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Review Article

PROSPECTS OF BIOCHAR IN CLIMATE CHANGE MITIGATION IN INDIAN AGRICULTURE - AN ANALYSIS

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Abstract- Biochar technology in Indian agriculture is at nascent stage need widespread adoption for the benefit of enhanced soil carbon sequestration, GHG off-set, improvement in soil health and enhancing crop yields. Crop residues availability from major crops grown in the country, logging and processing residues of trees and organic residues from municipal solid wastes and different recycling mode was assessed in the context of climate change mitigation. The results found that the annual surplus crop residue production is around 249 Mt may likely to increase in the near future. The charring of the residues could bring gas emission down about 4.8% to 10.7 % of total net GHG's emission per annum. It can be more of benefit if adapting the refined method of production process. The cost involved for residues collection and transportation limits the adaptation however an establishment of institutional system at grass root level with farmer participation may create way to maximize climate change mitigation potential of the biomass residues. Therefore, biochar production could be the two in benefits of waste management as well as offsetting GHG of different sectors.

Keywords- Crop residues, Biochar, Soil carbon sequestration, Climate change mitigation, Waste management

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Introduction

The climate change mitigation and adaptation practice are become a great challenge to scientific as well as forming communities. Truly speaking, consumption of non-renewable energy such as coal, petrol, diesel, fertilizer etc, are the main culprits for climate change when we compare the greenhouse gas emission across the sectors. The natural cycle of carbon and nitrogen imitate that the biomass are recent materials taken carbon up by crop from atmosphere and let back off. As the weather variables changed in great deal, it is time to get into the immediate action. The positive soil carbon feedback is a major way to bring back carbon from atmosphere. The field application of organic matter is important for both restoring and maintaining soil quality and sustaining crop yield. The farm yard manure, crop residues, compost of waste materials and green manure and green leaf manures are the source for soil organic matter has been applied to derive the cheap nutrients in agriculture. On other hand, this is an improved management practice for soil carbon build up promoted as one of the climate change mitigation practices in agriculture [1]. However, the large portion of carbon and nitrogen in the organic matter emitted as carbon di oxide, methane and nitrous oxide to atmosphere considered non-eco-friendly agriculture when only a very meager of carbon retained in the soil. The restoration of the marginal carbon in soil needed a continuous adaption of the management practices as they are highly sensitive to change of cultivation practices. According to Jha, *et al*., 2007 [2], the waste production from Chennai, a mega city in India contributed CO_2, CH_4 and N_2O emission about 1.16 Gg y^{-1}, 0.12 Gg y^{-1}, and 1 t y^{-1}, respectively that need environmentally sustainable management of wastes both avoidances of the gas emission and extra carbon sequestration in soils. The commitment of gas emission intensity cut off about 20-25% of GDP between 2005 and 2020 advocate for value addition of organic materials for less gas emission while maintaining soil quality and crop yield in the sustainable agriculture [3].

Recently, the biochar, charred material from organic matter thermalization become popular for the high amount stable carbon in the back drop of climate change mitigation over biomass materials. The biochar is reported to improve the soil quality and crop yield. However, we don't have much of report on crop residues generation and their availability for biochar production and climate change mitigation potential in India. Therefore, this paper is aimed for two aspects 1. Quantification of crop residues generation from agriculture and forestry and city waste in India 2. The biochar production, carbon sequestration and climate change mitigation potential from the wastes in Indian agriculture.

Reasons for low soil carbon content in India

Indian soils are inherently low in organic carbon (<0.5%) and nitrogen for high decomposition rate of biomass under tropical climatic condition. Before introduction of fertilizer technology in agriculture, the complete crop nitrogen requirement came through organic sources had also ensured adequate amount of soil carbon input that had not impacted much on maintaining soil quality and soil productivity. Recently, the frequency of farm yard manure application in agriculture changed from every crop season to once in a year. The recommendation of FYM application has gradually come down to 6.5 t ha^{-1} from 25 t ha^{-1} due to inadequate availability [4-5]. Lately, the area under prevailing double cropping system in the rainfed regions are mostly getting changed to single crops for poor rainfall distribution. Thus, soil carbon sequestration potential of rainfed agriculture going to be fall down for low annual crop residues input to soils. The situation is further aggravated for removal of the wastes for fuel wood, animal feed and thatching purpose in the rural areas particularly dry land region [6]. In irrigated agriculture condition, the field residue burning is another carbon negative farming practice prevailing for easy residue removal, high labour wages, quick field preparation and pest and disease control to the succeeding crops.

