Climate Change

Biochar

Mitigation of Climate Change and Soil Restoration

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March 2010

This document provides an introduction to biochar carbon sequestration, summarizes the prospects for mitigating climate change, soil degradation and loss of biodiversity and identifies potential applications in Indonesia as a complementary approach for REDD activities.

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Summary

The world's soils hold more organic carbon (C) than that held by the atmosphere and vegetation. Therefore the land has an unparalleled capacity to act as a sink for green house gases making it imperative to focus on activities that enhance rehabilitation, protection and sustainable management. Biomass burning and the removal of crop residues reduce C in soil and vegetation, which has implications for soil fertility and the global C cycle.

The drawback of conventional C enrichment in soils (such as reduced tillage intensity) is that this C-sink option depends on climate, soil type and site specific management. The issues of permanence, leakage and additionality are the greatest obstacles for land use and forestry (LULUCF and REDD) carbon projects. Furthermore, the "permanence" and vulnerability of these sinks is likely to change in a warming climate. Therefore C sequestered by LULUCF projects is generally considered only temporarily sequestered.

Biochar C sequestration is fundamentally different to other forms of bio-sequestration. Carbonization of biomass increases the half-life time of the remaining C by order of magnitudes and can be considered a manipulation of the C cycle. While fire accelerates the C cycle the formation of biochar (= carbonized plant material, charcoal, black carbon) decelerates the C cycle. Biochar production transforms C from the active (crop residues or trees) to the inactive C pool. Therefore issues of permanence, land tenure, leakage, and additionalty are less significant for biochar projects. However most C offset schemes do not accept the avoidance of CO_2 emissions from decomposing plant material. The definition of a C sink should be revised to include the difference between a sink to the inactive C pool, such as biochar, and a sink that remains in the active C pool, such as reforestation.

Tropical land use systems provide unique conditions for biochar C sequestration. The humid tropics produce more biomass than anywhere else and the abundance of "waste" biomass is huge. Decomposition of labile soil organic carbon (SOC) is fast and in strongly weathered tropical soils, SOC plays a major role in soil productivity. Therefore both, the conditions to produce biochar as well as the benefits of soil biochar applications are greatest in the humid tropics. Biochar carbon sequestration is that it can be implemented with or without additional energy production on a small scale (improved kilns, stoves, gasifiers) as well as a large scale (e.g., biorefinery).The C sequestration potential for different land use systems in Indonesia are:

- 7.7 Mg of CO_2 ha^{-1} yr^{-1} if slash-and-burn is replaced by slash-and-char
- 15 Mg of CO_2 ha^{-1} yr^{-1} if all available residues are carbonized in oil palm plantations
- 4.2 Mg of CO_2 ha^{-1} yr^{-1} if all available residues are carbonized in wood plantations and,
- Range from 66 to 136 Mg of CO_2 ha^{-1} if all available residues are carbonized after logging operations.

Required research and policy actions involve:

- A strong support for biochar C sequestration at international negotiations (post-2012 agreement).
- Research and optimization of biochar use in all land use sectors.
- Development of appropriate carbonization technology for various land use systems
- Preparation and development of a Project Design Document and Methodology for various land use systems

Biochar enriched soils like Chernozems and in particular Terra Preta soils are among the world's most fertile soils and prove that soil SOC enrichment beyond the maximum capacity is possible if done with a recalcitrant form of C such as biochar. Biochar offers unique options to address issues emerging from the conflicts between cultivating crops for different purposes, such as for energy or for food. Thus it could have an important impact on food security, land/soil degradation, water quality, and biodiversity.

Executive Summary

Maintaining and increasing soil organic carbon (SOC) is crucial to maintain soil fertility. SOC improves physical, chemical and biological properties of soils and is of particular importance in the tropics, where there is a greater proportion of nutrient poor soils with greater susceptibility to SOC loss. The degradation of SOC is also a main source of greenhouse gases (GHG). The global SOC pool in the upper 1 m for the world's soils contains 1.3 times more carbon than the standing biomass. Therefore soils represent a considerable carbon (C) sink, but also a huge source of GHG if agricultural practices are not changed. Before the introduction of mineral fertilizers a complex crop rotation and fallow system was established in order to maintain SOC; nutrient cycling and SOC conservation was of prime importance. Today however even mineral fertilized fields show yield decreases, reduced nutrient cycling and reduced nutrient-use efficiency of applied fertilizer if SOC declines.

Soils containing charred plant materials are among the most productive soils in the world. High levels of charcoal C resulting from repeated historical burning of grasslands, open woodlands, and agricultural crop residues have been reported in soils from Australia and Germany. As the SOC pool declines due to cultivation, the more resistant charcoal fraction increases as a portion of the total C pool. However, only a small percentage of the original C remains in the form of charcoal after a forest fire. Waste biomass (crop and forestry residues, fallow vegetation) could be carbonized and the resulting biochar used as soil amendment. Biochar consists of mainly C and is characterized by a very high recalcitrance against decomposition. Thus biochar decelerates (manipulates) the second part of the C cycle (decay, mineralization) and its non-fuel use would establish a C sink and may increase soil fertility.

Most impressive is the transformation of one of the world's most infertile soils into one of the most productive ones in the Brazilian Amazon. If anthropic (unintentionally formed) or anthropogenic (intentionally formed), these dark soils are the product of human activities and termed *Terra Preta de Índio*. The deposition of nutrient-rich materials and charcoal within the zone of habitation and associated garden areas created these soils. The resulting soil contains high concentrations of charcoal; significantly more plant available nutrients than in the surrounding Oxisols. Terra Preta soils still contain elevated carbon contents, despite their age of 500 to 2,500 years and intensive cultivation. With certainty charcoal was intentionally used in U.S. and European agriculture. The book "Brief Compend of American Agriculture" published in 1846 mentions multiple uses of charcoal mainly for nutrient (nitrogen) conservation purposes. Probably the oldest description of charcoal use in agriculture comes from Japan and rice husk biochar has been used since the beginning of rice cultivation in Asia.

In an attempt to recreate Terra Preta, initial biochar research was conducted in the humid Tropics. Tropical land use systems provide unique conditions for biochar carbon sequestration. The humid Tropics produce more biomass than anywhere else and the abundance of "waste" biomass is huge. Decomposition of labile SOC is fast and in strongly weathered tropical soils, SOC plays a major role in sustaining soil productivity. Therefore both, the conditions to produce biochar as well as the benefits of soil biochar applications appear greatest in the humid Tropics. As a result slash-and-char was described as an alternative to slash-and-burn. A review of 24 studies revealed that soil biochar additions improved productivity in all of them ranging from 20 to 220% at application rates of 0.4 to 8 Mg C ha^{-1}. Such increases in productivity were explained by improving soil chemical, biological and physical properties. Decreased acidity and exchangeable aluminum and increased mineral nutrition on acidic tropical soils were found by several studies. But also mineral nitrogen fertilization was more efficient on soils containing biochar.

Biochar can be produced with or without additional energy production on as small scale (improved kilns, stoves, gasifiers) as well as a large scale (e.g. biorefinery). Improved kilns would be most suitable for infield carbonization techniques to carbonize biomass as alternative to slash-and-burn, while pyrolysis technology with additional energy generation could be employed where large amounts of biomass accumulate (e.g. oil palm plantations). In Sarawak, Malaysia fallow vegetation (secondary forest) accumulates 47 Mg dry matter in the first 5 years. Replacing slash-and-burn with slash-and-char would sequester 7 Mg of CO_2 ha^{-1} yr^{-1}. Biomass production in oil palm plantations was estimated to be 1.55 Mg ha^{-1} yr^{-1} of empty fruit bunches (EFB), 1.64 Mg ha^{-1} yr^{-1} fiber, 1.10 Mg ha^{-1} yr^{-1} shells, 11.4 Mg ha^{-1} yr^{-1} pruned fronds and about 3.60 Mg ha^{-1} yr^{-1} palm trunks and fronds (at renovation, every 20 to 30 years). The carbon sequestration potential would be almost 15 Mg ha^{-1} yr^{-1} if all biomass sources would be carbonized. Timber plantations have a C sequestration potential of 4.2 Mg ha^{-1} yr^{-1} if all available residues are carbonized.

Biochar carbon sequestration has some significant advantages over other forms of bio-sequestration. Issues such as leakage, permanence and additionality are less severe with biochar because it transforms C from an active to an inactive C pool with low vulnerability. The turnover rate and the quantity of C could be used to assess the C sequestration potential. However biochar as a soil amendment, as other soil management practices, is not acknowledged by the UNFCCC as a C sink. Therefore biochar C needs to be traded on the voluntary C market. Biochar C offsets might fetch a considerable higher price as they may have strict additionality, and strong social and environmental benefits.

1. Introduction to Biochar

1.1 The Values of Soil Organic Carbon (SOC)

Before the invention of mineral fertilizers, management of SOC was the only way to restore or maintain soil fertility. Sedentary farmers either depleted their SOC stocks for nutrients, facing nutrient depletion, or found ways to maintain SOC. Over decades, small-scale African farmers have removed large quantities of nutrients from their soils without using sufficient quantities of manure or fertilizer to replenish the soil. As a result Africa south of the Sahara is the only remaining region of the world where per capita food production has not increased over the past 40 years (Sanchez 2002).

The relationship between soil fertility and SOC was well known in the first half of the 19th century as the German agronomist Albrecht Thaer published his "Humus Theory". Thaer's approach, and quantitative assessment of agro-ecological and economic sustainability of farming systems was used with success during half a century, until 1849 when Sprengel and Liebig published on mineral nutrition of plants (Feller et al. 2003). From then on the "minimal nutrition theory" progressively abandoned recycling of nutrients from settlements to agricultural fields (Manlay et al. 2007). But it took more than 60 years until the German chemist Fritz Haber found a way to synthesize ammonia. This was the basis of all subsequent nitrogenous fertilizers. Since 1950 (after the world wars and Great Depression) the problem of nutrient depletion was addressed by mineral fertilization (McNeill and Winiwarter 2004). This boosted crop production and replenished nutrient stocks but did not treat soil degradation accompanied by accelerated loss of SOC. Most soils have lost 30 to 75% of their antecedent SOC pool or 30 to 40 Mg C ha^{-1} (Lal et al. 2007). The observed loss of SOC is associated with yield decreases (Grace et al. 1995), reduced nutrient cycling and reduced nutrient-use efficiency of applied fertilizer (Yamoah et al. 2002).

Throughout the world intensive agricultural land use often has resulted in soil physical and chemical degradation, erosion, and higher losses than input rates of nutrients and organic materials. In contrast, the intentional and unintentional deposition of nutrient-rich materials within human habitation sites and field areas has in many cases produced conditions of heightened fertility status (Woods 2003). An anthropogenically-enriched dark soil found throughout the lowland portion of the Amazon Basin and termed *Terra Preta de Índio* is one such example (see Figure 1). Its fertility is the secondary result of the transport of natural and produced foods, building materials, and fuel to prehistoric dwelling places (Woods 1995). These materials and their byproducts were then transformed and differentially distributed within the zone of habitation and associated garden areas. The resulting soil contains high concentrations of charcoal (Glaser et al. 2001a); significantly more plant available nutrients than in the surrounding Oxisols (Lima et al. 2002). This is in contrast to today's urban wastes in the region which are deposited as contaminated toxic material far away from settlements or into the rivers. The existence of Terra Preta proves that infertile Ferralsols and Acrisols can be transformed into permanently fertile soils in spite of rates of weathering 100 times greater than those found in the mid-latitudes. Such a transformation cannot be achieved solely by replenishing the mineral nutrient supply, however; SOC is also of prime importance for insuring the retention of soil nutrients (Zech et al. 1990).

Figure 1. The left picture shows the anthropogenically-enriched dark soil horizon of a typical Terra Preta soil, intensive cash crop production on Terra Preta (right picture).

According to Duxbury et al. (1989) and Sombroek et al. (1993) it is important to separate effects due to organic matter per se (maintenance and improvement of water infiltration, water holding capacity, structure stability, cation exchange capacity (CEC), healthy soil biological activity) from those due to decomposition (source of nutrients, Figure 2). The SOC pool is an important indicator of soil quality, and has numerous direct and indirect impacts on it such as, improved structure and tilth, reduced erosion, increased plant-available water capacity, water purification, increased soil biodiversity, improved yields, and climate moderation (Lal 2007a). This is essential to sustain the quality and productivity of soils around the globe, particularly in the tropics where there is a greater proportion of nutrient poor soils with a greater susceptibility to SOC loss (Feller and Beare 1997).

