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Expert Commentary

SOIL CHARCOAL AMENDMENTS MAINTAIN SOIL FERTILITY AND ESTABLISH A CARBON SINK – RESEARCH AND PROSPECTS

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CHARCOAL AS SOIL AMENDMENT

Sustaining soil fertility is a major agricultural constraint in the Amazon Basin (Tiessen, et al., 1994), thus shifting cultivation accompanied with slash and burn agriculture is the prevailing agricultural practice in the humid tropics.

In addition to the predominant and unproductive Ferralsols and Acrilols, an exceptional dark soil is well known by the indigenous people and colonists for its sustained soil fertility. According to its dark color and origin ,the soil was termed *Terra Preta de Indio*. Smith (1879) and Katzer (1903) were among the first who described the *Terra Preta's* properties and presumed its cultural origin. Later their assumptions were strengthened by the soil scientists Sombroek (1966) and Zech, et al. (1990). *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 Ferralsols and Acrisols (Zech, et al., 1990; Glaser, et al., 2000). *Terra Preta* soils contain up to 70 times more black C than the adjacent soils. Due to its polycyclic aromatic structure, black C is chemically and microbially stable and persists in the environment over centuries (Glaser, et al., 2001b). Today, the anthropic origin of *Terra Preta de Indio* is generally accepted and its fertility is most likely linked to an accumulation of P and Ca, associated with bone apatite (Zech, et al., 1990; Lima, et al., 2002) and black C as charcoal (Glaser, et al., 2001a). The evidence that *Terra Preta* was manmade, and thus the proven feasibility to transform one of the most infertile soils into one of the most productive soil inspired charcoal research.

Slash and Char was described as an alternative to slash and burn (Lehmann, et al., 2002) and (Steiner, et al., 2004b) observed that charcoal is currently used by Amazonian settlers to improve soil fertility. If a forest is burned, only around 2-3% of the above-ground C is converted into charcoal (Fearnside, et al., 2001), but charcoal production can capture 50% of the above-ground C. If the charcoal is not used as fuel (e. g., soil amendment) it has a very high recalcitrance against biological or chemical decay and stores the carbon over centuries or millennia. *Slash and char* is an alternative agricultural method producing charcoal out of the aboveground biomass instead of converting it to CO_2 through burning. If re-growing resources are used, *slash and char* could establish as a significant carbon sink and could be an important step towards sustainability and SOM conservation.

On a global scale, the total carbon release flux due to fire is of the order of 4-7 Pg of carbon per year. This flux is almost as large as the rate of fossil fuel consumption (about 6 Pg per year in 1990) (Goudriaan, 1995). Fearnside (2000) calculated a total net emission of carbon from tropical land uses, equivalent to approximately 29% of the total anthropogenic emission from fossil fuels and land-use change. These numbers emphasize the potential for C management if only biomass is utilized being ablaze each year.

As a result of intensive research done in the 1980s, carbonized materials are formally authorized for use as soil amendment material in Japan. Thus Japan used 27% of the total charcoal consumption (50,835 Mg in 1999) for purposes other than fuel. By far the biggest proportion was used for agriculture (30.6%) followed by livestock industries (22.3%), gardening and golf courses (7.6 %) (Okimori, et al., 2003). A Japanese company established charcoal production at an Indonesian tree plantation for pulp production. Their feasibility study with conventional charcoal-making methods showed that 77,000 Mg charcoal could be produced per year, and the carbon emission reductions by the project reaches 62,000 Mg C yr^{-1} (= 230,000 Mg CO_2 yr^{-1}) at an annual wood harvest of 10,000 ha (Okimori, et al., 2003).

SOIL FERTILITY ENHANCEMENT

Antal and Grønli (2003) mentioned that most potting soils, herbicides in carbon-based formulations, and culture media formulations contain charcoal or activated carbons, although the scientific rationale for these applications is absent. Recent studies showed that soil charcoal amendments are indeed capable of increasing soil fertility. Charcoal significantly increased plant growth and nutrition in a pot experiment by Lehmann, et al. (2003) and a field experiment by Steiner, et al., (2007c). The authors proposed that charcoal can improve soil chemical, biological, and physical properties, but could not completely discern the mechanisms of fertility enhancement. Lehmann, et al., (2003) found significantly reduced leaching of applied fertilizer N in charcoal containing pots. This was corroborated by the findings of Steiner, et al., (2007a in submission) and Steiner, et al., (2007b in submission).

