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Biochar: An Emerging Technology for Climate Change Mitigation

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Abstract: Climate change, a consequence of anthropogenic activities, is threatening the life on earth to persist for a longer period of time. Greenhouse gases emission including CO_2 concentration in the atmosphere are the most adverse situation that are prevailing on the planet. Unexpected events may occur more frequently that will be detrimental for sustainable life. The emission of greenhouse gases especially elevated CO_2 should be ceased to combat the harsh outcomes of climatic variations which will affect billions of people if its plinths are not stopped i.e. elimination of greenhouse gases particularly CO_2. The inhabitants of the developing countries have suffered and will suffer greatly from the consequences of climatic uncertainity as the rain patterns will observe a huge shift that will encourage the floods and water scarcity. To cope with the challenges of climatic changes and sequestration of C based greenhouse gases, effective and practical techniques are required to be opted for proper storage within the soil. A major intervention is the pyrolysis technique that converts biomass in absence or limited oxygen and controlled conditions of temperature and pressure to a carbon rich compound shortened as biochar from biomass-charcoal. Biochar, has been characterized as a stable, long lasting product of pyrolysis with potential of increasing agricultural production as soil amendment, C-sequestration from sustainably sourced feedstock. This review provides a glimpse of current scientific research in biochar as a climate change mitigation tool. Biochar at the rate of 0.5% being a carbon rich product has potential to improve total organic carbon in soil from 23-30% along with its other agronomic uses for soil improvement in terms of soil CEC, pH, bulk density, water and nutrient holding capacity, microbial activity enhancer, remediation of polluted and degraded soil besides its C-sequestration potential for mitigation of climate change.

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1. Climate Change and Its Rationale

Climate change is an elementary threat for the human life as it flourished due to anthropogenic activities. The Arctic sea ice loss is mainly due to the anthropogenic activities since 1979 (IPCC, 2013). According to NASA 2013, the climate scientists agreed on the point that earth's lower atmosphere and oceans are warming with temperature and sea level rise due to global warming (Bernstein et al. 2007). Climate change is characterized by anomalies in state of the climate which may be recognized as the deviation from the means or inconsistency in its properties lasting for a protracted period usually one to three decades or longer owing to natural variability or because of human activities. As defined by United Nations Framework Convention on Climate Change (UNFCCC), climate change is linked with the human

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activities directly or indirectly that changes the configuration of the global atmospheric conditions and which is in addition to natural climate changes observed over equivalent time periods (FAO, 2008) and now it has been accepted globally as an undeniable reality and greatest challenge to cope in modern time.

Billions of people, particularly in developing countries, will suffer from the impacts of climatic vulgarities in next few decades as predicted by Intergovernmental Panel on Climate Change (IPCC). Rainfall patterns of areas would be shifted that will contribute to unadorned water scarcities or overflowing, and increasing trend in temperatures will cause the shift in crop's growth periods. Crop yields may reduce in tropical areas by an increase in temperature to a predicted value of 1 to 2.5 °C by 2030. The entire world population would experience the health and life risks by food shortages and distribution of disease vectors (IPCC, 2014).

The entire problem of increase in global warming, the greenhouse gases play a vital role that increase the atmospheric temperature. Among these gases, atmospheric carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4) are the important ones. By an estimation (Smith et al., 2007), agriculture sector contributed globally an emission of 5.1-6.1 Pg CO_2 equivalents per year, which is 10-12 % of the entire global human related emissions of greenhouse gases (GHGs) in 2005. Agriculture has came up as one of the big factors that have been polluting the environment and accelerating global warming. Agriculture sector discharges significant amount of nitrous oxide and methane to the atmosphere, the emission of greenhouse gases from the agricultural ecosystems may be reduced by enhancing soil organic carbon sequestration and storage in soil while reducing the emissions of methane and nitrous oxide by proper management (Mosier et al., 2006; Smith et al., 2008). Owing to extensive use of nitrogen fertilizers, about two third of global N_2O is emitted from the soil. With the reduction in the use of N-fertilizers, mitigation of N_2O can be accomplished which can only be feasible by increasing amount of nitrogen adjusted by crops through improved management of N and this could be possible by a pyrolised material or the charred product biochar (Cayuela, et al., 2013).