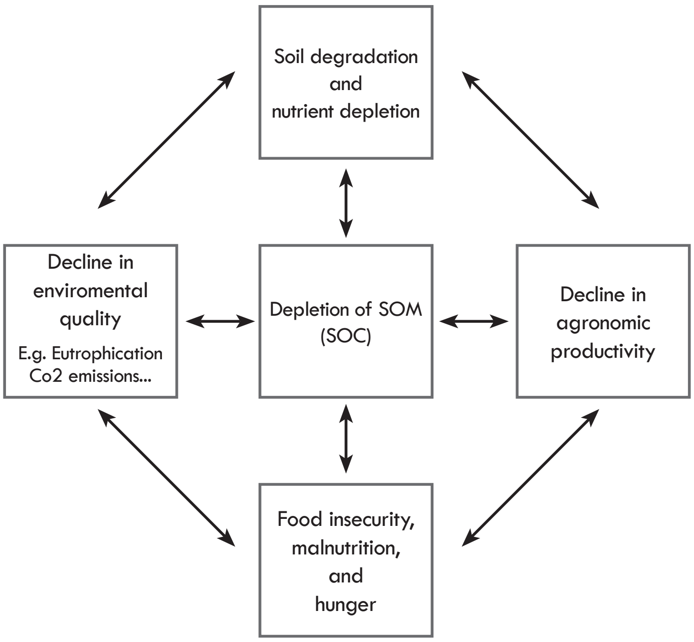

Figure 2. shows the values of soil organic carbon (SOC) and its implications on the environment, agronomy, and quality of life. Redrawn and lightly modified from Lal (2004)

1.2 Greenhouse Gas (GHG) Emissions from Agriculture

Measurable anomalous emissions of GHG began already 8000 years ago. These early anthropogenic CO_2 emissions were caused by forest clearing in Eurasia for agricultural purposes, and methane (CH_4) emission rose from widespread rice irrigation about 5000 years ago (Ruddiman 2003). After 1750 the increase in atmospheric CO_2 was mainly caused by fossil fuel combustion but emissions from land use change contributed about 30%, from which more than half is estimated from depletion of SOC. This depletion is exacerbated by further soil degradation and desertification (Lal 2003). These losses from the earth's native biomass and from soil due to cultivation amount approximately 170 Pg (x 10^{15}) C, most of it as CO_2 in the atmosphere (Sauerbeck 2001a). The global SOC pool in the upper 1 m for the world's soils contains 1220 Pg C, 1.5 times the total for the standing biomass (Sombroek et al. 1993). As most agricultural soils have lost 50 to 70% of their original SOC pool (Lal 2003) they represent a considerable C sink if efforts are made to restore SOC, but also a huge source of GHG if soil management and deforestation rates are not reduced. There is high agreement and much evidence that with current climate change mitigation policies and related sustainable development practices, global GHG emissions will continue to grow over the next few decades (25-90% between 2000 and 2030) (IPCC 2007).

1.3 Replenishing SOC Pools with Biochar

Increasing SOC with conventional means e.g. conservation tillage, use of manures, and compost, conversion of monoculture to complex diverse cropping systems, meadow-based rotations and winter cover crops, and establishing perennial vegetation on contours and steep slopes can sequester C.

However the sequestration potential depends on climate, soil type, and site specific management. Climate, particularly rainfall and temperature, is an important factor for SOC formation from decomposing biomass residues. Therefore the SOC pool is in dynamic equilibrium with climate and soil management. From biomass to humus a considerable fraction of C is lost by respiratory processes, and also from humus to resistant soil C. Only 2-20% of the C added as above ground residues and root biomass enters the SOC pool by humification. The rest is converted to CO_2 due to oxidation, and furthermore the SOC pool is not inert to oxidation (Lal 2004). Soils can only sequester additional C until the maximum soil C capacity, or soil C saturation, is achieved, which requires a steady input of biomass and careful management practices. The drawback of SOC enrichment with conventional methods is that this C-sink option is of limited duration (permanence). The new SOC level drops rapidly again, as soon as the required careful management is no longer sustained. SOC of cropland increases only if either SOC additions are enhanced or decomposition rates reduced (Sauerbeck 2001a).

Figure 3. demonstrates the historical knowledge about the recalcitrance of charcoal. Wooden poles were (are) blackened (carbonized) on the outside to increase their persistence in soil.

Reduced decomposition is an advantage of charcoal as soil amendment (biochar). Seiler and Crutzen (1980) were the first to point out the potential importance of charcoal formation to the global C cycle. In natural and agroecosystems residual charcoal is produced by incomplete burning. As the SOC pool declines due to cultivation, the more resistant charcoal fraction increases as a portion of the total C pool (Skjemstad 2001; Skjemstad et al. 2002; Zech and Guggenberger 1996) and may constitute up to 35% of the total SOC pool in ecosystems (Skjemstad et al. 2002). Therefore, biomass burning has important negative and positive impacts on C dynamics. Carbon dating of charcoal has shown some to be over 1500 years old, fairly stable, and a permanent form of C sequestration (Lal 2003). Kuzyakov et al. (2009) assessed a half-life of 1400 years for carbonized plant materials (Figures 3 and 11).

1.3.1 Biochar Carbon Sequestration – A Manipulation of the Carbon Cycle

Carbon dioxide 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 C 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. Reduced decomposition is an advantage of carbonized organic matter (charcoal, biochar). Thus, biochar formation decelerates the C cycle and has important implications for the global C cycle. In natural and agroecosystems residual charcoal is produced by incomplete burning (Seiler and Crutzen 1980). Biochar can be produced by thermo-chemical conversion of biomass. The storage of C in charcoal was proposed in 1993 (Seifritz 1993). Seifritz proposed to produce charcoal (biochar) 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). The existence of Terra Preta demonstrates that increasing SOC contents beyond a perceived maximum within native ecosystems is possible if done with a recalcitrant form of C such as biochar. Terra Preta soils still contain large amounts of biochar derived SOC in a climate favorable for decomposition, hundreds and thousands of years after they were produced.

Burning biomass in the absence of O_2 produces biochar and products of incomplete combustion (PIC). The PIC include burnable gases such as hydrogen (H_2) and methane (CH_4). These gases can be used to fuel the conversion of biomass into biochar and/or renewable energy generation. Larger molecules can be condensed into bio-oil and also used as a renewable fuel. The resulting biochar consists of mainly C and is characterized by a very high recalcitrance against decomposition. Thus biochar decelerates (manipulates) the second part of the C cycle (decay, mineralization) and its non-fuel use would establish a C sink (Figure 4). Lenton and Vaughan (2009) rated biochar as the best geo-engineering option to reduce CO_2 levels.

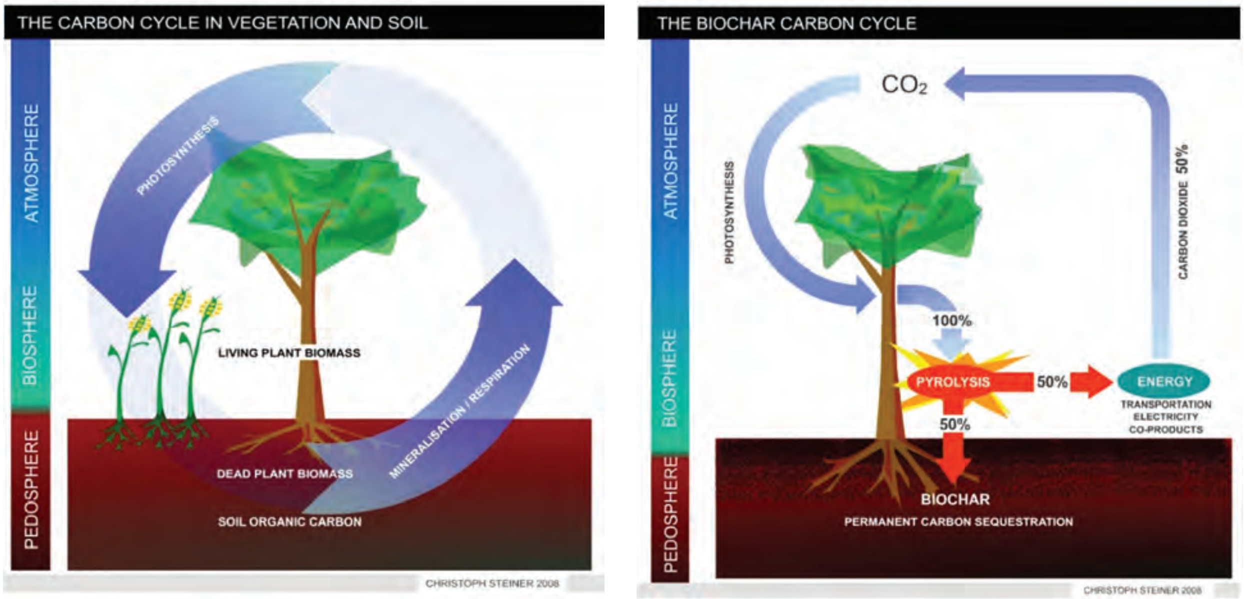

Figure 4. Illustrates the manipulation of the carbon cycle through biochar formation. In full grown ecosystems (e.g. climax forest) CO2 uptake by photosynthesis and generation through respiration and decay is in equilibrium. Biochar formation (left) can transfer carbon from the active to the inactive pool. Approximately 50% of the carbon stored in biomass can be captured in biochar and the flammable gases be used for renewable energy generation.

1.4 Biochar and Soil Fertility

The recalcitrant nature of charcoal makes biochar a rather exceptional SOC constituent for enhancing crop productivity. Whether biochar can improve soil quality to the same extent as decomposable organic materials, however, is a valid question. Recent studies showed that biochar is indeed capable of increasing soil fertility (Glaser et al. 2002; Iswaran et al. 1979; Ogawa 1994b; Topoliantz et al. 2005). Biochar significantly increased plant growth and nutrition in a pot experiment by Lehmann et al. (2003) and a field experiment by Steiner et al. (2007). The authors proposed that biochar can improve soil chemical, biological, and physical properties. Lehmann et al. (2003) also found significantly reduced leaching of applied fertilizer nitrogen (N) in charcoal containing pots, which was also corroborated by the field experiment by Steiner et al. (2008). Biochar also likely affects the the quantity of soil microbes (Steiner et al. 2004a) as well as their composition (Birk 2005). The majority of experiments conducted show that biochar soil amendments result in enhanced colonization rates of tree and crop species by mycorrhizal fungi (Warnock et al. 2007). Rondon et al. (2007) also found increased biological N fixation by common beans through charcoal additions and Gehring (2003) found an increased occurrence of N-fixing nodules in plants in forests on Terra Preta compared to adjacent soils. Finally, microbes were also demonstrated to interact with the biochar by enhancing the CEC (the charge surface available for nutrient retention) of the biochar (Glaser et al. 2001a). Lehmann and Rondon (2006) reviewed 24 studies with soil charcoal biochar additions and found improved productivity in all of them ranging from 20 to 220% at application rates of 0.4 to 8 Mg (i.e., metric tonnes or $1x10^6$ g) C ha^{-1}.

1.4.1 Importance for Tropical Agriculture

In strongly weathered tropical soils, SOC plays a major role in soil productivity (Tiessen et al. 1994) because it represents the dominant reservoir of plant nutrients such as N, phosphorus (P), and sulfur (S) and CEC. Generally, SOC contains 95% or more of the total N and S, and between 20 and 75% of the P in surface soils (Duxbury et al. 1989). On soils with low nutrient retention capacity the strong tropical rains easily leach available and mobile nutrients, such as inorganic N fertilizers, rapidly into the subsoil where they are unavailable for most crops (Giardina et al. 2000; Hölscher et al. 1997; Renck and Lehmann 2004) making conventional fertilization highly inefficient. A loss in C contents reduces the ability of the soil to retain nutrients especially in soils with low activity clays such as in highly weathered soils of the humid tropics (Sanchez 1976).

Aluminum (Al) toxicity and acidity are further constrains on many tropical soils. Biochar has been shown to reduce Al availability (Steiner et al. 2007) and application increased legume production in a study by Topoliantz et al. (2005) due to decreased soil acidity and exchangeable Al but increased calcium (Ca) and magnesium (Mg) availability. Aluminum can reduce crop production severely (Sierra et al. 2003).

Figure 5. shows sorghum plants growing on mineral fertilized (NPK) soil. The plot to the left got additional biochar amendment (11 Mg per ha). (Embrapa Research Station, Manaus, Brazil)

Charcoal provides a good habitat for the propagation of useful microorganisms such as free-living nitrogen fixing bacteria and mycorrhizal fungi (Ogawa 1994a). Ogawa (1994a) holds the charcoal's weak alkalinity, porosity and ability to retain water and air responsible for the stimulation of microbes.

1.4.2 Historical Use

Besides the manmade and biochar containing Terra Preta soils, biochar (the residues from charcoal production) is frequently used as a soil conditioner in Brazil (Steiner et al. 2004b) and according to Okimori et al. (2003) 27% of the charcoal consumption in Japan, is used for purposes other than fuel. The largest proportion is used as soil amendment on agricultural land (30.6%) followed by applications in the livestock industry (22.3%). The historical use might have been much more common than previously thought. Allen (1847) published "A Brief Compend of American Agriculture" in 1847 and describes several agricultural applications for charcoal (biochar) including disease prevention (rust and mildew), ammonia retention, and mentioned its extensive use in France. Also the recalcitrance of carbonized materials was well known and utilized to increase the durability of wood (Figure 3).

1.5 Advantages of Charcoal Carbon sequestration

1.5.1 No competition between SOC restoration, bio-fuels and food production

Numerous researchers warn of deleterious effects on soil fertility if crop residues are removed for bioenergy production (Blanco-Canqui and Lal 2007; Lal 2005; 2007a; Lal 2007b; Lal and Pimentel 2007; Sauerbeck 2001b). Blanco-Canqui and Lal (2007) found that an annual corn stover removal rate of > 25% reduces SOC and soil productivity. Pyrolysis with biochar C sequestration provides a tool to combine sustainable SOC management (C sequestration), and renewable energy production. While producing renewable energy from biomass, SOC sequestration, agricultural productivity, and environmental quality can be sustained and improved if the biomass is transferred to an inactive C pool and redistributed to agricultural fields. The uses of crop residues as potential energy source or to sequester C and improve soil quality can be complementary, not competing uses.

1.5.2 Decentralized and Low-Cost Technology

Carbon capture and sequestration usually assumes geo-sequestration (CO_2 capture in depleted oil and gas fields, saline aquifers etc.) as the sequestering tool. To capture C as CO_2 is very cost-intensive (Ho et al. 2005). These technologies require vast capital inputs and large scale projects. Using this technology for coal power plants can at best reduce its CO_2 emissions, while using re-growing biomass would establish a C sink. Charcoal producing gasifiers can have a broad range in size and in technological complexity. Biochar can be produced as a byproduct from cooking (biochar producing kitchen stoves, see appendix 6.2). Decentralized small scale projects are feasible and large capital investments are not necessary. As charcoal is a byproduct of gasification, no C capture technology is necessary. There is no risk of harmful CO_2 leakage from biochar.

