BIOCHAR CARBON SEQUESTRATION

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MANIPULATING THE CARBON CYCLE

Carbon dioxide (CO_2) is removed from the atmosphere through photosynthesis and stored in organic matter. When plants grow they utilize sunlight, CO_2, and water (H_2O) to synthesize organic matter and release oxygen (O_2). This accumulated organic matter is returned to the atmosphere by decomposition of dead plant tissue or disturbances, such as fire, in which large amounts of organic matter are oxidized and rapidly transferred into CO_2 (Figure 1). Terrestrial carbon is primarily stored in forests (Dixon et al. 1994). In undisturbed full-grown forest ecosystems, the turnover time of carbon takes decades, and uptake by photosynthesis and release by decay is balanced.

Reduced decomposition is an advantage of biochar. Thus, biochar formation has important implications for the global carbon cycle. In natural and agroecosystems incomplete burning produces residual charcoal. As the soil carbon pool declines due to cultivation, the more resistant biochar fraction increases as a portion of the total carbon pool (Zech and Guggenberger, 1996, Skjemstad 2001, Skjemstad et al. 2002) and may constitute up to 35 percent of the total (Skjemstad et al. 2002). Carbon dating of charcoal has shown some to be over 1500 years old, fairly stable, and a permanent form of carbon sequestration (Lal, 2003).

Biochar can be produced by thermo-chemical conversion of biomass. Burning biomass in the absence of oxygen produces biochar and products of incomplete combustion (PIC). The PIC includes burnable gases such as H_2 and CH_4. These gases can be used to fuel the conversion of biomass into biochar and/or renewable energy generation (Figure 2). Larger molecules can be condensed into bio-oil and also used as a renewable fuel. The resulting biochar consists of mainly carbon and is characterized by a very high recalcitrance against decomposition. Thus biochar decelerates the second part of the carbon cycle (decay, mineralization) and its non-fuel use would establish a carbon sink.

Figure1. Simple Carbon Cycle

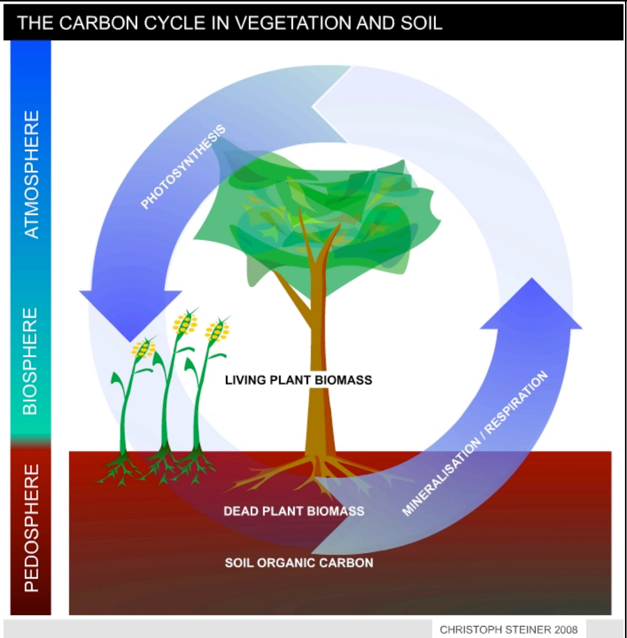


Figure 1 shows a simplified version of the carbon cycle in vegetation and soil. Plants take CO_2 from the atmosphere to synthesize tissue (plant biomass). As long as biomass is growing it accumulates carbon. During decomposition of dead biomass and humus the carbon is released as CO_2. In undisturbed ecosystems the accumulation and release of CO_2 is in equilibrium.

