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Review Article

A Review on Bio-Char: A Byproduct of Bio-Wastes

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A B S T R A C T

Bio-char is an organic by-product of pyrolysis of various organic feedstocks. They get burnt at different temperatures and pressures (probably high) to produce highly carbonaceous organic by-product. Bio-char is recalcitrant by nature as it remains in soil for longer durations and do not get decomposed easily by microbial actions. Bio-char is a highly porous structure depending upon the different feedstocks. It has various physical and chemical properties vary from various feedstocks used. Bio-char has the adsorption capacity which adsorbs the various heavy metals present in the soil. It has a larger surface area, provides a habitat for the soil micro flora and fauna. It has been used in agriculture for the reclamation of the various soil contaminations and also for the induction of disease resistance in various plant species against different destructive plant pathogens. Due to their unique properties it has been widely accepted in the agriculture sector for increasing the quality and quantity of the production. So it is very correct to consider the Bio-char as a "SOIL GUARD" as it conserves the natural nature of the soils.

Keywords

Bio-char, Recalcitrant, Induced resistance, Feedstocks

Introduction

In today's scenario it has been widely seen that the use of the excessive pesticides and fertilizers and other synthetic amendments has increased the quantity of the production upto an extent but at the same time it costs a lot to the quality of the environment, soil and human health. The excessive utilization of synthetic approaches lead to catastrophic events which have deteriorate the natural habitat of the soil that later on affects the plant production and quality of the production. The residual nature of synthetic chemicals used in agriculture leads to the formation of heavy metals into soil which have been very toxic for the plants, soil micro flora and fauna, aquatic and terrestrial animals, humans etc. So there is always a need of a system or an amendment which will not causes serious ill effects on the soil's natural behavior and other factors of the environment. Various types of organic amendments has been induced in order to overcome the losses made by the application of these toxic and life destructive chemicals. These organic approaches include various by-products made up from the degradation of the organic materials into a useful materials and Bio-char, is one of them. In recent year Bio-char has been shown a great contribution in the remediation and reclamation of disturbed natural soils and environmental behaviors. Bio-char has shown its contribution in the induced

resistance against the various plant pathogens which cause various sever kind diseases in various plant species. The application of Bio-char in soil helps to regain the natural form of the soils by activating the micro-life in the soils and regaining its nutrient strength. Bio-char is proved as an efficient and effective measure in order to prevent the contamination of the soils. Bio-char has shown a new sight of light to the agriculture researchers and the farmers in order to take a turn from the conventional type of agriculture activities and researches.

Origin of bio-char

Terra preta is a very fertile, dark in color and anthropogenic soils found in Amazon basin also called as the "Amazon dark earth" or "Indian black earth". The concept of the Bio-char has been originated from these soils in past times. It has been shown that the soils of the terra preta has black mass of the Bio-char which make it very fertile and dark in color which has been made up naturally by the activity of the temperature and pressure on organic matter present in the soil, in the absence or little amount of oxygen through thousand years of time. Bio-char is a kind of charcoal, supplemented as a soil amendment considered as a heterogeneous material generated or produced by pyrolysis, which is a thermal combustion occurs at the temperature varies from 200°C to 900°C and in the limited oxygen supply. A great variety of organic materials which includes crop wastes or residues (Yuan *et al*., 2011), woodchips (Spokas and Reicosky, 2009), urban or municipal-wastes (Mitchell *et al*., 2013), slugde from sewage (Mendez *et al*, 2012), manures and other organic amendments (Uzoma *et al*., 2011), and from bones of the animals (Vassilev *et al*., 2013) were used in the preparation of Bio-char. This (pyrolysis) 2000 year-old practice creates a valuable product which will acts as a soil enhancer that can be able to hold the carbon, boost up the food security (maintain the production and the availability of the food from the agriculture) and increase the biodiversity of the soil (flora and fauna). The process produces a fine material which is highly porous (charcoal) that help the soils to retain their nutrients and water levels. Bio-char is widely found in soils all over the world as a result of the vegetation fires and historical practices for soil management (https://www.Bio-char-international.org/Bio-char/). The International Bio-char Initiative defined Bio-char as "a solid by product material which is obtained from the thermo-chemical conversions of biomass in an environment in which there is a limited oxygen supply" (IBI, 2012). Bio-char also considered as "Black future for Plant Pathology" (Bonanomi *et al*., 2015). The Bio-char has been proved to be a very innovative and advanced technique for agriculture sector in order to bring a diversion in the conventional agriculture practices.

