Terra Preta and Terra Mulata: pre-Columbian Amazon kitchen middens and agricultural fields, their sustainability and their replication

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Abstract

Anthropogenic Black Earths (hortic Anthrosols) occur in many places of the Amazon region, in patches that vary from 5 to over 300 ha. They are locally known as Terra Preta (do Indio) and are apparently kitchen middens of pre-Columbian Amerindian settlements that have transformed the original soils (Ferralsols, Acrisols, a.o.) into black Fimic Anthrosols, with approximately double the amount of soil organic matter (SOM), higher amounts of Phosphorus, Calcium, Magnesium, Zinc and Manganese, and presence of ceramic artefacts.

Recent field studies indicate that these soils are often accompanied by bands of soils with dark brown rather than black colour and near absence of artefacts, but still with the same high amount of SOM. They are locally called Terra Mulata, and would appear to be the lasting result of intensive agricultural use by erstwhile Indian communities. The SOM of both the Terra Preta and the Terra Mulata is very stable and at the same time more re-active than the SOM of the original soils under primary forest cover.

An interdisciplinary and inter-institutional project is in the making, to establish the reasons for the sustainability of the qualities of both types of anthropogenically enriched soils; to obtain an inkling on the land use practises of the former Indian tribes that led to such a lasting enrichment, and to develop a replicating land management package for the benefit of more sustainable and more concentrated present-day small-holders settlement. A technical and socio-economically successful package would substantially contribute to sequestering of atmospheric CO_2 into the managed soils, and at the same time leave more primary forest intact with its own CO_2 stock and sink function and biodiversity values.

Keywords: Amazon region, anthrosols, pre-Columbian settlements, soil organic matter, carbon sequestration, tropical forest conservation

Introduction

Anthropogenic black earths are of frequent occurrence in the Amazon region, especially the Brazilian part. They are locally known as *Terra Preta*, *Terra Preta-do-Indio,* or *Terra Preta arqueológica/antrópica* and are the lasting effect of intensive occupation by pre-Columbian Amerindian tribal communities in the region. They have been mentioned and described by archeologists and anthropologists (Denevan, 1992; Whitehead, 1996; Petersen *et al.*, 2001), but also by ecologists, agronomists and soil scientists (Sombroek, 1966; Smith, 1980; Moran, 1990; Kern and Kämpf, 1989; Pabst, 1993; Costa and Kern, 1999; Glaser, 1999; McCann *et al.*, 2000; Mann, 2000; Cleary, 2001; Kern *et al.*, 2001). There are also two web-sites on the matter, one in Germany (English): www.geo.uni-bayreuth.de/bodenkunde/terrapreta/index.html, and one in Brasil (Portuguese): www.museu-goeldi.br/pesquisa/ecologia/tpa/paginas_ imagens/tpaindex.htm. Terra Preta (TP) soils contain artefacts (ceramics, potsherds, stone tools, charcoal), are black or very dark brown till at least 50 cm depth, have high levels of plant-available P levels (above 100 mg kg^{-1}) and are less acid than the surrounding soils. Nowadays, they are preferentially sought for agricultural settlement by traditional small-holder subsistence farming communities, who recognise them easily even when under high forest cover – the tree species assemblage being different. The soils occur usually in small patches averaging 20 ha, but 300-500 ha. sites have been reported as well, especially for the uplands (*terra firme*) in the neighbourhood of confluences of main rivers: Rio Negro-Rio Solimões near Manaus, Rio Madeira-Rio Amazonas near Itacoatiara, Rio Tapajós- Rio Amazonas near Santarém, and Marajó island in the mouth of the Amazonas-Tocantins system [composite map with all known sites and maplets of Belterra and Caxiuanã sites to be shown at oral presentation].The smaller patches of TP soils are also found in upper catchment areas, all along the main tributaries of the Amazon, along rivulets (*igarap*és) feeding into these main tributaries such as former ring villages of the Upper Xingu (Heckenberger *et al.*, 1999), and along age-old forest tracks between river systems (McCann, 1999). For south-eastern Amazonas state and north-eastern Rondonia, recent geo-pedological surveys for ecologic-economic zoning yielded estimates of TP sites every 5 km along the *igarapés,* and an over-all spatial coverage of one per 2 km^2 (verbal comm. Horbe, CPRM; Jarbas and Rodrigues, Embrapa-Soils; and Josuel Ravoni of SEDAM, respectively). Terra Preta soils occur also in the Amazon parts of Colombia (Araracuara area: Andrade, 1986; Eden *et al.*, 1984; Mora, 1999), of southern Venezuela and of Peru, but apparently less frequently.

