Soil fertility management and its contribution to the formation of amazonian dark earths in urban homegardens, Santarém, Pará, Brazil

A. M. G. A. WinklerPrins[A] and N. Falcão[B]

[A]Department of Geography, Michigan State University, East Lansing, MI, USA, Email antoinet@msu.edu
[B]Agronomy Section, Instituto Nacional de Pesquisas da Amazônia, Manaus, Brazil, Email nfalcao@inpa.br

Abstract
In order to understand how anthropogenic soils, Amazonian Dark Earths, may have been formed in the past, this study considered soil fertility management in 40 homegardens in the Amazonian city of Santarém, Pará, Brazil. We compared the soil chemistry of a soil conditioner created by the slow burning of organic household debris known as Terra Queimada (TQ) with adjacent non-TQ soil. We found that the TQ had significantly higher CEC, higher pH and was in general much more fertile than the adjacent soil. Although preliminary and small-scale, this study supports the hypothesis that ADEs were likely formed through cool, slow burning, and that this process can likely be recreated to help improve low-fertility soils in the Amazon region.

Key Words
Soil fertility management, anthropogenic soils, Amazonian Dark Earths, carbon.

Introduction
Amazonian Dark Earths (ADEs), also known as *Terra Preta* (*do Índio*) (Black Earth [of the Indians]) soils, are highly fertile organic-rich anthropogenic soils ('Hortic Anthrosols') found throughout the Amazon Basin in small patches ranging in size from about 2 to 300 ha (Sombroek 2002; Kern *et al*. 2003). Overall it is estimated that there are 6,000-18,000 km^2 (or 0.1%-0. 3% of 6 million km^2) ADE in the region, but the majority (80%) of ADE sites are very small (<2 ha) (Wood and McCann 1999; Kern *et al*. 2003; Sombroek *et al*. 2003). Organic waste of native Amazonians likely had a major influence in the high level of organic material typically found in ADEs (Wood and McCann 1999). Vegetative food remains such as those from manioc and fruit processing as well as animal residues such as bones, exo-skeletons and carapaces of armadillo, tortoise, crab and shells produce great quantities of organic residue that is not consumed but does remain in place (Wood and McCann 1999). These organic materials are responsible for the increase of a number of elements present in ADEs (Kern 2001). Pabst (1991), in studying ADEs in the region around Belterra, Pará, Brazil, confirmed that the humic fraction in ADEs is six times as stable as the humic fraction in Oxisol. The significant stability of the organic material of ADEs is why Amazonia's native peasantry, the Caboclo people, consider ADEs the most fertile soil available in the region today, and actively seek it out for cultivation.

Research to date confirms that Amerindians are responsible for the formation of ADEs approximately 500 to 2,500 years ago. What is still not well understood is how ADEs were formed initially and how they might continue to be formed by residents of the region today. Strategies of soil management in urban homegardens today offer a window into ADE formation rooted in daily practice, which may, over time, result in ADEs. In many parts of the world, including the Brazilian Amazon, homegardens are small-scale agricultural production systems. They are multi-layered agroforestry systems for the production of food, fibers, medicinal plants and construction materials, most of it for subsistence (Kumar and Nair 2006. Much research in homegardens has been centered on the agrobiodiversity of homegardens and their role in conserving that diversity, but the soil management of these gardens has not been considered even though it is what is important in terms of ADE formation. In this context, research on homegardens has documented a soil management process locally known as *Terra Queimada* (TQ), or 'burnt earth' (WinklerPrins 2002; WinklerPrins and de Sousa 2005). This practice involves the sweeping of homegarden organic debris such as leaves, branches, seeds, peelings are other household residues such as fish or chicken bones to a remote area of the yard where everything is burned, using a slow and cool burning technique. This process creates TQ. The process of burning has two functions, 1) it gets rid of household garbage; and 2) creates a soil conditioner that is rich in organic materials and nutrients that is used to fertilize plants in homegardens. The basic objective of this research was to evaluate the changes in soil fertility as a result of the use of *Terra Queimada* (TQ), burned earth, in homegardens in the Municipality of Santarém, Pará, Brazil, considering that this process may serve as a possible modern-day ADE formation analog.

Materials and methods

This research was conducted in 40 homegardens in the Amazonian city of Santarém, Pará state, Brazil. In each homegarden two samples were taken in the TQ pile and two from an adjacent (non TQ) soil. Each sample was collected at 0-10 cm, 10-20 cm, and 20-30 cm depths. Samples were dried and passed through a 2 mm sieve. Chemical analysis was conducted to determine the values for $pH_{(H2O)}$ and $pH_{(KCl)}$ l, P, Ca^{2+}, Mg^{2+}, K^+, Al^{3+} and $H^+ + Al^{+++}$. Also calculated was base saturation (BS), cation exchange capacity (CEC), and percentage of Al saturation (% m) (Embrapa 1997). Data were calculated and analyzed using descriptive statistics using the ASSISTAT 8.0 program.

Results and discussion

Soil acidity limits plant production indirectly by limiting available macro and micro-nutrients and the existence of some toxic elements such as Al and Mn. The acidity of the soil could be caused by the increase in concentration of CO_2, through rainfall or microorganism respiration, roots or the decomposition of organic material. The removal of the absorbed bases through cultivation and lixivation also work together and augment the acidity of the soil. All these factors that influence the acidity index of the soils could be present in the agricultural systems on ADE, some with different levels of intensity.