Characteristic features of bio-char

Bio-char is a highly carbonaceous material which is composed of the polycyclic aromatic (Singh and Cowie, 2008) hydrocarbons including various other functional groups (Noack and Schmidt, 2000) in their chemical compositions. The physical structure of the Bio-char is highly porous which facilitates the significant amount of various organic acids essential for soil health like humic acid and fulvic acid (Trompowsky *et al*., 2005). The Bio-char prepared from the different feedstock's have various physical, chemical properties, porosity, surface area and negative surface charge which helps in the availability of the nutrients or retention of the nutrients within

the soil for a longer period of time (Biederman *et al*., 2012; Czimczik *et al*., 2002). The Bio-char is a type of heterogeneous material made up of types of organic wastes which includes a wide variety of organic products which burned in absence of oxygen. It is a heterogeneous product since it is hydrophilic, hydrophobic, acidic and basic as well in nature and such variations are due to only of various materials used to produce it (Lua and Yang, 2004). Bio-char have various types of porosity parameters which determines its surface area viz., nano (<0.9 nm), micro (<2 nm), macro (>50nm) (Downie *et al*., 2009). Due to aromatic properties of the black carbon it is considered as recalcitrant in soil and hence remains for a longer period of time in the soil and provides a long term carbon sequestration in the soil and atmosphere (Kuhlbusch *et al*., 1996*;* Skjemstad *et al*., 1996). The key feature of the Bio-char is its highly porous structure and large surface area that provides a wide range of benefits to the micro- flora present in the soil and helps them to enhance their overall growth and their population (Lehmann *et al*., 2003). The presence of Bio-char in soil enhances the cation and anion exchange capacity of soils through which micro-flora and fauna of the crops gets benefited (Lehmann *et al*., 2003). Black carbon or Bio-char due to their aromatic nature is very resistant to decay in the soil and for that reason it occupies a significant part of soil's carbon fraction, aided by the potential of carbon for a prolonged period in the soil, Bio-char remains unchanged in the soil after the application (Liang *et al*., 2008). The materialistic properties of Bio-char are totally different of the other uncharred organic matter in the soil, this happens due to special process responsible for the preparation of the Bio-char which is quite different from the others (Schmidt and Noack, 2000). Fresh Bio-char have different type of properties than the normal as different type organic wastes have been used for Bio-char preparation, for example, greater pyrolysis produces the Bio-char of low CEC and of lower charge densities (Lehmann, 2003; Chan and Xu, 2009) and high ash biomass produces the Bio-char with slightly greater CEC and charge densities (Chan and Xu, 2009). Bio-char is consist of fused aromatic carbon atoms rather than the diffused carbon atoms which will account it special properties such as recalcitrant and non-leachable. The pH of Bio-char varies with variation in temperature, the greater will be the temperature the greater will be the pH (Cheng *et al*., 2006). Bio-char prepared at low temperature have mostly the amorphous carbon structure with lower aromaticity as compared to Bio-char prepared at high temperatures (Smernik and McBeath, 2009; Keiluweit *et al*., 2010). Most of the chemical, physical and electrical properties of Bio-char has been changed as the final heat treatment temperature and the time increases until the Bio-char has been reached at a point where almost most of the carbon is changed into the form of graphite (Antal and Gronli, 2003). With the increase in the heat treatment temperature, some of the metals present in the feed-stock have been volatilized and ash phases change their morphological properties as from crystalline to amorphous structures and also there is a change in their chemical properties (Wornat *et al*., 1995; Boocock and Bridgwater, 2006).

