Chapter 7
Prospects of Biochar in Alkaline Soils to Mitigate Climate Change

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Abstract Climate change is one of the most threatening issues persisting on the planet earth; challenging the existence of life due to greenhouse gases emission including atmospheric carbon dioxide concentration. Additionally, unpredicted shift in climatic indicators may hinder the sustainability of life. It is, thus, imperative to combat these harsh climatic variations by controlling emission of greenhouse gases especially carbon dioxide. Soils serve as source and sink for greenhouse gases including carbon dioxide, methane and nitrous oxide. Therefore, the accurate quantification of storage and emission capacities are needed to obtain reliable global

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budgets that are necessary for land-use management, global change and for climate research. The inhabitants of the developing countries have suffered and will suffer greatly from the consequences of climatic uncertainty 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 emission of greenhouse gases, effective and practical techniques are required for the storage within the soil. An efficient and cost-effective method for this purpose could be the pyrolysis of biomass in the absence or limited oxygen and controlled conditions of temperature and pressure to a carbon-rich compound called as biochar since biochar has been characterized as a stable and long-lasting soil amendment possessing a wide potential of increasing agricultural production, carbon sequestration, and environmental quality. Researchers have been explored and investigated its applications mostly in acidic soils but data regarding its potential benefits in alkaline soils is lacking. This chapter will provide an insight into latest scientific research of biochar as a viable option for combating climate change hazardous in alkaline arid soils. The characteristics of biochar responsible achieving these benefits will also be discussed. Additionally, modification techniques of biochar suiting alkaline soil will be the part of this chapter since the use of biochar as soil amendment is normally not recommended for alkaline soils due to its alkaline nature. However, as a cost-effective soil amendment, especially for climate change mitigation, needs detailed discussion to highlight all aspects of biochar could be exploited for alkaline soils being a carbon-rich product has potential to improve total organic carbon in soil 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 carbon sequestration potential for mitigation of climate change.

Keywords Climate change · Biochar · Organic carbon · Alkaline soils

7.1 Introduction

Climate change has boomed due to anthropogenic activities and is becoming a major threat to human life (IPCC 2013). The environmentalists have established that the earth's lower atmosphere and oceans are warming sea level rising due to global warming and now it has been accepted globally as an undeniable reality and greatest challenge to cope in modern time (Bernstein et al. 2007). The patterns of rainfall would be shifted which will contribute to unadorned water scarcities or runoff. Furthermore, increasing trend of atmospheric temperatures will force change in crop growth pattern which may reduce crop yields 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 2014a, b; Fahad and Bano 2012; Fahad et al. 2013, 2014a, b, 2015a, b, 2016a, b, c, d, 2017, 2018, 2019a, b).

The agro-ecosystems are both sources and sinks for greenhouse gases and their contributions in mitigating climate change depends on dual strategy (i) decreasing greenhouse gas emissions (ii) increasing sinks so that the net impact on global warming is less than at present. The emissions of carbon dioxide, methane and nitrous oxide occur due to various agricultural activities including land plowing, fertilization, and animal husbandry (Denman et al. 2007). Therefore, the reductions in emission of greenhouse gases can be obtained through decreasing the fast conversion of organic carbon to carbon dioxide and by better management of agricultural wastes to control the release of methane and nitrous oxide. Current sinks include carbon capture in crop biomass and soil organic matter. In addition, oxidation of atmospheric methane by soil bacteria also contributes in this respect. These sinks can be enhanced by increasing net primary productivity to capture more atmospheric carbon dioxide and by promoting more oxidation of methane by soils (Lehman et al. 2010). The entire problem of increase in global warming and greenhouse gases increases the atmospheric temperature ultimately. Among these gases; carbon dioxide, nitrous oxide, and methane are important.

