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**Slash and Char as Alternative to Slash and Burn –
soil charcoal amendments maintain soil fertility
and establish a carbon sink**

Dissertation

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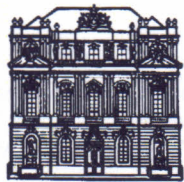
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CHAPTER III

SLASH AND CHAR—AN ALTERNATIVE TO SLASH AND BURN PRACTICED IN THE AMAZON BASIN

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3.1 Abstract

Residues of charcoal production are used to improve soil quality in the vicinity of Manaus and in other parts of Brazil. This newly described agricultural practice seems to be of high significance, practically and scientifically seen. In a series of experiments we are actually studying the effects of charcoal in agricultural practice. The soil charcoal amendments maintain soil fertility and transfer carbon from the atmosphere into refractory soil organic matter (SOM) pools, which can improve and maintain the productivity of highly weathered infertile tropical soils. The agricultural practice of slash and char produces charcoal out of the aboveground biomass instead of converting it to carbon dioxide (CO₂) through burning. Slash and char practiced as an alternative to slash-and-burn throughout the tropics could serve as a significant carbon sink and could be an important step towards sustainability in tropical agriculture.



3.2 Keywords

carbon sink, charcoal, slash-and-burn, slash and char, tropical agriculture, *Terra Preta*

3.3 Introduction

The forested area in the tropics continues to decrease. It is a challenge to preserve large areas of tropical forest to counteract the accelerating climate change and loss of biodiversity. The cumulative deforested area (including old clearings and hydroelectric dams) in Amazonia through 1991 had reached 427 thousand km² or 11% of the 4 million km² original forested portion of Brazil's 5 million km² legal Amazon region (Fearnside 1997).

Large-scale cattle ranching is mainly responsible for this decline in forest area. But new settlers along the roads also contribute to deforestation through slash-and-burn agriculture. In 1990 and 1991, 31% of the clearing was attributable to small farmers (Fearnside 2001).

Slash-and-burn is an agricultural technique widely practiced in the tropics and is considered to be sustainable when fallow periods up to 20 years follow 1-3 years of agricultural activity. In many parts of the world, the increasing population size and socio-economic changes including pioneer settlement made slash-and-burn agriculture unsustainable, leading to soil degradation. In Rondônia, a state in the southwest corner of the Brazilian Amazon region, intense migration resulted in an increase in the human population at a rate of 15% per year between 1970 and 1980—a doubling time of less than five years. The population of the northern Amazon region increased by 5% per year over the same period (Fearnside 1983). The soil nutrient availability already decreases after one or two cropping seasons. Subsequently field crops have to be fertilized for optimum production, or fields have to be abandoned and new forests have to be slashed and burned, the common practice.

Soil nutrient and SOM contents are generally low in the highly weathered and acid upland soils of central Amazonia, and soil degradation after clearing is mainly caused by a loss of SOM as CO₂ into the atmosphere and of nutrients into the subsoil. This process is well known and explains some aspects of the low fertility levels of many soils in the tropics under permanent cropping systems (Zech *et al.* 1990). In strongly weathered soils of the tropics, SOM plays a major role in soil productivity because it represents the dominant reservoir of plant nutrients such as nitrogen (N), phosphorus (P), and sulfur (S). Generally, SOM contains 95% or more of the N and S, and between 20 and 75% of the P in surface soils (Zech *et al.* 1997). SOM also influences pH, cation exchange capacity (CEC), anion exchange capacity (AEC), and soil structure. SOM mineralization decreases the total retention capacity of available cations in tropical soils, where SOM is often the major source of negative charge. Maintaining high levels of SOM in tropical soils would be a further step towards sustainability and fertility on tropical agricultural land, thus reducing the pressure on pristine areas.

3.4 Carbon Emissions in Slash and Burn Agriculture

Tropical forests account for between 20 and 25% of the world terrestrial carbon (Bernoux *et al.* 2001). Fearnside (1997) calculated net committed emissions of forest burnings in Amazonia. This is calculated as the difference between the carbon stocks in the forest and in the equilibrium replacement landscape. He estimated the above-ground biomass of unlogged forests at 434 Mg ha⁻¹, about half of which is carbon. In most agricultural systems the tendency has been for population pressure to increase, leading to increased use intensity over time and shorter fallow periods, with resulting lower average biomass for the landscape. The net committed emissions for 1990 land-use change in the Brazilian Legal Amazonia are 5% of the total global emissions from deforestation and fossil fuel sources (Fearnside 1997). Although most emissions are caused by medium and large ranchers, the emissions of the small farmer population in the Amazon Basin were estimated to be between 34 and 88 million Mg CO₂-equivalent carbon in 1990 (Fearnside 2001).