Application in temperate and tropical soils and checking of differentiation in results

Temperate soils are the high land soils, made up by the various decompositions and degradations of the rocks for over a thousand years of time under the effects of the various biological and environmental

factors. These soils are rich in organic matter and are very fertile in nature. The color of these soils are usually dark which indicates their good physical and chemical conditions. Near about 40% of the land surface of earth has been modified by the wildfires and such events leaves the low organic carbon residues on the soil's surface, as the natural combustion process is an oxygen rich process (Preston and Schmidt, 2006). According to the global meta-analysis it is shown that Bio-char has an average or low effects on the crop yield in temperate regions as compare to tropical regions where the outcomes were seem to be 25% average increase with the Bio-char application in the soils (Simon Jeffery *et al*., 2017). The burning of the natural organic waste in the absence of the oxygen under various pressures and in natural conditions produces highly carbonaceous organic black product (black carbon). Black carbon, a term is used to describe (Bio-char) within the soil surface which is either deposited from the atmosphere or from direct combustion of the vegetative matter (Rawlins *et al*., 2008). Soils within the temperate regions has been made up of the variable quantities of the black carbon wastes which is highly stable. Such soils are known as the "Dark earth of the Indians" (Christopher *et al*., 2010). The incorporation of the Bio-char in soil increases their soil structure, porosity, texture, infiltration and various other properties (Lehmann *et al*., 2007). The addition of Bio-char in the soil has been proved in order to increase the field capacity of the soil which will help the soils to hold the water or moisture for a longer duration. In the temperate regions there are considerable distribution of the vegetation matter that, on decomposition either under natural and the atmospheric conditions produces a significant changes in the soils of the temperate regions (Glaser and Amelung, 2003). Bio-char application in the temperate regions not only increases their soil productivity but it is also seen that it increases the soil physical and chemical properties also (Simon *et al*., 2007). The heterogeneous nature of the Bio-char has been contributed to the development of the micro and macro flora in the temperate regions (Lua and Yang, 2004). In the tropical areas Bio-char has increased crop production by liming and fertilization, consistently overcome the various limiting factors of tropical areas like acidity, basicity, low nutrients level and organic matter (Simon *et al*., 2017).

Although Bio-char induces various changes in the soils of the temperate regions but it seems that the overall output of the production of the crop in the temperate regions has shown a limited increase than the tropical regions.

Effect on soil biota and their interactions with bio-char

The micro flora within the soil plays a magnificent role in the soils natural behavior and activities. Soil microflora or soil biota is very essential for the soil because of their dynamic roles or activities within the soils. They are necessary for the healthy nature of the soils which is very much required for the plant growth. Soil Bio-char application have various types of significant effects on the microflora present in the soil at varying degree. Mycorrhizal fungi an endo-mycorrhizal symbiotic root colonizing fungi, which live in a symbiotic relationship with the higher plant's roots in favor to provide them a sufficient amount of phosphorus and various other nutrients. Bio-char application has an important effect on the growth of these types of fungi in the soils (Mahmood *et al*., 2003*;* Warnock *et al*., 2007). Bio-char applications have the diverse types of effects on the arbuscular mycorrhizal root