Figure 2. Manipulated Carbon Cycle

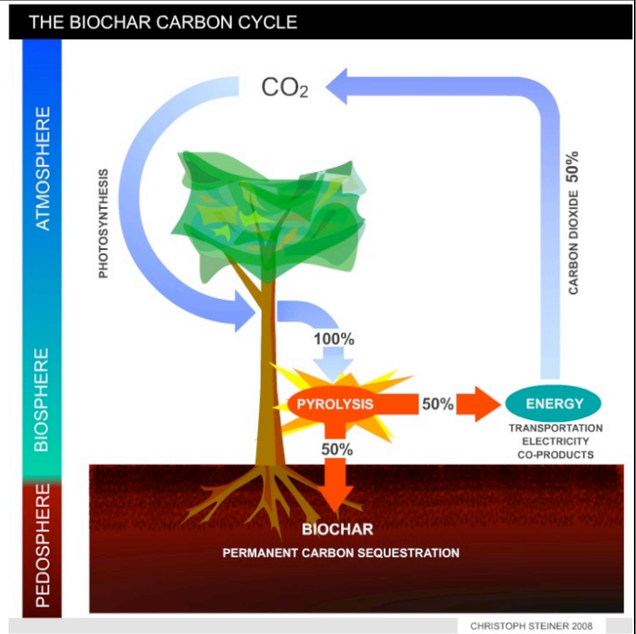


Figure 2 illustrates the manipulated carbon cycle due to biochar carbon sequestration. Biochar is recalcitrant against decomposition and remains in the soil for centuries or millennia. Thus pyrolysis can transfer 50% of the carbon stored in plant tissue from the active to an inactive carbon pool. The remaining 50% of carbon can be used to produces energy and fuels. This enables carbon negative energy generation if re-growing resources are used. (I.e. with each unit if energy produced CO_2 is removed from the atmosphere).

TERRA PRETA – A BIOCHAR ENRICHED SOIL

The storage of carbon in charcoal (biochar) was proposed in 1993 (Seifritz 1993). Seifritz proposed to produce charcoal and dispose it in landfills. This proposal did not receive much attention, until recent research on Terra Preta revealed the importance of charcoal to maintain soil fertility particularly in the humid tropics (Glaser et al. 2001b, Steiner 2007).

Terra Preta is a man-made soil occurring in the Amazon Basin (Figure 1). These soils were enriched with nutrient rich bones (Lima et al. 2002) and charcoal (Glaser et al. 2001a). As a result, the most infertile soils were transferred into most productive soils (Figure 3). These soils have been created centuries and millennia ago, but are still valued by the local population for their sustained soil fertility. Terra Preta is one example among other charcoal enriched soils but is probably the most striking. Its existence proves that long-lasting soil organic carbon (SOC) enrichment can be done in a humid tropical environment with low carbon sequestration capacity if done with a recalcitrant form of carbon such as biochar.

Figure 3. Terra Preta

(a)  (b) 

Note: (a) A typical Terra Preta horizon: On the bottom the yellow infertile Ferralsol and on the top the biochar enriched anthropic A horizon. (b) Cash crop cultivation on Terra Preta, near Manaus, Brazil.

SLASH-AND-CHAR AS ALTERNATIVE TO SLASH-AND-BURN

Recent field experiments inspired by the re-creation of Terra Preta showed that biochar could sustain fertility on poor tropical soils. Biochar significantly increased plant growth and nutrition in pot and field experiments (Lehmann et al. 2003, Steiner et al. 2007, Figure 4). The biochar did not provide many nutrients but significantly reduced leaching of applied nitrogen fertilizers. Increased nutrient retention is one favorable property of Terra Preta (Glaser et al. 2002). Increasing the fertilizer use efficiency is of prime importance on these highly permeable soils under high rainfall intensity in the tropics (Steiner et al. 2008). This has important consequences as the synthesis of nitrogen fertilizers consumes large amounts of fossil energy and the cost of nitrogen fertilizer increases dramatically with increasing energy prices. The effects on soil biology seem to be essential as biochar has the potential to alter the microbial biomass (Steiner et al. 2004a) and composition (Birk 2005) and the microbes are able to change the biochar's properties (Glaser et al. 2001a). The majority of experiments conducted show that biochar soil amendments result in enhancement of beneficial fungi (Warnock et al. 2007) and nitrogen fixing microbes (Rondon et al. 2007). The improved productivity ranges from 20 to 220 percent at application rates of 0.4 to 8 tons carbon per hectare (Lehmann and Rondon 2006).

The research showed that charcoal can improve soil chemical, biological, and physical properties and led to the description of slash-and-char as an alternative to slash and burn (Steiner 2007) 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 carbon is converted into charcoal (Fearnside et al. 2001), but charcoal production can capture 50 percent of the above-ground carbon. If re-growing resources (fallow vegetation or crop residues) are used, slash-and-char could become a significant carbon sink and an important step towards sustainability and SOC conservation.

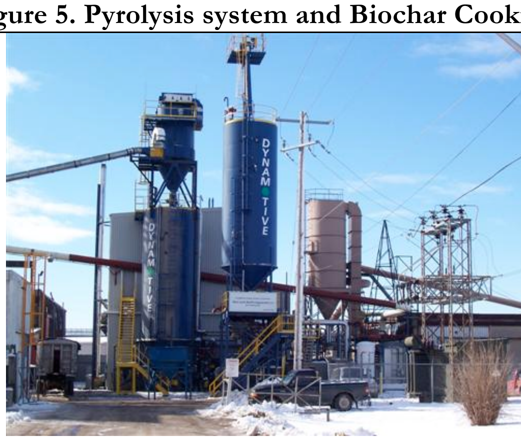
Figure 4. Sorghum plants growing on mineral fertilized (NPK) soil.

