Bulletin of the Rubber Research Institute of Sri Lanka, (2010) **51**, 61-69

BIOCHAR AND ITS POTENTIAL USES IN RUBBER PLANTATIONS

R S Dharmakeerthi

Soils in the tropics, such as those in rubber growing areas of Sri Lanka, are the outcome of extensive weathering processes of parent materials (mostly rocks) over millions of years. During this period important plant nutrients are released from the parent material but have been leached down the profile due to heavy rainfall making these soils very unfertile. Continuous cultivation further degrades these soils and the land becomes less and less productive over time. The degradation of soil occurs mainly through the loss of top soil due to water erosion and decrease of organic matter content in the soil due to accelerated decomposition. Application of organic materials such as compost, green manure, animal manure, dead mulches, are therefore often recommended to improve the fertility of these soils.

Increasing organic matter content in the soil and maintaining it over a long period also helps to reduce concentration of CO_2 in the atmosphere, a green house gas that contributes to global warming. In some countries agro management practices are specially designed for this purpose. For example, minimum tillage or zero-tillage has been found to increase soil organic matter content in temperate countries. Crop residue management strategies, such as composting and in situ mulching, are also being practiced. Planting crops and/or varieties of a crop that pumps more C into the soil through their root system, is another approach.

However, under hot and humid climates in the tropics, these organic materials decompose so fast, about 60 to 80% within one or two years, that constant application of organic material is inevitable. Recently, focus has been to achieve both above mentioned objectives, increasing the soil fertility and sequester atmospheric CO_2, by land application of biochar (Lehman, 2007). It is also believed to provide a long term benefit for soil fertility and therefore a sustainable technology to improve highly weathered or degraded tropical soils.

What is biochar?

Biochar, biologically derived charcoal, refers to the carbon-rich materials produced from the slow pyrolysis (heating in the absence of oxygen) of biomass. Biochar is highly recalcitrant to microbial decomposition and therefore persist in soil for several hundred years, providing the benefits to the soil and acting as a long term sink for atmospheric CO_2.

Land application of biochar is not a new concept. Amerindians in the Amazon basin, motherland of para rubber (*Hevea brasiliensis*), have applied large amounts of charred materials, the residues from biomass burning, into their lands for a long period of time. This has resulted a blackish color soil which are much more fertile than the adjacent soils that have not received charcoal. The applied carbon can still be found in these lands, thousands of years after abandoning them by the Amerindians when the Europeans invaded their lands. These manmade soils, Anthrosols, are called *Terra Preta de Indio* or Amazonian dark earth. Similar practices have been recorded in some other parts of the world. In addition, traditional shifting cultivation or the chena cultivation also adds charcoal into soil, though not entirely intentional.

Comparison with chena cultivation

Small-scale farmers slash the natural vegetation at varying stages of regeneration, or even primary forest and burn the biomass to allow a crop to be grown. Under this system soil fertility declines rapidly and competition from weed increases (Nye and Greenland, 1960). Once this leads to a deterioration in crop yield the land is left fallow to regenerate. Typical fallow periods in such a system range from 5–25 years, while cropping periods are 1–3 years long.

Practice of land application of biochar is different from chena or shifting cultivation which adopts slash-and-burn techniques. During burning of the above ground biomass, the nutrients are rapidly released into the soil. These nutrient additions have positive effects on soil fertility only for a short period. Additionally, burning releases large amounts of the greenhouse gases CO_2 and N_2O which lead to global warming. Only about 3% of the aboveground biomass would be converted into forms similar to biochar under a typical slash-and-burn system whereas more than 50% of biomass could be converted into biochar under a slash-and-char cultivation system (Lehman and Rondon, 2006).

Making biochar

Biochar can be made basically from any organic residue or waste. Feedstocks currently used include timber mill wastes, tree bark, crop residues (including straw, nut shells and paddy husk), organic wastes including distillers grain, bagasse from the sugarcane industry, tea wastes, poultry litter, dairy manure, sewage sludge and paper mill sludge. Rubber timber wastes, firewood and nursery wastes could also be used to produce biochar.