Although many people typically attribute carbon dioxide emissions to energy production, there are other important contributing activities, such as transportation and agriculture. The most recent Intergovernmental Panel on Climate Change (IPCC) reported that the agriculture, forestry, and land-use sector was responsible for about one-quarter of global greenhouse gas emissions. Why have emissions from agriculture been increasing with time? There are two key contributors to increasing emissions. Firstly, a growing global population requires an overall higher food production. This increased requirement for food has led to both expansion of agricultural land and intensification of farming practices (IPCC 2014a, b). Agricultural land often expands into previously forested areas, and this process of deforestation releases carbon dioxide stored in trees and soils. These emissions are included in the accounting related to agriculture, forestry, and land use and it is estimated that up to 80% of deforestation is the result of agricultural expansion. Secondly, global economic growth has not only resulted in an increase in food demand but also in changes in dietary composition; that is, changes in what we eat. Economic growth is typically related to an increase in meat consumption. Livestock is an important source of greenhouse gas emissions, with variations between animal and chicken products (Tilman and Clark 2014) (Fig. 7.1).

Biochar is a carbon-rich product produced through thermochemical processing of biomass under an oxygen-deficient environment. It has been a hot topic of research in recent years due to its versatile role in soil biogeochemical processes. The most important ecological functions of biochar include acting as a long-term carbon sink for climate change mitigation (Bird et al. 2017). Moreover, biochar not only sequester carbon but, also equally important for reduction of greenhouse gases emission including ammonia and nitrous oxide as investigated by Woolf et al. (2010) that 12% per annum reduction in emission of carbon dioxide, methane and, nitrous oxide is possible with biochar when it was used for carbon sequestration into

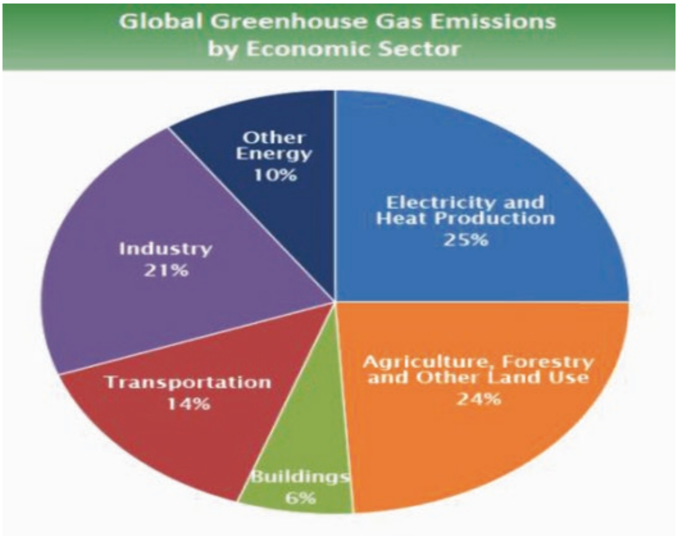

Fig. 7.1 Share of GHGs by different economic sectors. Source: IPCC (2014a, b)

soil. Recent researches further confirmed that biochar application to soil is very efficient in mitigating greenhouse gas emissions and climate change (Zhang et al. 2010). It has been proved that the addition of biochar is environmentally friendly and it has potential economic value in the better agricultural productivity by saving water quality and reduced emission of these greenhouse gases. The most significant feature of biochar is the carbon sequestration in soil for a very long period of time. Consequently, 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 (Rasul et al. 2016).

It has been estimated that biochar systems can mitigate up to 1.8 Pg carbon, per year without endangering food security, habitat or soil conservation – a larger climate-change mitigation potential than using the same biomass for bioenergy (Woolf et al. 2010). From a global and policy perspective, the potentially negative impacts of biomass use on climate forcing must be considered. These include the effects of soot and trace gases that are emitted into the atmosphere during combustion. Airborne transport and deposition of soot has been implicated in the acceleration of polar ice melt, but conversely in facilitating cloud formation and 'global dimming'. Since, biomass burning accounts for 10% of global methane and 1% of nitrous oxide emissions. Although biochar production may contribute to these emissions but in long term till the major shift it would help in decreasing these emissions (Woolf 2008).