colonizing fungi because in some instances it have been seen that Bio-char increases their activity (Herrmann *et al*., 2004; Matsubara *et al*., 2002) but in some instances it have adverse effects as it decrease the P-availability and root colonization (Warnock *et al*., 2010). It is proposed that the Bio-char causes alterations in the soil's physio-chemical and biological properties which will affect the availability of nutrients in the soil (Miller *et al*., 2002). The exact connection between Bio-char and soil microbes has not been yet evaluated. The composition of the metabolic processes as well as decomposer community of a different variety of soil microbes may play an important role in determining the connection between Bio-char and soil microbial life (Fukami *et al*., 2010). The effect of Bio-char has not only been seen in the soil microbes but it is also seen in the nutrient cycle changes within the plant growth and soil (Wardle *et al*., 2008; Kuzyakov *et al*., 2009). Changes in the microflora in the soil in respect to their activity and growth will also affect the nutrient cycle in the soil (Wardle *et al*., 2008). Effects of Bio-char in the soil micro fauna also depends upon the various soil properties in which the Bio-char is being added. The chemical stability of the Bio-char enables it that no microorganism in the soil will able to diffuse the carbon and nitrogen or any other resource present in the Bio-char as directly like the other carbon organic compounds (Lehmann *et al*., 2009). Effects of the Bio-char on the soil biota has been greatly influenced by the alteration of structure and physio-chemical properties between Bio-char and soil (Downie *et al*., 2009). The abundance of soil biota in soil treated with the Bio-char has been shown by various scientists in their research papers on various tests used for evaluating the population of the soil biota viz., phospholipid fatty acid (PLFA) extraction (Jin, 2010), fumigation extraction (Jin, 2010; Liang *et al*., 2010), total genomic DNA extracted (O'Neill, 2007; Grossman *et al*., 2009). According to Rillig *et al*., 2010, the Bio-char produced by the hydro-thermal carbonization could greatly influence the functioning of the Endo-mycorrhizal fungus in the soil which will proved to be beneficial for the plants by root colonization mechanism. The microbial biomass shows great variation in the soil with the changes in the soil pH level, the variation lies between 3.7 to 8.3 under various climatic conditions and other soil limiting factors (Aciego and Brookes, 2008). The bacterial population seen to be raised upto a certain level with the pH ranges upto 7 but the fungal mycelium do not show any sustainable growth characteristics (Rousk *et al*., 2010). The bacteria may use to adhere at the surface of the Bio-char allowing them not to loss during leaching (Pietikainen *et al*., 2000). The phenomenon of adsorption of such types has been found by the Cassidyet *et al*., 1996. The addition of the Bio-char provides a food source to the soil biota (microbes) which is recalcitrant in nature and of high porosity, the Bio-char provides enough space for the habitat of the soil microflora which will reduces the predation cause by the soil biota (Warnock *et al*., 2007; Zackrisson *et al*., 1996). The effect of Bio-char on the soil biota is also depend upon the various feedstock's used for the Bio-char production and also on various combustion techniques used for its production (Chun *et al*., 2004; Glaser *et al*., 2002). The application of the Bio-char has increased the soil biota activity by the percentage of Streptosporangineae (~6%), Hypomicrobiaceae (~14%), Bradyrhizobiaceae (~8%) and Thermomonosporaceae (~8%) (Craig R. Anderson, 2011). The bacteria belongs to family Bradyrhizobiaceae, is a rhizobial bacteria which live in association with

leguminous plant roots.

Bio-char as an amendment for plant disease management

The first discovery in the induced resistance was done by Ross in 1961 in a systematic manner. The phenomenon of the "induced resistance" is also known as the "acquired resistance" or "acquired immunity" (Kuc, 1983). The induced resistance has been defined as the activation of the various PR proteins, enzymes and chemicals by the activity of the various biotic and abiotic agents acting externally (Kloepper *et al*., 1992). The phenomenon of induced disease resistance has been started by using various chemical formulations in order to reduce the incidence of diseases within the field crops and vegetables so as to maintain their production quantity and quality from these crops. This has been seen that phosphoric acid against *Phytophthora* diseases causes various harmful defects in the various plant species including tomato, chili, potato and citrus plants (Guest and Daniel, 2006; Daniel *et al*., 2005). The addition of the Bio-char in the pots of pepper (*Capsicum annuum*) and tomato (*Lycopersicum esculentum*) has been seen to induce the resistance against the two air borne pathogens and damage from the mites also (Elad *et al*., 2010). Also this has been seen that the addition of the Bio-char in the pots of the strawberry has induced the resistance against the three air borne pathogens within the plants which has seen directly increasing the production of plants (Harel *et al*., 2012). Bio-char has been proved very effective against various air borne diseases (Zhang *et al*., 1996) caused by various fungus species like *Botrytis cinerea* and some species of powdery mildew and other soil borne diseases (Noble and Coventry, 2005) caused by *Phytophthora* spp., *Fusarium* spp., *Rhizoctonia solani* etc. Most probably five mechanisms are there for the resistance of the diseases in the plants caused by Bio-char (G. Bonanomi *et al*., 2015). These are Induction of systemic acquired resistance in the host plants (Ross, 1961); Increase the activity of the essential microbial population in the rhizosphere (Mahmood *et al*., 2003); Modification of soil qualities (physical, chemical, biological, nutritional) (Lehmann *et al*., 2007); Direct fungi-toxic effect of Bio-char (Spokas *et al*., 2011); Sorption of various allelopathic or toxic chemicals from the soils (Beesley *et al*., 2011)

