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Role of Biochar in Agroforestry

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***Abstract* - Huge Quantities of unused and excess crop and Agroforestry residues in India are becoming an issue of concern due to inefficient crop residue management practices. Annually 523Mt crop residues are generated in India, out of which 127Mt is surplus. These residues are either partially utilized or un-utilized due to various constraints. As per the latest report published by Global Biochar Market is estimated to reach $17,050 Thousand by 2024; growing at a CAGR of 16% from 2016-2024. Direct incorporation of residues into the soil can conserve soil nutrients and organic content but causes considerable crop management problems due to delay in decomposition. The word Biochar is Greek word Bio means Life and Char means Coal obtained through Carbonisation, Pre-Columbian Amazonians produced boichar by smoldering agricultural waste in pits or trenches. It is not known if they intentionally used biochar to enhance soil productivity. European settlers called it Terra preta indio, that contain variable Quantities of organic black carbon considered to be of anthrogenic origin. Biochar production and application to soil Amendment covering benefits beyond carbon sequestration. This includes improvement of soil physical properties that benefits for crops, improved retention capacity and availability of soil nutrients, improved biological activity and consequently higher yields and societal advantages through Mitigation of Global warming through Carbon Sequestration. A protocol was developed to produce biochar through low –cost CRIDA biocahr kiln at community level or at individual farmer's level, to produce biochar from crop and Agroforestry residues. A recent study in mid-hills in the Himalaya Nepal showed that there were significant (P<0.05) positive effects on soil chemical properties, crop growth (height) and crop productivity due to effect of Biochar and FYM application on a degraded soils in a coffee Agroforestry system. For future studies the long-term impact of residual Biochar for soil amendment on crop yield improvement, nutrient availability carbon sequestration potential, and GHG's Mitigation.**

***Index Terms* - Biochar, Climate Mitigation, FYM, Coffee Agroforestry system.**

INTRODUCTION

Huge Quantities of unused and excess crop and Agroforestry residues in India are becoming an issue of concern due to inefficient crop residue management practices. Annually 523Mt crop residues are generated in India, out of which 127Mt is surplus (Pathak et al., 2006). These residues are either partially utilized or un-utilized due to various constraints. As per the latest report published by Global Biochar Market is estimated to reach $17,050 Thousand by 2024; growing at a CAGR of 16% from 2016-2024.

What is Biochar?

Biochar is a fine-grained, carbon-rich, porous product remaining after plant biomass has been subjected to thermo-chemical conversion process (pyrolysis) at low temperatures (~350–600°C) in an environment with little or no oxygen (Amonette and Joseph, 2009). Biochar is not a pure carbon, but rather mix of carbon (C), hydrogen (H), oxygen (O), nitrogen (N), sulphur (S) and ash in different proportions (Masek, 2009). The central quality of biochar and char that makes it attractive as a soil amendment is its highly porous structure, potentially responsible for improved water retention and increased soil surface area.

Definition on Agroforestry

ICRAF (1982): "Agroforestry is a collective name for land-use systems and practices where woody perennials are deliberately integrated with crops and/or animals on the same land management unit. The integration can be either in spatial mixture or in temporal sequence. There are normally both ecological and economic interactions between the woody and the non-woody components in Agroforestry."

Definition on Biochar

"Biochar is a charcoal-like substance that's made by burning organic material from agricultural and forestry wastes (also called biomass) in a controlled process called pyrolysis ".

The carbon-rich residual solid by-product of thermo-chemical degradation of crop and agroforestry residues in an oxygen depleted environment (pyrolysis) is termed 'biochar' (Lehmann et al., 2011). Although it looks a lot like common charcoal, biochar is produced using a specific process to reduce contamination and safely store carbon. The term biochar was invented in 2005, by one of the most outspoken advocates of its large-scale use, the late Peter Read, who defined it as 'finely divided pyrolysed biomass prepared for soil improvement'. Biochar obtained by slow pyrolysis from biomass waste with the primary goal of soil improvement (Lehmann et al., 2006), is highly porous, fine-grained, carbon dominant product rich in paramagnetic centers having both organic and inorganic nature, with large surface area possessing oxygen functional groups and aromatic surfaces (Amonette and Joseph, 2009; Atkinson et al., 2010).

