings on each soil focused on swiddens. Average performance ratings, in bold type,

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[11] Fruit gardens, while found on both Latosols and Black Earth, were more common on the former. It was apparent from direct questioning that garden placement is determined by place of residence rather than soil fertility per se. Furthermore, soil quality tends to be subsumed to other more important criteria in the selection of sites of residence, such as the location of prime fishing grounds, the spatial extent of terra firme and aesthetic concerns. A similar study in regions where house gardens are common on Black Earth is needed, in particular given the more probable association between Black Earth formation and the tight nutrient cycling between house and house garden.

Table 2
Informant ratings[a] of crop performance on *Terra Preta* and *Terra Comum*

Crop class	Crop name	Avg. rating, *Terra Preta*	Avg. rating, *Terra Comum*
Cereals and legumes	Maize	2.00 ± 0.00	0.29 ± 0.62
	Red Bean	2.00 ± 0.00	0.38 ± 0.64
	Rice	2.00 ± 0.00	0.25 ± 0.71
Edible gramineas	Sugar Cane	1.50 ± 0.80	1.13 ± 0.88
Fruit crops	Banana	0.42 ± 0.67	1.41 ± 0.70
	Coconut	2.00 ± 0.00	0.55 ± 0.69
	Lemon	1.42 ± 0.90	1.42 ± 0.79
	Papaya[b]	2.00 ± 0.00	0.50 ± 0.80
	Pineapple	1.45 ± 0.82	1.71 ± 0.62
Root crops	Bitter manioc	0.75 ± 0.87	1.88 ± 0.31
	Sweet manioc	1.33 ± 0.65	1.55 ± 0.79
	Yam	1.50 ± 0.80	1.88 ± 0.31
Vegetable crops	Bell Pepper	2.00 ± 0.00	0.32 ± 0.64
	Cucumber	2.00 ± 0.00	0.50 ± 0.67
	Okra	2.00 ± 0.00	0.35 ± 0.67
	Onion	1.64 ± 0.67	0.40 ± 0.66
	Squash	1.92 ± 0.29	0.50 ± 0.67
	Sweet pepper	2.00 ± 0.00	0.50 ± 0.81
	Tomato	2.00 ± 0.00	0.10 ± 0.32
	Watermelon	1.90 ± 0.32	0.22 ± 0.36
	West Indian Gerkin	2.00 ± 0.00	0.88 ± 0.80
Edible volunteers	*Carirú*	2.00 ± 0.00	0.20 ± 0.42
	Star nut palm	1.83 ± 0.39	1.92 ± 0.29
Average of means		1.72	0.82

[a] A rating of two corresponds to excellent crop yields, and of zero to those that do not produce on any given soil. All values are averaged informant responses.

[b] Some individuals are volunteers, while others are fully domesticated varieties.

indicate that Terra Preta is more capable than Terra Comum of producing high yields for a broad range of common crops.

Botanical data derived from the monitoring of quadrants in Black Earth and Latosol swiddens provide different information than crop performance ratings by showing *actual* cropping behavior. One would expect these data to differ from mere technical assessments of alternative cropping practices, by reflecting farmer assessments of technical, cultural and economic trade-offs of diverse crops. Crop classes in Table 2 were also employed to classify data from botanical quadrants. Data analysis according to (1) the percentage of swiddens containing members of each crop class, (2) the percentage of swidden area (% of quadrants from each swidden) containing members of each crop class, and (3) crop abundance (the proportion of individual plants from each crop class) highlights diverse facets of cropping behavior (Table 3).

From cognitive and botanical data in Tables 2 and 3, it is clear that Latosols are preferred for the cultivation of bitter manioc, the regional staple. While crop performance ratings are highly variable, many fruit trees also appear to grow better on Latosols. Evidence for this is found in Table 3, and in the statement made by a long-time user of Black Earth: “Nutrients for [vegetables, cereals and legumes] are better on Terra Preta, and