The use of Bio-char has been actively and widely adopted in order to overcome the various climatic changes that causes the harmful or deteriorative effects on the composition of the soil and its various properties. Mehri *et al*., (2015) showed that the Bio-char derived from the green house wastes was effective to control the *Botrytis cinerea* causing the grey mold in tomato. Harel *et al*., (2012) and Elad *et al*., (2010) reported that the Bio-char prepared from the wood chips and wastes from the greenhouse under the controlled conditions has been effectively reduced the incidence of powdery mildew which is caused by the *Leveillula taurica* on tomato. The Bio-char prepared from the *Eucalyptus* had shown the control of damping off which is caused by the pathogen *Phytophthora* and *Pythium* in various species of plants (Jaiswal *et al*., 2014). Mehari *et al.,* (2015) has provided the direct evidence about the Systemic Acquired Resistance (SAR) and Induced Systemic Resistance (ISR) pathways that are involved in inducing resistance in plants due to the application of the Bio-char. SAR is based upon the activity of salicylic acid pathway or metabolism while ISR is based upon Jasmonic acid and ethylene pathways or metabolism. Amaya Atucha (2015) has been found that the Bio-char also helps to reduce the re-plant diseases in peach. Drew and

Soo-Hyung Kim (2012) has shown the use of Bio-char in soil and proved that Bio-char helps to reduce the stem lesions which have been caused by the *Phytophthora* spp. in the seedling of tree plants for this experiment Drew and Kim used maple tree seedlings and proved that the Bio-char is very effective organic tool for the protection of plants.

Bio-char potential in the restoration and remediation of contaminated soils

Remediation and restoration is the most difficult task in the modern agriculture. This is due to the excessive consumption of the toxic chemicals into the soils in order to increase the production at the cost of soil health. The soil toxicity or contamination is a very easy task in today's scenario but the restoration tasks are much more difficult and time inducing. They requires a period of time which is much more than the time taken for the deterioration of the soils. The Bio-char application has been shown a great move in their reclamation. Bio-char are the biological residues, having diverse properties (Lehmann *et al*., 2009) which have been absent in any other organic residues.

Due to these properties, Bio-char have been widely used to reclaim the contaminated soils with liming effects, reducing pollutants mobility by combining with the contaminated particles or adsorption (Luke Beesley *et al*., 2011). Bio-char application changes the bulk density of the soils this is because it contains both micro and macro pores (Downie *et al*., 2009) that can hold the water or air more tightly than other. The addition of the Bio-char in the soil reduce the emission of harmful gases in the atmosphere such as nitrous oxide and methane (Randon *et al*., 2005*;* Yanai *et al*., 2007*).* Such changes leads to the reduction in the contamination level of soil and environment. The Bio-char changes the bulk density of the soil which will enhance the soil structural properties, either responsible for the reclamation of contaminated soils. Bio-char aggregates provides the various functions such as the restoration of the soil biota, soil moisture regulations and nutrient management (Tisdall and Oades, 1982). According to the Brussaard *et al*., (2007) the amendment of any organic material in the soil will help to reduce its contamination and help to ensure their fertility and productivity. According to Moore *et al*., (2004) the quality and quantity of the organic matter added in the soil for its reclamation also effects the procedures. The greater amount of carbon decomposition (also known as priming) has been seen in the soil treated with the Bio-char (Wardle *et al*., 2008). Bio-char has been used to eliminate the inorganic compound from the soils such as atrazine and other toxic metals like Pb (lead) which are very toxic to soils, plants and human health also (Ahmad *et al*., 2014; Xinde Cao *et al*., 2011).