Charcoal formation during biomass burning is considered one of the only ways transfer carbon into refractory pools (Fearnside *et al.* 2001; Glaser *et al.* 1998, 2001; Zech *et al.* 1990) and can have important effects on atmospheric composition over geological time scales. At a burn of a forest being converted to cattle pasture near Manaus, charcoal represented just 1.7% of the pre-burn biomass. The mean carbon content of charcoal manufactured from primary forest wood in the Manaus region is assumed to be 75% (Fearnside *et al.* 2001). Soils under tropical forest contain approximately the same amount of carbon as the abundant vegetation above it, being about 3% in the surface horizon and about 0.5% in the subsurface horizons down to 100 cm depth (Sombroek *et al.* 2000). The soils of Brazilian Amazonia may contain up to 136 Tg of carbon to a depth of 8 m, of which 47 Tg is in the top 1 m. The current rapid conversion of Amazonian forest to agricultural land makes disturbance of this carbon stock potentially important to the global carbon balance and net greenhouse gas emissions. Soil emissions from Amazonian deforestation represent a quantity of carbon approximately 20% as large as Brazil's annual emission from fossil fuels (Fearnside and Barbosa 1998).

3.5 Black Carbon in Soil – *Terra Preta de Índio*

Little attention has hitherto been given to black carbon as an additional source of humic materials. Black carbon is produced by incomplete combustion of biomass, creating various forms such as charcoal, charred plant residues, or soot.

The soils in Brazilian Amazonia are predominantly Ferralsols, but in addition a patchily distributed black soil occurs in small areas rarely exceeding 2 ha. This is the so-called *Terra Preta de Índio*. Because of the similarity in the soil mineral composition and in texture to that of immediately surrounding soils (from more or less sandy to very clayey), and because of the occurrence of pre-Columbian ceramics and charcoal in the upper horizons, these soils are considered to be anthropogenic (Glaser *et al.* 2001; Sombroek 1966). According to Sombroek (1966) *Terra Preta* is very fertile, and after clearing of forests the soils are not immediately exhausted as the Oxisols are. *Terra Preta* contains significantly more carbon (C), nitrogen (N), calcium (Ca), and phosphorus (P), and the cation exchange capacity (CEC), pH value, and base saturation are significantly higher in *Terra Preta* soils than in the surrounding Oxisols (Glaser *et al.* 2000; Zech *et al.* 1990).

Terra Preta soils contain up to 70 times more black carbon than the surrounding soils. Due to its polycyclic aromatic structure, black carbon is chemically and microbially stable and persists in the environment over centuries (Glaser *et al.* 2001). C^{14} ages of black carbon of 1,000 to 1,500 years suggest a high stability of this carbon species (Glaser *et al.* 2000). It is assumed that slow oxidation on the edges of the aromatic backbone of charcoal forming carboxylic groups is responsible for both the potential of forming organo-mineral complexes and the sustainable increased CEC (Glaser *et al.* 2001). It can be concluded that in highly weathered tropical soils, SOM and especially black carbon play a key role in maintaining soil fertility.

Black carbon has become an important research subject (Schmidt and Noack 2000) due to its likely importance for the global C cycle (Kuhlbusch and Crutzen 1995). Long-term studies with charcoal applications are needed to evaluate their effects on sustained soil fertility and nutrient dynamics.

3.6 Slash and Char an Alternative to Slash and Burn

After clearing the land for agricultural production, farmers use the wood for charcoal production. The charcoal is produced in kilns close to the forest edge (figure 3-1). The annual charcoal production of Brazil is 3.3 Gg (GERAIS 1985). As of 1987, 86% of Brazil's use of charcoal was for industry (i.e., iron and steel) and 14% for residential and commercial

purposes. Of wood used for firewood and charcoal in Brazil in 1992, 69% came from plantations, 29% from firewood collection and 2% from sawmill scraps (Prado 2000).



Figure 3-1. The charcoal drawing illustrates slash and char in practice. A = Vegetable planted in charcoal residues; B = banana planting hole filled with chicken manure, soil, and charcoal; C = on the sieve table marketable pieces are separated from charcoal dust and small pieces, which are used in agriculture.

Only about 85% of the produced charcoal is marketable. On a sieve-table the different sizes are sorted out and filled into sacks for selling. Large amounts of broken charcoal pieces and charcoal dust pass through the sieve (figure 31, C). These charcoal residues can be used in agriculture. The percentage of dust could be increased when organic materials other than wood are included in the charring process.