Archeologically, a number of different ceramic phases are distinguished, associated with former tribal chiefdoms (Hilbert, 1968), most of them having their peak of cultural development between 500 and 1500 AD. Most researchers now estimate the total Indian population in Amazonia to have been between 5 and 10 million at the time of the Spanish and Portuguese conquest (Roosevelt, 1996; Denevan, 1998; Petersen *et al.*, 2001)-soon to be decimated and then becoming by-and-large nomadic (Cleary, 2001).

In a number of cases the patches of TP are surrounded by a broad band of Terra Mulata (TM) soils. They are dark greyish brown rather than black in their upper horizons, have less elevated P levels, no or very few artefacts, but still elevated levels of soil organic matter in comparison with the undisturbed forest soils. They have been described by Sombroek (1966) for the Belterra area south of Santarém, by Woods and McCann (1999) for the Arapiuns area west of Santarém, by Kern (1996) for the

Caxiuanã area east of the lower Xingú area, by Horbe (verbal comm.) along the Rio Juma, 100 km north of Apui on the TransAmazonica, and by Jarbas Cunha (in prep.) for the Humaitá area on the Madeira river. These authors consider such areas as pre-Columbian agricultural fields around the former Indian major villages, in-between the kitchen middens or homestead fields of the TP sites proper and the unaltered soils of the forests, where only foraging took place. Whereas the increase in soil organic matter and mineral fertility on the homesteads may have taken place accidentally, the TM areas would be the result of intential application of human or animal manure, green manure from forest or river, charcoal and ashes, fishing and hunting remains and calcium from pounded mollusc shells or root accretions (Roosmalen, pers. comm). This would allow a semi-permanent horticultural type of food production once a piece of forest-land had been cleared strenuously with stone hand-axes and subsequent burning.

Both TP and TM soils are surrounded by natural soils under primary forest, where most of the organic matter is concentrated in the upper 20 cm. They may be Ferralsols (mainly xanthic, sometimes orthic or rhodic), Acrisols or else, have a sandy to clayey texture, variable stoniness, and nearly invariably a high amount of exchangeable Al (pH 4.5 or lower). It is nowadays generally accepted that the TP and TM soils are not the result of natural soil forming factors on rich parent material, but the lasting effect of anthropogenic influences on natural forest soils that happened to be located on strategic river bluffs, indigenous forest tracts between tribal communities, heads of rapids, etc. In fact, the deeper subsoils of the TP and TM soils have still the same clay mineralogy, colour, texture and structure as the nearby natural soils.

Characteristics and Classification Criteria

A geographic database is being compiled of all the sites where Terra Preta and Terra Mulata soils have been identified, accompanied by relevant site- and soil profile descriptions and analytical data, and several representative soil monolith sequences. There will be a substantial variation in detailed characteristics of both soil types, in dependence of the original soil, the length of the pre-Columbian occupation, the precise land use and management practises of the various Indian groups and chiefdoms, and the type of water of the neighbouring river. The latter, in particular, will have caused major differences. The plant- and animal resources of clear waters (no sediment load, but neutral pH and presence of calcium: *agua clara* or *agua azul*) are different from the muddy river waters (an appreciable load of sediments and a variety of cations: *agua branca* or *barrenta*), or from the black waters (no sediments nor cations, but very acid due to the presence of humic acids: *agua preta*). The latter situation occurs most frequently in the area of podzolised soils in the upper and middle courses of the Rio Negro, where TP patches are rare and small. TM soils have been indirectly reported for the lower Rio Negro area only (Prance and Schubart, 1977).