According to a technical report published by Food and Agriculture Organization (FAO) in 2008, agriculture accounts for less emission of CO_2 while playing significant roles in the emissions of N_2O and CH_4 whose impact goes far more than CO_2 (FAO, 2008). The emission of gases reported from the soils and enteric fermentation were 60% percent of nitrous oxide and 50 % of methane respectively. As per estimation, there is increase in methane and nitrous oxide emission of 17% from 1990 to 2005. This amount could further increase till 2030 by 35 to 60 percent more. This could mainly happen by the extensive use of nitrogen fertilizers and livestock production which is struggling to fulfill the escalating demand of food by the ever increasing population suggesting to think about sustainable solutions to these problems.

2. Biochar

Biochar is the product obtained by the process of pyrolysis in the complete or partial absentia of oxygen with temperature range for pyrolyzing is about 400 to 900 °F (204 to 482 ℃) (Swanson, 2013). Less char is produced from biomass by the utilization of limited amount of oxygen and usually higher temperatures to burn the flammable gases mixture called syngas (Swanson, 2013). The overall process is an exothermic which can be successful tool for energy production. Biochar is obtained at relatively low temperature (< 700 °C) as a carbon rich product after the pyrolysis of plant biomass or organic material (Lehmann and Joseph, 2009). Moreover, biochar not only sequester C but also it is equally important for the reduction in emission of GHGs such as N related from the livestock production as NH_3 and N_2O (Galloway and Galloway, 2008). Woolf et al. (2010) reported that annually 12 % reduction in net release of CO_2, CH_4 and N_2O is possible when the pyrolised material is used for sequestration of C into soil. Recent assessments indicate that increased and well-managed biochar production with subsequent application to soil could perform a noteworthy part in mitigating greenhouse gas emissions and climate change (Lehmann et al. 2006, Woolf et al. 2010). Zhang et al. (2010) also described that biochar might be helpful in the reduction of nitrous oxide and methane release from agricultural soils. Addition of biochar has proven environmental friendly as it has the potential economic value in the better agricultural productivity, saving water quality and reduced emission of these GHGs. The important benefit involves the carbon sequestration in soil for a longer time period. With beneficial effects, biochar is under greater attention of climate and policy analysts. So its technical and practical feasibility with targeted benefits to soil and climate must be considered thoroughly.

Pertaining to climate change mitigation in agriculture, biochar could be a helpful tool as it assumed to be one of the best counters for increasing soil organic carbon when pyrolyzed from crop straw and added to the soil. This will enhance the soil fertility and better functioning of the ecosystem as reported by (Lehmann et al., 2006; Sohi et al., 2009). Biochar exhibited a great potential of climate change mitigation than the burning of same biomass for bioenergy and applied to soils for mitigation strategies (Woolf et al., 2010). Biochar has various beneficial effects that includes the enhancement of soil water holding capacity, source of bioenergy, tool for the reclamation of degraded soils, reduction of soil nutrients and chemicals runoff from agricultural fields (Woolf et al., 2010).According to, the positive and negative impacts of C sequestration as biochar on environment should be measured (Lehmann et al., 2006). By incorporating biochar in soil, NH_3 and N_2O emissions could decrease to a substantial level. This could happen in certain ways including the uptake and adsorption of nitrogenous compounds by biochar. Soil porosity levels, water holding capacity and soil physical properties can be improved by the addition of biochar into the soil which would result in reduced emission of N_2O. The important aspect of adding biochar into the soil lies in the fact that it improves the nutrient availability level in the soil which can change the plant growth resulting in the microbial activity for the less production of N_2O (Bailey et al., 2011; Smith et al., 2010). et alBy increasing the biochar residence time in soil, biochar can be oxidized and this alter its properties (Abiven et al., 2011; Brodowski et al., 2005; Hilscher and Knicker, 2011). Biochar will have an increased residence time in the soil when it is oxidized that will result in changing properties of biochar. It can be added in soil and changes with passage of time make it effective. Research studies on biochar related to grazed pasture system is very limited as much of work was done on other aspects like N cycling and N fluxes. For the application of biochar, there should be an improved understanding in the grazed pastoral ecosystems for the study of N cycling and N losses from such sites (Taghizadeh-Toosi, 2011).