Table 3
A comparison of cropping practices on Latosols and Black Earth

Crop class	% of Swiddens with class × crop		% of Swidden area with class × crop		% of total plants from each crop class	
	Black Earth	Latosols	Black Earth	Latosols	Black Earth	Latosols
Cereals and legumes	11.70	0.00	51.77	0.00	11.65	0.00
Edible gramineas	0.57	3.93	1.83	8.43	0.53	0.55
Edible volunteers	38.02	25.23	91.28	85.31	4.74	1.74
Fruit crops	5.91	23.77	20.20	58.89	17.86	7.43
Root crops[a]	12.32	36.69	42.74	100.00	32.74	80.03
Vegetable crops	28.19	4.39	74.43	9.25	26.18	0.66
Bitter Manioc	7.67	28.59	36.81	98.38	30.22	77.52

[a] Bitter manioc is included in this crop class and corresponding figures, yet has been isolated below to indicate the specific role of this culturally important crop.

for fruit trees Yellow Clay is better." It is possible that the limited spatial extent of the more fertile Black Earth and acceptable yields of fruit and root crops on the more abundant Latosols would encourage farmers to "save" Black Earth for more nutrient-demanding crops. Yet some farmers claim that yields of some crops are actually depressed on Black Earth:

> So we planted [banana on Terra Preta] . . . but it didn't produce, it never produced, no. The plant grew, pretty even, and then when it began to fruit, it produced very small banana. Manioc, same thing. Lots of plant [vegetative growth]; it grows a lot, but doesn't produce.

There are several factors that could be causing this negative yield response in manioc. The higher sand content and rapid drainage on Black Earth could be causing soil-moisture stress for the manioc crop, a problem that is exacerbated with high soil density[12] (Lal, 1981). Yet manioc plants failed to show signs of stress and displayed vigorous vegetative growth. Significant drops in soil potassium prior to swidden abandonment (German and da Silva Cravo, 1999) may inhibit yields due to the high potassium requirements of manioc (CIAT, 1975). Obigbesan (1977) cites inadequate supplies of potassium as a common reason for excessive vegetative growth and limited root production in manioc. Yet other authors support the apparently contrary idea that high soil fertility is responsible for depressed yields. According to one author, "under conditions of very high fertility, cassava[13] tends to produce excessive vegetation at the expense of tuber formation"

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[12] Despite the coarse texture, soil compaction tends to make Black Earth heavier per unit volume than Latosols.

[13] Cassava is an alternative term for manioc (*Manihot esculenta*), and also encompasses bitter and sweet varieties.

(Onwueme, 1978, p. 110). Others found manioc to be highly sensitive to over-fertilization (Howeler, 1981) and to have a higher distribution index (root growth divided by top growth rate) under conditions of low fertility (Lal, 1981). This growth pattern has been linked to excessive nitrogen, in particular (Ngongi, 1976; Obigbesan and Fayemi, 1976).

This sensitivity to high fertility may have emerged as a result of environmental conditions where wild relatives evolved, or through the domestication process as individuals were selected for maximal performance in an infertile environment. While the literature makes no specific reference to this other than the specificity of cultivated plants to distinct environments (Vavilov, 1992), fertility increase from an absolute standpoint may fail to translate into higher yields for a crop so well adapted to its environment. If this is true, the negative yield response of manioc on Black Earth is likely to have been exacerbated in the past, given the likelihood that limited nutrient additions under current cultivation practices (German, 2001) have actually lessened the fertility of Black Earth on contemporary landscapes.

In addition to depressed yields, incentives for the cultivation of bitter manioc and other root crops with extended periods of maturation are limited by increased weed invasion on the more nutrient-rich anthrosols. One Black Earth farmer states:

> I don't have much knowledge of many *Terras Pretas*, but this one there, I have worked a long time on her, and manioc [isn't feasible] because it requires a lot of labor. I was saying today, it takes 3, 4 weedings for you to harvest some manioc... Vegetables, if they were 90 days old, you could harvest the whole crop. And vegetables, you work in a small area. Not with manioc. Manioc must be planted in a large area. Vegetables no, in a half-day, you weed it all.

These greater labor requirements lead farmers to favor fast-growing crops on Black Earth, minimizing the progressive increase in labor required to control weeds as the swidden matures through earlier swidden abandonment. Denevan (1992b) has demonstrated how technology shapes land-use by altering the costs and benefits (primarily labor) associated with clearing new tracts of land versus keeping existing swiddens in production. The absence of metal axes prior to European arrival would have provided additional incentives for keeping existing fields in production due to the extra labor required to clear new areas of forest for agriculture. This may have made the extensive weeding required for manioc cultivation on Black Earth less of a constraint. Yet without a positive yield response to compensate for increased labor investment in weed control, it is still unlikely that these soils would have been favored for manioc cultivation.