The data available thus far point to a much higher soil organic matter (SOM) content of the two soil types-often double the normal amount-which has moreover a high degree of permanency. The hetero-trophic respiration by microbial digestion is apparently low for the subsurface and subsoil layers, resulting in high percentages of stable or "recalcitrant" SOM with C/N values of 12 or higher. At the same time this SOM is apparently more re-active than the organic matter in the primary forest soils: the CEC-SOM values are 50-100% higher (Sombroek, 1995). [graph with additional curve points to be shown at oral presentation]. This means that the soils concerned can accept and subsequently release substantially more fresh plant nutrients.

Detailed studies on the specific composition of the SOM of TP and TM soils are few (Glaser, 1999), A specific microbial activity may be involved, with certain microbes acting as inoculate (Woods and McCann, 1999). Studies on bacterial functional redundancy" of the soils (Sparovek, in press) may elucidate this aspect.

The values of plant-available phosphorus are strikingly high in the TP variant (often over 150 mg kg^{-1} extractable P in the subsurface layers), but only moderately high in the TM variant (50-150 mg kg^{-1} for the few profiles analysed), in comparison with normal forest soils (Sombroek, 1966; Smith, 1980). Detailed studies on fractional composition of the phosphorus in TP/TM are underway (Glaser; Cravo; Comerford and Falcão).

The amounts of exchangeable bases are higher than in the forest soils, but the base saturation is only moderately high: 20 to 70%, compared to about 15% in non-enriched soils, and associated with pH values of 4.5-5.5, instead of 4.0-4.5. Calcium and Magnesium values are always higher, but their total amounts vary strongly-no doubt related with the calcium content of the nearby river water, or the availability of other local nutritional resources.

Agricultural occupation by present-day small-holder farmers without access to commercial fertilisers can be maintained for several years without appreciable diminution of the chemical fertility status, but TP sites of longer occupation show a definite decline in agricultural productivity (Jarbas Cunha, in prep.). There are also some indications (Cravo, verbal comm.) that permanent horticultural crops on Terra Preta sites may come to suffer from a shortage of potassium and micro-nutrients such as boron, the latter causing deformation of Papaya fruits (*mal de cara-de-gato).*

Classification criteria

For pedologists it may be obvious that kinds of horthic Anthrosol are concerned. The data available thus far do not yet permit a field-relevant detailed pedologic and archaeological classification scheme, but some suggested classification criteria are as follows (ref.: World Reference base for Soil Resources, FAO/ISRIC, 2001; US Soil Taxonomy, 1992 and EMBRAPA's new Classificação de Solos Brasileiros, 2000):

- Thickness of organic matter-rich layer: at least 50 cm when clayey, may-be at least 70 cm when sandy;
- Colour (in moist condition; Munsell terminology and notation): black, very dark brown, brownish black or dark brown, i.e. value and chroma 3 or less, and sometimes with a reddish tinge-compare "mollic" and "umbric". For the soil profiles with abundance of ceramics-the TP proper-the colour values and chromas may be only 2 or less (reddish black, brownish black, or very dark reddish brown), comparable with the criterion "melanic";
- High organic-carbon content, averaged over 50 cm depth: 1.4% organic carbon or more (comparable with "humic" denominations for some Ferralsols and Nitisols);
- High value of CEC per percent organic carbon: more than 50% higher than in the adjacent normal soil (to be established by graphical method of Embrapa-Solos);
- High amount of easily extractable phosphorus content: more than 100 mg kg^{-1} Olsen-extractable P_2O_5 in the fine earth fraction, more than 150 mg kg^{-1} Mehlich-extractable, or more than 250 mg kg^{-1} extractable in 1% citric acid; in all cases averaged over the first 50 cm depth (critical values to vary with texture class);