Soil respiration and the microbial population growth rate were found significantly altered by charcoal amendments. Steiner, et al., (2004a) found increased microbial activity on charcoal amended plots. *Terra Preta* soils were marked by a very low soil respiration but very high population growth after substrate (glucose) additions. Unmanaged forest soils (Ferralsol) had a higher respiration rate but a very low population growth potential. These results reflect

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the relatively high biodegradable soil organic matter (SOM) content of primary forest topsoil but low available nutrients (requirement for microbial population growth), in contrast to refractory *Terra Preta* SOM with high available soil nutrient contents. Thus we conclude that nutrient availability in *Terra Preta* is independent from SOM decomposition. The effects on soil biology seem to be essential as charcoal has the potential to alter the microbial biomass (Steiner, et al., 2004a) and composition (Birk, 2005) and the microbes are able to change the charcoal's properties (Glaser, et al., 2001a). Rondon, et al. (2006) found increased biological N fixation by common beans through charcoal additions and Gehring (2003) increased occurrence of nodulating plants in forests on *Terra Preta* than on adjacent soils.

BIOCHAR PROSPECTS AND ESSENTIAL RESEARCH

The global potential of biochar (non fuel use charcoal) reaches far beyond *slash and char*. Inspired by the recreation of *Terra Preta*, most biochar research was restricted to the humid tropics. More information is needed on the agronomic potential of charcoal, the potential to use alternative biomass sources (crop residues) and production of by-products to evaluate the opportunities for adopting a biochar system on a global scale. Biochar as soil amendment needs to be studied in different climate and soil types. Today, crop residue biomass represents a considerable problem as well as new challenges and opportunities.

A system converting biomass into energy (hydrogen-rich gas) and producing charcoal as a by-product might offer an opportunity to address these problems. Charcoal can be produced by incomplete combustion from any biomass, and it is a by-product of the pyrolysis technology used for biofuel and ammonia production (Day, et al., 2005).

The acknowledgement of biochar as carbon sink would facilitate C-trading mechanisms. Although most scientists agree that the half life of charcoal is in the range of centuries or millennia, a better knowledge of the charcoal's durability in different ecosystems is important to achieve this goal. An access to the C trade market holds out the prospect to reduce or eliminate the deforestation of primary forest, because using intact primary forest would reduce the farmer's C credits. Fearnside (1997) estimated the above-ground biomass of unlogged forests to be 434 Mg ha^{-1}, about half of which is C. This C is lost if burned in a slash-and-burn scenario and lost at a high percentage if used for charcoal production. The C trade could provide an incentive to cease further deforestation; instead reforestation and recuperation of degraded land for fuel and food crops would gain magnitude. As tropical forests account for between 20 and 25% of the world terrestrial C reservoir (Bernoux, et al., 2001), this consequently reduces emissions from tropical forest conversion, which is estimated to contribute globally as much as 25 % of the net CO_2 emissions (Palm, et al., 2004).

Today most biomass gasification systems tend to suppress the creation of residuals, like total organic carbon (TOC) and ashes. C-emission trading options and a better knowledge of charcoal as soil additive would add value to these residues. Further, this would facilitate the use of alternative biomass, those which are currently avoided to due their higher TOC residuals. The tarry vapors constitute a significant loss of carbon during carbonization (Antal and Grønli, 2003), although representing another valuable product. Despite a lack of research, these condensed vapors are used for agricultural purposes mainly in Asia and Brazil (GERAIS, 1985; Glass, 2001; Steiner, et al., 2004b).

Japanese researchers attempt to produce charcoal with a specific pore size distribution to favor desired microorganisms (Okimori pers. communication). Pore structure, surface area, and adsorption properties are strongly influenced by the peak temperature during charcoal production (Antal and Grønli, 2003). Increasing porosity is achieved with increasing temperature but the functional groups are gradually lost. In this context, it is also important to discern the mechanisms of nutrient retention (mainly N) due to charcoal applications. The charcoal's low biodegradability (Kuhlbusch and Crutzen, 1995), low nutrient content (Ogawa, 1994; Antal and Grønli, 2003), and high porosity and specific surface area (Braida, et al., 2003) makes charcoal a rather exceptional SOM constituent. *Terra Preta* research has shown that oxidation on the edges of the aromatic backbone and adsorption of other organic matter to charcoal is responsible for the increased CEC, though the relative importance of these two processes remains unclear (Liang, et al., 2006).

Energy from crop residues could lower fossil energy consumption and CO_2-emissions, and become a completely new income source for farmers and rural regions. The biochar by-product of this process could serve to recycle nutrients, improve soils and sequester carbon. A review by Johannes Lehmann (2006) and the article "*Black is the new green*" (Marris, 2006) emphasize the potential of bio-char on a global scale. A global analysis by Lehmann, et al. (2006) revealed that up to 12% of the total anthropogenic C emissions by land use change (0.21 Pg C) can be off-set annually in soil, if slash and burn is replaced by slash and char. Agricultural and forestry wastes add a conservatively estimated 0.16 Pg C yr^{-1}. If the demand for renewable fuels by the year 2100 was met through pyrolysis, bio-char sequestration could exceed current emissions from fossil fuels (5.4 Pg C yr^{-1}). The described mixture of driving forces and technologies has the potential to use residual waste carbon-rich residues to reshape agriculture, balance carbon and address nutrient depletion.

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