CHARACTERISTICS OF BIOCHAR

1. Physical Characteristics:

From a physical point of view, biochar has a low bulk density due to its porous structure leading to a high specific surface area ranging from 50 – 900 m² g-1 (Schimmelpfennig and Glaser, 2012), and a high-water holding capacity (Glaser et al., 2002).

The Pyrolysis temperature is the main regulating factor which governs Characterization of Biochar. It also depends on the type of feedstock used.

Table 1. Physical Characteristics of Biochar

Low Temperature (400^0C & below)	High Temperature ($600-90^0$ C)
Surface area 120sq.m/gm	Surface area 460 sq.m/gm
Suitable for controlling release of Nutrients	Material analogous to activated carbon.
Lower ash content.	Higher ash content

1. Chemical Characteristics:

From a chemical point of view, the most striking feature of biochar is its polycondensed aromatic structure (Glaser et al., 1998) caused by dehydration during thermo chemical conversion (Schimmel-pfennig and Glaser, 2012) leading to its black color. This structure is also responsible for its relative recalcitrance compared to other organic matter in the environment. In addition, basic ash compartments lead to a high pH value. Several reports state that pH (Yu et al., 2014; Narzari et al., 2015) and EC (Singh et al., 2010; Naeem et al., 2014) of biochars increased with increasing pyrolysis temperatures. High pH values of biochar may be due to hydrolysis of carbonates and bicarbonates of base cations such as Ca, Mg, Na and K present in the source materials (Gaskin et al., 2008) and greater separation of basic cations and organic anions from organic materials with increase in pyrolysis temperature (Yuan et al., 2011). He reported that the EC of the crop straw derived biochars increased with increasing pyrolysis temperature.

Table 2. Chemical Characteristics of Biochar

Low Temperature (400^0C & below)	High Temperature ($600-90^0$ C)
Lower carbon content	Higher carbon content
Higher amount of N,S,K& P compounds	Lower amount of N,S,K& P compounds
Lower pH,EC & extractable NO_3-	Higher pH,EC & extractable NO_3-
Higher extractable P,NH4+, and phenols	Lower extractable P,NH4+, and phenols

Several reports state that pH (Yu et al., 2014; Narzari et al., 2015) and EC (Singh et al., 2010; Naeem et al., 2014) of biochars increased with increasing pyrolysis temperatures. High pH values of biochar may be due to hydrolysis of carbonates and bicarbonates of base cations such as Ca, Mg, Na and K present in the source materials (Gaskin et al., 2008) and greater separation of basic cations and organic anions from organic materials with increase in pyrolysis temperature (Yuan et al., 2011). He reported that the EC of the crop straw derived biochars increased with increasing pyrolysis temperature. The carbon-rich residual solid by-product of thermo-chemical degradation of crop and Agroforestry residues in an oxygen depleted environment (pyrolysis) is termed 'biochar' (Lehmann et al., 2011).

Effects of Biochar incorporation into the soil

Soil health:

Numerous studies have reported on the beneficial impacts of biochar addition on soil health improvement and GHG emissions reduction which are of critical importance in tropical environments in combating climate change induced drought and to improve soil health. Biochar additions have positive effects on the soil health directly and indirectly.

The incorporation of biochar into soil alters soil physical properties like bulk density, penetration resistance, structure, macro-aggregation, soil stability, pore size distribution and density with logical implications in soil aeration, water availability of soil, water infiltration, water holding capacity, plant growth and soil workability; positive gains in soil chemical properties include: retention of nutrients, enhances cation exchange capacity and nutrient use efficiency, decreases soil acidity, decreases uptake of soil toxins and increases the number of beneficial soil microbes. A brief review about these interactions is presented in Table 3.

Table 3.Transforming a low-value crop residue into a potentially high-value carbon source and its soil application has several important benefits (Venkatesh et al., 2015)

Physical properties	Chemical properties	Biological properties
• Decreases bulk density, improves soil workability, reduces labour and tractor tillage and minimizing fuel emissions • High negative charge of biochar promotes soil aggregation and structure • Positive effect on crop productivity by retaining plant available soil moisture due to its high surface area and porosity	• Liming effect provides net carbon benefit compared to standard liming • Enhance the fertilizer use efficiency, reduce the need for more expensive fertilizers and improves the bioavailability of phosphorus and sulphur to crops • Reduce leaching of nutrients and prevents groundwater contamination • Carbon negative process, stable carbon, longer residence period and reduces Green House Gas emissions from soil.	• Enchance the abundances activity and diversity of beneficial soil bacteria, actinomycete and arbuscular mycorrhiza fungi • High surface area, porous structure and nutrient retentive capacity of biochar provides favorable microhabitats by protecting them from drought, competition and predation