In 2008–09, 98.58 Mt of crop residues (15.9 % on total crop residues) were burnt in the Indian farm, mostly are belongs to rice, wheat and sugar cane crop field. The burning of crop residues emitted the 8.57 Mt of CO, 141.15 Mt of CO_2, 0.037 Mt of SOx, 0.23 Mt of NOx, 0.12 Mt of NH3 and 1.46 Mt NMVOC, 0.65 Mt of NMHC and 1.21 Mt of particulate matter to the atmosphere in 2008–09 in India [7]. According to IPPC method of estimation, the contemporary level of field residue burning practice adds about 0.23 million tons of CH_4 and 0.006 million tons of N_2O per annum [8].

Materials and Methods

The potential crop residues refer to the crop waste available from agriculture, and forestry sector and organic waste from urban sector which can be completely diverted for biochar production with compromising other routine use in the social system whereas the surplus residues are materials obtained after the meeting out regular needs. The crop wastes production in agriculture estimated based on grain and crop residues ratio given in the literature and average of food grain production obtained form 2001-11 [Table-1]. The current period crop residues production was also estimated using food grain data in 2014-15 and crop residues and economical part ratio has given in the literature [9]. The collected data of total round wood production (Fuel and industrial round wood from 2003-2012) in and outside of the forest, residue generation ratio (0.6), residue recoverable fraction (0.25) and bulk density (0.50) from literatures, we have estimated annual logging and industrial processing waste output in India [10]. The city waste production in the 59 major cities obtained calculated based on the average value of three years data (1999-2000, 2004-05 and 210-11) obtained from Central Pollution Control Board, 2012, India [11]. The organic matter generation from municipal solid waste was calculated based on the literature data represent 40-60% easily decomposable organic matters present in the city waste collected from India [12]. One kg of carbon sequestration in soils is equal to avoidance of 3.66 kg CO_2 gas to atmosphere.