- High levels of Manganese (above 500 mg kg^{-1}) and of Zinc (above 50 mg kg^{-1});
- Presence of artefacts/ceramics, averaged over 50 cm: higher or lower than 1% by volume, for TP and TM, respectively;
- Abundance of "krotovinas", i.e. mesofauna channels below the blackish horizon, filled with organic matter-rich soil material as an additional criterion;
- Presence of charcoal ("black" or "pyrogenic carbon") in the fine-earth fraction of at least 1% by volume, averaged over the first 50 cm, as another additional criterion?

Further subdivisions can be made on over-all texture (sandy vs. clayey) and on pH or base saturation (<35, 35-50, 50-80 and > 80%). Some possible prefixes are: para-hortic, proto-hortic, hypo-hortic, hyper-hortic, molli-humic or umbri-humic. Tropo-plaggic could be applied if a clear thickening of the profile has taken place through solid earth additions, such as on burial mounds.

Re-discovering and Applying the pre-Columbian Indigenous Techniques for Sustainable Land Use

Field research

For a number of the TP sites the enrichment may have been accidental as kitchen-midden formation. For others, especially where TM bands of considerable extent are present, a special land management technique would have been involved, which resulted in a lasting soil organic matter increase and a substantially higher chemical soil fertility.

The present-day remnants of the Amerindian population groups in the Amazon region have moved from their original sites to new areas (Cunha, 1992), with nomadic phases in-between, and often they do not know how the TP/TM in their new living places happened to come about (Pabst, 1993). There are only a few verbal reports (Roosmalen; Mosimann da Silva) that in isolated upper catchment areas such as the upper Xingú, current Indian land use practises may still be reminiscent of pre-Columbian practises. Local interviews, patient on-the-spot recording of such practises on annual basis, and screening of fragmentary descriptions by early travellers will give some insight.

A number of research items can be formulated, as follows:

- Considering that relatively high contents of SOM, of phosphorus and of calcium/magnesium appear to be characteristic for TP/TM soils, how would former Amerindian groups have collected the required high amounts of the basic materials, in an environment of strongly weathered and acid soils: Were these materials forest litter or non-wooded undergrowth; aquatic grasses; fish bones and residues, shells, Ca-containing root exudates; animal bones; (purposely produced) fine charcoal, ashes, or all of them together.
- What techniques were used to turn these basic materials into the characteristic stable and at the same time active SOM of the TP/TM soils: manual grinding and mixing, rotting and composting, or intentional animal manure production.
- If an animal digestion or trampling- and manure producing stage was essential (as in the case of the north-western European *plaggen* soils), then what type of animals were used in pens, corrals or stables, given the absence of cows and sheep. Could land- and /or aquatic giant turtles (*jabotis* or *tartarugas*) have been used for the purpose, as

might be concluded from the Carvajal narrative (original in 1542; re-edited in1934) on their abundance in erstwhile Amerindian villages.

Laboratory research

Advanced laboratory research on sample material of representative sequences of TP-TM-TC (the latter standing for the common, natural soil) may focus on the following questions:

- Are specific meso-fauna or microbial communities (worms, bacteria, mycorrhizal fungi) involved in the creation and reproduction of the stable SOM in the TP/TM, soils;
- What are the precise physico-chemical characteristics of the stable SOM in TP and TM soils respectively;
- Is the SOM stability the result of crypto-crystalline complexation with the predominant clay mineral such as kaolinite, through linkages with Ca and P compounds or elements, or is it the “black” or “pyrogenic” carbon of charcoal application on its own, or a combination of both;
- What is the reason for the relatively high activity per unit of SOM in the TP/TM soils, in comparison with non-enriched counterpart soils (TC), in the form of substantially higher nutrient- and moisture storage capacity;
- How long will these favourable properties of the TP/TM have been lasting after abandonment by the Amerindians (^{14}C and $*^{13}C$ analysis), and to which degree are they degrading under present-day occupation by small-holding subsistence farmers who do not use indigenous soil improving techniques on permanent fields.