1.5.3 Reducing Deforestation

The C trading market holds the prospect to reduce deforestation of primary forest, because cutting intact primary forest would reduce the farmer's C credits. (Fearnside 1997) estimated the above-ground biomass of unlogged forests to be 434 Mg (x 10^6) ha^{-1}, about half of which is C. This C is lost if burned in a slash-and-burn scenario and lost to a high percentage (> 50%) if used for biochar production. Only re-growing plant biomass can establish a C sink. 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. Further improving and sustaining soil fertility reduces the need to clear and burn new forest areas in shifting cultivation systems. As tropical forests account for between 20 and 25% of the world terrestrial C reservoir (Bernoux et al. 2001), this would reduce emissions from tropical forest conversion which is estimated to contribute globally as much as 25 % of net CO_2 emissions and up to 10 % of N_2O emissions to the atmosphere (Palm et al. 2004).

2. Carbon Sequestration Potential

The global amount of crop residue produced is estimated at 2.802 Pg yr^{-1} for cereal crops and 3.8 Pg yr^{-1} for 27 food crops (Lal 2005). An enormous amount of biomass is burned each year without any use. Kim and Dale (2004) estimate that globally 1.6 Pg of stover and straw (from the 7 most important crops) are wasted per year. Frequently biomass (forests, fallow vegetation, grassland, crop residues) is burned to get rid of it, adding CO_2 to the atmosphere for only marginal and short term increases in soil fertility. Burning of biomass (slash-and-burn, crop residue burning) is a common practice, releases nearly all the C stored in the biomass immediately as CO_2 and barely adds SOC buildup in agricultural soils.

Approximately 0.7 Pg of rice straw is wasted In Asia annually (Kim and Dale 2004). Before the introduction of mineral fertilizers, rice residues were a valued resource and mostly returned to the soil as organic fertilizer. Since then, the importance of organic soil amendments has declined continuously and they are likely to play a minor role in the management of nutrients in favorable rain-fed environments. This is the result of the availability of cheap inorganic fertilizer and the increasing opportunity costs of organic fertilizer use (Pingali et al. 1998). Simultaneously, increasing yields lead to ever greater quantities of rice residues available and intensification of land use results in insufficient time for decomposition. As a consequence residues accumulate in the field and can cause considerable crop management problems. Increasing residue incorporation in flooded rice paddies increases CH_4 emissions, a very potent greenhouse gas. Many Asian farmers find it more expedient to burn crop residues than to incorporate them into the soil (Haefele, IRRI, personal communication).

Worldwide, the total C release from fire is 4-7 Pg of C yr^{-1}. This flux is almost as large as the rate of fossil fuel consumption (about 6 Pg yr^{-1} in 1990, Goudriaan 1995). Tropical forest conversion is estimated to contribute globally as much as 25 % of the net CO_2 emissions (Palm et al. 2004). These numbers emphasize the potential for biochar C management if only the biomass is utilized that is burnt with no use except for getting rid of it.

2.1 Carbon Trade

Access to the global C trade is a prerequisite for the above mentioned management practices. According to Lal (2007b) the global C market has a potential grow to $1 trillion by 2020 or before. This market must be made accessible to land managers, especially in the tropics where sustaining SOC and soil fertility is most challenging and CO_2 emissions due to land use change are highest.

A review by Lehmann et al. (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, biochar sequestration could exceed current emissions from fossil fuels (5.4 Pg C yr^{-1}).

A biorefinery processes biomass into a spectrum of marketable products and energy. One such product could be biochar. However there is an opportunity cost attached to biochar carbon sequestration. This is the cost of energy still contained in the carbonized biomass. If pyrolysis gears for maximizing biochar production (roughly 30 to 35% of the feedstock is converted to biochar), approximately 50% feedstock energy is contained in the biochar. However, more than 60% of the emissions reductions of biochar production with energy co-generation are realized from C sequestration in the biochar (Roberts et al. 2010). Therefore the price of carbon is critical to the cost-effectiveness of biochar projects (Pratt and Moran 2010; Roberts et al. 2010). However even the most expensive biochar projects revealed cost-effectiveness of other carbon negative technologies such as carbon capture and storage (Pratt and Moran 2010).

2.1.1 Basic Considerations

A general advantage to fossil fuel replacement with charcoal is the local production and use. This avoids transportation costs and export of plant nutrients from agricultural soils. Further there is a significant benefit from long-lasting SOC enrichment. The conventional management of biomass often results in anoxic conditions and a release of CH_4 and N_20. Management options avoiding anoxic conditions involve composting, combustion, gasification and pyrolysis of biomass. If carbonized plant materials are not used as a fuel it should be possible to claim C credits from avoided CO_2 emissions (mineralization) in addition to currently claimed avoided CH_4 and N_2O emissions. When biochar is used as a soil amendment, the avoided emissions are 2 -5 times greater than when used as a fuel (2–19 Mg CO_2 ha^{-1} y^{-1}) and potential revenue from C emission trading alone can justify optimizing pyrolysis for biochar production (Gaunt and Lehmann 2008). As long as re-growing biomass is used, biochar C sequestration facilitates the capture of CO_2 from the atmosphere and can thus help to reduce the historic C debt. As such it is unique and different from traded reductions in emissions.

The conversion efficiency of biomass to biochar depends on factors such as carbonization technology, feedstock, temperature, and pressure. The yield is inversely proportional to the temperature of carbonization, and the C content of biochar directly proportional to the production temperature (Antal and Grønli 2003).

The biochar yield can be calculated by:

$$Y_{char} = m_{char}/m_{biomass}$$

Where m_{char} is the dry mass of biochar produced from the dry mass of the feedstock $m_{biomass}$. This does not reflect the fixed-C content of the biochar because it does not take the C content into account. Efficiencies of traditional carbonization techniques range from 8 – 36%. As the C content of biochar is higher than that of the feedstock we can assume a higher fixed-C yield (Y_C):

$$Y_C = Y_{char} \text{ (\%char C / \% biomass C)}$$

Where % char C is the % C content of the dry biochar, and % biomass C is the % C content of the dry feedstock biomass. Reasonable fixed-C yields are around 50%. Therefore approximately 50% of the feedstock C can be captured and sequestered as biochar.

Carbon has an atomic weight of 12 and oxygen 16. The molecular mass of CO_2 is 44 (CO_2/C ration 44/12 = 3.667). The amount of CO_2 captured in biochar ($CO_2^{biochar}$) can be calculated with the following equation:

$$CO_2^{biochar} = 3.667\ m_{char}\ (\%char\ C\ /\ 100)$$

The average C content of biochar is around 80% and consequently one metric ton of average biochar can sequester 2.93 tons of CO_2.

A complete emission analysis is required to estimate a potential C sink. Such analysis needs to consider emissions of other greenhouse gasses such as CH_4 and N_2O. An observed reduction on N_2O and CH_4 after biochar applications deserves particular attention due to the much higher global warming potentials of these gases compared to CO_2. Rondon et al. (2005) observed a 50% reduction in N_2O emissions from soybean plots and almost complete suppression of CH_4 emissions from biochar amended (20 Mg ha^{-1}) acidic soils in the Eastern Colombian Plains. Yanai et al. (2007) observed an 85% reduction in N_2O production of rewetted soils containing 10% biochar compared to soils without biochar. A significant reduction in N_2O production was also found by Spokas et al. (2009) in a Minnesota agricultural soil. Such additional GHG reductions may have an enormous potential and the mechanisms of CH_4 and N_2O reduction needs to be discerned in more detail. A potential impact of biochar soil additions on N_2O production and fertilizer efficiency may outweigh the use of biochar for energy (Gaunt and Lehmann 2008). For land use systems the alternative use of the feedstock needs to be considered. The decay of feedstock may lead to considerable CH_4 emissions. Avoided deforestation due to enhanced soil fertility and fossil fuel substitution of pyrolysis systems need to be considered to evaluate the full potential of biochar C sequestration.

2.1.2 Infield Carbonization Techniques as Alternative to Burning

The potential of infield carbonization techniques is huge in terms of biomass (C) turnover. An enormous amount of biomass is burned each year without any use. Traditionally charcoal is produced by biomass combustion under partial exclusion of oxygen. This involves earthen ditches, kilns, brick kilns (Figure 6), barrels and other devices to control the gas flow. This technology can be applied small scale and without transportation of feedstock or biochar. However these techniques do not utilize the full potential of pyrolysis in terms of renewable energy production. Pyrolysis uses the products of incomplete combustion (PIC) such as H_2, CH_4 and other hydrocarbons to produce energy and fuels. Incomplete combustion products are quite important if released to the atmosphere. This is due to the fact that they have higher global warming potentials (GWP), than does CO_2 (Table 1). Therefore biochar production without avoiding PIC emissions can produce a net increase in global warming commitment (GWC, the sum of the global warming potentials of the gases emitted in a process) (Pennise et al. 2001). A full estimation of the C sequestration potential would require evaluation of emissions from the alternate fate of the feedstock input if it were not used for biochar making (e.g. CH_4 and N_2O emissions from accumulating and decomposing biomass or from biomass burning), along with the emissions from its production in kilns. However PIC emissions can be easily flared off and thus avoided (Figure 6).

Table 1.

Global warming potentials of different greenhouse gases (GHG) published by the IPCC (Forster and Ramaswamy 2007) and emissions from biomass burning (Andreae and Merlet 2001).

	Global Warming Potential (GWP)			Emission Factors from Biomass Burning [1]		
GHG	20 yr	100 yr	500 yr	Tropical Forest	Charcoal Making	Agricultural residues
CO_2	1	1	1	1580	440	1515
CH_4	72	25	7.6	6.8	10.7	2.7
N_2O	310	289	153	0.20	0.03	0.07

[1] Emission factors are given in gram species per kilogram dry matter burned.

Figure 6. Traditional carbonization technique ("rabo quente" in Brazil). Products of incomplete combustion (PIC) are released to the atmosphere. B) The improved carbonization technique burns (PIC), thus reducing greenhouse gas emissions and improving carbonization efficiency. http://www.biocoal.org/3.html

The costs for an improved kiln (Figure 6B) are approximately 500 Euros. Such a kiln produces around 350 kg of biochar per batch. The production cost of biochar in traditional brick kilns (Figure 6A) in Brazil is about 50 USD Mg^{-1} and depending on access to markets the resale value as fuel was estimated to be between 70 and 120 USD (Swami et al. 2008). This would require a minimum carbon offset cost of 23 to 40 USD per Mg CO_2. Considering other benefits such as reduced CH_4 and N_2O emissions, reduced deforestation and increased fertilizer efficiency and yields would reduce the costs per CO_{2e}. Pratt and Moran (2010) evaluated the cost-effectiveness of different biochar systems and concluded that the largest abatement potentials are in Asia for biochar stove and kiln projects Biochar projects in Asia and Latin America are competitive relative to other climate change mitigation measures being explored today.

2.1.3 Pyrolysis with Biochar Carbon Sequestration

Pyrolysis of waste biomass can provide gaseous and liquid fuels and biochar as a soil amendment (Bridgwater 1999). Biochar can be used to sequester C and cycle nutrients back into agricultural fields. Pyrolysis is ideally established where biomass accumulates for instance at palm oil mills, poultry production, timber processing facilities, agricultural production and processing. As long as re-growing biomass is used, pyrolysis with biochar C sequestration enables C negative energy production, i.e. for each unit of energy produced CO_2 is removed from the atmosphere (Figure 4 and 7).

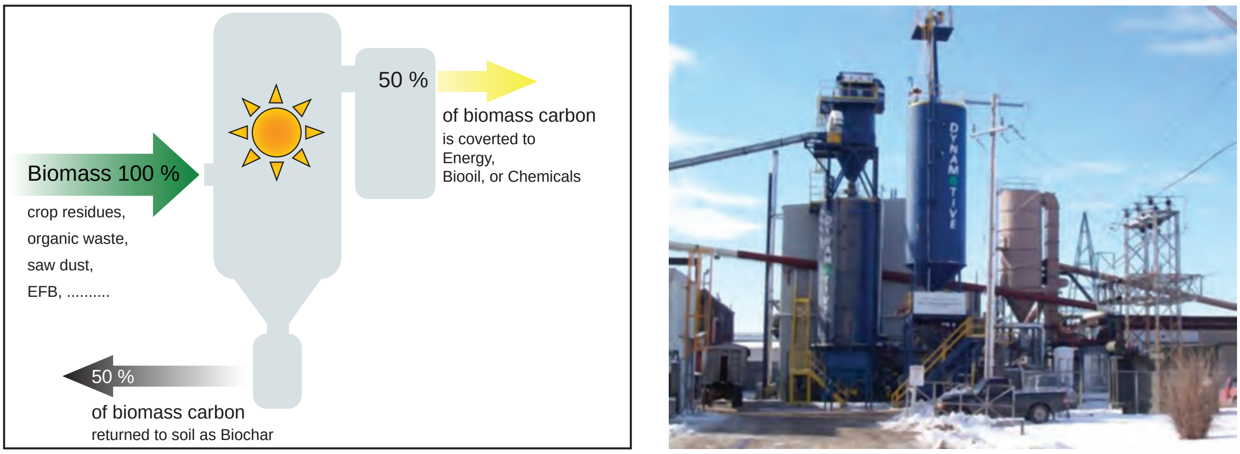

Figure 7. Pyrloysis with biochar carbon sequestration. 50% of the feedstock carbon can be returned as biochar to agricultural fields while producing renewable energy (www.dynamotive.com).