According to the studies carried out by Spokas and Reicosky (2009), non-CO_2 GHGs emission could vary by the application of biochar to the soil that might have changed biochar properties as well. When biochar amendment of birch material at 9 t ha^{-1} was used, this resulted in the increased CH_4 uptake with no decreasing trend of N_2O emissions from agricultural soils of Southern Finland (Karhu et. al 2011). By using the ruminant's urine with application of biochar, 50% decrease in N_2O flux was observed in a case study carried out in New Zealand by Taghizadeh-Toosi et al. (2011). Zhang et al. (2010) added the 10 and 40 t ha^{-1} wheat straw biochar resulted continuous decrease in total N_2O emission with 40-51% with nitrogen application and 21-28% without N application while without accounting the N application, methane (CH_4) emissions increased by 34-34% which were the result of his first year experiment. When Knoblauch et al. (2010) conducted a study of 2 years, they found that methane emissions increased significantly with the use of 41 t ha^{-1} carbonized rice husks on a rice paddy so its optimum use is direly needed and more studies recommended for fully characterizing the biochar material.

3. Mitigation Potential of Biochar

Greenhouse gases sink enhancement and reduction in the sources was due to the human involvement into the system. Mitigation is the use of technology to reduce inputs and the emissions per unit output. According to a report by FAO (2008), mitigation from climate change perspective is implementation of policies to cut greenhouse gas emissions and enhancement of sink capacity. Intergovernmental Panel on Climate Change (IPCC) reports the global potential for technical mitigation in agriculture sector exclusive of forestry and fossil fuel offsets from biomass, and including all gasses would be between 5500 and 6000 Mt of CO_2 equivalent per year by the year 2030 and 89% of which were supposed to come from sequestering carbon in soils. This valuation of mitigation potential remained an important tool for policy and setting priority at the national level (FAO, 2008).

Carbon sequestration is one of the most inspiring options with variable ranges of interaction among available inovations. For the welfare of the living things by making the soil more productive and for enhancing the water holding capacity of soil, there is dire need of increasing soil carbon concentrations with the help of better management options. This practice would reduce the use of chemical fertilizers while decreasing land degradation and increasing the food security with improvement in ecological processes (FAO, 2008). In recent years, the production and application of charred or "carbonized" biomass has received tremendously increased interest as a technique that may have significant climate change mitigation potential (Woolf et al. 2010). Charred biomass deliberately incorporated into soil for long term carbon stabilization and soil amendment is typically referred to as biochar which is different than charcoal which has mainly its use for energy and further can contribute to emissions rather than sequestration of C and this differentiate them on the basis of their applications (Swanson, 2013).

4. Environmental Benefits of Biochar

Certain environmental benefits can be achieved by the use of pyrolyzed biomass i.e. biochar. According to Sohi et al. (2009) physico-chemical properties of soil could be enhanced by the addition of biochar in soil that will retain the water and nutrients which will be helpful for maintaining balance in irrigation and fertilizer requirements. By the addition of biochar in soil, it would ultimately adsorb pesticides, nutrients and minerals, resulting in the prevention of these chemicals to reach ground water.

Biochar based soil amendments have been reported extensively to improve biogeochemical processes and microbial communities in the soil. An increasing interest has been noted in biochar use for its role in improving soil fertility and for enhancement of sequestering carbon in soil as a technique to confront global climatic changes along with enhancing various ecosystem services (Lehmann, 2007). Supplementation of biochar to soils has potential to change the physico-chemical properties of soils such as soil organic carbon content, soil pH and cation exchange capacity (Lehmann, 2007) along with nutrient cycling, while reducing the greenhouse gases emissions that's why in climate smart agriculture the inclusion of biochar practices would definitely prove beneficial.