It is more likely that Black Earth became an important resource in prehistory as more nutrient-demanding and nutritious crops were introduced to the region. The high yield potential of protein-rich grains and legumes on Black Earth (Table 2) and their total absence on Latosols (Table 3) would suggest that soil modifications were not only attractive but necessary to derive significant yields from these crops in prehistory. The potential benefits derived from the introduction of maize and beans to the region in pre-Columbian Amazonia is due to the more rapid maturation and the greater nutritional benefits of these crops in relation to traditional root crops. While Black Earth is also favored for the cultivation of vegetable crops, with the exception of squash these tend to be exotic crops or high-yielding varieties of more recent introduction and of limited value as staple crops.

Grouping crop performance ratings in Table 2 by crop origins provides a historical perspective on the influence of available domesticates (considered here as technology[14]) on incentives for agricultural intensification and labor-intensive soil modification through time. Associating crop performance ratings with place of origin and time of introduction to the region highlights the benefits derived from each soil class through time. From Table 4, it is evident that the benefits of Black Earth cultivation, as reflected in the yield potential of existing crops, may have been significantly reduced prior to the assimilation of exotic crops from outside of Amazonia. The relatively early introduction, greater nutritional value, and higher yield potential of maize and beans on Black Earth suggest that these crops may have provided the first significant incentive for Black Earth cultivation and intentional soil modification prior to European arrival. Most significant to human nutrition and human carrying capacity may have been the introduction of maize, beans and squash from other regions throughout the Americas.[15]

The poor performance of culturally important native domesticates on Black Earth is perhaps the primary indication that Black Earth cultivation in prehistory was subject to important contingencies such as the introduction of non-native crops. If potential benefits of Black Earth cultivation were, in fact, increased by the availability of exotic crops, the relative timing of these introductions in relation to Black Earth formation would be critical for reconstructing the causes of increased sedentism and site evolution.

The date of 2400 BP corresponds with increased frequencies in maize phytoliths in the Ecuadorian Amazon and the appearance of carbonized remains of maize along the Orinoco, suggesting "that maize agriculture was becoming more intensive and dispersing throughout the Amazon Basin around this time" (Piperno and Pearsall, 1998, p. 260). Given that all but one Black Earth site studied by Heckenberger et al. (1999) on the Lower Negro produced radiocarbon dates of 2310 BP and later, it is possible that maize was present at the time of Black Earth site occupation and transformation. Yet Roosevelt (1980, 1998) suggests that maize became a staple for many groups only in the latter part of the period preceding European arrival. Furthermore, Açutuba—by far the largest, most structurally elaborate Black Earth site on the Lower Negro-produced radiocarbon dates of 6850 ± 100 BP. This predates known reliance on maize, other cereals or legumes by native groups. Soil modifications resulting from independent cultural processes (increased population density, centralization of political-economic activity, etc.) in which Black Earth plays no functional role here becomes more plausible.

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[14] While not purely artifactual (of human origin), domesticates are technological to the extent that they originate through human activity and ingenuity, involve information generation, and influence material culture.

[15] Even these benefits should be assumed only with more direct paleobotanical evidence from Black Earth sites. This is particularly true for maize, for which the absence of a strong tradition of consumption or technology for processing dry grain leads farmers to feed the seed to livestock rather than their own families. While it is common to consume fresh ears of corn, I never observed any human consumption of dry grain on the lower, middle or upper Rio Negro, suggesting the absence of (or historical disjuncture with) a regional tradition of maize consumption.