Gaunt and Lehmann (2008) evaluated a sequestration cost of U.S. \$9-16 Mg^{-1} CO_2 for biochar projects with energy production. A strategy that combines pyrolysis for bioenergy production with biochar carbon sequestration is more effective than producing solely bioenergy (Gaunt and Lehmann 2008; Roberts et al. 2010). These assessments consider costs and emissions from feedstock production and transportation. However large quantities of feedstock (see 3.2) accumulate in oil palm plantations at the mill without additional costs.

2.1.4 Charcoal Producing Stoves

In addition to biochar C sequestration, biochar producing stoves would reduce GHG by providing a more efficient and cleaner way to use fuel, an ability to utilize alternative fuels (crop residues) and thus reducing deforestation for firewood collection (Figure 8). Such stoves were successfully implemented in areas where biomass is scarce and firewood is the main energy source (e.g. arid zones in Africa and Asia, see appendix for www sources 6.2).

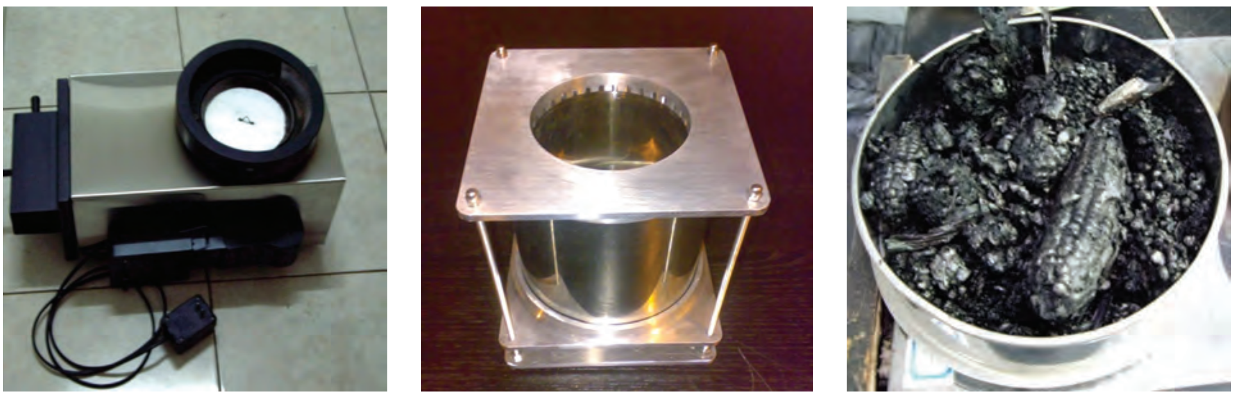

Figure 8. shows biochar producing cooking stoves. Left picture shows carbonized corncobs remaining after gasification.

2.2 Carbon Trade Options and Obstacles

2.2.1 Compliance Market

The biochar approach constitutes a significant adaptation tool to climate change, in addition to sequestering C. There is the need to include holistic approaches into the negotiation agenda of UNFCCC focusing on increased land productivity, which simultaneously takes into account the issues of climate change, land degradation and loss of biodiversity.

However biochar as a soil amendment, as other soil management practices, is not acknowledged by the UNFCCC as a C sink. There is growing consensus that biochar sequestration should be eligible as a C sink type under the UNFCCC, and interest in biochar from the agricultural community is expanding worldwide. The process to include biochar C sequestration started at the UNFCCC conference in Bali and was supported by the UNCCD and Micronesia in Poznan. Biochar C sequestration received additional support by several other countries towards COP15 in Copenhagen.

2.2.1.1 Obstacles for LULUCF and REDD

These bio-sequestration options are challenging and complex due to uncertainties in biological systems affected by climate change such as increased temperatures, altered precipitation patterns, and changes in disturbance regimes (fire, insects, and disease). Leakage, permanence and additionality (certain REDD projects and some CCX offsets, in particular those involving no-till agriculture) are issues of particular concern in LULUCF projects. The "permanence" and vulnerability of these sinks are likely to change in a warming climate. Potential future losses must be compensated (Gaunt and Cowie 2009). Therefore C sequestered by LULUCF projects is generally considered only temporarily sequestered from the atmosphere (Kollmuss et al. 2008). It can also be difficult to prove that the forest would have been cleared if it were not for the offset project, i.e. it may be difficult to prove the additionalty of certain REDD projects. The CDM board and Gold Standard deals with these challenges by either excluding or strictly limiting LULUCF projects.

However biochar C sequestration is fundamentally different to other forms of bio-sequestration. Potential drawbacks such as difficulty in estimating greenhouse gas removals and emissions resulting from LULUCF, or destruction of sinks through forest fire or disease do not apply for biochar soil amendments. Biochar production transforms C from the active (crop residues or trees) to the inactive C pool. The definition of a C sink should be revised to include the difference between a sink to the *inactive C pool*, such as biochar, and a sink that remains in the *active C pool*, such as reforestation. Biochar C sequestration might avoid difficulties such as accurate monitoring of soil C which are the main barriers to include agricultural soil management in emission trading. Independently from its use as soil amendment the turnover rate and the quantity of C could be used to assess the C sequestration potential (Gaunt and Cowie 2009). The issues of permanence, land tenure, leakage, and additionalty is less significant for biochar projects than for projects that sequester C in biomass or soil though management of plant productivity.

Nevertheless, article 3.3 of the Kyoto Protocol counts C stock change in soil, as well as biomass. Article 3.4 allows parties to include sequestration in plants and soil through management of cropland, grazing and land and existing forests. The Millennium Development Goals (MDG) Carbon Facility's[1] mission is to improve access to C finance be enabling a wider range of developing countries and project types to participate in the C market. They promote projects that generate additional sustainable development and poverty reduction benefits, thereby contributing to all MDGs. The Facility operates within the framework of the CDM and JI and is a joint project between UNEP and Fortis Bank. As such it might provide support to include biochar C offsets in the compliance market.

Most schemes do not recognize avoidance of CO_2 from biomass decomposition. One possible exception is the California Climate Action Registry[2], which recognizes ongoing storage of C in wood products and probably the Voluntary Carbon Standard (VCS)[3]. Currently only afforestation/reforestation methodologies had been accepted by the CDM board. Forestry and other land use projects play a much larger role in the voluntary offset market.

2.2.2 Voluntary Market

The demand for voluntary offsets will come from private and corporate actors who wish to go beyond regulatory requirements and will be supplied by mitigation projects in sectors that are not capped. Thus the voluntary C market seems to be the right place to initiate biochar C offsets. The key role of the voluntary market is to shape the rules and procedures for offsets in future compliance markets. The voluntary market can help achieve emissions reductions with projects that are too small for CDM, projects, set in countries without a Kyoto target, or reductions that are ineligible for CDM for formal reasons other than quality. Therefore the voluntary market seems to be the right place to initiate biochar offsets. Biochar might be considered "gourmet offset" (projects with strict additionality, strong social and environmental benefits) and such offsets often fetch a considerable higher price in the voluntary carbon market.

2.2.2.1 Standards and Methodologies:

Climate, Community and Biodiversity (CCBS)[4], is a partnership of NGOs, corporations and research institutions, such as Conservation International, The Nature Conservancy, CARE, Sustainable Forestry Management, BP and CATIE. The CCBS aims to support sustainable development and conserve biodiversity. The CCBS is a Project Design Standard only and does not verify quantified emissions reductions. It does not verify C offsets nor does it provide a registry. Biochar might be suitable as project types include "Introduction of new cultivation practices".

Plan Vivo[5] is very small and provides sustainable rural livelihoods through C finance. Plan Vivo System includes soil conservation and agricultural improvement. Because of the grass-roots approach of Plan Vivo, conservation and community benefits are very high, yet standards of this type usually remain small because they are very costly compared to cheap C options available on a globally traded C market.

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1 http://www.mdgcarbonfacility.org/
2 www.climateregistry.org
3 http://www.v-c-s.org/
4 http://www.climate-standards.org
5 www.planvivo.org

The Voluntary Carbon Standard (VCS) uses the acronym AFOLU (Agriculture, Forestry and Other Land Use) for its bio-sequestration projects which includes agricultural land management (ALM), improved forest management (IFM) and reducing emissions from deforestation (RED) It is the first C standard to cover all the major land use activities, whether forestry or agriculture related, under a single verification framework. Carbon Gold submitted a biochar methodology "General Methodology for Quantifying the Greenhouse Gas Emission Reductions from the Production and Incorporation into Soil of Biochar in Agricultural and Forest Management Systems" in 2009[6].

2.2.3 Branded Carbon

Branded carbon is the inclusion of the expenses for C sequestration in the price of products. Similarly to "organic" products this would also require standards and certification. It is likely that the C footprint of products gains importance for consumer's choice and that labeling of the C footprint becomes common. Producing renewable energy with biochar C sequestration would theoretically allow the production of "carbon negative" products.

6 http://www.v-c-s.org/methodology_gmfqtgger.html

3. Land Use Systems

3.1 Slash-and-burn

3.1.1 Agricultural Constraints in the Humid Tropics

Presently, migration is the predominant solution to soil organic C and nutrient depletion for an estimated 300 to 500 million people, which affects almost one third of the planet's 1500 million ha of arable land (Giardina et al. 2000; Goldammer 1993). This agricultural system of "shifting cultivation", indicating that small farmers move from one spot to another as soil fertility declines, is commonly known as "slash-and-burn" agriculture (Figures 9 and 10). In "slash-and-burn" forest vegetation, either primary or secondary forest, is felled ("slashed") and burned to provide nutrient inputs and raise the pH at the soil surface (Sommer et al. 2004). Fields of 0.5 to 1 ha in size are generally cropped for two to three years before they are abandoned due to declining crop yields and invasion by weeds which is when the fallow period begins again. Hiratsuka et al. (2006) assessed forest recovery of naturally regenerated vegetation after the 1998 forest fire in East Kalimantan, Indonesia. Aboveground biomass accumulation in secondary forests is strongly dependent on the dominant pioneer tree species and averaged 16 Mg ha^{-1} five years after the fire. In old secondary forests in East Kalimantan accumulated aboveground biomass values have been found to remain small, totaling 44 to 55 Mg ha^{-1} in approximately 11-year-old forests. Nykvist (1996) found 58 Mg ha^{-1} 8 years after a forest fire.

The main cause of crop yield declines is decreasing SOC contents. Soil infertility and an inability to buy fertilizers force poor farmers throughout the tropics to clear new land every 2-3 years when SOC reaches critically low levels (Tiessen et al. 1994). The critical limit of SOC concentration for most soils of the tropics is ~1% (Aune and Lal 1997).Traditional shifting "slash-and-burn" agriculture can be sustainable if adequate fallow periods (i.e., periods without crop production) allow regeneration of the SOC pool (Kleinman et al. 1995). An adequate fallow period varies by location but likely ranges between 12 and 20 years. In Central Kalimantan 1 year of rice cultivation is followed by a shortened fallow of 3 to 7 years which was 15 to 20 years of fallow previously (Jong et al. 2001). According to Jepsen (2006) fallow vegetation accumulates 47 Mg dry matter after 6 years. They found a high biomass accumulation rate during the first 5 years and stagnation of biomass accumulation after the 6^{th} year lasting for at least 10 years. These findings might suggest a 5 years fallow period for slash-and-char cycles.

Figure 9. Slash-and-burn: accelerated release of nutrients and carbon (Photo Steve Welch).

The burning of fallow biomass is a cheap and easy practice for land clearing. A key disadvantage to burning, however, is the loss of nutrients such as N or S due to volatilization (i.e., the conversion of the elements from a solid organic to a gaseous inorganic form) as well as losses of P and K as part of fly ash (i.e., ash particles that travel long distances from the burn site in hot rising air resulting from the fire). Sommer et al. (2004) evaluated that burning of a 3.5- and 7-year-old fallow removed 97 and 94% of the C, 98 and 96% of the N, 90 and 63% of the P-, and between 45 and 70% of the cations K, Mg, and Ca that were components of the aboveground fallow biomass through either volatilization or ash-particle transfer. The almost complete loss of C reduces the organic matter input and thus SOC formation, which is crucial for maintaining soil fertility. Increasing pressure on land by a growing human population, market factors, and changes in agricultural practices, has led to land use intensification, and a decrease in the length of possible fallow periods. This shortening of the fallow period and/or lengthening of the cropping period is leading to a loss of crop productivity and sustainable livelihoods for small farmers. Failing to adjust land management techniques to these changing agricultural practices has led to soil degradation and to an increased need for agrochemicals such as fertilizers and pesticides. According to the Ministry of Forestry in Indonesia (2009) 77,806,881 ha of land is severely damaged in Indonesia. On this critical land the functions of water retention, erosion control, nutrient cycling, climate regulation and C retention are completely depleted. Almost 60 million ha are designated for rehabilitation in forest areas and more than 40 million ha outside forest areas.

Figure 10. Slash-and-burn agriculture in East Kalimantan.

To overcome these limitations of low SOC soils with low nutrient availability and low nutrient-retention capacity will require alternatives to slash-and-burn and alternative fertilization methods (Fernandes et al. 1997; Ross 1993). Lambin et al. (2001) concluded that the main causes of deforestation and land use change are rather peoples' responses to economic opportunities, as mediated by institutional factors than population growth and poverty alone. Opportunities and constraints for new land uses are created by local as well as national markets and policies. Global forces become the main determinants of land-use change, as they amplify or attenuate local factors. Therefore these forces can and should be used to direct land use in a more sustainable direction.