Most of the research conducted so far regarding potential benefits of biochar as soil amendment and climate change mitigating tool has been focused on acidic soils but biochar prospects in alkaline arid soils cannot be ignored since alkaline soils ($pH > 7$) are mostly situated in arid and semi-arid areas of world covering about

700 million hectares around the world (FAO 2002). These soils characterized by low organic carbon (Brady and Weil 2010), high soil pH, with deposition of calcium carbonate-containing loess materials, or developed from calcareous parent materials. These affect the microbial activity and soil microbial biomass causing changes in soil respiration, especially when the soil is dry (Mavi et al. 2012). In alkaline conditions, increase in soil organic carbon mineralization and bulk density is a common issue which reduces flocculation of aggregates and breaks down soil structure which also promotes soil erosion and degradation (Wong et al. 2008). Organic matter plays an important role in forming soil structure but common organic biomasses are prone to rapid mineralization in alkaline soils. Hence, biochar can play a crucial role in alkaline soils due to its recalcitrant nature and ability to limit greenhouse gases emission. A detailed discussion regarding benefits of biochar to mitigate climate change will be carried out in next heading of this chapter to reveal its significance for alkaline soils.

7.2 Prospects of Biochar to Mitigate Climate Change in Alkaline Soil

The idea of using biochar for carbon sequestration and climate change mitigation has earned wide popularity among the researchers during the recent time due to its versatile potential of excellent soil amendment and greenhouse mitigation strategy for sustainable environmental management (Paustian et al. 2016). The most vital capability of biochar is its recalcitrant and resistant nature against rapid mineralization compared to other organic amendments. Lehmann (2007) indicated that biochar has potential to retain carbon in host soils for hundreds to thousands of years as it can be proved from Terra Preta soils of the Amazonian region in Northern Brazil (Wang et al. 2016). It is still under debate that how biochar mitigates greenhouse gases emission. It could be conversion of agriculture and forestry wastes in biochar may minimize carbon dioxide and methane emissions compared to natural mineralization of original waste.

Biochar has potential to control emission of greenhouse gases through three primary pathways (i) bioenergy produced by pyrolysis may minimize greenhouse gases emission by converting biomass carbon into recalcitrant carbon, (ii) biochar can increase soil quality which may increase net productivity which ultimately reduces economic pressure to convert native lands to agricultural production, (iii) biochar applications may directly reduce GHG emissions from soils (Fidel et al. 2019). Several researchers have investigated that (1) biochar improves soil aeration and immobilization of available nitrogen in the soil, resulting in the suppression of denitrifier activities (2) increases soil pH and the relative abundance of the bacterial nitrous oxide reductase nosZ gene that reduces nitrous oxide to elemental nitrogen more efficiently (3) increases adsorption of organic compounds and microbial inhibiting compounds, such as ethylene (4) increases adsorption of nitrous oxide, nitric oxide and ammonia onto the biochar surface. But the extent of the reduction in emissions is, however, dependent on several factors such as biochar type, soil and environmental conditions (Borchard et al. 2019). Biochar may also reduce greenhouse gases emissions by influencing soil microbial community size (Zhang et al. 2014), composition (Lehmann et al. 2011) and by providing substrates to microbes (Singh et al. 2010) and water/oxygen. Additionally, biochar is believed to change soil redox conditions (Cayuela et al. 2014). Overall, most of studies reported that biochar reduces emissions (Case et al. 2015; Ameloot et al. 2016) however some also revealed contrary findings (Cheng et al. 2012; Wang et al. 2014).

Considering all above-stated information, it is important to understand potential benefits biochar in alkaline soils since most of biochars are commonly alkaline in nature (Jiang et al. 2012) which may contribute their liming effects to soils and alkaline soils already have alkaline soil pH. However, biochar pH generally ranges from acidic to alkaline (Chan and Xu 2009) but lower pH biochars are normally neglected. Biochar pH increases with increasing pyrolysis temperature as acidic functional groups are depleted at higher temperatures (Ippolito et al. 2016). But, biochars those are produced at low temperatures could be acidic (Zhang et al. 2017). Similar findings were reported by Hagner et al. (2016) who produced birch biochar at 300 °C and 375 °C having acidic pH 5.1 and 5.2, respectively while Novak et al. (2009) pyrolyzed Pecan shell at 350 °C and switch grass at 250 °C which has pH 5.9 and 5.4, respectively. Meager literature available in this respect shows that the lower pH produced at lower temperature could be acidic which initially increase plant-available nutrients in arid calcareous soils (Ippolito et al. 2016). Similarly, neutral biochars may also behave differently from normally available alkaline biochars in environmental processes after being added into soils.