Results and Discussion

Biomass Source production for biochar production in India

Crop residues, municipal solid wastes and forest residues status and challenge

The crop type, climatic condition and management factors determine the quantum of crop residue production in agriculture. It has increased from 626 Mt in 1996 to 799 Mt in 2014 that pretends more availability in agriculture in the future course of time for the adaptation of improved crop vigour and management practices. The crop residue has multi-dimensional utility like fuel wood, fodder crops, thatching and electricity production. The cereal and pulses crops residues mostly used for animals feed, while the cellulose rich materials like red gram, cotton stalk, maize stalk and their cob and other woody and twigs materials intended for fuel wood and thatching purposes [13]. Thus, the residues are not completely available for biochar production. The diminishing nature of grazing land and low per capita land availability in India as well as world coerced to meet the green fodder deficit from the crop residues. In India, it is about 40 % of dry fodder annual requirements substituted from crop residues limits for biochar production [14]. In regard to geographical distribution, the large amount of cereal crop wastes comes from the states of Uttar Pradesh, Punjab, West Bengal, Andhra Pradesh and Haryana for their larger area under cereal crop cultivation. Likewise, the states of Uttar Pradesh, Maharashtra and Tamil Nadu are contributing more sugarcane trashes. The Gujarat, West Bengal and Maharashtra states gives out much of fiber crop residue and the large proportion of unusable part from oil seed generated in the states of Rajasthan and Gujarat [7]. In addition to the residues, the waste comes from agro-based industries such as rice mill, bagasse from sugar mills; ground nut shell and castor shell are also suitable for biochar production [15]. The potential crop residues from cereals, oilseeds, sugar crops, pulses and fibre crops are 367Mt, 55Mt, 91Mt, 33Mt and 81 Mt respectively. Similarly, the actual crop residues, which is available after meeting all other routine use for the above said categories are respectively 96Mt,14Mt,58 Mt, 6 Mt and 47 Mt. The cereal crops residue shares bulk of the production among the food grain groups, in which the rice (26%) and wheat (19.7%) crops produce large biomass residues. The sugarcane crop cultivation is not wider as much as the cereal crops occupied but stands third at14.5% of total crop residue generation for the higher crop productivity [Fig-1]. An assured (surplus after other uses) annual crop residue supply of 223.4 Mt (in 2014) from agriculture gives unambiguous source mean for biochar production obtained from the literature given by Hiloidhari, *et al*.,(2014) [9]. India is the second largest country in terms of human population and much of the people residing in the cities dispose regularly huge amount of waste in the streets. The per capita waste generation of major cities, typically Mumbai, New Delhi, Calcutta and Chennai in India is about 0.2 to 0.5 kg per day which is composed of household and industrial wastes need an efficient disposal system [16]. The increasing production of wastes closely associated with country population growth and their mobilization to cities in search of employment. They are mostly dumped as such in the outskirts of urban and cities that serve as source for many disease-causing agents in addition GHG's emission. As open field firing of wastes directly contributes environmental pollution, the social system looking for alternative management of wastes. India is a geographically large democratic country could collect huge mass of organic waste can be a large potential to be used for biochar production and amendment in agriculture. The municipal solid wastes have already been very efficiently used for biochar production and application in agriculture without any heavy metal concern in Japan is a good example that can be adapted in India [17]. This seems very friendly and ecological approach compare to the existing system as it brings a lot of stable carbon to soils over the routine practice of dumping and firing it in a place. However, it is need to be tested for practical amenabilities and way for further improvement in handling of wastes for biochar conversion. The city wastes in India has 40-60% easily compostable organic matters add about 14.6 Mt per annum that can be effectively used for biochar production. Indian have ever been maintaining the policy of one-third of the country's total land area under forest tree cover got an increase of area about 5,081 square kilometers between 2013 and 2015 accounted 21.34 percent increase in the forest area. The forest sector is looking for additional ways to use woody biomass as an economic tool to bring more acres into active management and address challenges such as wildfire risks, excess fuel loading, habitat restoration, and forest health concerns. Small diameter trees as well as dead or dying trees have little or no value in most traditional forest product markets. These materials may provide benefits as feedstocks for renewable energy production. The annual total round wood production (329 mcum) and the processing of 22.2 mcum round wood generate the logging (24.7 Mt) and processing residues (1.85 Mt) of 26.5Mt; can be available for biochar production [18-19]. The present tree felling is more than the permissible cut (60 Mt per annum) due to demand from industries and other reasons. It is not an ecological approach and the government policy intervention to reverse into permissible cut may be expected soon that we have not taken the contemporary data for residues quantification in the forestry sector. Instead, the data for permissible cut in and outside of the forest considered here. It can add annually 22 Mt of logging and processing residues [20]. The calculated data is highly corroborated by the Department of International Development report -2011. It reported that annually ~176 Mt of surplus agro biomass available together from agriculture (76%), waste land (14%) and forest (10%) for biochar production in India.

Biochar production in India

Pyrolysis is defined as the process of thermal decomposition of dry materials form crop and other waste materials in partial or total absence of oxygen that manipulated to yield large biochar proportion with an objective to use as soil amendments in agriculture. Based on temperature, residence time and heating rate, the pyrolysis process usually categorized into three groups namely slow pyrolysis, fast pyrolysis and gasification. There are numerous organic materials are used for biochar production such as different kind of wood materials, crop residues, weeds, waste materials from agro industries, cow dung, poultry manure, house hold waste etc. The physical nature and chemical composition of biomass determines biochar yield as well as its quality [Table-2]. In India, the biochar mostly produced at small scale from Prosopis sp and other common woods for normal routine use, thus the actual production statistics is not available. This is produced by traditional earthen kilns (Heap methods) and earthen mound kilns (Heap methods with Chimney provision for air and heat control) methods,

Table-1 *Annual gross and surplus biomass generation from the major agriculture crops in India*