Application research

Once the above field and laboratory research items are elucidated, a number of application related items have to be solved:

- Can the favourable properties of the TP/TM soils be emulated/replicated on other sites, without depleting the surrounding countryside and within a time span of decades rather than centuries;
- What would be the most promising combination of methods to create new TP/TM, and can they be integrated in current agro-forestry practises and secondary forest (*capoeira*) management? If this is to include an animal husbandry stage, then which animals should be involved most effectively - from technical, economic and social points of view;
- Would the present-day small-holder rural population of the region be receptive to apply the required extra manual labour, and would they need incentives, financially or otherwise, such as an assured supply of lime and rock-phosphate;
- Which local institutions can best guide the experimental phase of a TP/TM replication programme, and how long should the testing last to become sure of the permanency of the newly added SOM;
- What is the quantitative potential, in the form of tonnes of Carbon sequestered and the reduction of hectares of deforestation, if the creation of new TP and TM soils in the Amazon region would be undertaken systematically? How much international financial support per ha or farm household, through the Clean Development Mechanism of the Kyoto Protocol or else, would be needed annually;
- Finally, can and should the acquired insights and subsequent sustainable development packages be made beneficial to the remnants of the former Amer-indian

tribes inside and outside their formal reserve areas, in the form of extension and/or financial compensation for the re-use of the traditional knowledge systems of their ancestors – considering the concept of communal intellectual property rights (Posey, 2000).

Towards a Terra-Preta-Nova Project

Discussions of the above series of questions and hypotheses have led to the formulation of a multi-disciplinary and multi-institutional Brazilian research+development project called Terra Preta Nova (TPN), with participation of scientists from other Latin American countries, the USA and Europe. Its aims are: to contribute to the contracted and sustainable use of Amazon soils by small-holding farmers, through the replication/emulation of the anthropogenic black earths of the pre-Columbian Indian tribal communities. It would also contribute to the maintaining of the carbon stock- and sink functions of the Amazonian primary forests and their soils, and would better preserve the Amerindian Amazonian cultural legacy. .

The activities of the envisaged project are as follows:

- Region-wide surveys and local interviews on TP and associated TM occurrences, genesis, and related ethno-(agro)biodiversity aspects;
- Anthropologic and archeologic site research and directed salvage activities in areas of rapid settlement (such as Apuí, Humaitá, Itaituba, Novo Progresso; Araracuara in Colombia)
- Routine and specialised analysis on sample material, aiming to establish the reasons for the high stability and the high cation exchange capacity of the increased soil organic matter concerned;
- Laboratory experiments on the manufacturing of stable and active soil organic matter, using early indications from the surveys and the interviews;
- Directed agronomic and agro-forestry experiments in farmers' fields, to replicate TP/TM, in conjunction with existing projects on recuperation of degraded Amazonian lands;
- Extension of the resulting package(s) of TPN soil management practises to priority areas of integrated environmental management - i.e. those areas where conservation of the natural vegetative cover and sustainable small-holder settlement should go hand-in-hand (*Reservas de Desenvolvimento Sustentavel*)
- Awareness promotion on the value of the indigenous patrimony, through state-level educational publications, reference collections on TP/TM material, local archaeological exhibitions, etc.

It is hoped that the Global Environmental Facility (GEF, as an outcome of the Rio de Janeiro World Summit of the Environment in 1992), will be interested in co-financing of the project, through its focal area #13, entitled "Conservation and sustainable use of biological diversity important for agriculture".

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