Soil quality and fertility improvement: Biochar is a high carbon containing material (more than 50%) produced by heating of biomass in absence of oxygen. Biochar application to soil leads to several interactions mainly with soil matrix, soil microbes, and plant roots (Lehmann and Joseph, 2009). The types and rates of interactions depend on different factors like composition of biomass as well as biochar, methods of biochar preparation, physical aspect of biochar and soil environmental condition mainly soil temperature and moisture. Biochar can act as a soil conditioner by improving the physical and biological properties of soils such as water holding capacity and soil nutrients retention, and also enhancing plant growth (Sohi et al., 2010).

Several authors have reported that biochar has the potential to: (i) increase soil pH, (ii) decrease aluminum toxicity, (iii) decrease soil tensile strength, (iv) improve soil conditions for earthworm populations, and (v) improve fertilizer use efficiency (Table 4.).

Table 4. Effect of biochar on different soil properties

FACTOR	IMPACT	SOURCE
Cation exchange capacity	50% increases	*(Glaser et al., 2002)*
Fertilizer use Efficiency	10-30% increases	*(Gaunt and Cowie, 2009)*
Liming agent	1 point pH increase	*(Lehman and Rondon, 2006)*
Soil moisture retention	Up to 18 % increase	*(Tryon, 1948)*
Crop productivity	20-120% increase	*(Lehman and Rondon, 2006)*
Methane emission	100% increases	*(Rondon et al, 2006)*
Nitrous oxide emission	50% increases	*(Yanai et.al 2007)*
Bulk density	Soil dependent	*(Laird,2008)*
Mycorrhizal fungi	40% increases	*(Wamock et.al 2007)*
Biological nitrogen fixation	50-72% increases	*(Lehman and Rondon, 2006)*

Need for recycling of crop and Agroforestry residue into biochar for use in Indian agriculture (adapted from Venkatesh *et al.*, 2015)

- To improve soil health through efficient use of crop residue as a source of soil amendment/nutrients.
- To improve soil physical properties viz., bulk density, porosity, water holding capacity, drainage etc, through incorporation of biochar.
- Substantial amounts of carbon can be sequestered in soils in a very stable form .
- Addition of biochar to soil enhances nutrient use efficiency and microbial activity.
- To enhance soil and water conservation by using the biochar in rainfed areas.

- Minimize reliance on external amendments for ensuring sustainable crop production. Mitigation of greenhouse gas emissions by avoiding direct crop residue burning by farmers.
- To enable destruction of all crop residue borne pathogens.
- Conversion of residues into biochar helps to reduce the bulkiness both in terms of weight and volume and make the product easier to handle compared with that of fresh and uncarbonized crop and agroforestry residue (Jeffery et al., 2011; Masto et al., 2013).

Constraints in recycling of crop and Agroforestry residue (adapted from Venkatesh et al., 2015).

- Unavailability of farm labour, higher wage rates for collection and processing of crop residue.
- Lack of appropriate farm machines for on-farm recycling of crop and Agroforestry residue
- Inadequate policy support / incentives for crop and Agroforestry residue recycling

BIOCHAR PRODUCTION TECHNOLOGY

Biochar production from a variety of high-molecular lignocelluloses residue resource is a carbon-neutral process (Thomsen et al., 2011). A variety of thermal conversion processes can be used to prepare biochar (Deal et al., 2012). Pyrolysis systems employed to process unused and excess crop and Agroforestry residues for biochar production can be categorized into four types: (1) slow pyrolysis, (2) fast pyrolysis, (3) flash pyrolysis, and (4) gasification.

Slow pyrolysis performed under lower temperature (<400-500°C) and with long contact times often results in a high yield of biochar (35%) (Meyer et al., 2011). Faster pyrolysis or gasification operates at higher temperatures (<800°C) and gives a high yield of combustible gases in relation to the solid biochar (12%) (Laird et al., 2009). The most commonly employed method is slow pyrolysis.