Table 4
Crop performance ratings classified by crop origin

Crop origin	Crop	*Terra Preta* (Avg. ratings)	*Terra Comum* (Avg. ratings)
Lowland South America, Amazonia	Bitter Manioc	0.75 ± 0.87	1.88 ± 0.31
	Pineapple	1.45 ± 0.82	1.71 ± 0.62
	Star nut palm	1.83 ± 0.39	1.92 ± 0.29
	Mean	1.34 ± 0.69	1.84 ± 0.41
The Americas	Bell pepper[a]	2.00 ± 0.00	0.32 ± 0.64
	Maize	2.00 ± 0.00	0.29 ± 0.62
	Papaya	2.00 ± 0.00	0.50 ± 0.80
	Red bean	2.00 ± 0.00	0.38 ± 0.64
	Squash	1.92 ± 0.29	0.50 ± 0.67
	Sweet manioc	1.33 ± 0.65	1.55 ± 0.79
	Sweet pepper	2.00 ± 0.00	0.50 ± 0.81
	Tomato[a]	2.00 ± 0.00	0.10 ± 0.32
	West Indian Gerkin[a]	2.00 ± 0.00	0.88 ± 0.80
	Mean	1.92 ± 0.10	0.56 ± 0.68
Old world	Banana	0.42 ± 0.67	1.41 ± 0.70
	Coconut[b]	2.00 ± 0.00	0.55 ± 0.69
	Cucumber[a]	2.00 ± 0.00	0.50 ± 0.67
	Lemon	1.42 ± 0.90	1.42 ± 0.79
	Okra[a]	2.00 ± 0.00	0.35 ± 0.67
	Onion	1.64 ± 0.67	0.40 ± 0.66
	Rice[a]	2.00 ± 0.00	0.25 ± 0.71
	Sugar cane	1.50 ± 0.80	1.13 ± 0.88
	Watermelon[a]	1.90 ± 0.32	0.22 ± 0.36
	Yam	1.50 ± 0.80	1.88 ± 0.31
	Mean	1.64 ± 0.42	0.78 ± 0.64

[a] Despite the somewhat widespread usage of these crops on small landholdings today, farmers continue to depend on centralized markets for seed. This may suggest the predominance of these crops on Black Earth is a relatively recent phenomenon.

[b] The coconut was domesticated in the western Pacific region, yet had made it to the Americas prior to European arrival. Without any information on its arrival to the Amazon region, it would be premature to consider it a crop available to the occupants of Black Earth sites prior to contact.

The specific sequence of events leading to qualitatively distinct pedological and cultural processes on Black Earth sites is still unclear. What is clear is that the availability of nutritious crops exhibiting a favorable yield response to Black Earth and cultural processes occurring outside of Amazonia are likely to have influenced cultural developments on these sites.

4.2. Political-economic factors as historical contingencies to crop selection and Black Earth cultivation

It is important to recognize that farmer decision-making reflects a desire not only to maximize yields, but to derive other cultural and economic benefits. In recent decades, much literature has focused on the strong influence of centralized markets on subsistence practices, even in remote regions (Anderson, 1995; Ozorio de Almeida, 1992; Rudel and

Horowitz, 1993). Despite the tendency to view economic activities of traditional Amazonian groups as localized, apolitical and tightly coupled to local environmental conditions (Gross, 1975; Rappaport, 1984), there is increasing evidence that political-economic influences among even the most isolated groups have important impacts on land-use (Chernela, 1993; Whitehead, 1993). They are also likely to have affected the decision-making of early Black Earth occupants by affecting the relative benefits of intentional soil modification (and Black Earth cultivation) and other economic activities. Field observations and informant ratings point to an array of additional economic and cultural factors that influence the cultivation practices of contemporary Amazonian farmers. The role of specific political-economic factors is emphasized here.

Discrepancies between crop performance and actual cropping practices on Black Earth in the Central Amazon may be attributed, in part, to these influences. Correlation coefficients are useful for highlighting relationships between actual behavior (crop selection) and the factors influencing these practices. When farmers rated crop performance on each soil class, they were also asked to rate crops according to additional influences as identified through semi-structured interviews. Among these, two political-economic factors were pointed out for their influence on crop selection: profitability (“more lucrative”), and the rate at which crops mature and yield cash returns (“produces quickly”). Farmers then rated crops according to each incentive or criterion, as was done for crop performance (Table 2). Results were scaled from zero to one (crop x offers few or significant advantages for criterion y, respectively) to facilitate interpretation.