The Bio-char amendment in the highly weathered soils of humid Asia causes the various changes in the soil as it increased the pH from 3.9 upto 5.1, cation exchange capacity (CEC) has also been changed from 7.41 to 10.8 cmol/kg and bulk density has been reduced from 1.4 to 1.1 mg/m^3 (Jien *et al*., 2013). After the addition of the Bio-char in the contaminated soils various types of the reactions has been carried out by the Bio-char in order to reclaim the contaminated soils. These were dissolution-precipitation, acid-base reaction, adsorption-desorption and redox reactions (S.D. Joseph *et* al., 2010). All such types of reactions in the soil by Bio-char has been depend upon various types of factors including the feed-stocks composition, composition of the fraction of minerals in the soil, processes

used for the pyrolysis, particle size of the Bio-char, various environmental conditions and soil properties (Steiner *et al*., 2007; Kuzyakove *et al*., 2009; Cowie and Singh, 2008; Bruun *et al*., 2008). The Bio-char prepared from the low temperature pyrolysis which have more likely less compressed structure of carbon which shows a greater reactivity in the soil than Bio-char's prepared by the high temperature pyrolysis process (Steinbeiss *et al*., 2009). Due to the greater reactivity of the low temperature, Bio-char's have been mixed with the sludges and minerals in order to balance the nutrient level of the amendment which will being used in the soils for their reclamation (Chia *et al*., 2010). When the Bio-char is being added to the soil, organic molecules present in the soil get adsorbed on the Bio-char particles; these molecules include the various residual herbicides and pesticides present in the soil after their application. T

hese molecules have been adsorbed by various reactions carried out by Bio-char within the soil including cation bridging, H-bonding, covalent bonding and many more other types of the linkages (Kuzyakov *et al*., 2009). According to a research it has been seen that Bio-char application reduced the contamination of the soils by lead, cadmium and zinc minerals upto a great extent and along with the biomass production of rapeseed on the contaminated soils in order to reclaim the productivity and fertility of the contaminated soils again (David Houben *et al*., 2013).

Bio-char affects the soil in both ways that means they affect the water retention and soil nutrient retention powers in order to maintain the productivity and fertility of the soils (Glaser *et* al., 2002; Steiner *et al*., 2007). The Bio-char produce from the hardwood helps in the reduction of the Polycyclic Aromatic Hydrocarbon (PAH) from the pore water present in the soil (Beesley *et al*., 2010) so Bio-char has been proved as an effective mechanism or process to regain the natural nature of the contaminated soils.

Economical and climatic aspects of bio-char

In 21st century every concept and method has been firstly relates with their economic and technical aspects for their success. The Bio-char has been done the same with its unique features. In agriculture the economic aspects are seen in the form of the final output or the final production of the crop. It has been found that Bio-char application increases the crop production upto a normal level as compared to other crops in which no Bio-char incorporation was done (Lehmann *et al*., 2007). Various authors showed by their field analysis and their field trials that the Bio-char induction increases the crop production at random rates in various areas under various climatic and soil conditions in different types of crops (Blackwell, 2009; Lehmann, 2007; Mahmood, 2015).