This process involves direct thermochemical decomposition (exothermic reaction) to transform low-density residue matrix into a biochar at a temperature range of 450-500˚C under low-oxic or anoxic conditions in a closed reactor (Jeffery et al., 2011; Gul et al., 2015).

To make biochar technology popular among the farmers, it is imperative to develop low-cost biochar kiln at community level or at individual farmer’s level. Hence, a low-cost portable biochar kiln was developed at ICAR- CRIDA (Central Research Institute for Dry land Agriculture), Hyderabad to produce biochar from crop and Agroforestry residues.

1.CRIDA BIOCHAR KILN:

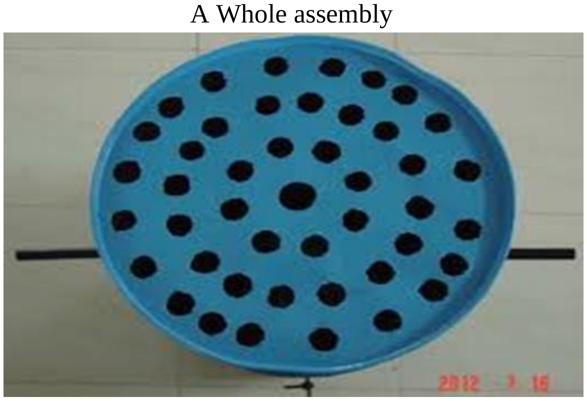
In designing the kiln, both the requirements of controlling the loading rate and rate of thermo-chemical conversion periods to stop the process when all of the crop and agroforestry residues have been converted to biochar have been addressed. A brief description of the kiln (Venkatesh et al., 2015) is given below

- Kiln design functions with bottom-lit direct natural up-draft principle .
- The cylindrical metal drum kiln of about 212 L capacity is based on a single barrel design of vertical structure with perforated base. The gross volume of the kiln is about 0.21 m3
- The cabinet is circular in cross section and consists of an intact bottom and top section.
- The kiln is about 28 cm in radius and 86 cm height with one square shaped hole of 16 x 16 cm cut at the kiln top, for loading residues, which can be closed at the end of conversion by a metal lid (about 26 cm in length and 26 cm in width) with a handle (110 cm).
- For making of vents, three concentric circles at equidistant interval of approximately 9 cm were marked from the center of kiln base to rim of the kiln
- A total of 40 holes (4 cm in diameter each) were cut at the base of the cabinet in the first (16 nos.), second (16 nos.) and third (08 nos.) equidistant concentric circles from bottom rim .
- Alternating and staggered arrangement was maintained by alternating the vents in all the three circles to avoid row arrangement.
- In addition, a central vent of about 2.5 cm radius was made in the centre of the cabinet base to fix a metal pole of about 110 cm height and 2 cm radius temporarily while loading biomass to create central vent.
- Under open atmospheric conditions, the central and concentric staggered vents at the kiln base hasten hot exhaust gas movement through the residues for uniform heat transfer by primary air

movement while the kiln's top hole vents out the released water vapours and hot gases .

- A strip of metal handle (17.5 cm length and 1.3 cm in radius) was welded at around 3/4th height of kiln, to serve as lifting jack at the end of each test.
- A metal lid (26 cm in length and 26 cm in width) with handle (88 cm in length) was made to fit top square hole to stop the conversion process.

A Whole assembly



B. Bottom section

Figure 1: Low-cost portable biochar kiln (Source: Venkatesh, 2017)

Features of CRIDA biochar kiln (adapted from Venkatesh et al., 2015)

- Portability: Easy mobility of the kiln to the source of crop and Agroforestry residue and with access to most remote places helps to reduce collection, handling and transporting expenses
- Simplicity: Farmer-friendly, convenient-to-use and minimize operational labour costs
- Adaptability: Designed for non-competitive and surplus crop and Agroforestry residue
- Affordability and Durability: Least expensive kiln (approximate cost: ` 1200/-) to match the needs of the small and marginal farmers and kiln can be operated for multiple batch process.

2. HEAP METHOD

Charcoal making is one of the traditional practices to generate income in various parts of India. In traditional method, a heap of pyramid like structure (earth kiln) is prepared by keeping wood logs and roots of plants for making charcoal. To allow the combustion products to escape, vents are opened starting from the top and working downwards.