S.No	Particulars	Crops	Average Gross economic grain/part production from (2002-11) (Mt) [9]	Residue to final economic produce (ratio)[29]	Annual gross Crop residues production (Mt) (2002-11)	Annual Surplus crop residues production (Mt) 2014
1	Cereals	Rice	91.49	1.8	164.68	43.5
2		Wheat	77.35	1.6	123.76	28.4
3		Sorghum	7.06	2.0	14.12	9
4		Pearl millet	8.69	2.0	17.38	5.1
5		Maize	16.9	2.5	42.25	9
6		Barley	1.4	1.3	1.82	0.2
7		Small millet	0.23	1.2	0.27	0.1
8		Ragi	1.97	1.3	2.56	0.3
9	Oil seeds	Rape seed and Mustard	6.78	2.0	13.55	4.9
10		Sesame	0.38	1.2	0.46	0.1
11		Linseed	0.17	1.5	0.25	0
12		Niger	0.11	1.0	0.11	0
13		Safflower	0.18	3.0	0.55	0.5
14		Soybean	9.23	1.7	15.68	4.6
15		Ground nut	6.89	2.7	18.6	3
16		Sunflower	1.03	3.0	3.09	0.6
17		Other oil seeds	1.37	2.0	2.74	5.1
18	Sugar crops	Sugar cane	302.4	0.3	90.72	55.7
19	Pulses	Red gram	2.53	2.5	6.32	1.4
20		Gram	6.36	1.6	10.17	1.6
21		Other pulses	5.72	2.9	16.59	3.0
22	Fibre crops	Cotton	22.03	2.8	60.58	46.9
23		Jute	10.2	2.0	20.41	0.4
		Total	580.5		626.6	223.4

Table-2 *Biochar production strategies and yield of biochar, bio-oil and syngas [30]*

Charing Process	Criteria	Liquid (Bio-oil, %)	Solid (Biochar, %)	Gas (Syngas, %)
1. Slow Pyrolysis	Moderate temperature (450-550ºC) and long residence time	75	12	13
2. Fast Pyrolysis	High temperature (550-700ºC) with short hot vapour residence time	30	35	35
3. Gasification	High temperature (>750ºC) with long vapour residence time	5	10	85

Table-3 *The annual biochar production and climate change mitigation potential for soil carbon sequestration for the available potential and surplus biomass in agriculture, forestry and municipal organic solid waste in India*

Particulars	Annual Average gross residues production (Mt) (2002-11)	Biochar production (Mt)		Fixed carbon value (Mt)		Climate change mitigation potential: CO_2 equivalents (Mt)		Annual surplus residues production (Mt)	Biochar production (Mt)		Fixed carbon value (Mt)		Climate change mitigation potential: CO_2 equivalents (Mt)	
		SLP:	FP:	SLP:	FP:				SLP:	FP:	SLP:	FP:		
		-35%	-12%	-60%	-80%	SLP	FP		-35%	-12%	-60%	-80%	SLP	FP
1. Agriculture crop residues	626.6	219.3	75.2	131.6	60.2	473.7	216.5	223.4	78.2	26.8	46.9	21.4	168.9	77.2
2. Organic solid waste from 59 major cities	14.6	5.1	1.7	3.1	1.4	11	5	14.6	5.1	1.7	3.1	1.4	11	5
3. Forestry residues (logging& processing)	26.5	9.3	3.2	5.6	2.5	20	9.2	11.3	4	1.4	2.4	1.1	8.6	3.9
Total	667.7	233.7	80.1	140.2	64.1	504.8	230.8	249.3	87.27	29.9	52.4	23.9	188.5	86.2
After consideration for annual oxidation loss (2% C) in soils				137.4	60.8	494.7	218.9				51.3	23.5	184.7	84.5