3.7 Alternative Slash and Char in Practice

There is evidence that slash and char is practiced in a wide area of the Amazon Basin. Coomes and Burt (1999) reported from the Peruvian Amazon near Iquitos that for most households, charcoal production is an integral part of their swidden-fallow practices. On field excursions on an unpaved side road leading from the Brazilian highway BR 174, 30 km into the forest, all visited farmers settled on this road practiced slash and char. The agricultural practice of slash and char is also found in the state of Pará south of the city Belém. Paragominas is known for its timber industry. There the residues from sawmills are used for charcoal production, and the residues of charcoal production for agriculture. These findings suggest that charcoal residues are frequently used for agriculture where charcoal is produced.

Farmers around Manaus were visited to observe their agricultural practices. There is a high demand for charcoal in the nearby city of Manaus caused by a preference for barbecued meat (*churrasco*). The majority of the farmers use a permanent kiln. In such a kiln about 1,400 kg of charcoal can be produced per filling. A farmer with no access to the nearby city markets sells the charcoal for US\$ 0.17 per 2-kg sack. At the main road (BR 174) which goes from Manaus to Presidente Figueiredo, the sacks already have a price of US\$ 0.27. In Manaus the same unit is sold for US\$ 0.5 - 0.67 (US\$ 1=3 Brazilian *reais*).

Coomes and Burt (1999) investigated charcoal producers near Iquitos in the Peruvian Amazon region and found that the mean kiln producing 945 kg of charcoal requires a labour investment of 26 days. In their study area, charcoal is produced in an earth-mound kiln, which demands more labour than the permanent kiln type used near Manaus. A charcoal

producer near the EMBRAPA experimental research station loads his permanent kiln every 12 days. The labour investment is relatively small for the four production stages. Wood is collected and prepared in 1 day by 4 workers (family members), combustion is supervised for 4 days, and charcoal is cooled for 8 days, and then sacked by 4 workers in 1 day. Cooling and combustion supervision require almost no labour input, allowing time for new wood procurement, charcoal bagging, or agricultural activities. Charcoal producers close to rivers shorten the cooling process by using water. Either 80-100 50-l sacks with a mean weight of 15 kg or 400-500 sacks weighing 3 kg are filled. The producer sells a large sack for US\$ 1.00 and a small one for US\$ 0.23. On the nearby major road (AM-010), the big sacks are sold for US\$ 1.67 and the small ones for US\$ 0.50. The monthly income from charcoal production is between US\$ 200 and US\$ 260, which is three to four times the minimum salary of US\$ 66.

Charcoal producers report that the residues are used for their own agriculture and are also picked up by large-scale farmers. These cash crop farms are usually cleared by bulldozer and do not produce their own charcoal. Four types of charcoal use in agriculture were observed:

1. The residues from charcoal production are mainly used as an amendment in planting holes. Mainly bananas (or other fruit trees) are planted in such holes. Typically, the holes are about 30 cm wide and 50 cm deep. These planting holes are filled with chicken manure, charcoal, and soil (figure 3-1, B).
2. The slash and char farmers produce a kind of charcoal compost. Around the charcoal kilns they dig holes in which the charcoal residues are deposited in layers alternating with organic matter, ashes and soil. After 1 year of decomposition the farmers use the created material as fertilizer applied on the soil surface. Analyses of such a charcoal-compost show that it has a high pH value (6.9 in H₂O) and is extremely rich in Ca (2,360.79 mg kg⁻¹), Mg (1241.2 mg kg⁻¹), and K (521 mg kg⁻¹).
3. Charcoal residues are used for vegetable and herb production in home gardens. These gardens are planted in elevated planters, and the crops are grown about 1.5 m above the ground to avoid damages caused by domestic animals. These planters are filled with soil, charcoal residues, compost, chicken manure, and other forms of organic matter (figure 3-1, A).
4. Charcoal residues are applied on the soil surface. Farmers report that this maintains soil moisture especially during the dry season.