3.1.2 Slash-and-Char - Biomass Carbonization

Slash-and-char is inspired by recreation of Terra Preta (Figure 1). Terra Preta is an anthropogenically-enriched dark soil found throughout the lowland portion of the Amazon Basin fully termed *Terra Preta de Índio*, as it is believed to result from Amerindian activities. Critically, however, the investigated soils contain high concentrations of charcoal (Glaser et al. 2001a). These high charcoal soils also have significantly more plant available nutrients than in the surrounding infertile Oxisol soils (Lima et al. 2002).

The goal of slash-and-char is the purposeful creation of biochar through efficient mechanisms of carbonization and incorporation of this material into the soil for sustained and enhanced fertility and crop productivity. Carbonization of biomass was proposed and described as an alternative to burning biomass by Steiner (2007) and Steiner et al. (2004b) observed that charcoal is currently used by Amazonian settlers to improve soil fertility. If re-growing resources such as fallow vegetation or crop residues are used for carbonization, the process of biomass carbonization will not only improve crop productivity but could become a significant C sink and an important step towards reducing climate impacts of deforestation through slash-and-burn activities.

3.1.2.1 Prospect to Conserve and Enhance Soil Fertility and SOC Contents

Slash-and-char could provide an alternative to slash-and-burn and is capable of increasing SOC contents and thus maintaining soil fertility. Given the application of biochar to the soil surface and an expectation for minimal mineralization of the biochar the SOC levels can be increased rapidly. Multiple repetitions of the cropping – fallow – carbonization cycle would allow for a build-up of SOC, potentially to levels found in Terra Preta (Figure 11).

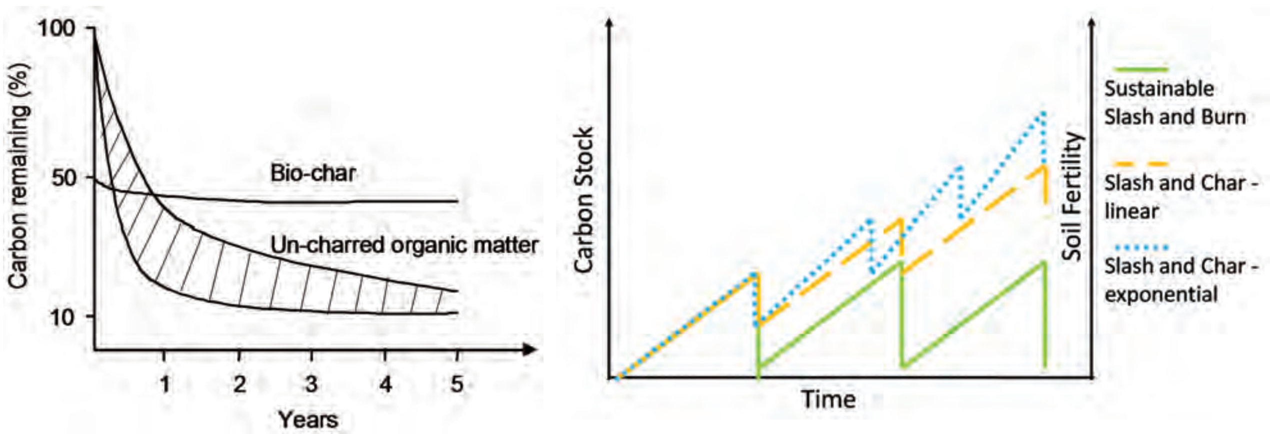


Figure 11. Illustration of the potential of biochar for SOC enrichment. The decay of un-charred biomass is particularly fast in the humid tropics (steeper line) and the carbon losses match those from carbonization within months (J. Lehmann, et al. 2006). Right figure: Sustainable slash-and-burn agriculture (green line) maintains carbon stocks and soil fertility over several cropping-fallow cycles. Slash-and-char would capture up to 50% of the C stored in the fallow vegetation and transfer the C into recalcitrant SOC pools. Assuming a faster regeneration of biomass (blue line) the gains in SOC could grow exponential (Steiner, unpublished).

3.1.2.2 To enhance fertilizer use efficiency

SOC is the main source of cation exchange sites (CEC) on the prevalent kaolinitic soils in the humid tropics (Figure 12) and therefore are extremely important for nutrient retention and supply (Zech et al. 1990). Terra Preta soils show not only a doubling in the organic C content but also a higher CEC than would be expected from the sum of the colloidal activity of the organic matter and the kaolinitic clay minerals individually (Sombroek et al. 1993). In Terra Preta soils it appears the oxidation of the charcoal creates carboxylic groups on the edges of the aromatic core, which are responsible for the increased CEC and reactivity of charcoal in the soil (Glaser et al. 2001a).

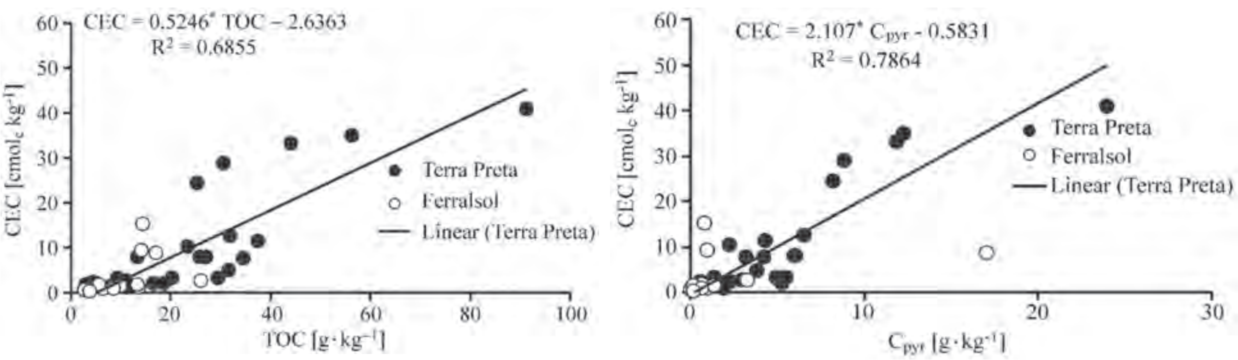


Figure 12. Relation between effective cation exchange capacity (CEC) and the amounts of total organic carbon (TOC) and pyrogenic carbon (Cpyr, charcoal) in Terra Preta soils and surrounding Ferralsols in Central Amazonia (n = 24, p < 0.001, (Glaser et al. 2002)

Cheng et al. (2006) demonstrated in an incubation experiment that already 4 months at 30°C could significantly increase the CEC of biochar. Liang et al. (2006) concluded that oxidation of biochar particles, adsorption of organic matter to biochar surfaces and a higher specific surface area contribute to greater CEC. The described alternatives should allow an intensification of land use without degradation and make investments into long-term soil fertility feasible.

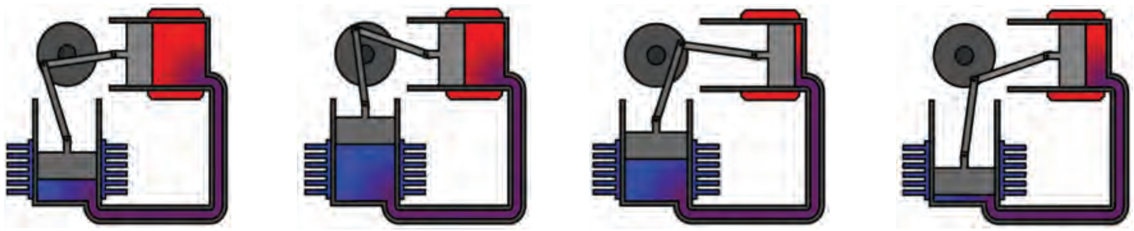
3.1.2.3 Prospect to Provide an Additional Income Stream (Carbon Sequestration)

An additional income stream from the creation and utilization of biochar will facilitate the purchase of fertilizers and other basic farming equipment. It will provide the resources to invest in cleaner biochar production technology and utilize pyrolysis for renewable energy production. Such an income stream will be generated from the global C trade. The C trade will provide an incentive to cease further deforestation while simultaneously promoting reforestation and recuperation of degraded land for fuel and food crops. Sustaining soil fertility would also reduce the need to clear and burn new forest areas after soil fertility declines in shifting cultivation systems.

3.1.2.4 Prospect to Develop Renewable Energy Generation from Biomass Carbonization.

Currently most subsistence farmers are without electrical power supply. Most electricity is supplied by diesel generators and fuel is rather expensive at remote places. A cheaper supply of power will provide cost saving and could create opportunities for crop irrigation, as well as post harvest storage of crops.

The heat from biomass carbonization is ideally utilized by a Stirling engine. A Stirling engine is an external combustion engine and can utilize any source of heat. The heat energy is converted to mechanical work, which could be used to power a water pump for irrigation or a generator for electricity. The excess heat from carbonization could be used to run a Stirling Motor (Figure 13). This motor is an external combustion engine in contrast to an internal combustion engine.



1. Most of the working gas has been heated and expansion has pushed the hot piston to the bottom of its travel in the cylinder. The expansion continues

2. The gas is now at its maximum volume. The hot cylinder piston begins to move most of the gas into the cold cylinder, where it cools and the pressure drops.

3. Almost all the gas is now in the cold cylinder and cooling continues. The cold piston, powered by flywheel momentum compresses the remaining part of the gas.

4. The gas reaches its minimum volume, and it will now expand in the hot cylinder where it will be heated once more, driving the hot piston.

Figure 13. The complete action of an alpha type Stirling engine. Blue is the cold cylinder and red the hot cylinder. (Source: http://en.wikipedia.org/wiki/Stirling_engine)

The Stirling motor needs little maintenance, is noted for its high efficiency, quiet operation and the ease with which it can utilize almost any heat source. A biomass fired Stirling engine could be the best technical and economical solution for small scale grid-independent power production in the power range of 5 to 100 kW. A simple prototype developed for rural villages showed an efficiency of 25% (Podesser 1999). As such the Stirling engine would be ideally suited to use the heat from biomass carbonization to either generate power and/or pump water.

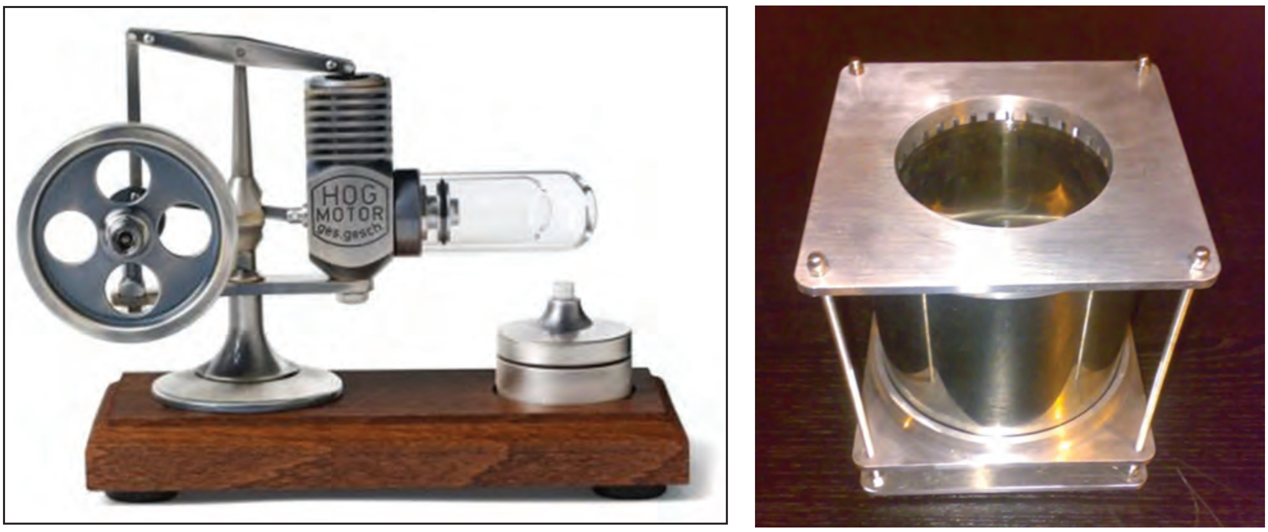


Figure 14. A simple form of the Stirling engine (left) powered by a small oil lamp and a simple pyrolytic stove developed for rural areas in developing nations. We intend to combine both in an optimized form for rural energy and biochar production.

3.1.3 Potential Obstacles to Slash-and-char

Monitoring, reporting and verification might pose significant obstacles in a rural small holder community. Community monitoring might be possible to reduce costs and was successfully applied in some REDD programs (Angelsen et al. 2009). Further, monitoring of biochar C is most likely much easier and has less leakage than accumulating biomass in growing vegetation. The payment of a flat rate per hectare to measure and monitor changes in C stocks rather than being paid for C gains was also suggested for REDD programs. Although it might seem that this would remove the incentive to restore C stocks, the payment could be tied to a management agreement. In a slash-and-char system C could be exchanged for fertilizers and an agreement that the biochar is used as soil amendment. The fertilizer would be needed for the particular area and would increase crop yields substantially. The income is still generated from agriculture but on a much higher level.

According to (Börner et al. in press) the exclusiveness of rights to the land is one fundamental precondition for REDD and payments for environmental services and poses another obstacle to many REDD programs. Farmers may have fairly secure tenure over plots they are currently cultivating, but weak tenure for fallow plots. The longer the plot has been fallow the less secure the tenure. Insecure tenure reduces the incentive for long-term fertility improvements and those receiving the payments cannot exclude other people who could use forest and land resources in ways that are incompatible with providing the contracted service. This does not apply for biochar C sequestration because the C once sequestered in the soil is permanent. There is no risk that altered management practices would reduce the C stock.

Implementation costs might pose the greatest obstacle. Ex-ante credits, such as those issued by the Plan Vivo System can provide the necessary capital. Ex-ante refers to reductions that are planned or forecasted but have not yet been achieved. In this case buyers donate toward intended emission reductions. If waste biomass is available the production of biochar can be rather quick and the exact quantity relatively certain (in comparison to accumulation in growing biomass). Therefore guaranteed forward deliveries (reductions in the near future) are feasible.