The various experiments showed that there is an average increase of 10% of total crop yield after the application of the Bio-char in the soil (Jeffery *et al*., 2011). Along with positive effects there are also some negative effects of Bio-char application in the soil such as decrease in the efficacy of atrazine in the fields (Wisnubroto *et al*., 2010). Since the Bio-char have the high water retention capacity which will lead to the increase in soil water regimes (Novak *et al*., 2012). Such features are helpful to cultivation practices induced in the sandy or dry areas. Bio-char amendment has been significantly proved effective in 85% and non-significant in 12% of the various case studies respectively (Bonanomi *et al*., 2007). The Bio-char have the larger surface area other

than any kind of the organic material which is several hundred to thousand folds depending upon the materials and techniques used for Bio-char production (Downie *et al*., 2009; Chan *et al*., 2008). Due to such kind of properties Bio-char is being used for the various purposes like industrial, medical applications, decontamination of soils, sediments and waste waters. The Bio-char prepared at the high temperature was proved to be very effective in the adsorption of the trichloroethylene from the groundwater or from the water in the soils (Ahmad *et al*., 2012).

The application of the Bio-char in the soil increases pH of acidic soils (Zwieten *et al*., 2010) and increases nutrient level of the soil (Liang *et al*., 2006), which will help to reduce cost of the various soil reclamation activities which costs a huge economy. The large Bio-char particles have been found in the forest fires or wildfires as remain within the soils for a period of thousand years (Gouveia *et al*., 2002; Pessenda *et al*., 2001; Gavin *et al*., 2003). Now a day's various types of techniques have been evolved for the commercial production of the Bio-char over a large scale (Maris, 2006; Titirici *et al*., 2007; Gronli and Antal, 2003).

The Bio-char which have been prepared from different techniques almost shows the same chemical properties with minor variations within the physical structures (Noack and Schmidt, 2000; Gleixner *et al*., 2001). The addition of the Bio-char is economical when mixed within the soil or in the potting media at the rate of 5 % by weight but it would causes various deleterious effects when used at the rate of 10 to 20 % by weight (Harel *et al*., 2012; Elad *et al*., 2010). The Bio-char helps in reduction of the emission of GHG's (greenhouse) gases by regulating the carbon sequestration in the environment and the soil (Stewart *et al*., 2013). The studies on Bio-char application in the soil have showed that the incubation period of the Bio-char in the soil can last upto thousand years which maintains the carbon balance in the soil for a longer period (Kumar *et al*., 2013, Chang *et al*., 2012).

Bio-char as a tool for waste management systems

Increased development of various sectors of the society leads to the increase in production of the wastes in a large amount every year. The main catastrophic to this development is that, "How to manage such huge amount waste produce by the various sectors of the society due to urbanization or industrialization". Various advance techniques have been induced or developed in order to manage the wastes like 3R's policy of recycling; reusing; and reduce. The wastes produced by the industries have been used in many ways by recycling it or by reusing it (Thoresen, 1982) but the organic waste produce by the society becomes a diverse factor in order to recycle or reuse them again.

Although various approaches have been implemented in order to manage the organic wastes like compost making, manure formation etc. (Jeyabal *et al*., 2001; Polprasert, 1989) but still lots of organic waste from agriculture sector has been wasted every year without their conversion into a useful component. So the production of the Bio-char provides an approach for recycling the organic wastes into useful products which have been used for a variety of functions in agriculture (Zwieten *et al*., 2001). As per the today's scenario there is a major problem of handling the organic waste produces by the agro-food industries therefore the production of Bio-char from

the agro-food industries' waste provides a sustainable and efficient soil and environment management (Aditya Parmar *et al*., 2014). The other organic products prepared from the organic wastes after bacterial decomposition and anaerobic degradation shows changes in carbon level of the soils for a particular period of time because such materials start degrading within soils after their application but it is quite different in case of Bio-char because it is of recalcitrant nature (Steiner *et al*., 2007; Glaser *et al*., 2002; DeLuca and Aplet, 2008). Amendment of Bio-char in the soil also reduces the loss of preexisting organic matter in the soil (Wardle *et al*., 2008). The variations in Bio-char preparation from different feedstocks, rates of their application in the soils for the management of different diseases may vary plant to plant, soil to soil and disease to disease, that makes it complicated in order to generalize the results of Bio-char at basic levels in a standardized form (Noack and Schmidt, 2000).