Table 1 demonstrates how the soil management process used in urban homegardens can produce a material rich in macro and micronutrients and is important for cultivated plants. The average $pH_{(H2O)}$ values encountered in the 0-10 and 10-20 cm soil layers in the TQ are extremely high and reveal a direct effect of burning and the production of pyrogenic charcoal and ashes, neutralizing the effects of Al^{+++} and also of H^+. The elevation of $pH_{(H2O)}$ directly reflects the decrease in exchangeable acids, demonstrating values of Al^{+++} between 0.12 and 0.14 cmol/kg, values considered extremely low. The values of $pH_{(H2O)}$ in TQ are higher than those of the non-TQ adjacent soils, and this impacts the values of the exchangeable acids (Al^{+++}) and potential acidity ($H^+ + Al^{+++}$) demonstrating that TQ represent lower values of these variables.

Table 1. Average values of chemical attributes of TQ and adjacent non-TQ soils in the 40 homegardens sampled in the Municipality of Santarém, Pará, Brazil.

Soil Type	Depth	pH	pH	N	P	K+	Ca++	Mg++	Al+++	Al+H	Fe	Zn	Mn
	(cm)	H_2O	KCl	g/kg	mg/kg	-------------------cmol/kg-------------------					--------mg/kg--------		
Terra Queimada	0—10	6.4	5.9	1.0	460	0.59	4.34	0.83	0.12	0.86	112	26	32
Terra Queimada	10—20	6.6	5.9	0.9	366	0.40	3.56	0.70	0.14	1.44	137	21	25
Adjacent soil	0—10	5.9	4.6	0.5	72	0.07	0.81	0.08	0.44	2.59	184	4	5
Adjacent soil	10—20	5.5	4.3	0.4	54	0.06	0.62	0.06	0.54	2.71	203	2	3

In general Oxisols are extremely acid, with $pH_{(H2O)}$ values between 4.0 and 5.0 (Sombroek, 1966). Samples of Distrophic Yellow Latosols (Brazilian classification), collected at the Fazenda Aruanã, in the Municipality of Itacoatiara, Amazonas state, exhibit average pH values of 4.20 in the topsoil and 4.24 in samples from the subsoil (Falcão & Silva, 2004), the same was found by Moreira & Malavolta (2002), in the same type of soil under *cupuaçu* trees and manioc. Samples from Yellow-Red Ultisols collected at 0-20 cm, with an agroforestry systems in the Municipality of Manacapuru, demonstrate $pH_{(H2O)}$ values of about 4.5 (Falcão, 2001). Soils in our sample do not exhibit the low pH values typical of regional Oxisols, even though these are the underlying natural soils found in homegardens.

Parameters such as CEC and base saturation (BS) are all much higher in TQ than in adjacent soils (Table 1). These elevated levels of CEC are not just the result of a higher quantity of organic material, but also due to the existence of a higher density of charges available on the carbon (Sombroek *et al*., 1993; Liang *et al*. 2006). This property of organic carbon is specific to soil carbon with high amounts of pyrogenic charcoal, such as found in ADEs (Glaser *et al*. 2001; Cunha *et al*. 2007). The reasons for the higher efficiency of nutrient retention of pyrogenic carbon is because: (a) pyrogenic charcoal has a much higher specific surface than charcoal made under high burn conditions; (b) represents a much denser negative change per unit of the surface area, consequently a higher overall charge density (Liang *et al*. 2006). This elevated charge density can, in principal cause oxidation of the pyrogenic carbon itself or through the adsorption of non-pyrogenic charcoal (Lehmann *et al*. 2005). Both processes have been observed in ADEs (Liang *et al*. 2006). The chemical values presented in Table 1 for TQ demonstrate very similar characteristics to those found in ADEs, likely because of the cool, slow and repeat burning that occurs in the TQ piles in homegardens. The values of Ca, Mg, K e Al as well as the CEC and BS as shown in Table 1, demonstrate soil fertility parameters that are much higher in the TQ soil than in the adjacent non-TQ soil.

P is a nutrient that is very important for plant growth, given that many natural soils do not contain sufficient available phosphorus for high productivity. The total P contained in the earth's crust is approximately 0.12% and in soils it can vary from 0.02 to 0.5%, with an average of 0.05%. Sombroek (1966), while studying ADE profiles in the region around Belterra, Pará state, encountered elevated levels of total P_2O_5 in both the topsoil and the subsoil. He also observed that the highest values were encountered in ADEs, with a much clayier texture. In the current study we encountered values of available P that were much higher in the TQ. These results support the hypothesis that large quantities of animal bone were burned, resulting in a large amount of available P for plants. Potassium values were higher in TQ and much lower in adjacent soils. Another element that was much higher in TQ than in adjacent soils was Zn. Given the results of our study to date, we can conclude that present-day soils management in homegardens, particularly the creation of TQ, supports the hypothesis that this soil management practice was used by indigenous people to initially form ADEs.

Acknowledgements
We are immensely grateful to the Santarém householders who let us into their backyards and let us sample their soils, burn piles, and let us interview them. We also extend sincere gratitude to Sandoval Morais, Steve Aldrich, and Perpetuo Socorro de Sousa Oliveira for their important roles in making this research a reality.

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