3.1.4 Recommended R&D

A field experiment and demonstration project should be conducted to compare slash-and-char with slash-and-burn (optional slash and mulch) in terms of agricultural productivity, nutrient use efficiency, and C sequestration potential. This involves:

- Soil fertility and productivity
- Fertilization efficiency
- Biomass mineralization and GHG emissions
- Optimization and improvement of the biomass carbonization technique
- Development of energy generation from biomass carbonization

3.2 Oil Palm Plantations

The total area of land officially designated to oil palm in Indonesia was estimated to be around 6.2 million ha in 2006 with an annual expansion of 0.4 million ha. Together Indonesia and Malaysia account for about 90% of the ca 36 million Mg of crude palm oil (CPO) produced globally.

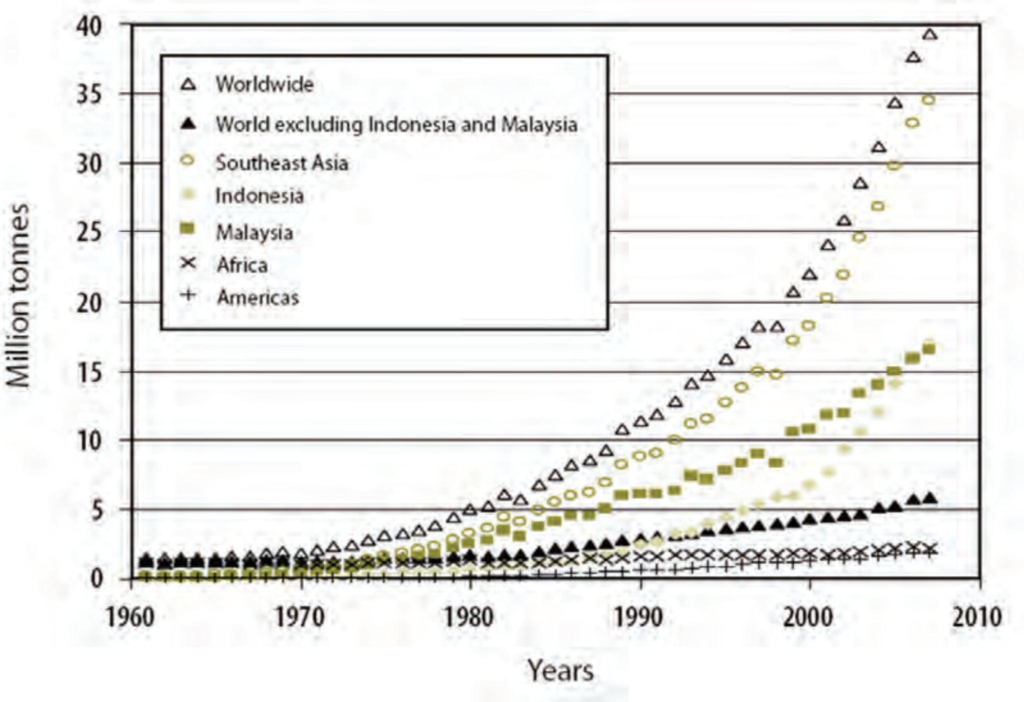


Figure 15. Palm oil production in from 1961 to 2007. Increase in world production is driven by increases in Indonesia and Malaysia. Source: from Sheil et al. (2009) based on data from FAOSTAT.

Currently, 77% of palm oil is used for food (Sheil et al. 2009) but the interest to produce bio-fuel is growing rapidly. Although the potential of oil palm to supply renewable fuel is very high the associated C emissions from land use change can exceed those from fossil fuel combustion. Gibbs et al. (2008) estimated C payback times under different scenarios. Under current conditions, the expansion of biofuels into tropical forests will always lead to net C emissions for decades to centuries, while expanding into degraded or already cultivated land will provide almost immediate C savings. Therefore depending on the replaced vegetation oil palm plantations can either be a sink or a source of greenhouse gases. The C payback time on peatland is an estimated 900 years. CIFOR reviewed (Sheil et al. 2009) the C stock of tropical peatlands which are supposed to be one of the world's largest near-surface reserves of terrestrial organic C. Undisturbed they can absorb 100 kg C ha^{-1} yr^{-1}. However, when drained and cultivated peatland is releases C and an estimated 3300 Mg of CO_2 are emitted on per ha of peat swamp forest drained and converted to oil palm over 30 years. This makes it imperative to preferentially establish new plantations on land with low C stocks and find ways to increase the C sequestration capacity of oil palm plantations.

The mills typically process 60 Mg of full fruit bunch (FFB) per hour, with a power requirement of 1020 kW. Usually only fiber and about 30% of the shells are used to generate power. The available amount of biomass is 13.2, 8.1 and 3.3 Mg h^{-1} with a moisture content of 65%, 42% and 7% for EFB, fiber and shells respectively. The heat value of EFB, fiber and shell is 3700, 4420 and 4950 kcal kg^{-1} dry weight, respectively (Yusoff 2006). Biomass production in oil palm plantations was estimated to be 1.6 Mg ha^{-1} yr^{-1} of empty fruit bunches (EFB), 10.4 Mg ha^{-1} yr^{-1} pruned fronds and about 90 Mg ha^{-1} palm trunks and fronds at renovation (Figure 16), every 20 to 30 years (Yusoff 2006) (Table 3). A mill with a capacity of 60 Mg FFB hr^{-1} produces 83,000 Mg of EFB yr^{-1} (Salétes et al. 2004b). EFB is usually sent back to the estate to be used as mulch in the fields and usually between 30 and 40 Mg are applied ha^{-1} yr^{-1}. Nevertheless these materials are not always used and are either burned or accumulate in farm areas or near the oil mills (Figure 16). EFB are traditionally incinerated for its ash which is used as fertilizer (Yusoff 2006). However, due to smoke generation, burning of EFB is discouraged in many countries. Accumulation of biomass such as empty fruit bunch and palm trunks can cause management problems such as increasing the risk of disease and pests.

Figure 16. Accumulating "waste" biomass at oil palm plantations. Dead palms at renovation and EFB emit greenhouse gases and attract pests and diseases.

EFB are a valued fertilizer due to its high K content, but exposed to rainfall they are subject to substantial leaching of mineral nutrients. Thus, any delay in application leads to a significant drop in the agricultural value of fresh EFB. The losses from EFB can amount the equivalent of US$ 27 000 in fertilizer value for four days of storage, and can reach US$ 73 000 for temporary storage of two weeks before application in the field (Salétes et al. 2004a). Once applied in the field the nutrient (Salétes et al. 2004b) and C (Zaharah and Lim 2000) release of raw EFB is fast and reaches 50%, 90% and 40% for P, K and Mg respectively, 10 weeks after spreading.

Alternatively EFB can be composted to reduce the weight and volume by 85% and 50% respectively. If the effluents are poorly retained a significant proportion of nutrients are lost due to leaching during composting. Salétes et al. (2004b) assessed losses of almost 50% of the P, 70% of the K, 45% of the Mg and between 10% and 20% of the Ca during composting. EFB are ligno-cellulose residues comprising 46% cellulose, and 16.5% lignin. Due to the high C:N ratio, which ranges from 45 to 70, N fertilization seems necessary in order to reach the optimum initial C:N ratio of 30. However Salétes et al. (2004b) found that co-composting of palm oil mill effluent (POME) with EFB supplies sufficient N. Around 30% and 17% the applied N was lost during composting, when fertilized or only received the N from the effluents, respectively.

Methane emissions can be considerably from anaerobic digestion of POME, decomposing EFB in piles and probably mulched EFB (Sheil et al. 2009). Methodologies to avoid these emissions have been accepted as CDM. These involve pyrolysis[7], combustion, gasification[8] and composting[9]. A project design document (CDM PDD) describes the co-composting of POME and EFB to avoid CH_4 emissions[10].

Instead of POME treatment in lagoons it is applied onto windrows of EFB in an aerobic co-composting technique. To ensure aerobic conditions the key parameters such as oxygen levels, temperature and humidity need strict control. In order to control these parameters roofing is absolutely essential and makes the process rather expensive. Composting requires 2.5 months and involves mechanical shredding, pumps and transportation.

However, if EFB are directly field applied or applied after composting decomposition and C release is fast. Four weeks after application, the dry matter is reduced by 50% and after 36 weeks only 18.5 and 25.3% of the C is left in the EFB stalk and spikelets, respectively (Zaharah and Lim 2000). Pyrolysis of these biomass sources would not only provide the energy needed but simultaneously prevent CH_4 generation and decelerate the C cycle by order of magnitudes (see section 1.3.1). Thus reducing emissions and increasing the C stocks in soil.

3.2.1 Pyrolysis and Carbonization

During carbonization of crop residues (EFB) K does not get lost. As a consequence K is found in even higher concentrations in the biochar as other elements such as O, H and C are volatilized (Gaskin et al. 2008). The reduction in volume and weight facilitates transport and storage of biochar and thus optimization of fertilization according to nutrient requirements (Figure 15, Table 2). EFB have a mean K concentration of 22.3 g kg^{-1}. Carbonization of EFB increased this concentration to 58.7 and 65.1 g kg^{-1}, if carbonized at 350°C or 600°C respectively. Furthermore, preliminary results suggest that leaching of minerals such as K is decelerated if EFB were carbonized (Bibens et al, unpublished).

Figure 17 EFB and carbonized EFB. Carbonization causes a significant reduction in volume and weight and concentration of nutrients (see Table 2).

7 http://cdm.unfccc.int/UserManagement/FileStorage/CDMWF_AM_C7UWTIEMRJ05M3D02XWDW80JN989IP
8 http://cdm.unfccc.int/UserManagement/FileStorage/HXJBK40UFD5I6WYCL3EP8S7N1OGR2Q
9 http://cdm.unfccc.int/UserManagement/FileStorage/BRT65K2ODSCGNLZIWQA7YFEMH04XJ9
10 http://cdm.unfccc.int/Projects/DB/DNV-CUK1177655097.9/view

Residual biomass is plentiful in oil palm plantation and can be divided in biomass accumulating at the mill and biomass remaining in the field (Table 3). At the mill pyrolysis technology might be deployed in order to generate the required energy and transfer all biomass into biochar. Pruned fronds remain in the field and represent a significant C source. However harvest, reduction in moisture content in a very humid environment and carbonization might be rather costly. Pruned fronds (un-carbonized) may serve as erosion control and provide a labile C source to support soil biological processes. However the treatment of entire palms (trunk and fronds) at renovation (every 25 years) has phytosanitary importance. Decomposing biomass attracts pests and diseases and current management options involve removal of trunks, chipping and burying of trunks. These options can be costly and carbonization might be an alternative. The high moisture content of oil palm trunks complicates biochar production. A mobile carbonization unit may consist of 3 chambers (batches) using the residual heat from carbonization to reduce the moisture content in a "drying patch" and the steam (moisture) to cool biochar (cooling batch).

Table 2 Nutrient concentrations in EFB, carbonized EFB and EFB Compost

	EFB[1]	Carbonized EFB[2]	EFB Compost[1]
N (%)	1.25	1.45	2.86
P (%)	0.11	0.31	0.34
K (%)	2.07	5.93	2.30
Ca (%)	0.42	0.54	1.27
Mg (%)	0.20	0.40	0.63

[1] Source (Salétes et al. 2004b) co-composted with nutrient rich POME
[2] Carbonized at 500°C University of Georgia

Figure 18. Biochar Malaysia Workshop 2009

"Carbonator" transfers 20 Mg of EFB into biochar per day. http://biocharmalaysia.blogspot.com/

Table 3. Main biomass streams in oil palm plantations and potential for biochar carbon sequestration at the mill and in the field.

Biomass	Biomass Mg ha-1 yr-1	Biochar – C1 Mg ha-1 yr-1	CO2 Mg ha-1 yr-1
At the mill			
EFB 8% of FFB (dry weight)	1.55	0.33	1.21
Fiber 8 % of FFB (dry weight)	1.63	0.34	1.25
Shell 5.5% of FFB (dry weight)	1.10	0.23	0.84
Total at the mill	**4.28**	**0.9**	**3.30**
In the field			
Fronds[3]	11.4	2.39	8.77
Trunks[4]	3.02	0.63	2.31
Fronds and rachis[4]	0.58	0.12	0.44
Total in the field	**15.00**	**3.14**	**11.52**
Total (mill + field)	**19.28**	**4.04**	**14.82**

Biomass data from Yusoff (2006) and Sheil et al. (2009). [1]Biochar-Carbon assuming a conversion efficiency of 30% and a mean carbon content of 70. [2]The dry weight of fronds from annual pruning, [3]every 25 years at renovation (75.5 and 14.4 Mg ha^{-1} 25 yrs^{-1})

Researchers of the Universiti Putra Malaysia (UPM) developed in collaboration with the Nasmech Technology Sdn Bhd a technology to carbonize EFB[11] (Figure 18). Heat generated from the process is not utilized for power generation. Black Carbon A/S[12] installed a pyrolysis unit with a gas furnace Stirling engine (Figure 19). The system generates biochar, 35 kW electricity (10% of the fuel input) and 122 KW heat (35% of the fuel input). The remaining biochar has a heating value of 32.9 MJ kg^{-1}. Using the char as biochar instead of charcoal causes opportunity costs and should therefore considered additional (CDM additionalty).