In addition, charcoal and charcoal byproducts are used in more technical ways. Coal from geological deposits and from various specialized procedures was successfully used for soil amelioration. Adding charcoal to soil can significantly increase seed germination, plant growth, and crop yields. Similar observations were made after additions of humic acids from coal deposits (Glaser *et al.* 2002). In the south of Brazil a liquid called *pirolenhoso* is extracted out of the smoke from charcoal production. This technique comes from Japan and the elixir has been used there for centuries to increase crop productivity and quality and to combat diseases and pests in agriculture (GLASS 2001). So far not much is known about the chemical composition of the product, which consists of more than 200 chemical compounds. For production the gases from the charcoal kiln are captured and channelled in a way to allow the condensation of the vapour. The extract is applied to the soil in a 1:100 dilution with water. In spite of the lack of research, in practice this byproduct of charcoal production has been showing efficiency in controlling nematodes and diseases. Used as fertilizer, it increases the vigour and improves the root building, the productivity, and the resistance of the plants, and it increases the sugar content in fruits, that also have accentuated colours and scents (GLASS 2001). A growing number of organic farmers have begun the production of *pirolenhoso*. They sell the product for US\$ 0.33 per l⁻¹ and a farmer can produce about 600 l

month⁻¹. The market for the extract is very large in Brazil as well as in other countries, mainly in Japan (GLASS 2001).

Other charcoal and byproduct uses include the following. A German company invented a product based on coal for the ecological improvement of all types of soils. The product is sold as a soil conditioner and used in organic farming and for restoration of degraded soils, mainly skiing slopes (TERRA-TEC). Chicken fodder is supplemented with charcoal. Mario Miamoto, the owner of a large battery farm near Manaus (AM 010, km 38) is adding 1% charcoal to the chickens' nutrition in order to assuage the malodorousness of the manure, thus increasing the chickens' appetite. He is using about 2.5 Mg of charcoal waste per month. The same is done with cattle fodder to prevent digestion disorders. Osvaldo Sassaki (pers. comm.) used charcoal successfully for the development of hydroponic systems at the University of Amazonas. Osvaldo Sassaki used charcoal in these experiments as a nutrient sorbing material (O. K. Sassaki, pers. comm.).

3.8 Advantages of Slash and Char

The advantages of slash and char agriculture as an alternative to slash-and-burn need to be investigated in more detail, but the following statements can already be made:

1. Charcoal production provides income for rural households. Financial income could be used to buy organic fertilizer like chicken manure, which is cheaper than charcoal and available around Manaus. The residues from charcoal production together with chicken manure can improve the soil's fertility and decrease the amount of leached nutrients (Lehmann *et al.*, 2003, Steiner *et al.*, chapters 5 and 8).
2. The income from charcoal marketing provides an incentive for longer fallow periods because households practicing slash and char agriculture prefer secondary forest regrowth of an age between 8 and 12 years. The removal of wood for charcoal production does not diminish agricultural productivity (Coomes and Burt 1999). The mean age of secondary forest cleared for traditional slash-and-burn agriculture is 5 years. The total biomass of secondary forest derived from farmland at the average age would be 50 Mg ha⁻¹, including fine litter and other dead aboveground biomass (Fearnside and Guimarães 1996), which is less than half the amount after a 10-year fallow (table 3-1). Slash and char as an agricultural practice provides increased soil fertility through active improvement by organic matter applications and by longer fallow periods. Additionally, the increased CO₂ reabsorption in longer fallow periods and the charcoal amendments to soil transfer more CO₂ from the atmosphere into biomass and finally into a stable form of SOM.

Table 3-1. Biomass accumulation of a secondary forest in the Brazilian Amazon (Fearnside and Guimarães 1996, with permission of Elsevier). The growth rate is highest in young succession stages creating an incentive for longer fallow periods for slash and char agriculture. Fallows between 8 and 12 years are sufficiently old for both charcoal production and agricultural cultivation (Coomes and Burt 1999).

Age (years)	Live biomass (Mg ha ⁻¹)				Root/shoot ratio	Average growth rate of total biomass since abandonment (Mg ha ⁻¹ year ⁻¹)	Growth rate of total live biomass in interval (Mg ha ⁻¹ year ⁻¹)
	Wood	Leaves	Roots	Total live			
5	29.2	4.0	13.8	47.0	0.42	9.4	9.4
10	70.8	6.0	23.1	99.9	0.30	10.0	10.6
20	110.8	10.0	24.2	145.0	0.20	7.3	4.5
30	113.8	9.5	27.7	151.0	0.22	5.0	0.6
80	135.4	8.0	28.5	171.9	0.20	2.1	0.4