which are simple and cost-effective but consume more time for char production. These methods have low charring efficiency at 8-12 % (w/w) [21-22]. It limits the biochar yield as well as stable carbon value of wood materials for the complete oxidization into carbon di oxide which escapes to atmosphere. The development of potable metallic kiln and drum method of biochar production (20-25 % w/w) improved the charring efficiency about 212 to 315 % over traditional methods for reduced heat loses and air content [23]. The biochar value of wood materials can be improved further, if we adapt the modern pyrolysis system. This system has chambers for the collection of liquid and gases substances comes from the thermal decomposition of organic materials in the pyrolysis system. This output of the system can once again be used effectively as fuel to the modern system by which it contributes almost negligible greenhouse gas to atmosphere in addition to overcome many of the limitation in the conventional methods [24]. However, the initial cost of machine is very high and it is very difficult to afford by small and marginal farmers who share large portion of farming community in India. The intervention of government policy is required as a part of the climate change mitigation action taken up by India to establish the system and ensure farmers participation in the climate change programme at Tehsil or village level. The generalized yield components of biochar, bio-oil and bio gas obtained from biomass thermalization process under a modern pyrolysis plant given [Table-2].

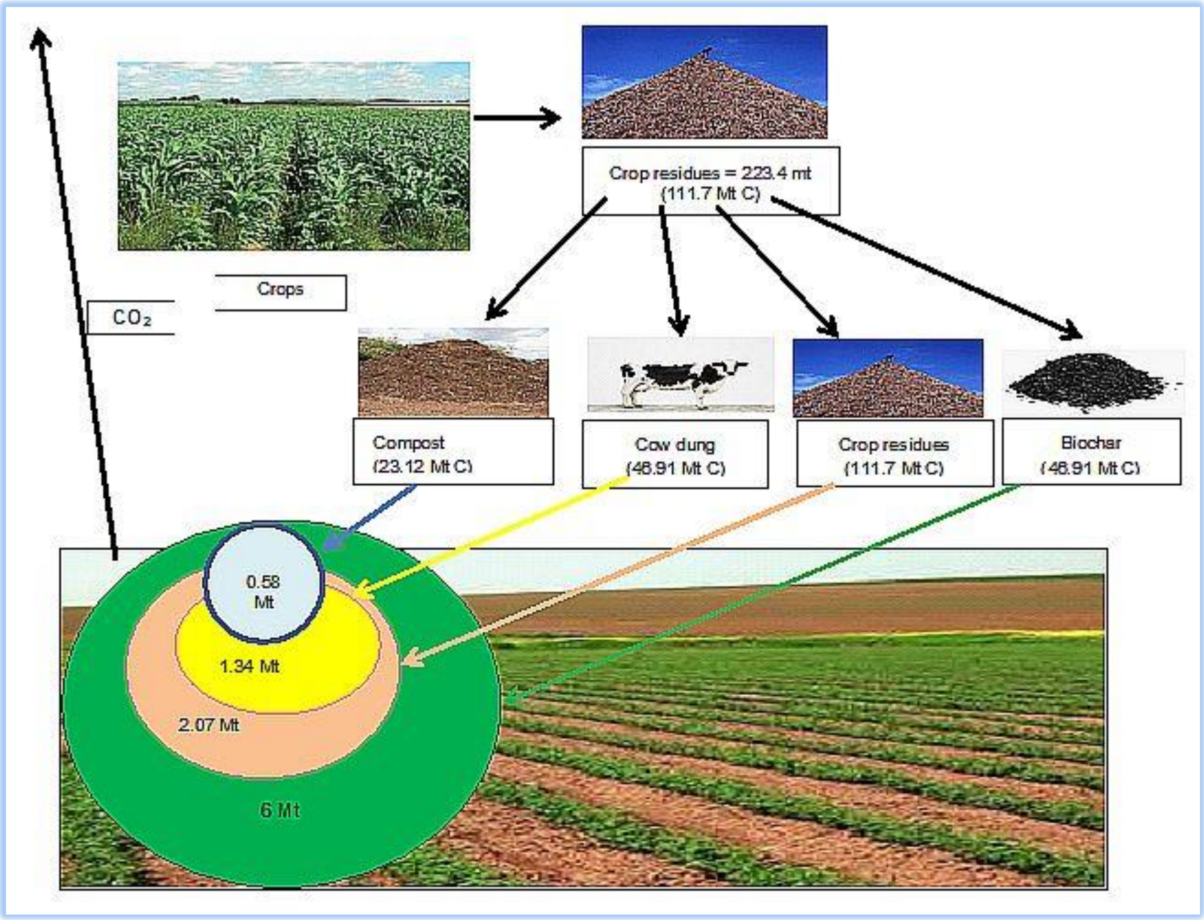

Fig-2 The annual carbon sequestration potential for the existing residues techniques and biochar in India