The biochar production process begins with biomass being fed into a pyrolysis kiln—a furnace that burns with little or no oxygen. Feedstocks are heated upto ~500˚C (pyrolysis occurs at temperatures between 300 to 700˚C but the quality of biochar is highest when made at around 500˚C) under no oxygen condition in a pyrolysis kiln. At the end of this, two main products come out of the kiln. The first is biochar, usually representing about 50% of the carbon content of the biomass. The other is biofuel. The biofuel is often syngas, which is a mixture of mainly hydrogen, carbon dioxide, nitrogen and methane, with a little carbon monoxide. The proportions of these gases vary according to the processes used to create the syngas. However, the important point is that syngas is combustible and so can be used as a fuel source. Depending on the process, the biofuel from the kiln could also be bio-oil, which can be used as a substitute for diesel in some engines. Generally, faster pyrolysis results in more oils and liquids, slower pyrolysis produces more syngas. Minimizing the oxygen present during pyrolysis optimizes the production of biochar

The ancient method for producing biochar as a soil additive was the “pit” or “trench” method. Here, organic matter is fired in a pit or trench and when the organic matter start to fire itself, the pit or the trench is covered with soil or clay to stop the oxygen flow (FAO, 1983). While this method still has the potential to produce biochar in rural areas, it does not allow the harvest of either the bio-oil or syngas, and releases a large amount of CO_2, black carbon, and other potentially toxic green house gasses into the air. Another method uses an external heat source to "cook" organic matter contained in a closed but vented chamber (Fig. 1) (Günther 2008). This is usually carried out in a metal or masonry chamber (furnace). This method results in a higher yield of high quality charcoal with less smoke and pollutants. Modern pyrolysis kilns controls oxygen flow, temperature and also extracts biofuels produced and therefore very efficient and yields high percentages of biochar (Brown, 2009). Recently, microwave technology has been used to efficiently convert organic matter to biochar on an industrial scale, producing about 50% biochar (Ananthaswamy, 2008).

Fig. 1. Small scale biochar production: A biomass filled, closed, small vessel is placed inside a large barrel (left) and then cooked (right)

Properties of biochar

Three main factors influence the properties of biochar: (1) the type of organic matter (feedstock) used for charring, (2) the charring environment (*e.g.* temperature, air), and (3) materials added during the charring process to increase nutrient content. The feedstock and additions strongly influences the direct effects of biochar amendments on nutrient contents and availability in soil while charring environment influence the C and ash contents and surface properties of biochar (Lehman, 2007).

Biochar is a fine-grained charcoal high in organic carbon (50 to 90%) and largely resistant to decomposition . The pH of biochar is usually alkaline and could be as high as 13 depending on the ash content. They are also rich in K and contain some Ca and Mg. Biochar has a very high specific surface area and the surfaces are charged negatively (Lehman, 2007). Therefore they also have a high cation exchange capacity. In addition, biochar is highly porous in nature and therefore very low in bulk density and posses a high water holding capacity. Some of the chemical properties of two biochar types (commercially available timber mill waste charcoal and rubber firewood charcoal produced at RRISL) are given in Table 1. The large variation in nutrient contents in the two biochar types is evident from this table.

Table 1. *Some chemical properties of biochar produced from timber mill waste and rubber firewood*

Biochar	**pH**	**CEC**	**Ash content**	**Total N**	**Avai-lable P**	**Exchangeable cations**		
						K	**Mg**	**Ca**
	1:2.5, water	cmol(+) kg^{-1}	%	%	—————— ppm —————-			
Timber mill waste	9.56	14.1	18	0.49	36	2661	407	5181
Rubber firewood	9.59	12.2	5	0.53	22	6194	186	957

Soil quality improvements

Compared to the original soils from which they were derived, Amazonian black earth *(Terra Preta)* typically have higher levels of organic matter, higher moisture-holding capacity, higher pH values, greater nutrient-holding capacity, and higher levels of bioavailable N, P, Ca and K (Glaser *et al.*, 2002). Research conducted over the last decade or so has confirmed that biochar application in soils improves most measures of soil quality. Few examples are discussed below.