When smoke production is stopped, the cooling process is started by covering stack with a layer of moist earth. The cooling process takes several days before the earth is removed and the biochar produced is separated from the surrounding carbonized portions. Earth-mound kilns equipped with a chimney are most advanced among earth kilns. The ability to alter the chimney diameter according to the oxygen demand, and precise control of the draft of the chimney, which is dependent on height, results in better control of the pyrolysis process (Emrich, 1985).

Biochar making from Prosopis julifera is practiced in the rain-fed tracts of Ramanathapuram district of Tamil Nadu during off-season. Generally, people use the heap method of charcoal production as it is easy and cost involved in char production is very low. Mostly fibre wastes of coconut, paddy straw or any available agriculture waste are used to prepare paste mixed with clay soil to cover the heap structure containing wood logs. Finally, it is covered with sand from outside and water is applied over it. Entire wood logs are converted into charcoal after burning inside the heap for 3-4 days. The charcoal is transported to various districts of Tamil Nadu and also certain states like Maharashtra and Gujarat for industrial purpose.

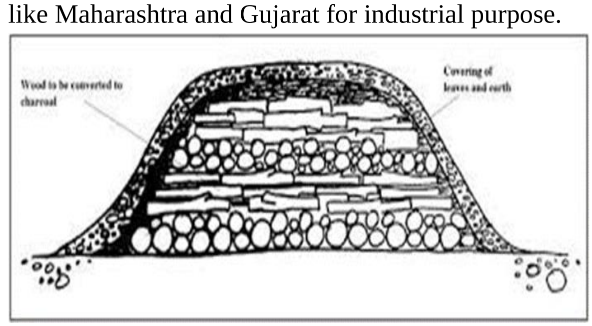


Figure 2. Traditional earth kiln (Source: http://en.howtopedia.org/wiki/Biomass)

Heap method of biochar preparation in Tamil Nadu (Source: Jeyaraman, TNAU)

3. Biochar Stove:

New stove technologies can produce both heat for cooking and biochar for carbon sequestration and soil building. Limited testing indicates that these stoves are much more efficient and emit less gas. The UN Environment Program now recognizes that Atmospheric Brown Clouds (ABCs) are a major contributor to climate change (UNEP, 2008). The study found that gasifier stoves, both natural draft and fan-assisted, had very low black carbon emissions. There are two basic types of stoves that can be used to produce charcoal and heat, the Top-Lit Updraft Gasifier (TLUD) and the Anila stove.

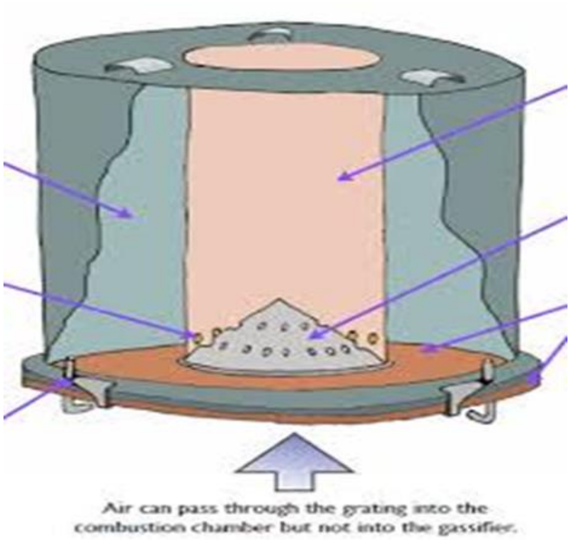


Figure 3. Biochar Anila stove (Source: Iliffe, 2009)

The modern Anila stove was developed by U.N. Ravikumar, an environmentalist and engineer with the Centre for Appropriate Rural Technology (CART) at India's National Institute of Engineering. The key aims of the design are to reduce the indoor air pollution that results from cooking and to take advantage of the abundance of bio-residues found in rural areas in developing countries. The engineering principle the underlines the Anila stove is top lit updraft gasification, which essentially means that the hardwood fuel burns from the top down and simultaneously combusts the syngas that is released by the biomass. The stove is made from steel and weighs about 10 kg (Iliffe, 2009).