Bio-char enriches macro and micro nutrients and denies their losses in the soil

Every organic amendment used for the reclamation of the soils or for any other purposes has its definite and different nutrient compositions that are essential for supply or availability of the nutrients in appropriate amounts in the soils from where they get transferred into plants used for their growth and production of the food (Schulz *et al*., 2013). Bio-char acts as a conditioner for the soils (Craig R. Anderson, 2011), Bio-char has not only been used as the organic amendment in the soils in order to induce the resistance within the plants against diseases but simultaneously acts as a fertilizer for plants proper growth and production (Glaser *et al*., 2001; Marris 2006). Organic biomass prepared from the compost and manures contain large amounts of carbon and other micro and macro nutrients (Chan and Xu, 2009). There is a little information about that the Bio-char is capable of immobilizing and denitrification of nitrogen in the soil (Deluca *et al*., 2009). It is seen that the Bio-char produced from various type organic wastes contain considerable amounts of carbon in their structure, for example, Bio-char prepared from *Acacia manginum* contains 398 gram, *Zea mays* contains 675 grams, *Saccharum* spp. contains 710 gram of carbon per kilogram of Bio-char respectively. Increased concentration of two possible micro-nutrients in the soils say boron (B)and molybdenum (MO) will lead to increase in the biological nitrogen fixation (BNF) by the *Rhizobium* in the legume crops sown in the soil treated with the Bio-char (Randon *et al*., 2007). Bio-char is helpful in the microbial mediated transformation of the various nutrients present in the soil makes them available to plants when they get transformed from organic to inorganic form (Berglund *et al*., 2004; DeLuca *et al*., 2002; Ball *et al*., 2010). The Bio-char has also been used to reduce the nitrogen loss during the poultry litter composting (Christopher Stelner *et al*., 2010). Potassium has been available by Bio-char to plants in a sufficient amount (Amonette and Joseph, 2009). The nitrogen supply from Bio-char to the plants has been shown a great variation depending upon the final temperatures of the pyrolysis, rate of heating, time of production of Bio-char, type of feed-stocks (Amonette and Joseph, 2009). The application of Bio-char reduces the emission of NO_2 from the soil in the environment upto an extent of 40 to 50 % (Zhang *et al*., 2010). The application of Bio-char in the fields of the paddy crop reduces production of the methane upto a great extent which didn't mean that there is absent of methanogenic archaea (soil microbes that are responsible

for the methane production in the paddy field) instead there is the abundance of the methanotrophic proteobacteria responsible for the oxidation of methane within the soil atmosphere (Feng *et* al., 2012).

In conclusion, it is a well-known fact that, "Soil is the basis of life". It is the life sustaining part of the earth. But due to adverse activities of human, the natural condition of soil has been changed to a greater extent. As it gets contaminated it affects the fauna and flora surviving in it. The contamination caused by various sectors viz., industries, medical services, agriculture etc. are the major areas for soil contamination. So there is a need to develop a kind of system or technique which will helps in reclamation of soils. Bio-char, an organic amendment acts as an essential component and amendment for contaminated soils. Bio-char regulates the natural conditions of soil which have been very useful for soil's flora and fauna. Bio-char have various chemical and physical properties which helps in the soil reclamation. Bio-char is a kind of "SOIL GUARD" which have large surface areas which enable bio-char to adsorb various kinds of soil contaminants and provides a healthy habitat for soil biota. Due to recalcitrant properties of bio-char it can remains in soil for several period of time than any other organic soil amendment. The dosage of bio-char amendment must be remain between 0.5% - 3% by localized placement to get maximum benefits. So it is recommended to use Bio-char in soils for sustaining the soil productivity and fertility.

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