Some recent studies have also revealed the modification of biochar for a specific purpose. In the next section we will discuss options of modification of biochar for its beneficial use in alkaline soils to achieve its potential benefits for mitigation of climate change.

7.3 Modification of Biochar for Alkaline Soils

In recent times research has been focused on the use of biochar in highly weathered soils but biochar use in less weathered temperate and arid systems is a relatively new concept. Soils under arid and semiarid climates are alkaline. Generally, increasing pyrolysis temperature increases nutrient content, specific surface area and pH of biochar (Kloss et al. 2012). Furthermore, increase in pyrolysis temperature will remove the acidic functional groups and causes biochar to become more basic (Ahmad et al. 2012) because higher pyrolysis temperature enhance minerals like potassium hydroxide, sodium hydroxide, and calcium and magnesium carbonate which ultimately results in rising pH of biochar (Cao and Harris 2010). So, the biochar is not suitable for alkaline soils generally. Beneficial use of biochar in alkaline soils is only possible when biochars are produced with lower pH. Thus, there is research gap to develop biochars for alkaline arid and semi-arid climatic regimes.

The inherent variability of biochars proposes that the biochars can be modified for specific situations. Biochars produced at low-temperature exhibit low pH and these could improve the environmental quality by reducing nutrient losses in calcareous soils (Ippolito et al. 2012). The addition of high levels of biochar adversely affected plant growth and there were no significant positive effects on growth and soil properties in calcareous soils. Addition of biochar increased soil pH and EC. It also increased the Proline content which created abiotic however biochar can be used as a soil amendment at application levels of less than 2.5% in alkaline soils (Mohawesh et al. 2018). Biochar can be modified by acid, alkali, oxidizing agents, metal ions, carbonaceous materials, steam, and gas purging. The selection of modification methods depends on the environmental application fields. The biochar has been used for soil remediation and amelioration, carbon sequestration, organic solid waste composting, decontamination of water and wastewater, catalyst and activator, electrode materials and electrode modifier (Wang and Wang 2019).

In order to obtain desirable biochar properties for climate change mitigation in alkaline soils, different modification methods could have been effective. In this manuscript, based on the previous work and recent advances in these modification techniques including ball milling, microwave modification, biological modification, etc. will be discussed while the focus will be on its environmental applications. The characteristics of modified biochars are mainly influenced through pyrolysis conditions, feed-stocks and modification techniques (Wang et al. 2017). A wide range of feed-stocks are used to produce modified biochars but the production conditions and applications of these biochars needs careful attention to understand their specific characteristics for long term beneficial applications. The adsorption properties of modified biochars are largely determined by their porosity, surface functional groups, and specific surface area. Therefore, according to different application requirements, the synthesis of these modified biochars can be directed since the characteristics of feed-stocks, preparation methods and conditions can change the performance of modified biochars (Tripathi et al. 2016).

The porosity of biochar can be modified to a certain extent by the selection of feed-stocks or by modifying raw material through biological, chemical and physical modification techniques or by a combination of any of these techniques. In biological modification, the biomass is pretreated with anaerobic digestion or bacterial conversion (Zhang et al. 2017). After anaerobic digestion, the digested biochar showed higher pH, surface area, cation and anion exchange capacity, hydrophobicity and more negative surface charge than pristine biochar (Inyang et al. 2010). The physical modification includes gas activation, magnetic modification, microwave modification, and ball milling. Physical modification improves pore structure, introduces oxygenic functional groups and more beneficial than chemical modification since physical modification agents are easy to control (Qian et al. 2015). The physical modification increases the adsorption capacity of modified biochar to organic pollutants by increasing the specific surface area and creating more micropores and mesopores on biochar. The advantages of physical modification include no added

