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Review

Biochar an alternate option for crop residues and solid waste disposal and climate change mitigation

P. Kannan[1]*, P. Arunachalam[1], G. Prabukumar[1] and M. Govindaraj[1,2]

[1]Dryland Agricultural Research Station, Tamil Nadu Agricultural University, Chettinad, Sivagangai, Tamil Nadu, India- 630102.
[2]Centre for Plant Breeding and Genetics, Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu, India- 641 003.

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Atmospheric rise of CO_2, N_2O and CH_4 over years, accelerated increase in global temperature, has led to uncertainty in monsoon rainfall and also leading to recurrence of drought, which in turn is severely affecting crop productivity and livelihood security of the farmers in Semi Arid Tropics. Agriculture contributes considerable amount of CO_2, N_2O and CH_4 emission into the atmosphere through different soil and crop management practices. Nevertheless agricultural activities contribute to global warming. The medium of crop production, soil is one of the major sinks of global warming gaseous and it helps to sequester more carbon and cut the N_2O emission by adopting smart soil and crop management techniques. Biochar is one of the viable organic amendments to combat climate change and sustain the soil health with sustainable crop production. It is an anaerobic pyrolysis product derived from organic sources and store carbon on a long term basis in the terrestrial ecosystem and also capable of reducing greenhouse gases (GHG) emission from soil to the atmosphere. Biochar application improved the soil health, increase the carbon capture and storage, reduce the GHG emission and enhance the crop yield with sustained soil health, which enables to meet out the food grain needs of the ever growing population.

Key words: Biochar, carbon sequestration, climate change, soil health, crop yield.

INTRODUCTION

Biochar is a charred by-product of biomass pyrolysis produced from biological wastes, crop residues, animal poultry manure, or any type of organic waste material. Pyrolysis is the chemical breakdown of a substance under high temperatures in the absence of oxygen (Lehman et al., 2003). Biochar application has been promoted in agricultural practice that creates a win-win situation by improving soil quality and enhancing agricultural sustainability concomitant with mitigating greenhouse gases (GHG) emissions. Recently biochar application gained momentum because of its capability of carbon sequestration, reducing soil compaction, improves soil physical condition, enhancing nutrient uptake from the soil and helps to reduce nitrous oxide emission (Lehmann et al., 2005; Lehmann, 2007). There is a large imbalance between carbon release to the atmosphere and carbon uptake by other compartments that leads to a continued increase in atmospheric CO_2 equivalent to a rate of 9.5 Pg of carbon per year (Peters et al., 2012). Hence, developing an alternate method for retaining carbon in a stable form which can be stored outside the atmosphere for a longer time is utmost importance.

*Corresponding author. E-mail: pandian.kannan@gmail.com.

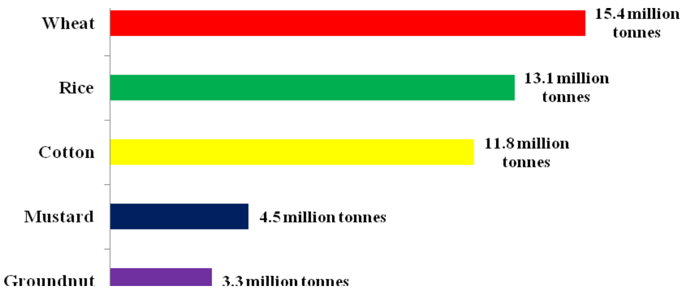

Figure 1. Quantum of crop residues generated in India.

Biochar has received increasing interest due to its potential in increasing soil carbon storage, improving soil fertility, as well as maintaining the balance of soil ecosystems, and it could act as a kind of soil fertilizer or amendment as stressed by Glaser et al. (2002) and Marris (2006).

Agricultural crop residues form a major source of biomass in India and annually about 69.7 million tonnes of crop residues are produced from the six major crops in India; the share of different crops is given in the Figure 1 (Biochar India, 2012). So, the conversion of crop waste in to biochar helps to offset CO_2 emission and increase the carbon sequestration in the soil under changing climate. Apart from crop residues, urbanisation has led to production of municipal solid waste (MSW), which is also challenging the scientific community to find a way out to dispose them safely. Biochar production from MSW has great scope and viable option for organic waste disposal than other methods of disposal. In India, municipal solid waste quantities are expected to increase from 34 million tonnes in 2000 to 83.8 million tonnes in 2015 and 221 million tonnes in 2030.It is also reported that per capita per day production will increase to 1.032 kg and urban population as 586 million in 2030 (Kaushal et al., 2002).

Among the Municipal Solid Waste (MSW), organic contribute major share of 50%, but only 10% is used for composting. Though composting is an eco-friendly technology yet it contributes significantly in GHG emission during pre-decomposition process. So finding out the alternate safe technology for scientific waste disposal is paramount important. The management of MSW is a tough task, due to the unavailability of suitable facilities to treat and dispose of the larger amount of MSW generated daily in urban areas. So there is an urgent need to develop scientific and eco-friendly disposal of municipal solid waste without environmental threats.