BIOCHAR FOR CLIMATE CHANGE MITIGATION

1. Carbon sequestration :

Sequestering Carbon in the Soil Using Biochar

Soils store three times more carbon than exists in the atmosphere. Plants absorb atmospheric carbon during photosynthesis, so the return of plant residues into the soil contributing to soil carbon. While much of this carbon ultimately returns to the atmosphere as soil microbes decompose carbon based plant biomass and release carbon dioxide, soil carbon stores can increase if the rate of carbon inputs exceeds the rate of microbial decomposition. Carbon sequestration refers to this process of storing carbon in soil organic matter and thus removing carbon dioxide from the atmosphere.

Biochar is produced from burning organic material at high temperatures with little to no oxygen availability. The potential of utilizing biochar to sequester carbon in the soil has received considerable research attention in recent years as part of efforts to develop climate smart agricultural practices. As the majority of biochar is carbon (70-80%) it can potentially contribute more carbon than plant residue (approximately 40% carbon) of similar mass. Furthermore, around 60% of this biochar organic carbon is of high stability and therefore resists decomposition more-so than plant material that has not been processed into biochar. That being said, many questions remain as to the effectiveness of biochar application in sequestering carbon.

While the exact mechanism responsible for this effect has not been conclusively identified, it may result from the stimulation of microbial activity as microbes utilize carbon and nitrogen present in biochar. Biochar remains a hot topic with regards to increasing soil carbon stores and helping fight climate change. However, many questions remain before definitive conclusions about what conditions allow for biochar to positively contribute to soil carbon sequestration.

According to Gaunt and Lehmann (2008), terra preta soils suggest that biochar can have carbon storage permanence in the soil for many hundreds to thousands of years. Large amounts of carbon in biochar may be sequestered in the soil for long periods estimated to be hundreds to thousands of years (Lehmann et al. 2006; Ogawa et al. 2006; Woolf, 2008; Bracmort, 2010).

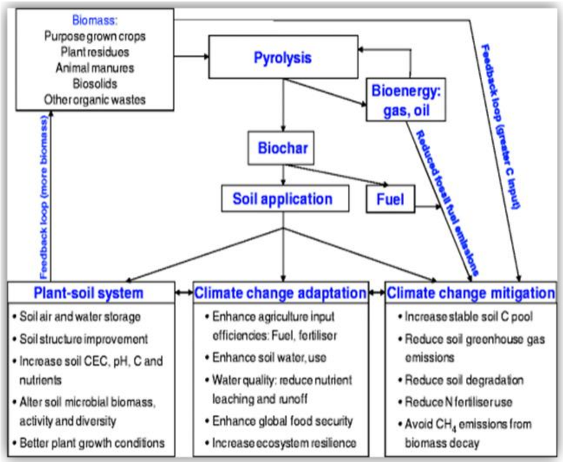


Figure 4 : Impact of biochar on climate change .Source: (Woolf 2010 & Mukherjee 2014)

The findings of a recent modeling study (Woolf et al., 2010) reported that biochar amendments to soil, when carried out sustainably, may annually sequester an amount of C equal to 12% the current anthropogenic CO2 emissions. They estimate that the maximum sustainable technical potential for carbon abatement from biochar is 1-1.8 gigaton (Gt) C per year by 2050.

2. Mitigation of greenhouse gas emissions :

Biochar application to soils has the potential to mitigate global warming via soil C sequestration, and provide other benefits, such as improving soil fertility, retaining soil moisture, and increasing crop yields (Woolf et al ., 2010; Mukherjee et al ., 2014)

Greenhouse gas mitigation strategies include reducing and avoiding emissions as well as enhancing the removal of GHGs from the atmosphere (Smith et al ., 2008). Soil carbon (C) sequestration through biochar amendment has been proposed as an effective countermeasure for the rising concentration of atmospheric GHGs (Lal, 1999; Pan et al .,2004; Smith et al ., 2008).

Apart from carbon sequestration, there are other environmental benefits that can be derived from the application of biochar in soils which include reduction in the emission of non-CO2 GHGs by soils as(shown in below Figure 5) Adapted with changes from Rogovska et al., 2008.

Biochar is reported to reduce N2O emission could be due to inhibition of either stage of nitrification and/or inhibition of denitrification, or promotion of the reduction of N2O, and these impacts could occur simultaneously in a soil (Berglund et al., 2004; DeLuca et al., 2006).