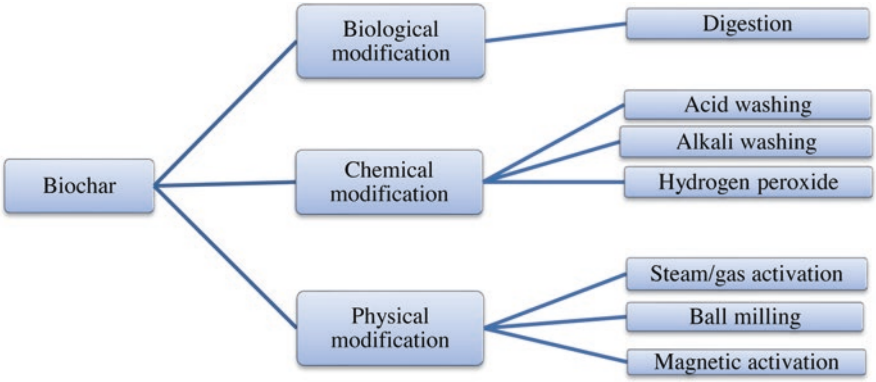

Fig. 7.2 Schematic diagram of biochar modification techniques

impurities and low cost. Chemical Oxidation means oxidation of the biochar surface to increase the oxygen-containing functional groups which increase its hydrophilicity, pore size and structure, adsorption capacity. Most commonly used oxidation chemicals are hydrochloric acid, nitric acid, hydrogen peroxide. It has been found that compared to hydrochloric acid, nitric acid provides more oxygen-containing functional groups. Chemical modification can significantly increase the acidic groups on the surface of activated carbon, improve the surface hydrophilicity of biochar and reduce the pH value which may suit alkaline soils to achieve the benefits of climate change mitigation.

An increasing interest in the beneficial application of biochar has opened up multidisciplinary areas for research. Biochar could be an efficient sorbent of various contaminants both organic and inorganic because of its huge surface area and special structure (Xie et al. 2015). The ultimate purpose is to apply differently modified biochars into environmental, agricultural, and energy sustainability. As a low-cost and efficient amendment, biochar could be used in different areas. The multiple areas where modified biochar applications could potentially be used in include carbon sequestration, soil fertility improvement, water/soil pollution remediation, and climate change mitigation (Tan et al. 2017) (Fig. 7.2).

7.4 Stability of Biochar in Alkaline Soils

The stability of biochar is fundamental to its efficiency in reducing greenhouse gas emissions. The most important feature of biochar is its very long stability in soil compared to other f organic amendments. The mineralization of other organic amendments is more rapid in alkaline soils due to temperature extremes (Nguyen et al. 2008). It has been well documented that other organic biomasses have much shorter retention in the soils compared to biochar. The average residence time of biochar in soil is about 10,000 years (Rasul et al. 2016). The stabilization of organic material in alkaline soils due to presence of calcium is better (O'Brien et al. 2015) which was also confirmed by Oades (1988) who reported better and longer soil organic carbon retention in alkaline calcareous soils which could be attributed to decreased solubility of organic carbon due to the presence of calcium. So, the addition of biochar to soil can serve as a carbon sink with greater potential. Several factors such as parent material, soil types and temperature of pyrolysis determine biochar stability (Leng et al. 2019) so studied regarding retention of biochar and its impact on combating climate change needs thorough investigations in alkaline soils since the data regarding this aspect is lacking but literature review shows that biochar with some modifications has great potential to be exploited as tool for climate change mitigation in alkaline soils.

7.5 Impact of Biochar on Soil Carbon Sequestration

The biochar sequestered carbon is highly resistant to decomposition due to its recalcitrant nature. Thus biochar application promotes carbon-negative process in the natural carbon cycle as it slows down the conversion of soil carbon to atmospheric carbon dioxide. It retains carbon to stable soil carbon pool. The advantageous effects of returning carbon dioxide from the atmosphere and addition of biochar reduce greenhouse gases emission and escalate soil functions (Lehmann et al. 2006). It has been estimated that Earth's soils are stored around four times more organic carbon than in atmospheric carbon dioxide (Lehmann 2007). While evaluating for carbon sequestration potential stability of biochar is an important parameter since only a long half-life will ensure a relevant sequestration potential by offering a wider resistance towards decomposition of biochar through soil microbial communities. Stability of biochar simply determines how long carbon held in the soil in the form of biochar will remain sequestered in soil system and at the same time how long it may influence emissions of greenhouse gas from the soil system and help in the counterbalancing the effect of climate change. It has been found that conversion of plant biomass to biochar using pyrolysis process followed by its application to the soil increases the residence time of carbon in the soil as compared to when same plant biomass applied directly to the soil. The benefits of biochar in terms of higher carbon sequestration have been found significantly greater with increase in the stability of charred product (Yadav et al. 2017). It has been widely reported that the biochar contributes to soil recalcitrant carbon pool (Marris 2006). Therefore, it is a promising strategy to sequester more carbon compared to traditional agricultural practices involving direct incorporation of plant biomass in the form of crop residues that result in rapid mineralization of carbon leading to larger carbon dioxide release in the atmosphere (Bruun et al. 2011).