Biochar climate change mitigation potential in Indian agriculture

The soil carbon sequestration and climate change mitigation in agriculture sector is high due to low soil carbon content (<0.5%) and large geographical area of 169.7 Mha cultivation land [25]. The soil organic carbon content increase for improved management practices such as pasture cultivation (13%), conservation tillage (10%), residue retention (8%) and fertilizer N application (tropical climatic condition [27-26]. The continuous adoption of the practices is needed to ensure the sequestered carbon ever stable in the soils but this has not been observed in the farmer field and we, too, could not force famers when it is not profitable to them. In this context, the deliberate soil carbon increase can be possible only with biochar addition due to high stability of aromatic carbon present in the biochar. There are many laboratory experiments confirmed the biochar longevity in soils. The pattern of carbon loss in the biochar incubated soils were found initially high for short period of time and decreased gradually to a low and constant value. In 12 months lab studies of wood biochar in vertisols, inceptisols, entisols and oxisols found that the mean residence time of biochars in soils ranged from 44 to 610 years. In another five years laboratory experiment study for biochar stability in soils, the eucalyptus saligna wood and leaves, paper mill sludge, poultry litter and cow manure (produced at the temperature range of $400-550^0$C) also accounted just 0.5 to 8.5% of total biochar C lose with mean soil residence time varied from 90 to 1600 years [28]. It must be lower in the real field situation over lab condition where we maintain optimum soil moisture and temperature condition throughout the study period. Thus, the conservative value of 2 % lose per annum have been taken to quantify the amount of carbon increase for biochar amendment in agriculture. As per our estimation, the India has annual potential to make biochar about 75.2 Mt to 219.33 Mt for fast and slow pyrolysis of biomass available from agriculture sector [Table-3]. The use of this crop residue for biochar alone can add soil carbon stocks about 61 to 137 Mt upon amendment in agriculture. However, more than 65% of the potential biomass in agriculture used for other purposes won't be available for biochar production.

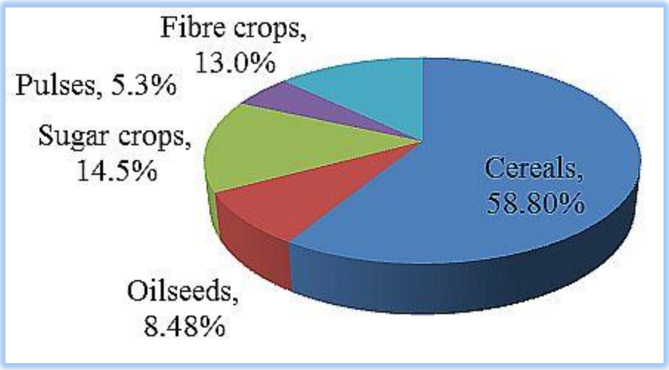

Fig-1 The annual crops residue generation from agriculture in India

Therefore, biochar obtained from surplus biomass has the true meaning for soil carbon sequestration and climate change mitigation without affecting the existing social and environmental system. The waste from agriculture alone can produce biochar about 78.2 Mt for slow pyrolysis and 26.8 Mt for slow pyrolysis of charring process. The stable carbon in the char is equal to 166 Mt and 76 Mt of CO_2 equivalents and about 5.5 to 16 % of the total net greenhouse gases emitted in 2007 in India. The crop residues usually returned to field through various ways. It may be routed through compost preparation, cow dung application after feeding to livestock and direct field application. Instead, the field application of crop residues in the form of biochar found greater potential for carbon sequestration. If the surplus amount goes through the conventional method of field applications it could increase soil carbon about 2.07, 1.31 and 0.58 Mt respectively for crop residues application, cow dung application and compost application. As half of the carbon in the residues are lost by absorption in the animal system and CO_2 in the compost preparation have reduced the soil carbon sequestration value compare to field residues application.