Table 5 highlights the relationship between these economic and pedological incentives on the one hand, and crop abundance on the other, through the calculation of Pearson’s correlation coefficients (r) for three measures of crop abundance (% of farms, % of

Table 5
Identifying the relative importance of diverse causal factors in farmer decision-making (cropping practices) on Black Earth and Latosols[a]

Cropping incentives	*Terra Preta*			*Terra Comum*		
	% Farms	% Swids.	% Plts.	% Farms	% Swids.	% Plts.
Yield potential[b]	0.43	0.15	− 0.32	0.79	0.74	0.52
Profitability	0.14	− 0.01	0.18	− 0.29	− 0.25	0.05
Rate of return	0.29	0.03	− 0.27	− 0.67	− 0.66	− 0.43
Outlier (bitter manioc) removed						
Yield potential	0.53	0.47	0.50	0.81	0.72	0.75
Profitability	0.14	− 0.04	0.35	− 0.67	− 0.62	− 0.21
Rate of return	0.33	0.25	0.33	− 0.68	− 0.67	− 0.60

[a] Values are correlation coefficients that represent the relative strength of association between crop ratings (of crop performance, economic returns and production cycle) and actual botanical data on each soil class (left column and top row, respectively).

[b] Calculations of yield potential were made on the basis of crop performance ratings. Additional parameters (“more lucrative, “produces quickly”) were assessed because they were stressed by a number of farmers through informal interviews, and therefore demonstrate the cultural importance of economic returns and short production cycles (respectively). Similar rating exercises were carried out for these parameters accordingly.

swiddens and % individual plants[16]). The "% of farms" measure is new, and is derived from the grouping of results from all swiddens cultivated by each collaborator and his or her nuclear family.

R-values are positive for most cropping measures, again demonstrating that soil fertility plays a causal role in crop selection. One exception (column 3) is found where bitter manioc is planted in abundance on Black Earth despite perceptions about depressed yields and increased labor inputs on these soils. The cultural importance of bitter manioc in the regional diet increases its abundance on Black Earth despite limited biophysical incentives for such a pattern. Furthermore, there is a disproportionate relationship between high economic incentives for planting cash crops on Black Earth, and the total area and duration of these crops in the swidden (both of which are relatively low). The importance of these crops to Black Earth farmers is therefore obscured in relation to bitter manioc, which is abundant both spatially and temporally in farmers' swiddens despite moderate to low returns in regional markets. In the bottom half of the table, the removal of bitter manioc, a strong outlier, from the calculation of r strengthens the association between soil chemistry and cropping behavior on Black Earth. This suggests that the selection of crops other than manioc on these soils is largely contingent upon soil chemistry, but that crop performance does not account for the full variability in cropping practices.

A second important observation involves the influence of political-economic factors, for which r-values are much lower than for crop performance ratings. This suggests that biophysical stimuli play a more important role in conditioning cropping practices than political-economics per se. If we were to interpret r values as evidence for causal relations between independent and dependent variables, high economic returns would seem to be a deterrent to cropping practices on the region's Latosols. This contradiction can be explained by the strength of association between soil fertility and cropping behavior on these nutrient-poor soils, which limits the ability of farmers to plant economically important crops on these soils. Low fertility is likely to be a stronger constraint than market influences are a cropping incentive, skewing r-values accordingly. In this case, regional markets are flooded with products derived from the few crops that thrive on these soils, lowering consumer demand and economic returns accordingly.

On Black Earth, this relationship between cropping behavior and political-economic incentives is weak, but nevertheless tends to be positive. This would suggest that soil fertility is less of a constraint on Black Earth, giving farmers greater latitude for responding to other, non-biophysical incentives. The negative values for Black Earth in the third column are reversed and positive values increased when the outlier (bitter manioc) is removed, again suggesting that economic incentives play an important role in Black Earth cultivation practices. While r-values for the "percentage of swiddens" measure are negligible for Black Earth, this is a poor indication of the economic benefits to Black Earth cultivation. This is due to the tendency of farmers to segregate cash crops spatially and temporally according to crop-specific management requirements, eliminating them from swiddens in which traditional root crops are planted.

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[16] The last two measures (% swiddens, % individuals) are the same as those in Table 2.

The tendency for political-economic incentives to have a greater influence on Black Earth cropping practices than on Latosols is better shown ethnographically. Local residents claim that the ability to cultivate fast-growing, non-traditional crops for sale in centralized markets allows them to generate significant returns in a limited period of time. The high fertility of Black Earth appears to de-couple agricultural practices from environmental constraints, giving farmers more latitude to select crops on the basis of economic returns or other cultural criteria.