7.6 Impacts of Biochar on Carbon Dioxide Emissions

Carbon dioxide is a potent greenhouse gas and is responsible for global climate change due to its increasing atmospheric level. Chemical nature of soil including alkaline soil pH and intensive agricultural practices with low potential of carbon retention in alkaline soils are responsible for the increase in atmospheric carbon dioxide since high temperature promotes rapid mineralization of organic matter in these soils. Biochar, as a key technology, has been widely added to farmland soils to moderate global climate change. Biochar is highly resistant to degradation due to its recalcitrant carbon and it has potential to improve soil quality (Zimmerman et al. 2011). The addition of biochar has been documented to alter the soil porosity, moisture content, pH, labile C and N pool sizes which would markedly impact soil carbon dioxide emissions (Stavi and Lal 2013). However, previous studies have shown that biochar addition with different raw materials and different soil types can have different effects (an increase, decrease or no effect) on the carbon dioxide flux in the laboratory or field experiments (Wang et al. 2014). The underlying mechanism of carbon dioxide emissions induced by the addition of biochar is still needed investigation, especially for alkaline soil to obtain maximum benefits. Some studies have shown that biochar addition of biochar promote mineralization of soil organic carbon and correspondingly increase emissions of carbon dioxide (Luo et al. 2011). However, some studies reported a decrease in mineralization rate thereby causing a decrease in carbon dioxide emissions (Singh and Cowie 2014). The interactions of biochar and soil properties contribute to the different processes of soil organic carbon mineralization (Cely et al. 2014). Therefore, it is important to clarify the changes in soil carbon mineralization and the variation in the behavior of biochar after its incorporation into the soils. Shen et al. (2017) found in his study that biochar amendments in agricultural soil may serve as a potential tool for climate change mitigation, with lowering carbon dioxide emissions and higher dry matter production in semi-arid farmland over a longer period.

7.7 Impact of Biochar on Nitrous Oxide Emission

In recent times, the focus of biochar conditioner research has been on soil gases flux particularly on nitrous oxide emission. Most of research findings revealed that biochar is effective in decreasing the nitrous oxide emission while few studies have shown negative or no effect. The impact of biochar on nitrous oxide emission is variable and depends on factors including soil type, soil moisture, fertilizer application, biochar feed-stock, and pyrolysis conditions (Zhang et al. 2010). Liu et al. (2014) stated that the potential mechanisms were explored by terminal restriction fragment length polymorphism and real-time polymerase chain reaction. A lower relative abundance of bacteria such as ammonia-oxidizing bacteria and nitrite-oxidizing bacteria were observed at 4% biochar application rate. Reduced copy numbers of the ammonia monooxygenase gene amoA and the nitrite reductase gene nirS coincided with decreased nitrous oxide emissions. Therefore, biochar may potentially alter nitrous oxide emission by affecting ammonia-oxidizing and denitrification bacteria which is determined by the application rate of biochar in soil. A consistent observation is that gas emissions are dependent on pyrolysis temperature and amendment rates and the ethylene generated by fresh biochars may be linked to decreased nitrous oxide production (Spokas and Reicosky 2009). One important reason to increase the atmospheric concentration of nitrous oxide ranging from 0.2 to 0.3% per year is due to human activities. Among which about 80% is derived from agriculture (Beauchamp 1997) caused by the intensive use of nitrogenous fertilizers. The reduction in soil nitrous oxide production and emissions following biochar application may be due to increased plant nitrogen use efficiency which leaves lesser nitrate in the soil for denitrification, or there may be some direct influence on the soil physical and chemical properties that are critical to soil nitrogen transformations. In alkaline soils where nitrogen losses are high could be due poor soil structure and high soil pH which favors the nitrate and ammonia losses thereby restricting plant uptake. Biochar improves soil structure and hinders nitrogen losses. This may reduce the nitrous oxide emission ultimately.