5. Stability of biochar in the soil

The most distinguished characteristic of biochar is its steadiness in the soil comparative to the other sorts of organic carbon constituents (Nguyen et al., 2008). Plant biomasses have shorter span of life in the soils than biochar which is more stable. It is believed that biochar has on average stability or residence period of 10,000 years in soils once applied which is several fold higher than any other organic matter. Moreover, Verheijen et al. (2010) were of the view that the residence periods for biochar made from woody biomass in soil is in the range of 10-1000 times extended as compared to other soil organic materials i.e. farm yard manure and compost. Consequently, biochar supplementation to soil can serve as a carbon sink with greater potential. Provided a definite amount of carbon that moves in cycles annually via plants, almost 50% of that could be brought out of the naturally existing cycle and can be sequestered in a sluggish biochar cycle. Several factors such as parent material, soil types and temperature of pyrolysis determine biochar stability (Lehmann and Joseph, 2009) so studies to check these diverse properties of various materials and processing times and pyrolysis conditions need to be experimented in long term planned sites and with various types of biomass to compute the quantified and realistic potential hidden in this state of the art intervention that helps in recycling and natural balance of carbon.

6. Carbon sequestration by biochar

Naturally, the balance in carbon cycle is maintained by the release of CO_2 from the decomposition of plant debris. This process is comparatively rapid than biochar. The fundamental phenomenon of biochar as a technical intervention is to 'uncouple' carbon cycle by preventing the rapid decomposition of plant biomass. This biochar material basically sequestered carbon (C) is highly resistant to decomposition due to its stable nature. Thus biochar application promotes carbon-negative process in the natural carbon cycle as it slows down the reversal of CO_2 from the geologic sink i.e. soil to the atmospheric sink and stocks carbon in a virtually stable soil carbon pool. Biochar's technical intervention has increased potential for adaptation in areas that have large agricultural industries including forestry, where production of huge amounts of waste feedstock in the form of biomass is available. The advantageous effects of bringing out CO_2 from atmosphere and incorporation of biochar in soil enables the emissions to be reduced in the form of greenhouse gases (GHGs) and escalate soil functions (Lehmann et al., 2006). Biochar application as a soil conditioner in certain circumstances could provide multifaceted benefits, including: i) cation exchange capacity (CEC) enhancement of soils (Glaser et al., 2002); ii) soil nutrients provision (Wang et al., 2012); iii) and crop yield increase (Graber et al., 2010); and iv) with soil pH neutralization (O' Neill et al., 2009). A decrease in non-CO_2 greenhouse gas emissions from soil is also reported, such as methane (Karhu et al., 2011). When biochar is applied it promotes adsorption of NH_3 and ammonium ions on biochar's surface (Taghizadeh-Toosi et al., 2011), consequently alters nitrogen ammonification, nitrification, denitrification, and volatilization (Clough et al., 2013).

7. Conclusion and Future Recommendations

Various technologies evolved and finished overtime except the ones which really benefitted humanity. The adoption of biochar still in Pakistan is under research phases and solid outcomes of the application of biochar are not yet evident but in long term studies it may show better outcome. Pakistan has big potential for recycling waste organic materials to produce biochar by pyrolysis, pyro gasification and other upcoming technologies which are efficient in production and combining with the bioenergy use along with production of biochar. Various feedstock like cotton sticks, bagasse, maize Stover and straw from rice and other cereal crops which have been used for burning mainly and their combination with manures and litter from rural poultry can produce nutrient enriched biochar for soil. The competition of utilization of farm waste must be considered for animal feed and bioenergy.

High pH soils constitute the major farmlands in Pakistan so low pH end product should be preferred as soil conditioner and the technology exists for that. Preliminary researches on biochar impact on soil properties have been encouraging so the biochar, bioenergy and soil amendment potential from changing climate perspective should be given due consideration at provincial and national level agricultural policies. Saline, eroded and degraded soils are common challenges to soil improvement due to unsustainable practices in Pakistan.

Suitability of biochar production in bulk at site specific and localized union council level setup may give a big opportunity for climate change mitigation and certified emissions reductions (CERs) or carbon credits earning could also be possible apart from its various benefits for soils. Technologies of pyro-gasification, and other advanced pyrolysis techniques can be very helpful for future development of biochar and bioenergy sector in the agricultural and energy domains.

Further research based studies on application, quantification of impact, feasibility of production and economics of using the biochar from environmental perspective may help in developing biochar science and technology in agricultural and environmental sciences. Pilot scale studies to long term large scale studies at the various research stations should be planned by the agricultural research and adaptive research wings. Pakistan biochar initiative has been launched from university of agriculture Faisalabad and efforts are being made and are also suggested for an integrated program at nationally important agro-ecological zones is the suggested next step for government and policy makers.

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