Figure 19. Pyrolysis unit in Denmark, Black Carbon A/S

Stirling engine for 35 kW electrical power generation

11 http://biocharmalaysia.blogspot.com/
12 www.blackcarbon.dk

Box I: EFB Management at PT REA Kaltim Plantations, East Kalimantan

The plantation covers 30,000 ha with two mills (60 and 80 Mg FFB h-1) and a third mill is planned. The management has its own conservation department and environmentally sound practices are implemented. This includes extra wide buffer zones (500 m on rivers > 10m wide) along rivers and streams, flowers to enhance biological pest control, and a legume cover crop. The cover crop produces an extra 1.5 Mg ha-1 yr-1 of biomass. Fiber and a proportion of the shells are used as boiler fuel. POME is treated by co-composting with EFB for 45 days. This reduces the volume (50%) and weight of EFB and enriches EFB with nutrients. The compost is produced at both mills. Each pile contains 2,000 Mg. The piles are frequently sprinkled with POME and receive an additional 3,500 mm of rain. The compost piles are not protected from rain, making effective moisture control impossible. Therefore this type of composting may not qualify for a CDM project. The main advantages are treatment of POME and nutrient enrichment of EFB. The final product has N, P, K, and Mg contents of 2.5%, 2.7%, 4.7% and 4.5% respectively with a C:N ratio of 17.

Combustion of fiber and shells for power generation

Composting of EFB and POME (2000 Mg of EFB per pile)

Composting with POME sprinkler

Finished product after 45 days

3.2.2 Recommended R&D

- An assessment of plant growth and fertilization efficiency of carbonized EFB in comparison to EFB incinerated EFB (ash) and composted EFB, with and without additional N fertilization. This could be done in the nursery.
- Development and implementation of infield carbonization technologies and pyrolysis for energy generation at the mill.
- Feasibility assessment of POME treatment with carbonized shells. Co-composting is likely to increase the CEC of biochar. (Cheng et al. 2006) demonstrated in an incubation experiment that already 4 months at 30°C could significantly increase the CEC of biochar and co-composting of nutrient rich manures with biochar significantly reduced N losses (Steiner et al. 2010).
- Develop a Project Design Document and Methodology for biochar C sequestration
- Assess the ability to regenerate disturbed topsoil (e.g. after construction of terraces).

3.3 Timber Plantations

Okimori et al. (2003) conducted a feasibility study to carbonize wood waste generated at an industrial plantation and pulp production enterprise situated southwest of Palembang, South Sumatra, Indonesia. The project was conducted in cooperation with PT. Musi Hutan Persada and PT. Tanjungenim Lestari Pulp & Paper. The company performs clear-cutting of *Acacia mangium* and supplied logs with more than 8 cm in diameter. Remaining biomass after logging are stems and branches less than 8 cm in diameter which dry weight was estimated to be 56.4 Mg ha^{-1}. Okimori et al. (2003) did not utilize bark and foliage which remained in the field. He estimated that 28.2 (50%) of the wood would be suitable for carbonization. Up to 72% (average 53%) of the A. mangium branches are decomposed after one year if not carbonized. The costs of biochar offsets were estimated to be around 17 USD Mg^{-1} CO_2. This feasibility study used traditional charcoal making techniques and would generate CH_4 emissions (see section 2.1.2). Only techniques burning the products of incomplete combustion should be deployed to maximize C sequestration.

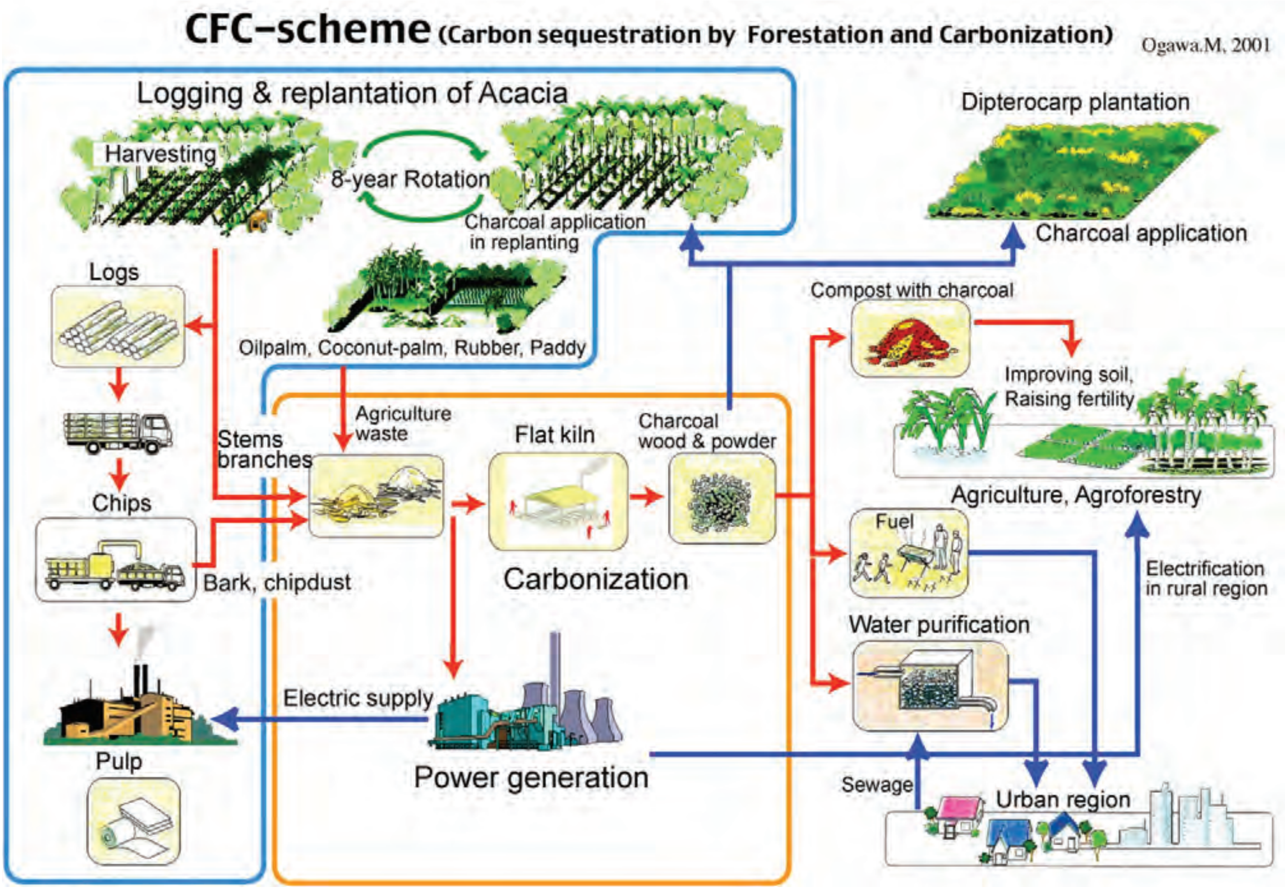


Figure 20. Okimori and Ogawa assessed the feasibility of biochar carbon sequestration in Acacia plantations in Sumatra, Indonesia. The uses for biochar involve direct application, co-composting, fuel, and water purification.

Box II: PT SUMALINDO LESTARI JAYA Tbk, UNIT 1 BATU PUTIH

The plantation covers 12,000 ha of which 9,000 ha are planted with Acacia mangium and Paraserienthes falcataria. The trees are harvested after 8 years and 1,000 ha are harvested annually. The plantation is thinned after 2 and 4 years. Logs and branches with a diameter of less than 7 cm remain in the field and serve to reduce the impact of heavy machinery during harvesting operations. Assuming a conservative carbonization efficiency of only 20% the annual biochar production from waste biomass (after harvesting) could be 5,640 Mg (0.7 Mg ha-1 yr-1), taking half of the available biomass (Okimori et al. 2003), which represents 17,000 Mg CO2 (2.1 Mg ha-1 yr-1). This does not include biomass from thinning operation after 2 and 4 years.

Fast growing tree species in 8 years rotation.

Acacia mangium and Paraserianthes falcataria after 2 years

After harvest 56.4 Mg of biomass remain in the field (Okimori et al. 2003). Biochar produced from residues could be used in the nursery.

3.4 Natural Forest Management

A significant amount of waste biomass is produced during logging operations. Reducing the impact on the remaining trees is crucial in order to allow a fast re-generation of the forest and C stocks. Bertault and Sist (1996) estimated that only about half of the extracted timber (53.7%) resulting in commercial volume and on average logging affects 40% of the residual trees of which about half is lethal. (Putz and Pinard 1993) calculated that more than 4 times as much necromass is generated than wood extracted in East Malaysia. Necromass decomposes fast and subsequently releases to the C as CO_2 and CH_4 to the atmosphere. Half of the logging residues are expected to decompose within 2 years and the further decay rate is estimated to be 19% yr^{-1}. Thus all large woody debris may be completely decomposed within 15 years (Putz and Pinard 1993). Reduced impact logging (RIL) can substantially reduce the impact on trees (30.5 % vs. 48.1%) however damage and dead trees cannot be entirely avoided (Bertault and Sist 1996; Priyadi et al. 2006). In forests subjected to conventional logging, C emissions exceed 100 Mg ha^{-1}. The use of improved timber harvesting practices in the tropical forests would retain at least 0.16 Pg of C yr^{-1}. However it is currently practiced in less than 5% of the tropical forests (Putz et al. 2008).

3.4.1 Potential and Obstacles for Biochar Carbon Sequestration

The potential gains in C due to reduced impact logging are cheap in comparison to biochar C sequestration. The costs were estimated at $3 per Mg of C but successful implementation is challenging due to the issues of permanence, leakage, land tenure etc. (see section 3.1.3). Short term (1 year) logging concessions have higher harvesting intensities and cause more damage than 20-year commercial selective logging concessions (Iskandar et al. 2006). A successful implementation of biochar C sequestration might create an incentive to increase waste biomass generation and fire is not an integral part of forest management in the humid tropics. It is uncertain if harvesting and removal of waste biomass and killed trees for biochar production would cause further damage. As long as the forest is not disturbed too much, re-growth is relatively fast and decomposing wood might play an important ecological role in forest regeneration (see Figure Box III). In order to conserve the C stock reducing the impact of logging and to allow the forest to regenerate (exclusion of slash-and-burn farming) is the most important measure. However even the most careful logging operations need to remove topsoil for access and transport. Biochar might be used to regenerate severely degraded soil (see Box III).

Table 4. Biomass Mg ha-1 converted into necromass after logging and would be potentially available for biochar carbon sequestration (biochar-C).

	CL[1]	Biochar[2]	RIL[1]	Biochar[2]
		Mg ha^{-1}		
Branches, stumps, and butt roots	67	16.75	46	11.5
Destroyed trees	67	16.75	14	3.5
Dead trees within 1 yr	7	1.75	4	1
Destroyed lianas	5	1.25	7	1.75
Understory plants	2	0.5	2	0.5
Total	148	37	73	18.25

1 CL = conventional logging, RIL = reduced impact logging, data from Pinard and Putz (1996).

2 Potential biochar production, assuming a conversion efficiency of 25%

Box III: PT SUMALINDO LESTARI JAYA Tbk Logging Concession

The logging concession covers 100,000 ha and is a collaboration between PT Sumalindo Lestari Jaya Tbk, The Nature Conservancy and a community involving 5 villages. The benefits for the communities involve profit sharing, employment and infrastructure improvements. Logging is operated with minimum damages to the remaining vegetation. However some soil degradation cannot be avoided in order to facilitate transport.

Fast decomposition in the moist forest environment. Decomposing wood provides plant nutrients and supports forest regeneration.

Severely degraded sites involve transportation infrastructure. Most of these sites are supposed for future harvesting operations. However reforestation might require intense soil improvement.

This picture shows an unsuccessful attempt to grow trees on severely degraded land. Biochar might be suitable to restore such areas.

3.4.2 Recommended R&D for the Wood Industry

Dr, Chairil Anwar Siregar, (soil scientist, Forest and Nature Conservation Research and Development Center of the Ministry of Forestry in Indonesia) assessed with colleagues the effect of biochar on the early growth of *Acacia mangium*[13]. They found significantly reduced acidity, increased pH, and increased nutrient content of soils amended with 10, 15 and 20% biochar. Plant and root growth was significantly enhanced. (Yamato et al. 2006) assessed the effect of carbonized Acacia mangium bark on the yield of maize, cowpea and peanut in South Sumatra, Indonesia. They found significantly increased yields and increased colonization rate of arbuscular mycorrhizal fungi. The application of bark biochar reduced acidity and increased total N, available P, CEC and exchangeable cations.

Further experiments could involve:

- Assessment of the effectiveness of biochars produced from different feedstock in comparison to un-carbonized biomass and ash from burned biomass under fertilized and un-fertilized conditions.
- Assessment of the suitability of carbonized wood residues to re-generate severely degraded soils in combination and comparison to organic (compost and manures) and inorganic fertilizers. This should involve C and nutrient dynamics in a long-term experiment (see Box IV).
- Assessment of the optimum biochar particle size for different applications.

3.5 Biochar a Supplement to Composting

The production of biochar does not compete with composting but could be a complementary approach. In general nutrient rich materials or materials with a low C:N ratio and high moisture content make a good compost whereas materials with a high C:N ratio (>30) are less suitable for composting. Woody materials are rather resistant to decomposition, require long composting times and additional N fertilization. Available C (wood waste) may also negatively influence compost stability and quality (N-immobilization). Therefore woody waste is frequently burned (for no other use than to get rid of it) or is deposited at landfills. These biomass sources are ideally suited for biochar production and can either be mixed with compost or used as a bulking agent during composting. Due to its recalcitrance, the use of biochar as bulking agent does not result in the addition of readily available C, and thus its use does not increase the effective C:N ratio. Recent research has shown that co-composting of biochar with N rich manures reduces N losses due to NH_3 volatilization by up to 50% (Steiner et al. 2010).