Extrapolations of these findings to earlier periods is difficult given the crop-specific incentives underlying cultivation of Black Earth, recent introduction of many common "Black Earth crops" and the disappearance of some traditional cultivars. It is, however, clear from the literature and above data that local and regional political-economic factors influence the potential benefits derived from a nutrient-enhanced environment. Furthermore, the availability of exotic crops with a positive yield response on Black Earth was more restricted in earlier periods, minimizing some of the incentives that today drive Black Earth cultivation (i.e., urban demand).

The absence of centralized demand for "Black Earth crops" may have restricted incentives for Black Earth cultivation and labor-intensive soil modification, or distinct political-economic incentives may have emerged to drive these activities. Newly introduced crops from other regions throughout the Americas, for example, may have been low enough in supply (due to low yields) and high enough in demand (due to their value as substitutes for faunal protein or in leveraging political power) to provide sufficient incentives for agricultural intensification. Collaboration among paleobotanists, human ecologists and archaeologists would be highly productive for reconstructing past relationships between crop introductions, political-economic influences and cultural and pedological aspects of site evolution.

4.3. Environment as historical contingency to agricultural intensification and sustained production

Linkages between environmental properties (structure, function, quality) and diverse resource procurement strategies are well documented (Frechione et al., 1989; Gragson, 1993; Moran, 1989). Given evidence for human modification of the environment (Balée, 1989; McCann, 1999; Mora et al., 1991), it is important to recognize that local environments have a history—both natural and cultural—and that human adaptive strategies both reflect and contribute to this history. This is also true for Black Earth, which is by definition historical (an outcome of historical rather than evolutionary processes), originating through soil changes for which anthropogenic processes are at least a trigger (Woods and McCann, 1999; Zech et al., 1990). The tendency of Black Earth farmers to engage in distinctive cropping practices on Black Earth and Latosols is an example of human adaptation to the "artifactual resources" of past inhabitants (Balée, 1992). It also demonstrates how both "natural" and "cultured" environments condition human behavior and ecological praxis at any point in time.

To better understand the role of Black Earth in broadening the range of viable production practices or enhancing the carrying capacity of localized environments prior to European arrival, it is important to look at how the environment itself may have changed through time. Recent authors have claimed that heightened biotic activity and nutrient retention capacity resulting from cultural amendments may lead to a sustained and progressive melanization of the soil matrix on Black Earth, independent of further organic inputs (Woods and McCann, 1999). Yet if enhanced productivity is to be sustained, nutrient losses from leaching, volatilization, the harvest, etc. must not exceed these and other nutrient-maintaining processes (Young, 1997).

The historical nature of archaeological soils, including concurrent and alternating periods of soil building and soil degradation (Woods, 1995), complicates attempts to utilize contemporary cultivation practices as a model for past land use. However, findings about the limits to current farming practices on Black Earth, and of the changes that occur in the soil through use, may illustrate what is needed for agriculture to be sustained on these soils.

Black Earth is known for its remarkable persistence in the face of intensive weathering processes (Pabst, 1991; Smith, 1980; Woods and McCann, 1999). This has been attributed to many factors, including the role of organic compounds in binding carbon to soil colloids (Smith, 1980), progressive melanization associated with heightened biological activity (Woods and McCann, 1999), the structure and stability of soil organic matter (Pabst, 1991), and the abundance of black carbon (Glaser et al., 2001). While maintenance of these characteristic properties of Black Earth is significant, I saw evidence for Black Earth degradation under conventional and traditional cultivation systems. This includes whitening of the epipedon from tillage and intensified weathering (i.e., from forest removal), a process observed by long-term Black Earth farmers and documented by Smith (1980).

The idea that spontaneous soil-building processes may overcome ongoing nutrient losses holds important implications for sustained production on Black Earth. The tendency for melanization to be offset by mineralization in well-drained tropical soils (Buurman, 1984) would suggest that there are important constraints to spontaneous soil-forming processes. Yet the properties of Black Earth have been known to defy scientific expectations for the region's soils. It is nevertheless important to identify specific processes that would contribute a continuous supply of nutrients to feed spontaneous growth in the face of mineralization losses, leaching and use (in particular for earth-bound elements). In the absence of spontaneous growth, agricultural productivity on these anthrosols would depend on nutrients already present in the anthropic horizon and on ongoing, culturally induced soil formation processes.