Soil organic C and total N increase with biochar additions. It also results in an increase in CEC in the soil which in turn decrease leaching losses of fertilizer (K^+, Ca^{2+} and Mg^{2+}). The cation exchange capacity was 5–20% higher for the biochar amended soils relative to the non-amended soils (Liang *et al.*, 2006). It has also found that biochar additions decreased NO_3^- leaching by 10% and P leaching by 40 to 70% (Novak *et al.*, 2009). Experiments conducted at the Rubber Research Institute of

Sri Lanka indicated that pH of the biochar amended soils increases up to 1-1.5 pH units soon after the addition and could remain high after 8 months (Dharmakeerthi *et al*., 2010). Increase in pH could positively influence P availability in soils while negatively influence on Mn availability.

Biochar may not only change soil chemical properties, but also improves soil physical properties such as soil water retention, aggregation and aggregate stability. Low organic matter contents are responsible for the low available water capacity and the weak structure of many agricultural soils. It is expected that increase in soil organic C content in soils after biochar application could enhance water availability to crops and decrease erosion as well. Soil bulk density was found to be significantly low for the biochar-amended soils than the non amended soils (Glaser *et al*., 2002).

Biochar also enhances microbial – especially mycorrhizal – activity, and is known to accelerate nitrification in forest ecosystems. The structure of biochar provides a refuge for small beneficial soil organisms, such as symbiotic mycorrhyzal fungi which can penetrate deeply into the pore space of biochar and sporulate in the micropores of biochar where there is lower competition from saprophytes (Warnok *et al*., 2007). Biochar addition to soil increases N_2 fixation by both free living and symbiotic diazotrophs (Rondon *et al.*, 2007).

Effect on crop growth

Biochar application can enhance plant growth by improving soil chemical characteristics (*i.e*., nutrient retention, nutrient availability), soil physical characteristics (*i.e*., bulk density, water holding capacity, permeability), and soil biological properties, all contributing to an increased crop productivity. The effect of biochar application on the growth of rubber plant has only recently been studied (Dharmakeerthi *et al.*, 2010). In a study conducted on tropical Zambian soils, shoot heights and biomass production of seven indigenous woody plants on under charcoal kilns has increased significantly (Chidumayo, 1994). A Japanese study has found that the heights of sugi trees (*Cryptomeria japonica*) increased by a factor of 1.26–1.35, and the biomass production increased by a factor of 2.31–2.36, five years after application of 0.5 Mg charcoal ha^{-1} (Kishimoto and Sugiura, 1985). There are some reports however, to suggest that biochar application as soil amendments have adverse effects on growth and yield of annual crops (Glaser *et al*., 2002) and have been attributed to an increase in pH for pH-sensitive plants, or due to pH-induced micro-nutrient deficiencies, or to reduced N availability. Dharmakeerthi *et al*. (2010) observed a negative impact from soil application of biochar on the growth of *Hevea* nursery plants, but suggested that this could be overcome by judicious application of chemical fertilizers.

Climate change mitigation

Among the many advantages of land application of bio-char the foremost concern is, the potential of it as a method of C-sequestration because the production and land application of biochar is considered to be a carbon negative process (Lehman, 2007). Carbon in biochar is argued to be less degradable and persists in the soil for a hundreds, if not thousands, of years. Therefore, the application of charcoal will lead to higher C sequestration in comparison to the application of equal amounts of non-charred organic matter that are commonly used in agriculture (Fig. 2). During the production of biochar, about 50% of the biomass C is lost. But this could be utilized as bioenergy and used back in the pyrolysis process or extracted as syngas and bio-diesel before they finally escaped to the environment. CO_2 produced from microbial decomposition of un-charred organic matter is lost directly to the atmosphere. Therefore conversion of organic residues into biochar and application of them into agricultural lands or plantations should give a unique opportunity to reduce production of CO_2 and sequester atmospheric CO_2. However, some of the C in biochars produced by low-temperature pyrolysis is bioavailable, while C in high-temperature biochars is either nondegradable by micro-organisms or the rate of microbial degradation is exceedingly slow.