Good soil management can help to regulate emissions of three key GHGs namely CO_2, CH_4 and N_2O from agriculture, which contribute to climate change. The science behind the role of soil management particularly, biochar on soil health improvement and its effect in reducing GHG emissions is still relatively young and the relationship between carbon and nitrogen in the soil is complex. More understanding of biochar production methods, application rate, impact on soil health improvement and climate change mitigating potential are needed to fine tune further. Following the existing features of good agricultural practice (GAP) is generally advantageous due to the wider production and environmental benefits gained. A number of studies have now highlighted the net benefit of using biochar in terms of mitigating global warming and as an active strategy to manage soil health and productivity (Lehmann, 2007, 2007a; Lehman et al., 2005; Ogawa et al., 2006; Laird, 2008; Matthews, 2008; Woolf, 2008). However, relatively few studies exist that make a quantitative assessment of biochar based soil management scenarios with regard to GHG, nutrient use efficiency and economic perspectives (Fowles, 2007; Gaunt and Lehman, 2008).

SOLID WASTE STATUS IN INDIA

Economic and demographic growth of cities, changing lifestyles of people, changing land use patterns and technological advancements led to increase in quantity and complexity of urban Municipal Solid Waste (MSW) generation and management. MSW generally includes degradable (paper, textiles, food waste, straw and yard waste), partially degradable (wood, disposable napkins and sludge) and non-degradable materials (leather, plastics, rubbers, metals, glass, ash from fuel burning like coal, briquettes or woods, dust and electronic waste).

Among the four geographical regions in India, Northern India generates the highest amount of MSW (40,500 Tonnes Per Day (TPD) or 14.8 million Tonnes Per Year (TPY)), 30% of all MSW generated in India; and Eastern India (23,500 TPD or 8.6 million TPY) generates the least, only 17% of MSW generated in India.

Among states, Maharashtra generates maximum MSW and in Union Territories, Delhi generates the highest amount of waste. MSW contribution of different states depicted in Figure 2. Biodegradable food materials and yard wastes normally dominate in MSW of developing countries while paper and hardboard dominate in developed countries (Joseph et al., 2003). Solid waste generated in Indian cities increased from 6 Tg in 1947 to 48 Tg in 1997 with per capita increase of 1 to 1.33% per year (Rao and Shantaram, 2003). About 0.5 to 0.7 kg capita^{-1} day^{-1} MSW is generated in urban India (Kameswari et al., 2003) with volatile matter content of about 10 to 30% (Rao and Shantaram, 2003). About three-fourth of the MSW generated from urban India is collected and disposed off in non-scientifically managed dumping grounds. Almost 70 to 90% of landfills in India are open dumpsites.

A major fraction of urban MSW in India is organic matter (51%). Recyclables are 17.5% of the MSW and the rest 31% is inert waste. The large fraction of organic matter in the waste makes it suitable for aerobic and anaerobic digestion. Aerobic digestion leads to heavy

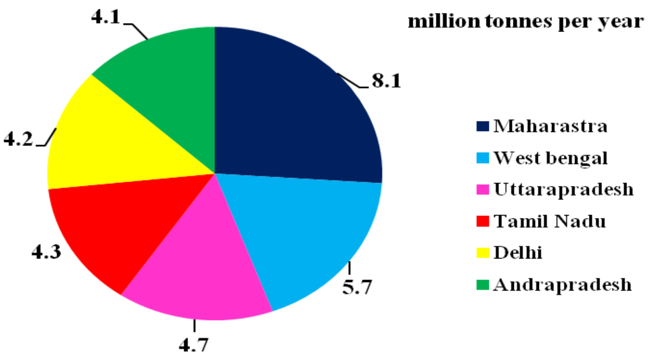

Figure 2. Maximum quantity of solid waste generating states of India.

Table 1. Biochar conversion efficiency of different Agricultural waste (Kannan et al., 2012).

Type of waste	Conversion efficiency (%)
Prosophis	35- 42
Rice husk	69-78
Red gram	36- 39
Maize	32-35
Cotton	38-46

metals leaching into the final compost due to presence of impurities and makes it unfit for use on agricultural soils.

BIOCHAR AND ITS IMPORTANCE

Biochar and its characteristics

Biochar is a fine-grained and porous substance, similar in its appearance to charcoal produced by natural burning. It is produced by the combustion of biomass under oxygen limited conditions (IBI-International Biochar initiatives). As a soil amendment, biochar creates a recalcitrant soil carbon pool that is carbon-negative, serving as a net withdrawal of atmospheric carbon dioxide stored in highly recalcitrant soil carbon stocks. World-wide, 41 Mt of charcoal are produced annually for cooking and industrial purposes (FAO, 2004). Most of this production is located in developing countries (40 Mt in 2002) rather than developed countries (1 Mt), with Africa being the highest producer (21 Mt) in comparison to South America (14 Mt) and Asia (4 Mt).