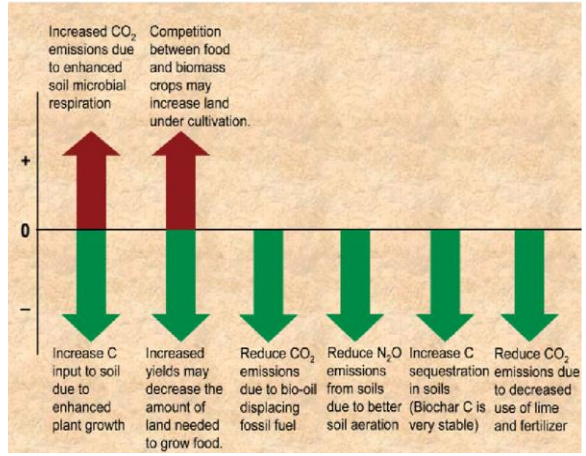


Figure 5: Net impact of biochar applications in soil on greenhouse gas emissions.(Adapted with changes from Rogovska et al., 2008).

BIOCHAR FROM AGROFORESTRY RESIDUES

A protocol was developed to produce biochar through use of low cost CRIDA biochar kiln at community level or at individual farmer's level. CRIDA biochar kiln was employed at farm level to study the conversion efficiency of Agroforestry residues (Pongamia shell, Eucalyptus bark, Eucalyptus twig, Leucaena twig and Gliricidia twig) at different loading rates and reaction time (Figure 6).

The highest conversion efficiency of 28.0, 28.0, 32.0, 32.0 and 21.0% was obtained at a loading rate of 40.0, 19.0, 43.0, 39.0 and 38.0 kg kiln-1 and a reaction time of 40.0, 22.0, 17.0, 27.0 and 30.0 min. for Pongamia shell, Eucalyptus twigs, Eucalyptus bark, Gliricidia and Leucaena twigs, respectively.

Order of nutrient recovery in different Agroforestry biochar in terms of Total N was Leucaena twig (20.9%) < Pongamia shell (24.9%) < Eucalyptus bark (28.5%) < Eucalyptus twig (35.7%) < Gliricidia twig (38.1%);

Total P was Eucalyptus bark (46.2%) < Leucaena twig (51.8%) < Eucalyptus twig (67.4%) < Gliricidia twig (68.4%) = Pongamia shell (68.4%) and Total K was Leucaena twig (24.2%) < Pongamia shell (29.1%) < Eucalyptus twig (31.7%) < Gliricidia twig (35.1%) <

Eucalyptus bark (35.7%). Total Carbon (%)and MWHC (g H2O g-1 of dry biochar) was 62 and 2.3 in Pongamia pod biochar; 48 and 2.3 in Eucalyptus twig biochar; 31.4 and 2.3 in Eucalyptus bark biochar; 43 and 2.8 in Gliricidia twig biochar; 46 and 3.8 in Leucaena twig biochar, respectively.

Figure 6 : Biochar from Agroforestry residue (Source: Venkatesh et al., 2016; CRIDA, 2014)

1. Eucalyptus twigs, 2. Gliricidia twigs, 3. Leucaena twigs, 4. Eucalyptus bark and
5. Pongamia shell

CASE STUDIES

1. Site Description:

The field trials were carried out at Sharswotikhel in Bhaktapur district (27º41′ 41.39″N, 85º24′11.59″E, altitude 1,372 m.a.s.l) of Nepal. The study site was located 12 Km north-east of Kathmandu city where the climate is sub-tropical with an annual rainfall of about 1500mm. The research trial was established within a coffee Agroforestry system where other crops like radish, soybean, garlic and chilly were intercropped in different seasons with coffee plant.

Figure 7: Research site in Bhaktapur district

2. Experimental Design

The field trial plot was on coffee Agroforestry trial with 24 coffee trees planted in three rows with spacing of 1.5 m between row and 1.5 m between plants. The plot was divided in to two blocks of 18 m2 each, and biochar was applied randomly two one of the blocks (see figure 2) FYM was applied to both blocks, initially at the rate of 20 t/ha, then during the second season, at a high dose of 40 t/ha due to the very low SOM status of the soil. Field experiment layout is depicted in figure8