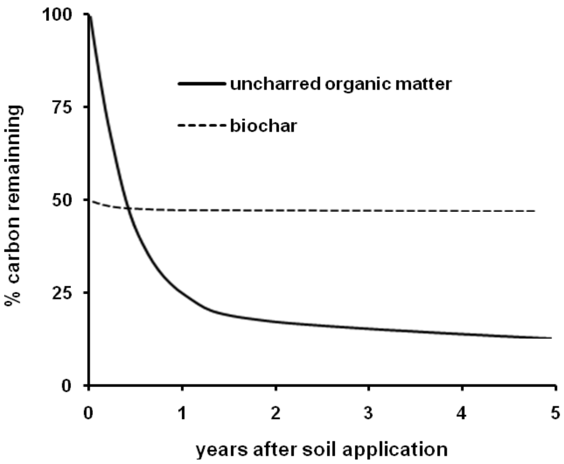

Fig. 2. Schematic representation of biomass C remainning after soil apllication in a tropical climate (Adapted from Lehman *et al*., 2006)

Biochar seems to have the potential to reduce the production of green house gasses such as N_2O and CH_4 (Rondon *et al*., 2005). If this claim is verified through more scientific research, this will be the most significant effect of land application of biochar, because these gases are more potent green house gasses than CO_2.

Potential in rubber plantations

Biochar application is new to plantation crop sector and one published report (Dharmakeerthi *et al.,* 2010) is available for rubber plantations in Sri Lanka. Biochar can be produced from rubber wood, nursery loppings, root stocks after tree felling or any other organic waste found in rubber plantations. Biochar, whether it is produced from rubber wood or other feedstocks, could be expected to have the potential to improve soil fertility, actively draw CO_2 from the atmosphere and sequester in soil, regenerate degraded lands, and reduce environmental pollution in rubber plantations. These beneficial effects of biochar are expected to sustain in soils over a long period of time.

In order to obtain the full potential of biochar as a C sequestration strategy and a soil amendment in rubber plantations, its agronomic effectiveness on rubber plants has to be investigated and confirmed. Particular attention should be given to evaluate the impact of very high C/N ratio and pH in biochar on the growth of rubber plant. Biochar is reported to have a small percentages of C rich volatile matter and therefore high C/N ratio could decrease N availability, at least temporarily, while pH increase in soil could affect micronutrient availability. High K content in biochar could alter K:Mg ratio in soils and may affect Mg nutrition of the plant, if corrective measures are not taken. Moreover, application of undecomposed organic matter has also generated some concerns related to management of cockshafer grub attack and white root disease in some rubber plantations in Sri Lanka. Therefore, breeding habits of the cockshafer grub beetle in biochar amended lands and the hosting of white root disease causing fungi in pore spaces of biochar has to be studied carefully.

Rubber plantations in the world are considered to be self sustaining agroforestry systems that also help to mitigate climate change by sequestering atmospheric CO_2 in its biomass. They could contribute even more positively to sequester atmospheric CO_2 and as a climate change mitigate technology than it is claimed to be now, by returning biomass back into the soil as slowly degradable biochar. Production of biochar using slow pyrolysis technology and land application of biochar is has been suggested as a C negative process. Energy required for the pyrolysis process of biochar production usually comes from burning of firewood. However, the heat generated in rubber factory furnaces could be utilized for biochar production without burning additional firewood or energy. Hence, biochar production in rubber plantations could be made even more C negative than usually practiced. Therefore, if future research could confirm its land applicability, biochar certainly has the potential to be a "***black gold***" for rubber plantations.