Conversion efficiency

Conversion efficiency analyses revealed that conversion of woody biomass to bio-char have shown an average recovery of 54% of the initial carbon in the biochar (Lehmann et al., 2003). But our study reported 32 to 78% recovery and these variation due to the nature of feed stock used and thickness of the feed stock. The conversion efficiency of different agricultural wastes was given in Tables 1 and 2. The crop wastes of 500 kg were converted into its biochar respective under anaerobic condition at 300 to 400°C by slow pyrolysis method. The conversion efficiency of various feed stock materials were in the range of 32 to 78%. The rice husk biochar was registered with a high conversion efficiency of 78% (Kannan et al., 2012).

Conversion using earthen pits and mounds will be more likely in a range of around 30 to 40%. The production of biochar from agricultural wastes requires specific skills. However, farmers who practice slash-and-burn are intimately familiar with cutting of biomass and the process of burning and many farmers in our study area regularly produce charcoal for sale in local markets. Therefore, charring organic matter in simple earthen mounds or pits should not be limited by the availability of local knowledge. The technique of using charcoal to improve the fertility of soils originated in the Amazon basin at least 2500 years ago. The native Indians of the region would create charcoal and incorporate it in small plots of land from 1 to 80 hectares in size. Terra Preta, as it is known, in Brazil, remains highly fertile even today, even with little or no application of fertilizers because of its highly fertile soils. The indigenous farmers in this region simply dug a deep ditch and, starting at one end, filled it in progressively with their household and personal wastes, covering it with a layer of soil as they went along, until the whole ditch had been filled-in again and covered over with soil. Then they started another ditch alongside the first and continued the bio-waste addition, until the whole plot was essentially a covered compost field (Woods et al., 2006).

Biochar can be used directly as a replacement for pulverized coal as a fuel. But one of major distinctions between biochar and charcoal (or char) is that the former is produced with the intent to be added to a soil as a means of sequestering carbon and enhancing soil quality.

There is a huge variability in physical biochar structures depending on the parent material and the conditions present at their formation, which leads to quite different turnover times in the soils (Czimczik and Masiello, 2007). Large charcoal particles originated from forest wildfires have been shown to remain in soils for thousands of years (Gavin et al., 2003). However, smaller particles as derived from grassland burning can hardly be detected in steppe ecosystems (Forbes et al., 2006).

There have been developed numerous chemical and technical methods to produce charcoals from a variety of biomass materials (Antal and Gronli, 2003; Marris, 2006; Titirici et al., 2007). Each production method needs a certain energy supply to activate the reactions and results in completely different biochar structures. However, hydrothermal carbonization looks especially promising energy- and process-wise. Once activated in a

Table 2. Chemical properties of biochar (Kannan et al., 2012).

Biochar	pH	EC (dS m^{-1})	OC (g/kg)	Total N (%)	Total P(%)	Total K (%)	Total Na (%)
Prosopis	8.4 - 9.7	0.63- 0.95	25 - 32	0.70-1.23	0.05-0.26	0.2- 0.5	0.34 -0.51
Rice husk	7.9 - 8.1	0.22- 0.52	34 - 57	0.63-1.78	0.07- 0.23	0.1 - 0.2	0.13 - 0.24
Maize	9.9 - 10.0	0.95-2.29	21 - 76	0.43- 2.06	0.08 -0.84	0.3 - 0.8	0.09 - 0.12
Cotton	9.81 - 10.6	0.28- 0.75	24 - 76	0.31- 0.67	0.15 -0.39	1.1 - 1.4	0.63- 0.75
Red gram	9.4- 10.8	0.83-1.4	17 - 67	0.53- 1.65	0.18- 0.46	0.8 - 2.5	0.71 - 0.81
Fodder sorghum	10.0- 11.8	1.3- 2.2	8.0 - 11	0.32- 1.02	0.16- 0.24	1.1- 3.9	0.71- 0.78

continuous process, 20 to 30% of the energy bound to the original biomass are liberated in the process, while keeping practically all carbon bound to the final structure (Titirici et al., 2007).

Biochar is the carbon-rich solid product resulting from the heating of biomass in an oxygen-limited environment. Due to its highly aromatic structure, biochar is chemically and biologically more stable compared with the organic matter from which it was made. It has been proposed as a technology which plays a useful role in building soil health and mitigating climate change. The properties of biochar vary widely, depending on the source of biomass used and the conditions of production of biochar (Lehmann and Joseph, 2009).