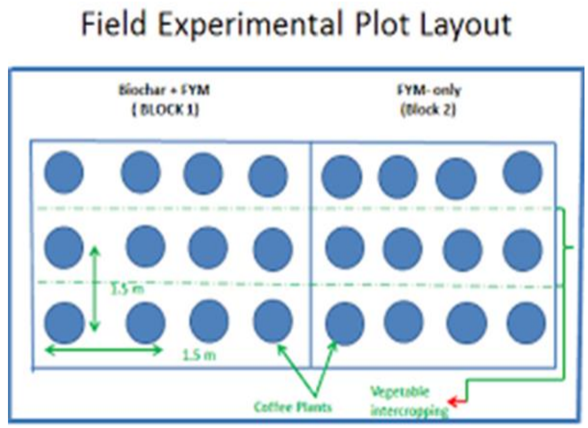


Figure 8: Experimental field with plot layout

3. Effect of Biochar Amendment on Crop Growth:

Application of biochar at the rate of 5 t/ha to the soil in a coffee Agroforestry system along with 20 t/ha FYM revealed statistically significant differences in crop growth at ($p < 0.05$) in coffee, chilly and garlic growth, and highly significant differences ($p < 0.01$) in radish and soybean growth in biochar treated plot compared to the control (Table 5).

Table 5 : Paired "t" test of Biochar effect on crop growth (height in cm)

Mean Values			
Crop types	Treatments	Control	't' Value
Coffee	n=10	n=10	4.73**
Radish	81.90	68.10	11.24**
Chili	9.40	6.76	-4.14**
Soybean	91.20	68.50	6.80**
Garlic	42.60	28.50	3.93**
	65.90	55.40	

Note:** Highly significant at P<0.01 level probability

4. Plant Yield Kg per Plot/Ton per Hectare Influenced by Biochar:

Application Crop yield (kg per plot/ton per hectare) of all crops radish, soybean, chilly and garlic were observed to be relatively higher in biochar & FYM amended soils in comparison to only FYM added soils. However, statistically significant differences were not observed (see Figure 9).

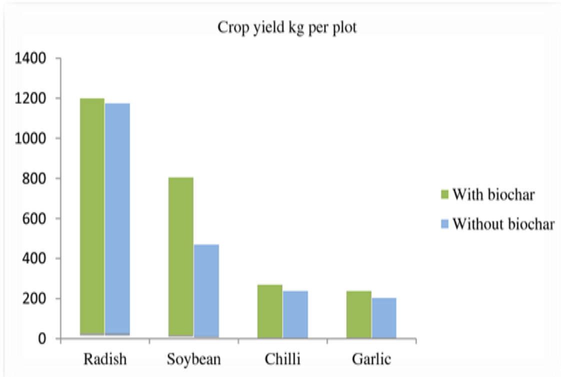


Figure 9: Effect of Biochar on crop yield

RESULTS ON CASE STUDY

Plant Growth as Affected by Application of Biochar and FYM:

It was noted that after the application of biochar along with FYM to the soil, plant growth (height) was significantly higher in treated plots than the control. This was attributed to the effect of biochar on soil, which largely influence the accumulation of SOM and improves other soil chemical properties, such as pH, which ultimately enhanced the quality and productivity of degraded and low-quality soils, similar finding that have been reported by Khan et al., (2013) and Bajracharya et al., (2015). Likewise, Scislowska et al., 2015 documented that the application of biochar to soils had positive effects on plant growth by improving soil nutrient availability, water holding capacity, carbon sequestration, CEC and soils pH level. Thus, biochar appears to have rapid effect in enhancing the vegetative growth of crops in the short run.

Influence of Biochar and FYM on Crop Yields :

The results of this study indicated that while the application of biochar along with FYM to degraded soil in a hill Agroforestry system generally increased the yields for a number of Vegetables, intercropped with coffee, the yields were not statistically different in the short term. However, it was observed that the yield of soybean was markedly higher than that of other crops. This could be due to the nitrogen fixing effect of the leguminous soybean crop. It could, however, be said that the effect of biochar amendment on crop yield improvement is likely to seen only in the long-term as the overall soil quality gradually improves.

CONCLUSION

From the discussion it can concluded that the Role of Biochar in Agroforestry system , that initial outcomes reveal that Biochar application helps in improving the physical and biological properties of soils such as water holding capacity and soil nutrients retention, and also enhancing plant growth. It may prove to be one of the most useful techniques in carbon sequestration but must be combined with enormous efforts to reduce GHG's emissions.

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