Note: The plot to the left got additional biochar amendment (11 tons per ha).
Source: Embrapa Research Station, Manaus, Brazil, Photo C. Steiner

BIOCHAR AN OPPORTUNITY ON GLOBAL SCALE?

The global potential of biochar (non fuel use of charcoal) reaches far beyond slash-and-char. Burning of biomass is a common practice, releases nearly all the carbon stored in the biomass immediately as CO_2 and barely adds SOC buildup in agricultural soils. Increasing interest in renewable energy raised the prospect to supply biochar from pyrolysis of waste biomass. Pyrolysis would facilitate bio-energy production and carbon sequestration if the biochar is redistributed to agricultural fields. Thus the uses of crop residues as potential energy source or to sequester C and improve soil quality can be complementary, not competing uses. Charcoal producing gasifiers can have a broad range in size and in technological complexity ranging from cooking stoves to large pyrolysis plants (Figure 5), which would allow integration in almost all agricultural and silvicultural systems.

Figure 5. Pyrolysis system and Biochar Cookin Stove



(a)

(b)

Note: (a) Fast pyrolysis by Dynamotive, Canada. (b) Biochar producing cooking stove
Source: Pictures with friendly permission of Dynamtove and Worldstove

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. Lenton and Vaughan (2009) rated biochar as the best geo-engineering option to reduce CO_2 levels. The United Nations Convention to Combat Desertification (UNCCD) started an initiative to include biochar in the post-2012 agreement on climate change mitigation and acknowledgement as carbon sink by the UNFCCC (UNCCD 2008).

BIOCHAR USE IN THE PAST

Before the introduction of mineral fertilizers, maintenance of SOC, nutrient cycling and conservation was of prime importance. This is the case for millions of people who do not have access to mineral fertilizers today. Migration is the solution to nutrient depletion for an estimated 300 to 500 million people affecting almost one third of the planet's 1500 million ha of arable land (Goldammer 1993, Giardina et al. 2000). However even mineral fertilized fields show yield decreases, reduced nutrient cycling and reduced nutrient-use efficiency of applied fertilizer associated with a loss of SOC (Zech et al. 1990, Goldammer 1993, Silva-Forsberg and Fearnside 1995, Hölscher et al. 1997). This soil degradation needs to be reversed and might require practices from the past to restore carbon depleted agricultural soils.

The book "Brief Compend of American Agriculture" published in 1846 mentions multiple uses of biochar in agriculture mainly for nutrient (nitrogen) conservation (Allen 1847). The author recommends the mixing of nutrient rich materials such as guano with biochar in order to absorb ammonia. Even human excrements were mixed with biochar dust and used to replenish nutrients in the field. It is mentioned that a dressing of biochar has been found so beneficial that it has been extensively introduced in France.

Probably the oldest description of biochar use in agriculture comes from Japan. In 1697 Yasusada Miyazaki termed it "fire manure" and described roasting organic wastes and mixing with nutrient rich manures (Miyazaki 1697). Rice husk biochar has been used for several thousand of years, since the beginning of rice cultivation in Asia (Ogawa 2008). Rice husk biochar was also mixed with nutrient rich materials in order to increase its fertilizing efficiency. A mixture of human waste and charcoal powder was called "haigoe" and was frequently used to fertilize crops (Ogawa 1994). As a result of these experience and research carbonised materials are formally authorized for use as soil amendment material in Japan, which is using 27% of its national charcoal production for purposes other than fuel, more than 30.6 percent of which is used in agriculture (Okimori et al. 2003).

CONCLUSIONS

Decomposition of dead biomass is part of the natural carbon cycle and releases the carbon as CO_2. Fire accelerates the carbon cycle. If biochar is made from re-growing waste biomass as an alternative to burning and used as soil amendment it can enhance biomass accumulation by improving soil fertility. Therefore biochar can be considered to be a mechanism to enhance photosynthesis (carbon capture) but decelerate the decay of the products of photosynthesis (release of CO_2). Thus the production of biochar is a way to manipulate the carbon cycle. Photosynthesis removes CO_2 from the atmosphere and biochar stores carbon in a solid and beneficial form. Furthermore, energy co-generation allows the production of carbon negative energy. This means the removal of greenhouse gases from the atmosphere with each unit of energy produced. The generation of Terra Preta soils seems to be possible and would require a material flow management involving carbon and nutrients. The global carbon trade holds out the prospect to achieve this goal to reverse climate change and soil degradation. Thus biochar offers a strong link between the UN Rio conventions.

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