The pH of the biochar produced from different agricultural feed stock materials ranged from 7.9 to11.8 which are of alkaline range. Among the various feed stock materials used, fodder sorghum stalk biochar (11.8) and red gram stalk bio char (10.8) are high in alkaline nature. Rice husk biochar registered low level of salinity (0.22 dS m^{-1}) whereas the other feed stock materials (0.28 to 2.29 dS m^{-1}) are likely to develop moderate level of salinity. Among the various agricultural feed stock materials, cotton and maize stalk biochar registered highest organic carbon content of 76 g kg^{-1} followed by red gram biochar 67 g kg^{-1}.

The nutritional composition of bio char materials varied from its source of feed stock materials. The total N varied from 0.31 to 2.06%. The biochar produced from maize stover registered highest total N of 2.06% and total P of 0.84% and fodder sorghum recorded maximum total K of 3.9%. The lowest total N of 0.31% was in cotton stalk bio char and the lowest total P of 0.23% and total K of 0.20% were recorded for biochar produced from rice husk.

Benefits of biochar

The usefulness of biochar in agriculture and protecting environment (Figure 3) are listed asa follows:

1. Helps to reduce atmospheric carbon dioxide levels
2. Provide essential ecosystem services as a collateral outcome
3. Provide sustainable economic opportunities for regional and rural industries
4. Benefit soil quality, remediate degraded soil and enhance agricultural productivity
5. Deliver net biodiversity outcomes in the soil and above ground
6. Provide an opportunity for beneficial recycling of certain urban and industrial waste materials.

Dynamic effects of biochar on soil health

Influence of biochar on soil physical properties

The intrinsic contribution of biochar on soil physical parameters such as wetability of soil, water infiltration, water retention, macro-aggregation and soil stability are critical importance in tropical environments in combating erosion, mitigating drought and nutrient loss and in general to enhance groundwater quality.

The studies conducted by Chan et al. (2007) reported a noteworthy improvement in texture and behaviour of a hard-setting soil, with a significant reduction in tensile strength at higher rates of biochar application. Biochar can be used as a soil amendment to increase plant growth yield, improve water quality, increase soil moisture retention and availability to plants (Steiner et al., 2007).

Chan et al. (2007) further showed that biochar application had improved some physical soil properties, such as increased soil aggregation, water holding capacity and decreased soil strength. An increase in saturated hydraulic conductivity of upland rice soil with biochar application has been reported by Asai et al. (2009). Glaser et al. (2002a) reported that charcoal-rich Anthrosols from the Amazon region, whose surface area was three times greater than that of surrounding soils and had 18% greater field capacity.

Influence of biochar on soil chemical properties

Addition of biochar to soil alters important soil chemical qualities; soil pH increased towards neutral values (Lucas and Davis, 1961), typically increased soil cation exchange capacity. Glaser et al. (2002) observed

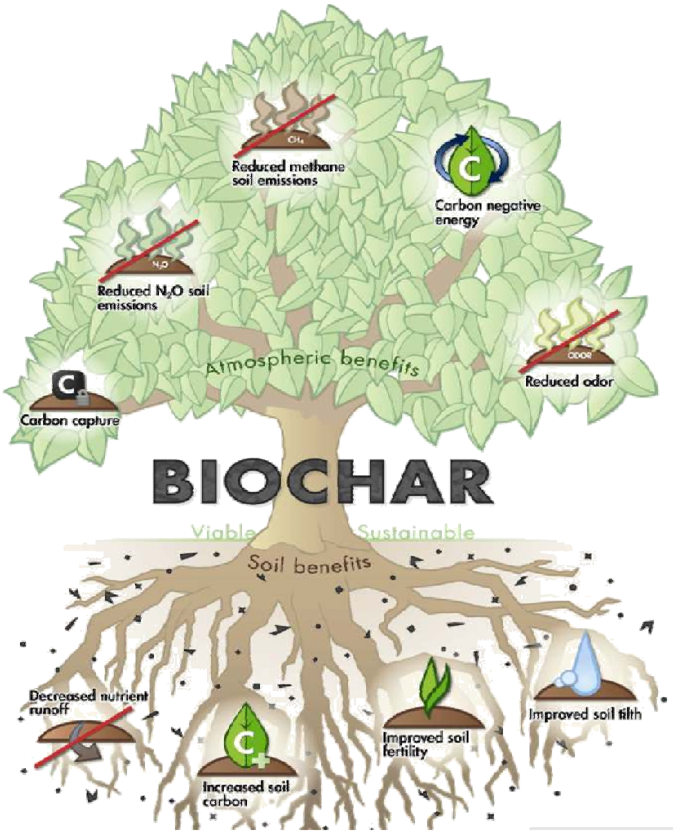

Figure 3. Multifold benefits of biochar (Adapted from Kavin D. Brown).

increasing trend of bio-available P and base cations in biochar applied soils. The optimal biochar combining fertilizer and carbon storage function in soils would activate the microbial community leading to nutrient release and fertilization and would add to the decadal soil carbon pool.