As per theoretical estimation, the biochar conversion may increase annually about 46 Mt soil carbons mainly for high amount of aromatic carbon present in the biochar lasting for many years [Fig-2]. The organic solid waste of 14.6 Mt can produce 5.1 to 1.7 Mt of biochar that can mitigate 5 to 11 Mt of CO_2 equivalents of greenhouse gas emission for stable soil carbon stocks. It shares about 8.8% of gas emission in the waste management sector [8]. The contemporary trees cuts would produce 3.2 to 5.6 Mt and could mitigate 9.2 to 20 Mt of CO_2 equivalents. It is equivalent to 2.75 to 6 % of GHGs' emission in the agriculture sectors and 0.5 to 1.1% of total net emission in 2007. The surplus wastes all together from agriculture, organic solid waste and forestry residues is 249.3 Mt which can would mitigate greenhouse gas emission about 4.8 to 10.7% of total net gas emission and 25 to 55% in the agriculture sector if used for biochar programme. Similarly, the International Biochar Initiative [31] organization also analysed with assumed values for a set of parameters including the fraction of global net primary production available to make biochar, the carbonization efficiency of the selected biochar production technology, the increase in productivity from land to which biochar is applied, and others for available crop residues in agriculture and forestry sectors. The annual offset potential of biochar as per their estimation ranged from 0.25 to over 2 billion metric tonnes carbon per year. In another study the Woolf, *et al*. (2010) also analysed global "sustainable" potential for biochar systems using a variety of literature-based assumptions and estimated that 1.8 Pg yr^{-1} CO_2-C equivalents could become avoided emissions if biochar systems maximized globally [32]. They also reported that the global implementation of biochar system could offset 12% of global GHG's emission in which 50% of reduction come from carbon sequestration, 30% from replacement of fossil fuels and 20% for avoided emission of GHG's It also reported that biochar production from corn stover and yard waste reduced 864 to 865 kg CO_2 equivalent of GHG's emission per tonne feed stock with 62-66% of increased soil carbons rather conventional use in alcohol production and compost preparation [34-37]. Similarly, sustainable biochar making and application from the surplus biomass in agriculture alone could able to reduce 756 to 354 kg of CO_2 equivalent per tonne of feed stock for increased soil carbon stocks rather other conventional uses. It would eventually reduce GHG's emission about 10.7% to 4.8 % of total net greenhouse gases emission in 2007 after taking 2% (value are assumed based on previous report) as maximum annual loss of labile carbon in biochar by biotic and abiotic oxidation.

Conclusion

The annual gross and surplus waste residue production in agriculture, forestry and city was together is 668 Mt and expected to increase in future for increasing crop productivity and food grain production in India. The biochar technology in Indian agriculture has more potential for soil carbon sequestration over the conventional methods of residues management. The surplus biomass could increase about 45.98 Mt soil carbons In India. If we sensitize biochar programme with the available waste residues from agriculture, forestry sectors and wastes from cities together could mitigate greenhouse gas emission from 4.8 to 10.7% in the total net emission with contribution about 25 to 55% from the agriculture sector in India. There are very few biochar research studies conducted for quantitative recommendation in agriculture. The future of biochar research in agriculture are, 1. How the biochar interacts with different soil types with respect to change in nutrient cycle, soil physical properties and bio-chemical properties. 2. Whether inclusion of biochar in the cropping system would bring more abetment of greenhouse emission over long term scale in agriculture. 3. What would be a long-term effect upon field application on soils and crops and on the applied biochar 4. Does the biochar will play a significant role in carbon trading for enhancement of soil carbon stock? If so, what would be the intervention on cost of cultivation as the extra cost involved in biochar production and transportation of biomass and biochar to the field and application?

Application of review: This is useful to the people who do research in environmental pollution, climate change mitigation and adaption practices, soil quality and soil resource conservationist.

Review Category: Biochar technology, Soil Science

Abbreviations:
GDP: Gross domestic product; GHG: Greenhouse gas

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