3. Charcoal could improve the soil quality by changing soil physical parameters such as bulk density, water retention, and water holding capacity, a significant advantage for plants, especially during the 4-month dry season.
4. Charcoal amendments seem to have insect repellent properties. Farmers report that charcoal amendments in banana planting holes keep the wide spread pest *Cosmopolites sordidus* (*broca-da-bananeira*) from affecting the plants. This beetle is a common crop pest in all areas of the world where bananas are cultivated (Fancelli 1999).
5. The regeneration of primary forest species is much greater in areas which are not burnt after felling. An unusually high occurrence of primary forest species from the families Lecythidaceae, Bignoniaceae, and Meliaceae was found in an area of secondary growth near Manaus. The area where original forest was cut, but not burned, to obtain wood for charcoal production is unusually rich in young primary forest species. Far less damage is done to the native gene pool when the area is not burned after clearing. This is true not only because of the propensity of many felled trees to regenerate from stump sprouts, but also because seed material is not destroyed (Prance 1975).
6. The CO₂ balance between biosphere and atmosphere as a result of charcoal production is neutral if regrowing wood from plantations or secondary forest is used. The use of charcoal in agriculture would create a carbon sink as a stable soil carbon pool.
7. An indirect advantage of slash-and-burn is that charcoal could also be produced in the wet season, when burning is not possible. Controlled year-round charcoal production would distribute emissions around the year and reduce the high aerosol emissions during the dry season. Artaxo *et al.* (2002) predict that the negative effects of burning are not locally restricted. The emitted aerosols reduce solar radiation about 40% in the critical PAR region, which could lead to an average 3°C drop in temperatures during the burning seasons over regions as large as 3 million km². The reduced temperature and solar radiation seriously affect photosynthesis, and further damages are caused by the phytotoxic gas ozone. Significant ozone concentrations, on the order of 80-100 ppb were observed in regions far from the burnings. Furthermore, the aerosol emissions could reduce precipitation in some regions by as much as 30%. Artaxo *et al.* (2002) assumed that as much as a half of the Amazonian forest could be being affected by secondary pollution. Altogether, these combined effects could reduce the amount of water evaporating from the Amazon's vegetation, affecting weather worldwide.

3.9 Slash and Char Research Activities

Charcoal powder was tested in a randomized multiple block field experiment near Manaus, Brazil. Charcoal amendments (11 Mg ha⁻¹) elevated the aboveground biomass production significantly on fertilized plots. In the second cropping period the yield of sorghum (*Sorghum bicolor*) was increased by 880% in comparison with plots receiving only mineral fertilizer without charcoal amendments. Charcoal amendments alone did not increase crop productivity. These results strengthen the hypothesis that charcoal retains nutrients and makes them plant available.

The claims that charcoal amendments in banana planting holes keep the widespread pest *Cosmopolites sordidus* (*broca-da-bananeira*) from attacking the plants could not be confirmed. In a greenhouse experiment 20 banana plants of 2 different varieties (*Caipira* and *Prata Zulu*) were planted in pots. The soil was amended with chicken manure and lime. Ten plants received additional charcoal amendments (one third of the volume). Four of the ten bananas were infected by *Cosmopolites sordidus* in the charcoal treatment, showing clearly that charcoal does not repel this species. On the other hand, 5 of 10 banana plants in the treatments without charcoal died, apparently because of a lack of drainage. Insufficient water drainage affected mainly the *Caipira* variety (4 of 5 plants). Insufficient drainage was also

observed in a banana plantation north of Manaus (BR 174, km 102) where rotten banana rhizomes were found in planting holes full of standing water.

Greenhouse experiments of Lehmann *et al.* (2003) showed that charcoal additions increased biomass production of a rice crop by 17% in comparison to a control on a Xanthic Ferralsol. Combined application of N with charcoal resulted in a higher N uptake than what would have been expected from fertilizer or charcoal applications alone. The reason is a higher nutrient retention of applied ammonium by the charcoal-amended soils.

3.10 Conclusions

The observed effects of charcoal applications in slash and char agriculture seem to match the properties of the fertile anthropogenic *Terra Preta* soils in the Amazon Basin. Charcoal production is a lucrative activity and transfers SOM into stable pools when residues are used in agriculture. Where charcoal is produced the residues are used for soil amelioration. Farmers evolved various techniques to use charcoal residues. Due to the relatively low nutrient content, charcoal is mixed with chicken manure for planting holes or a nutrient-rich charcoal compost is produced for surface application. This compost could act as a slow-release fertilizer. In our experiments, soil charcoal amendments improved crop growth and yield significantly. We are conducting further experiments to determine the mechanisms of soil improvement through charcoal amendments and the efficiency of slash and char agriculture. Should slash and char become common throughout the tropics it could serve as a significant carbon sink and could improve sustainability of tropical agriculture.

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