In the absence of long-term field trials, it would be difficult to determine the capability of Black Earth to sustain elevated levels of productivity. The relative influence of melanization and use regimes on the balance between soil-forming and soil-degrading processes is unknown, and Black Earth's unique characteristics make reasoning through inference particularly difficult. Ethnographic inference is equally problematic. Yet research on the swidden agricultural cycle illustrates limits to sustained cultivation under current use regimes and illustrates practices that would have precluded the preservation of Black Earth and its persistence on today's landscape.

Contemporary farmers utilize a number of strategies to enhance crop productivity on Black Earth, including the management of crop residues and weeds, the *coivara*[17] and

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[17] A system by which slashed vegetation is gathered and burned to create isolated pockets of nutrient-rich soil.

Table 6
The Swidden agricultural cycle on Black Earth and Latosols

Parameter	*Terra Preta*	Latosol
Average time in production (with outlier)	10.8 months	28.0 months
Average time in production (outlier removed)[a]	6.6 months	28.0 months
Average age of fallows[b]	51.5 months	131.1 months
% Swiddens cleared from mature forest	25.6%	72.7%

[a] When data in the first row are disaggregated, there are two strong outliers for Black Earth. One corresponds to a fruit garden planted within a swidden, which has been kept in production far beyond the average age at which swiddens are abandoned on *either* soil class. The second corresponds to swidden in which manioc and other crops were cultivated for seven consecutive years, contrary to the predominant tendency to abandon a swidden when yields of the more nutrient-demanding crops begin to decline (i.e. before extreme nutrient depletion). Data in the second row are therefore more representative of Black Earth management practices for the region.

[b] Despite the tendency for Latosol swiddens to be cleared from mature forest, I have utilized those cleared from fallow vegetation as the basis for calculations. This gives a time figure for Latosols that permits comparison of the two systems. In addition, it better reflects the linkage between time in production and *minimum* fallow age than a calculation based on mature forest. This is due to the fact that the amount of nutrients liberated from fallow is less than from mature forest, and therefore directly impacts the time a fallow is kept in production.

burning. With the exception of house gardens,[18] however, most of these are nutrient transformations and translocations within the agricultural system (German, 2001) rather than net inputs of nutrients. As such, the ability of fallow vegetation (and associated mycorrhizae) to scavenge nutrients from the atmosphere and subsoil is perhaps the primary factor influencing long-term site productivity. By studying fallow dynamics on Black Earth in relation to non-anthropogenic soils, limitations to sustained production in the absence of ongoing cultural amendments are identified.

Data in Table 6 indicate that both fallow and cultivation stages of the swidden agricultural cycle are significantly shorter on Black Earth. It was evident from farmer commentary and direct observation that rapid weed invasion, the shorter cropping period of most Black Earth crops and the greater ease with which young fallow can be cleared (a practice viable only on more nutrient-rich Black Earth[19]) are each important factors in swidden abandonment. Soil fertility decline ranks high among these factors, as demonstrated by the drop in soil potassium below that required for most crops (Van Raij, 1991; Yuste and Gostincar, 1999) at the time of abandonment (30.36 and 16.91 mg dm^{-3} at 0–10 and 10–30 cm depths, respectively). Furthermore, farmers tend to re-plant rather than abandon a swidden if soil fertility remains adequate. They also frequently describe the soil as “weak” at this time, suggesting that soil fertility decline is an important determinant of swidden abandonment. This is to be expected, given the tendency of nutrient-demanding cereals (planted only on Black Earth) to deplete nutrient reserves more quickly.

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[18] House gardens on Black Earth were limited in number on the lower Negro and Urubú, making swiddens the logical focus for comparative research. Research on house gardens is nevertheless needed to gain insight into practices that may have permitted sustained production on Black Earth and limited associated nutrient losses.

[19] Farmers claim that a minimum of 10 years of fallow is needed for site recuperation on Latosols, even for the cultivation of bitter manioc, a crop well adapted to acid, nutrient-poor soils.