The increase of CEC with the application of biochar has also been shown by Liang et al. (2006). According to the Yamato et al. (2006) and Glaser et al. (2002) application of biochar made from *Acacia magnum* could increase soil pH, Ca, base saturation, CEC and decrease Al^+ saturation. Novak et al. (2009) showed that the application of biochar in the acidic coastal soil increase soil pH, soil organic matter, Mn and Ca and decrease S and Zn.

Biochar application boosts up the soil fertility and improve soil quality by raising soil pH, increasing moisture holding capacity, attracting more beneficial fungi and microbes, improving cation exchange capacity and retaining nutrients in soil (Lehmann et al., 2006; Lehmann, 2007). Another major benefit associated with the use of biochar as a soil amendment is its ability to sequester carbon from the atmosphere-biosphere pool and transfer it to soil (Winsley, 2007; Guant and Lehmann, 2008; Laird, 2008) (Table 3).

Significant changes in soil quality, including pH increase, organic carbon and exchangeable cations were observed at higher rates (>50 t ha^{-1}) of biochar application. Bio-char addition significantly improved soil fertility in acid and highly weathered soils and it has the potential for widespread application under various agro-ecological situations by mobilizing and improving the complex of chemical, physical and biological properties of soil systems.

Influence of biochar on nutrient use efficiency

Knowledge on the link between biochar function and its interaction with nutrient elements and crop roots may throw light on understanding fertilizer use efficiency. The enhanced nutrient retention capacity of biochar-amended soil not only reduces the total fertilizer requirements but also copes up the climate and environmental impact on crops. Biochar significantly increases the efficiency and reduces the need for traditional chemical fertilizers with sustainable crop yields. Biochar helps to improve soil resources by increasing crop yields and productivity by the way of reducing soil acidity and reducing the need for some chemical and fertilizer inputs (Glaser, 2007).

The immediate beneficial effects of bio-char additions on nutrient availability are largely due to higher potassium, phosphorus and zinc availability and to a lesser extent of calcium and copper (Lehmann et al., 2003). Longer-term benefits of biochar application on nutrient availability mainly due to a greater stabilization of organic matter, concurrent slower nutrient release from added organic matter and better retention of all cations due to a greater cation exchange capacity.

High rates of biochar addition in the tropical environment have been associated with increased plant uptake of P, K, Ca, Zn and Cu (Lehmann and Rondon, 2006).

Biological nitrogen fixation by common beans was increased from 50 to 72% of total nitrogen uptake with increasing rates of biochar additions (0, 31, 62, and 93 t C ha^{-1}) to a low-fertility Oxisol (Rondon et al., 2007)

Biochar also adds some macro (P, K, N, Ca and Mg) and micronutrients (Cu, Zn, Fe and Mn) which are needed for sustainable agriculture (Major et al., 2010). It may significantly affect nutrient retention and play a key role in a wide range of bio-geochemical processes in the soil, especially for nutrient cycling.

A beneficial impact of biochar on the plant-available phosphorus has been observed in soils enriched with biochar, which in contrast to ammonium, is not a characteristic generally associated with soil organic matter (Lehmann, 2007a; Steiner et al., 2007).

Influence of biochar on soil microbial activity

Biochar provides a suitable habitat for a large and diverse group of soil microorganisms. A higher retention of microorganisms in biochar amended soils may be responsible for greater activity and diversity due to a high surface area as well as surface hydrophobicity of both the microorganisms and biochar. A strong affinity of microbes to biochar can be expected since the adhesion of microorganisms to solids increases with higher hydrophobicity of the surfaces (Mills, 2003).

Biochar is an effective to activate living things and improve natural environment. Carbonized biomass such as rice husk charcoal or wood ash have been valuable material as soil amendment.

1. Symbiosis between effective microbes and plant root through the medium of charcoal, that promotes the growth of plants
2. Biochar help plants' growth, rise up productivity and contribute sustaining the quality of soil.

It is well corroborated that biomass-derived black carbon (biochar) affects microbial populations and soil biogeochemistry. Both biochar and mycorrhizal symbiotic association in terrestrial ecosystem are potentially important in various ecosystem services provided by the soil *viz.,* contributing to sustainable plant production, ecosystem restoration, soil-carbon sequestration and mitigation of global climate changes (Warnock et al., 2007).

Although a positive effect of biochar amendments on crop yields was already known to ancient cultures (Glaser, 2007), to date little is known about the effects of biochar addition on soil microorganisms and consequently on the soil carbon balance.