According to Okimori et al. (2003) 63.5% of the wood waste generated at pulp mills is used to generate power the rest is deposited in landfills. This waste (mainly bark) could be used for biochar production and thus saving the costs for landfill disposal. Integrating biochar into existing compost (potting soils, soil amendments etc.) production (see Box IV) might promise a business independent of C credits or not (see Box IV) and would increase the value (mainly due to its stability) for land restoration purposes.

13 http://www.biorefinery.uga.edu/char%20sypm%2004%20%20PDF%20Files/presentations/CSieregar.pdf

Box IV: PT UNITEK BORNEO – Soil Restoration

The company specialized in recuperation of critically degraded land in particular after mining operations. UNITEC BORNEO is producing organic soil amendments including compost and manure suitable to increase organic carbon contents and nutrient supply of severely degraded soil. Further they use coconut fiber to manufacture a product for erosion control. Biochar would be a valuable addition to such products, increasing the recalcitrance of the product, nutrient retention, adding long-lasting soil organic carbon and extend the array of suitable raw materials (previously treated as waste materials).

Compost produced from aquatic plants is one of the main ingredients.

Organic soil amendment for soil restoration. The 10kg bags are sold for 15,000 IDR (1.6 USD).

These erosion control mats are produced from coconut fiber. They stabilize the top soil and facilitate seed germination.

Soil restoration at mining sites
Picture: http://www.unitekborneo.com/gallery/



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5. Acronyms and Glossary

AFOLU	Agriculture, Forestry and Other Land Use	**kg**	Kilogram
Al	Aluminum	**kW**	Kilowatt
ALM	Agricultural Land Management	**LULUCF**	Land Use, Land Use Change and Forestry
C	Carbon	**m**	Meter
Ca	Calcium	**MDG**	Millennium Development Goals
CCBS	Climate, Community and Biodiversity	**Mg**	Megagram (tone, 10^6 g)
CCX	Chicago Climate Exchange	**Mg**	Magnesium
CDM	Clean Development Mechanism	**N**	Nitrogen
CEC	Cation Exchange Capacity	**N_2O**	Nitrous oxide
CH_4	Methane	**NGO**	Non-governmental Organization
CIFOR	Center for International Forestry Research	**P**	Phosphorus
CO_2	Carbon dioxide	**PDD**	Project Design Document
COP15	Conference of the Parties, Copenhagen in December 2009	**Pg**	Petagram (10^{15} g)
CPO	Crude Palm Oil	**PIC**	Products of Incomplete Combustion
EFB	Empty Fruit Bunch	**POME**	Palm Oil Mill Effluent
FFB	Full Fruit Bunch	**R&D**	Research and Development
GHG	Greenhouse Gas	**REDD**	Reducing Emissions from Deforestation and Degradation
GWC	Global Warming Commitment	**RIL**	Reduced Impact Logging
GWP	Global Warming Potential	**S**	Sulfur
h	hour	**SOC**	Soil Organic Carbon
ha	Hectare (10,000 m^2)	**UNCCD**	United Nations Convention to Combat Desertification
IPCC	Intergovernmental Panel on Climate Change	**UNEP**	United Nations Environment Programme
IRRI	International Rice Research Institute	**UNFCCC**	United Nations Framework Convention on Climate Change
K	Potassium	**USD**	United States Dollar
kcal	Kilocalorie	**VCS**	Voluntary Carbon Standard
		yr	year

Additionality is a requirement for CDM projects, to ensure the project reduces emissions more than would have occurred in the absence of the project. Current guidance is available at the UNFCCC website

Anoxic conditions mean a total decrease in the level of oxygen.

Biochar is carbonized organic matter. Forms of biochar include charcoal, black carbon, pyrogenic carbon. Biochar is produced when biomass is partially combusted under reduced oxygen conditions.

Biological N fixation refers to the natural process, by which nitrogen (N_2) in the atmosphere is converted to ammonia (NH_3). Microorganisms can fix nitrogen and have important functions in plant nutrition.

Cation Exchange Capacity (CEC) is the capacity of a soil for ion exchange of cations between the soil and soil solution. As such CEC is a measure of nutrient retention capacity and capacity to protect groundwater from nutrient contamination. A low CEC increases the risk of nutrient leaching and reduces fertilizing efficiency.

C-debt (carbon-debt) refers to carbon dioxide (greenhouse gas emissions) in the past. This can be a c-debt industrialized countries have in relation to developing countries or the c-emissions during conversion of forest to agricultural land.

Chernozem is from Russian meaning "black soil" or "black land". Chernozem is very fertile and prodices high agricultural yield http://en.wikipedia.org/wiki/Chernozem

Global Warming Commitment (GWC) is the sum of the global warming potentials of the gases emitted in a process.

Half-life time is the period of time it takes for a substance undergoing decay to decrease by half.

Leakage is defined as the net change of anthropogenic emissions by sources of greenhouse gases which occurs outside the project boundary, and which is measurable and attributable to the CDM project activity. E.g. if a forest plantation displace farmers into forested areas. The emissions caused from deforestation would be leakage.

Mycorrhizal fungi are a symbiotic association between fungus and the roots of a vascular plant and are important for plant nutrition.

Necromass are dead organisms (e.g. decomposing plant or animal material)

N-fixing nodules. Some higher plants have formed associations with N-fixing microorganisms. These associations are usually found in nodules.

Permanence generally addresses the extent to which forests or other carbon sinks can permanently store carbon.

Post-2012 is also "post-Kyoto" refers to the agreement on climate change mitigation after Kyoto (2012).

Pyrloysis is a thermo-chemical process and produces gas, liquid products and a solid carbon rich residue. Pyrolysis of wood starts at 200-300 °C

Sequestration (C-sequestration) is a technique for long-term storage of carbon dioxide or other forms of carbon to mitigate global warming.

Sink (C-sink) is a natural or artificial reservoir that accumulates and stores some carbon-containing chemical compound for an indefinite period.

Slash-and-burn consists of cutting and burning of forests or woodlands to create fields for agriculture.

Slash-and-char is a proposed alternative to slash-and-burn where biomass is carbonized instead of burned.

Terra Preta in Portuguese "black earth" is a manmade soil found in the Amazon Basin. Terra Preta has a very high charcoal content and is characterized by high fertility.

Volatilization is the transformation of an element solid form to an element in gaseous form.

6. Appendices

6.1 Table of Activities

Date	Activity
24. 25. 01. 2010	Travel to Indonesia and arrival in Jakarta
26. 01. 2010	• Arrival in the GTZ office in Jakarta, briefing • Meeting with Listya Kusumawardhani Director, Natural Forest Production, Ministry of Forestry, Indonesia • Meeting Lee Yuen Chak (Executive Director) and Mahawira Singh Dillon (ECO Project Officer) PT SUMALINDO LESTARI JAYA Tbk
27. 01. 2010	• Meeting with Dr, Chairil Anwar Siregar and Dr. Titiek Setyawati Forest and Nature Conservation Research and Development Center, Forestry Research and Development Agency, Ministry of Forestry, Indonesia • Meeting with Dr. Nur Masripatin Director, Ministry of Forestry, Forestry Research and Development Agency, Centre for Social economy and forest policy • Dedi Haryadi Departemen Kehutanan
28. 01. 2010	Travel to East Kalimantan • Meeting and discssion with Tunggul Butarbutar and Syahrinudin
29. 01. 2010	• Meeting with Achmad Pribadi (Head of Research Planing Division) Dipterocarpa Research Center, Samarinda, Ministry of Forestry • Meeting with Deddy Hadriyanto Faculty of Forestry, University of Mulawarman
30. 01. 2010	• Meeting with Prof. Dr. Ir. Afif Ruchaemi (Dean) Forest Growth and Yield Science, Faculty of Forestry, Mulawarman University • Meeting with Dr. Mustofa Agung Sardjono Center for Social Forestry, Mulawarman University

Date	Activity
01. 02. 2010	Travel to PT. REA KALTIM PLANTATIONS
02. 03. 2010	Plantation tour and presentation at REA Meeting with: • Boey Chee Weng (Director of Estates) • Geetha Govindan (Vice Director) • Rob Stuebing (Conservation) • K. Murali Tharan (Estate Controller South)
03. 02. 2010	Visit composting facilities and travel back to Sumarinda
04. 02. 2010	Meeting with Dr. Ahmad Delmi, Head of Forest Department, Kalimantan Timur
05. 02. 2010	Visit of PT SUMALINDO wood processing facility
08. 02. 2010	Travel to SUMALINDO Wood Plantation HTI PT SLJ UNIT 1 BATU PUTIH
10.02.2010	Visit of TP SUMALINDO Logging concession
11.02.2010	Travel back to Sumarinda and visit of UNITEK Borneo
13. 02. 2010	Meeting with Prof. Dr. Daddy Ruhiyat Head of Soil Institute, Forestry Faculty and Provincial Advisor
15. 02. 2010	Presentation in the Governor's Office East Kalimantan
17. 02. 2010	Meeting with Dr. Petrus Gunarso, Direktor Program Tropenbos International, Program Indonesia
18. 02. 2010	Debriefing in Jakarta
19. 02. 2010	Travel to GTZ office in Palembang, Sumatra, Biochar Seminar with representatives from various agricultural and silvicultural sectors
21. 22. 02. 2010	Travel from Jakarta to Salzburg

6.2 Contacts, Initiatives and Technology Suppliers

Technology suppliers

Pyrolytic stoves

Contact	Comments
Nathaniel Mulcahy Tortona, **Italy** Tel: +39 340 5758344 e-mail: worldstove@gmail.com www.worldstove.com	Pyrolytic stoves without fan (electricity requirements)
Paul Anderson Tel: +1 309 4527072 e-mail: psanders@ilstu.edu http://www.bioenergylists.org/andersontludconstruction http://www.chipenergy.com/	
More stoves http://www.bioenergylists.org/stoves http://www.biochar-international.org/technology/stoves	

Biochar production (larger applications)

Contact	
Adam & Partner P.O. Box: 50108 Addis Abeba, **Ethiopia** Tel: +251 910883624 +251 913334326 email: scda@ymail.com http://www.biocoal.org/3.html	Adam Retort, improved charcoal production
Jim Fournier Biochar Engineering Corporation, 701 Pine Ridge Golden CO 80403, **USA** Tel: +1 303 2793776 e-mail: info@biocharenergy.com www.biocharengineering.com	Development and commercialization of pyrolysis technology
Pro-Natura International 15, avenue de Segur 75007 Paris, France Tel: +33 01 53599798 e-mail: pro-natura@wanadoo.fr www.pronatura.org	Production of charcoal from crop residues (green charcoal)

Contact	
Thomas Hartung BlackCarbon A/S Barritskov 36, Barritskovvej DK-7150 Barrit, Denmark Tel: +45 75 691177 e-mail: info@blackcarbon.dk www.blackcarbon.dk	Pyrolysis with combined heat and power cogeneration (Stirling engine)
Dynamotive Suite 1550, 1650 Tysons Boulevard McLean, VA 20=22102, **USA** Tel: +1 703 336 8450 info@dynamotive.com www.dynamotive.com	Development and commercialization of fast pyrolysis technology
Simple and clean biochar production Production of rice husk charcoal	http://www.twinoaksforge.com/BLADSMITHING/MAKING%20CHARCOAL.htm www.eprida.com/hydro/ecoss/background/ricehullcharcoal.pdf

Research Facilities in Indonesia

Contact persons and Institutions	Activities
Dr. Chairil Anwar Siregar Dr. Titiek Setyawati Forest and Nature Conservation Research and Development Center Jalan Gundung Batu 5 Bogor 16610, Indonesia Tel: (62) 0251 750067 e-mail: siregar@forda.org	Soil science, Experience and Interest in biochar research
Syahrinudin Mulawarman University, Samarinda + 08125514914 e-mail: syahri@ymail.com	Experience with biochar and interest in biochar R&D
Achmad Pribadi Head of Research Planing Division Dipterocarpa Research Center, Ministry of Forestry Samarinda Tel: 62-541-206364 e-mail: achmad.pribadi@gmail.com	
Deddy Hadriyanto Faculty of Forestry, Mulawarman University Sumarinda Tel: (62) 812 553 5548 e-mail: d_hadriyanto@yahoo.com	

NGOs

Contact persons and Institutions	Activities
Topenbos International, Indonesia Programme Petrus Gunarso, Programme Director Tel: (62) 251 8638410 e-mail: petrusgunarso@yahoo.com	Interest in biochar R&D
The Nature Conservancy Alan Subekti, REDD Field Manager Tel: (62) 542 745730 e-mail: asubekti@tnc.org	

Biochar Initiatives and Organizations

Organization	www
International Biochar Initiative	www.biochar-international.org
Biochar Consulting Services, Research and Information	www.biochar.org
Biochar Malaysia	http://www.icc.upm.edu.my/biochar/ http://biocharmalaysia.blogspot.com/
Australia and New Zealand Biochar Research Network	http://www.anzbiochar.org/
Japan Biochar Association	http://www.geocities.jp/yasizato/JBA.htm
Biochar Europe	http://www.biochar-europe.org/
Canadian Biochar Initiative	http://www.biochar.ca/
U.S. Biochar Initiative	http://www.biochar-us.org/
The Biochar Fund NGO implementing slash and char projects in Africa	http://www.biocharfund.org/
UK biochar Research Center	http://www.geos.ed.ac.uk/sccs/biochar
Internet Biochar Discussion Groups	http://terrapreta.bioenergylists.org/ http://tech.groups.yahoo.com/group/biochar/ http://tech.groups.yahoo.com/group/biochar-production/ http://tech.groups.yahoo.com/group/biochar-soils/ http://tech.groups.yahoo.com/group/biochar-policy/ http://ca.groups.yahoo.com/group/Biochar-Remediation/

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