While early Black Earth occupants might have used soil amendments to offset nutrient losses, short swidden cycles and ethnographic data among contemporary farmers demonstrate limits to sustained cultivation in the absence of ongoing anthropogenic soil-building processes. The importance of fertility decline in swidden abandonment on each soil makes it possible to use data on the swidden agricultural cycle to estimate the total time any given area could hypothetically be kept in continuous production under current use practices.

The average age of the vegetation cleared to establish a swidden on Black Earth is much younger than on Latosols (4.3 vs. 10.9 years), and the total time Black Earth swiddens are kept in production is much shorter (10.8 vs. 28.0 months). If we were to extrapolate over a 20-year period, Black Earth would be cultivated for a total of 27.3 months (2.3 years), while Latosols would stay in production a full 14.9 months longer (3.5 years). Black Earth production would need to be 35% higher to compensate for this shorter period of cultivation.

The greater benefits derived from the higher nutritional value and economic returns of "Black Earth crops" than from dramatic increases in yield limit the value of these calculations when studied in isolation. Yet swidden dynamics and field observations on the degradation caused by continuous cultivation clearly show that in the absence of ongoing cultural amendments, the carrying capacity of these environments would not be significantly greater than that of adjacent sites. Significant and ongoing soil amendments would therefore be necessary to sustain cultivation on these soils, particularly of nutrient-demanding crops like maize.

Given the diversity of factors influencing the age of vegetation cleared for a swidden (availability of soils and old forest, labor concerns, etc.), and historical changes in farming practices, crops and the soil itself, it would be impossible to determine prior use patterns on the basis of current use. Ethnographic data among contemporary farmers are nevertheless useful in a number of ways. First, they demonstrate that Black Earth productivity is not limitless. The specific mechanisms for maintaining site productivity must be identified if we are to conclude that Black Earth played an important role sustaining past inhabitants, while also surviving into the present as a well-preserved artifact of human ingenuity. Second, they point to promising areas for future research. Field trials and mass balance calculations on less degraded Black Earth sites, such as those that were left uncultivated during recent decades of rapid urban population growth (and increased demand for exotic crops), might be carried out to estimate the sustained yield potential of Black Earth. By identifying crops available to Black Earth inhabitants through time, paleobotanists can help target crops to be evaluated in field trials and identify likely nutritional benefits resulting from anthropogenic soil modification. Most importantly, these data would increase current understanding of the role of anthropogenic soil modifications in sustaining greater sedentism and population densities in prehistory.

5. Conclusion

Identification of important incentives and preconditions for Black Earth cultivation among contemporary farmers helps to illustrate how the benefits of anthropic soil-forming processes are likely to have varied through time. Dynamic technological, economic and environmental factors are shown to influence advantages and disadvantages of Black Earth cultivation, suggesting that the importance of Black Earth in sustaining regional populations has been highly variable. If incentives for cultivating an existing anthrosol are limited under certain circumstances, then the conditions under which labor-intensive soil enhancement would be feasible or desirable would be even more restricted. Caution should therefore be exercised in drawing causal relations between soil modification and cultural developments in pre-contact Amazonia, and in positing unbridled ecological praxis among traditional groups. That radical changes in the make-up of terra firme environments were brought about by human agency is unquestionable. That these modifications could be created at will—independent of a dynamic historical climate influencing available technology and labor, economic incentives for diverse practices, and environmental quality itself—is a claim altogether different in scope. Alternative trajectories of Black Earth site evolution (intentional or accidental, agricultural or depositional) and function (in agricultural intensification, population growth, etc.) must be supported accordingly.

This paper takes a distinct approach to ethnopedology, focusing not on the linkages between soil knowledge and management but on the ways in which dynamic historical circumstances play a role in management decisions. Black Earth and Latosol farmers in the Central Amazon do have a fully developed repertoire of soil knowledge that is passed on from generation to generation and modified on the basis of new historical circumstances (German, 2001). The presence of highly distinctive production practices on Black Earth shows how ethnopedological practices and understandings are dynamic, which in turn demonstrates the assimilation of environmental changes occurring as a function of natural and cultural processes. Yet the outcomes of ethnopedological inquiry are also useful in reconstructing the history of human interaction with the landscape, and for understanding the relative influence of technology, economy, environment and human agency on this history.

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