A greater microbial biomass was reported in forest soils in the presence of charcoal by Zackrisson et al. (1996) and higher microbial activity (CO_2 production as well as organic matter decomposition) was found in soils exposed to black carbon aerosols derived from charcoal making (Uvarov, 2000). The increase in soil biological activity has been reported by Rondon et al. (2007) for nitrogen fixation in *Phaseolus vulgaris* and by Chan et al. (2008) for earthworm and microbial biomass. Biochar application to soil has long tradition provided evidence that it has positive effects on the abundance of mycorrhizal fungi (Ishii and Kadoya, 1994).

Biochar versus climate change

Biochar production and utilization systems differ from most biomass energy systems because the technology is carbon-negative and it removes net carbon dioxide from the atmosphere and store it as stable soil carbon sinks in the terrestrial ecosystem (Lehmann et al*.,* 2006). The way in which biochar reduce the CO_2 emission are:

1. It reduces the need for fertilizer, resulting in decreased emissions from fertilizer production.
2. It increases soil microbial life which results in more carbon storage in soil.
3. It retains more nitrogen; emissions of nitrous oxide may be reduced.

Impacts on soil carbon sequestration

The stability of biochar carbon is intrinsic to fulfilling its role as a significant CO_2 sink, but in order to perform an agronomic role; it must also remain within the soil to which it is applied. There is a large imbalance between carbon release to the atmosphere and carbon uptake by other compartments that leads to a continued increase in atmospheric CO_2 equivalent to a rate of 4.1 to 109 tons of carbon per year (IPCC, 2007). Thus, it should be of utmost importance to develop new methods to retain carbon in a stable form that can be stored outside of the atmosphere for longer time periods. Biochar may persist in soil for millennia because it is very resistant to microbial decomposition and mineralization. This particular characteristic of biochar depends strongly on its properties, which is affected in turn by the pyrolysis conditions and the type of feedstock used in its production. Previous studies indicate that a bio-energy strategy that includes the use of biochar in soil not only leads to a net sequestration of CO_2 (Woolf et al., 2010), but also may decrease emissions of other more potent GHGs such as N_2O and CH_4 (Spokas et al., 2009).

The concept of carbon sequestration mechanism is given in Figure 4 and it represents the biosphere is through the process of photosynthesis or gross primary productivity that is the uptake of C from the atmosphere by plants. Part of this C is lost in several processes through plant respiration (autotrophic respiration); as a result of litter and soil organic matter (SOM) decomposition (heterotrophic respiration) and as a consequence of further losses caused by fires and drought. Currently, the biosphere constitutes a carbon sink that absorbs about 2.3 Giga tonnes of C per year, which represents about 30% of fossil-fuel emissions.

The extensive experimental research has shown that increasing atmospheric CO_2 concentration stimulates the process of photosynthesis and consequently plant growth (IPCC, 2000).

Biochar is one of the best technological solutions to reducing CO_2 levels arguing that biochar has the potential to sequester almost 400 billion tonnes of carbon by 2100 and to lower atmospheric CO_2 concentrations by 37 parts per million (Tim Lenton, 2009). Increased soil C sequestration also can improve soil quality because of the vital role that C plays in chemical, biological and physical soil processes and many interfacial interactions.

Biochar has the ability to significantly improve crop productivity, increase soil C and soil fertility; improve soil structure; sequester C in soil long-term and reduce