REFERENCES

Ananthaswamy, A (2008). Microwave factory to act as carbon sink. http://www. newscientist.com/article/dn14851?DCMP=ILC-hmts&nsref=news1_head_dn14851 DOA: September 24, 2010.

Brown, R (2009). Biochar production technology. In: *Biochar for Environmental Management: Science and Technology*. Lehman, J. and Joseph, S. (Eds.) Earthscan Publishers. pp 127-146.

Chidumayo, E N (1994). Effects of wood carbonization on soil and initial development of seedlings in miombo woodland, Zambia. *Forest Ecology and Management* **70**, 353–357.

Dharmakeerthi, R S, Chandrasiri, J A S and Edirimanne, V U (2010). Use of biochar as a soil amendment in rubber (*Hevea brasiliensis*) plantations: Effectiveness in young budding polybagged plants. In: *Proceedings of the 3rd Symposium on Plantation Crop Research.* (Eds. R S Dharmakeerthi and A M W K Senevirathna). September 30 - October 01, 2010. Colombo, Sri Lanka, Rubber Research Institute of Sri Lanka. pp 179-188.

FAO (1983). Simple technologies for charcoal making. *FAO Forestry Paper* **41**, FAO, Rome www.fao.org/docrep/x5328e/x5328e00.htm., DOA: September 20, 2010.

Glaser, B, Lehmann, J and Zech, W (2002). Ameliorating physical and chemical properties of highly weathered soils in the tropics with charcoal – a review. *Biology and Fertility of Soils* **35**, 219-230.

Günther, F (2008). The simplest of the simple: a two-barrel charcoal retort http://www.holon.se/folke/carbon/simplechar/simplechar.shtml#two%20barells. DOA: January 15, 2010.

Kishimoto, S, and Sugiura, G (1985). Charcoal as a soil conditioner. *International Achievements and the Future* **5**, 12–23.

Lehmann, J (2007). Bio-energy in the black. *Frontiers in Ecology and the Environment* **5**, 381-387.

Lehmann, J and Rondon M (2006). Biochar soil management on highly weathered soils in the humid tropics. In: *Biological Approaches to Sustainable Soil Systems*. Uphoff N. *et al.*, (Eds.) Boca Raton, FL, USA: CRC Press, Taylor & Francis Group. Pp. 517-30.

Lehmann, J, Gaunt, J and Rondon, M (2006). Bio-char sequestration in terrestrial ecosystems – a review. *Mitigation and Adaptation Strategies for Global Change* **11**, 403-427.

Liang, B, Lehmann, J, Solomon, D, Kinyangi, J, Grossman, J, O'Neill, B, Skjemstad, J O, Thies, J, Luiza, F J, Petersen, J and Neves, E G (2006). Black carbon increases cation exchange capacity in soils. *Soil Science Society of America Journal* **70**, 1719–1730.

Nye, P H and Greenland, D J (1960). The Soil under Shifting Cultivation. London, Commonwealth Bureau of Soils Technological Communication 51, 156p.

Novak, M J, Busscher, W J, Larid, D L, Ahmdna, M, Watts, D W and Nialtox, M A S I (2009). Impact of biochar amendment on fertility of southeastern coastal plain soil, *Soil Science*. **174**, 105-112.

Rondon, M, Ramirez, J A and Lehmann, J (2005). Charcoal additions reduce net emissions of greenhouse gases to the atmosphere. In: *Proceedings of the 3rd USDA Symposium on Greenhouse Gases and Carbon Sequestration in Agriculture and Forestry*; 2005 Mar 21–24; Baltimore, MD. University of Delaware. p 208.

Rondon, M A, Lehmann, J, Ramirez, J and Hurtado, M (2007). Biological nitrogen fixation by common beans (*Phaseolus vulgaris* L.) increase with biochar additions. *Biology and Fertility of Soils* **43**, 699-708.

Warnock, D D, Lehmann, J, Kuyper, T W and Rillig, M C (2007). Mycorrhizal responses to biochar in soil-concepts and mechanisms, *Plant and Soil* **300**, 9-20.