7.8 Impact of Biochar on Methane Emissions

Global warming caused by greenhouse gases emission is a serious threat to human society. Methane is an important greenhouse gas with 28 times global warming potential than carbon dioxide with a unit mass at 100-year scale (IPCC 2013). The pre-industrial atmospheric concentrations of methane were 0.715 ppmv which currently measures 1.774 ppm and maintain a 0.6% increase in speed annually (Zhu et al. 2011). Studies have shown that methane emitted from soil accounts for 15–30% of the total emissions every year (Qu et al. 2016). Pratiwi and Shinogi (2016) revealed that soil properties such as increased saturated hydraulic conductivity and macro-porosity which cause methane emission could be improved with biochar application. In addition, decreased methane emission may be related to N speciation. The results showed that biochar amendment significantly reduced methane emissions by 45.8 and 24.1 kg per hectare and suppression was weaker along with increasing biochar addition level. Reduced methane emissions might be associated with decreased ratios of methanogenic archaea to methanotrophic proteobacteria and the increase in oxygen supply due to biochar application supports a group of aerobic methanotrophs (Feng et al. 2012). Soil texture and biochar pH are two critical properties affecting the response of soil methane flux to biochar addition.

7.9 Impact of Ammonia Emissions and Nitrate Leaching

The global ammonia production by human activities such as combustion of nitrogen-containing biomass, fossil fuels and use of ammonia-based fertilizers is estimated 45.0 million tons per year. It is very necessary to investigate some suitable techniques for controlling ammonia emission. The absorption and incineration have been used to eliminate ammonia emissions before releasing it to atmosphere (Guo et al. 2005) but using dry adsorbents for controlling emission of is very efficient approach which has attracted much attention due to its simplicity and economic feasibility in configuration and operation (Rodrigues et al. 2007) and also reported that ammonia adsorption by activated carbon it was found that more amounts of adsorbent had to be used for higher efficiency. Biochar can be used for various purposes can also be promising for ammonia adsorption onto its surface. Since capturing ammonia from soil is practicable using biochar, removal of ammonia from foul air using biochar might also be possible in alkaline soils since it is a big issue due to temperature extremes.

Studies conducted in different parts of the world have shown that farmers often use the variety of nitrogen fertilizers that exceed the nitrogen requirement of crops. Most of the studies conducted on nitrate leaching are from the regions where rainfall is abundant and well distributed but studies under semiarid condition are scares (Uusitalo et al. 2001). The consumption of high level of nitrate may cause health problems such as cancer and teratogenicity effect. Sandy soils consist of coarse soil particles and have a loose texture, making these soils particularly vulnerable to water and fertilizer loss, as well as relatively nutrient-poor (Zhang et al. 2015). Alkaline soils are generally impermeable and have little organic matter, with pH levels typically exceeding 7.5 are prone nitrate leaching (Huo et al. 2017).

7.10 Conclusions and Future Research Directions

Climate change mitigation by using biochar reduces the emissions of greenhouse gases from the soil. At present it is impossible to predict the emission reductions with biochar but it is possible to probe the potential of biochar to mitigate the climate change. Available research data and results under various conditions strongly justify continued research and development efforts in understanding more about the benefits and potentials as well as limitations of biochar and expanding its use in land management. The beneficial role of biochar application on the broader issues of climate change mitigation and sustainable agriculture invites further research to explore its true potential. Various technologies evolved and finished overtime except the ones which really benefitted humanity. The adoption of biochar in alkaline soils is under research process and solid outcomes of the application of biochar are not yet evident but in long term studies involving all proposed modification will surely yield better outcomes since all the indicators are in favor to achieve desirable results including climate change.

Alkaline soils constitute the one-fourth of world's farmlands which require organic amendments for carbon retention and to reduce soil pH. Recent research has proved that biochar is the most stable carbon source to mitigate climate change. Additionally, oxidation of biochar over time and some modification strategies may result low pH biochar which can potentially be exploited to combat climate change and other benefits in alkaline soils.

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. These directions may provide some insights into how the biochar affects net climate forcing from soil greenhouse gases flux and offers recommendations for the development and improvement of efforts against climate change in alkaline soils.

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