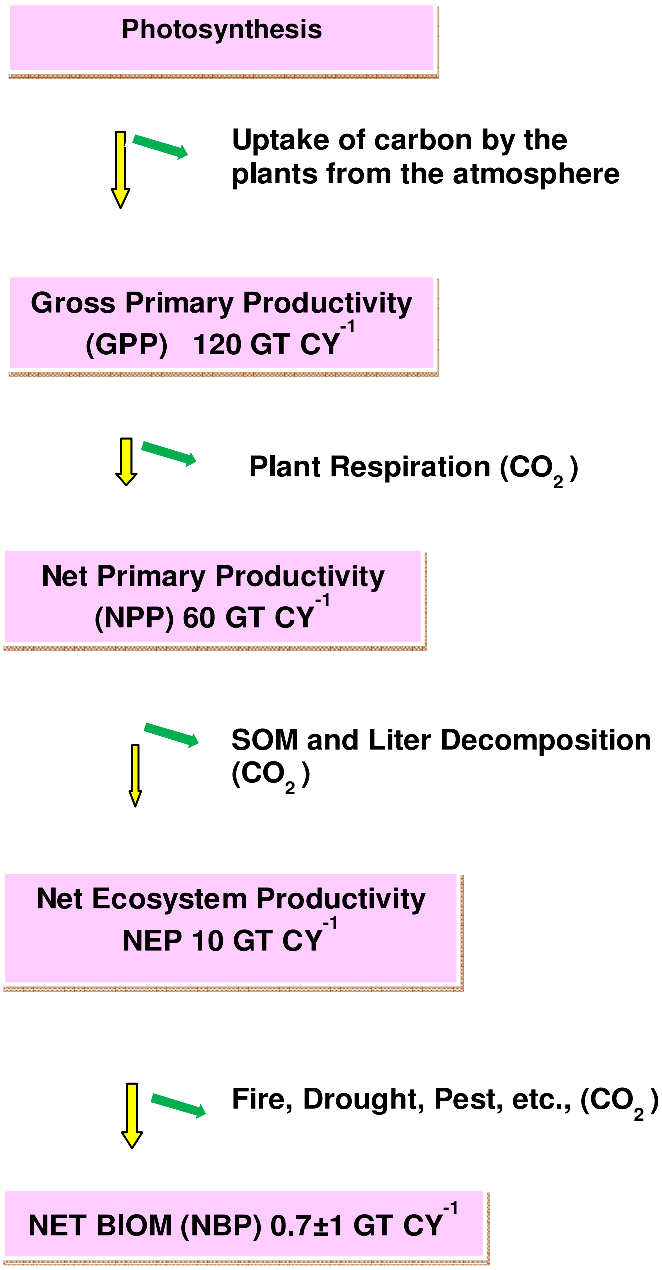

Figure 4. Terrestrial Global Carbon balance. Adapted from IPCC (2000).

emissions of non CO_2 GHGs from soil (Zwieten et al., 2010). It is an excellent soil amendment for sequestering carbon and water retention as well as providing a habitat for microbes (Mankasingh et al., 2009)

Biochar addition seems to generally enhance plant growth and soil nutrient status and decrease N_2O emissions. Its amendment reduced CO_2 production for all amendment levels tested (2, 5, 10%, 20, 40 and 60% weight by weight basis; corresponding to 24 to 720 t ha^{-1} field application rates). The recalcitrance of the biochar suggested that it could be a viable carbon sequestration strategy and might provide substantial net GHG benefits with long lasting reductions in N_2O production.

Biochar has potential to mitigate climate change as maximum of 1.8 Gt of CO_2 equivalents per year without affecting food security and ecosystem. This is equivalent to 12% of current anthropogenic CO_2 emissions annually (Woolf et al., 2010).

The extent of this stimulation varies according to different estimates, being larger up to 60% in forest and smaller about 14% for pastures and crops. To assess the carbon sequestration potential of adding biochar to soil, we must consider four factors viz., the longevity of char in soil; the avoided rate of GHG emission; how much biochar can be added to soils and how much biochar can be produced by economically and environmentally acceptable means.

Conversion of biomass carbon to biochar carbon leads to sequestration of about 50% of the initial carbon compared to the low amounts retained after burning (3%) and biological decomposition (< 10 to 20% after 5 to 10 years), therefore yielding more stable soil carbon than burning or direct land application of biomass (Lehmann et al., 2006). Biochar acts in several ways to aid in climate change mitigation. Firstly, the conversion of labile carbon from biological material to stable carbon (biochar) through slow pyrolysis can tie up C in the soil for many hundreds of years (Lehmann and Rondon, 2006). It has the potential to deliver the same crop yield with a lower application rate-with potentially significant greenhouse benefits. In more detailed assessments for the overall carbon balance of a biochar strategy (Gaunt et al., 2008), an assumed 10% reduction in the fertiliser required to maintain current crop yield was found to be a particularly important component of the net carbon benefit.

Impacts on soil N_2O and CH_4 emission

Char-amended soils have shown 50 to 80% reduction in nitrous oxide emissions and reduced runoff of phosphorus into surface waters and leaching of nitrogen into groundwater. Field experimentation with biochar in Columbia showed the 80% suppression of N_2O emissions and considerable amount of CH_4 emission reduction (Renner, 2007). Biochar application resulted 50 and 80% reduction in N_2O emissions in soybean plantations and grassland system (Rondon et al., 2005).

Natural emissions of N_2O from soil are a function of soil moisture status and possibly tillage (Pekrun et al., 2003). Because biochar in soil may modify the moisture regime and physical location of water within the soil matrix, it may mitigate the enhanced emission of N_2O that may occur in no-till systems. Methane emissions produced from agricultural soils, mainly under paddy rice agriculture, account for 12% of the global methane emission from all sources. Some studies have suggested that addition of biochar may partially suppress methane

Table 3. Response of biochar application on crop yield.

Crops	Soil type	Biochar rate (t ha^{1})	Fertilizer rate (kg ha^{-1})	Yield /biomass increase over control (%)	Additional information	Reference
Wheat	Ferrosol	10	1.25 g nutricote per 250 g soil (nutricote contain 15.2% N. 4.7% P, and 8.9% K)	+250	Similar response was observed for biomass yield of Soyabean and radish. Calcarosol amended with fertilizer and biochar however gave varied crop responses	Zwieten et al. (2010)
Radish	Alfisol	100	N(100)	+266 (biomass)	In the absence of nitrogen fertilizer application of Biochar did not increase the dry matter production of radish even at higher rate(100 t/ha)	Chan et al. (2007) Chan et al. (2008)
Rice	Inceptisol	30	Nil	+294	Sole effect of biochar	Noguera et al. (2010)
	Oxisol	88	Nil	+800	Interaction effect of earthworm and biochar	
	Oxisol	88	N(40),P(20),K(20)	-21	Interaction effect of earthworm and biochar	
Maize	Oxisol	20	N(156-170),P(30-43),K(83-138)	+28 (1st year) +30 (2nd year) +140 (3rd year)	In the first year after biochar application. No significant effect on crop yield was observed	Major et al. (2010)
Rice	Ferralsol	11	N(30),P(35),K(50)	+29(stover) +73(grain)	While charcoal addition alone did not affect Crop production, a synergistic effect occurred when both charcoal and inorganic fertilizer were applied	Steiner et al. (2008)
Groundnut	Alfisol	15	N(10), P(10) and K(45)	+55(pod)	Biochar addition mainly influence soil moisture retention their by enhance the nutrient availability in rainfed alfisol	Kannan et al. (2012)

emissions. A number of studies have now highlighted the net benefit of using biochar in terms of mitigating global warming and as an active strategy to manage soil health and productivity (Laird, 2008). Turning waste biomass into biochar reduces methane generated by the natural decomposition of the waste (International Biochar Initiative, 2008). It has the potential to reduce emissions of non-CO_2 GHGs from the soil. The soil is both a significant source and sink for greenhouse gases, such as CO_2, CH_4 and N_2O and it was well consonance with the result of Lehmann (2007).

Recent studies have indicated that biochar reduces N_2O emissions (Yanai et al., 2007) and increases CH_4 uptake from soil (Rondon et al., 2006). Biochar additions also significantly suppressed ambient CH_4 oxidation at all levels compared to unamended soil.

Effect of biochar on crop yield

Combination of higher biochar application rates with NPK fertiliser increased crop yield on tropical Amazonian soils (Steiner et al., 2007) and semi-arid soils in Australia (Ogawa et al., 2006).

Biochar application in low pH soil (<5.2) enhanced the carrot and bean yields over the control (Rondon et al., 2004). According to the Lehmann et al. (2006), increasing yields with increasing biochar applications up to 140 Mg C ha^{-1} on highly weathered soils in the humid tropics. This was not true for all crops, however, Rondon et al. (2004) found that biomass growth of beans (*Phaseolus vulgaris* L.) increased with biochar applications up to 60 Mg C ha^{-1} but fell to the same value as for control plots when biochar application was increased to 90 Mg C ha^{-1}. Lehmann (2007) conclude that crops respond positively to biochar additions up to 50 Mg C ha^{-1} and may show growth reductions only at very high applications.

Future challenges in biochar research

1. Developing low cost biochar pyrolysis equipments for conversion of organic waste in to carbon rich biochar for agricultural application by small and marginal farmers.
2. MSW disposal method through biochar process will be standardized and manurial potential of MSW will be evolved
3. Biochar based nutrient fortification and nutrient releasing pattern to be standardized
4. Optimization of biochar application for different agricultural crops will standardized through field experimental research in different ecosystem
5. Long term carbon sequestration potential of biochar in different ecosystem will be studied in detail through long term biochar field experiment
6. Acid soil reclamation potential and optimum dose of biochar will standardized through scientific approach
7. Biochar induced microbial dynamics and its role in nutrient availability mechanism to be understand
8. Erosion control and carbon saving potential of biochar will be assessed under different type of erosion
9. GHG mitigation potential of biochar will be using real time gas analysis and develop a prediction model for easy monitoring green house gas in agricultural system.
10. Biochar induced systemic acquired resistance and induced systemic resistance in plant disease and pest control may be explored in detail for different crops

SUMMARY

Many questions still remain to be answered regarding the mechanisms governing surface properties of biochar and how nutrient dynamics are affected by biochar. The opportunities for carbon sequestration and the reduction of GHG emissions have not been explored in different ecosystem, but they are potentially significant under changing climate. Further it is to be studied in detail for promoting biochar as a greening approach to the environment as well as human health. Published data for effect of biochar on trace gas emission is extremely limited, but has a potentially great impact on the net benefit of a biochar strategy. Good predictive models will be necessary for this to be reflected in future accounting for biochar projects. MSW disposal through biochar production one of the viable option and it has to be studied in detail about production, characterization and standardization for different crops. Long term effect of biochar application on soil physical, chemical and biological properties to be ascertained and its effect on crop yield to be studied in long-term experiment under changing climate.

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