Chapter 5
Biochar as Soil Amendment for Mitigating Nutrients Stress in Crops

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Abstract Global food security is threatened by decreasing soil fertility and climate change. Moreover, soil erosion and salinity are depleting mineral nutrients through leaching, precipitation, and complexation and gas emissions. This issue can be solved by the addition of biochar, which improves soil fertility, crop productivity and carbon sequestration in soils. Biochar has a high sorption capacity which minimizes nutrient leaching in groundwater and surface water, and thus promotes the timely release of nutrients to crop plants. Biochar also increases the nutrient stocks in the root zone, which improves nutrients uptake. Biochar reduces greenhouse gas emissions by improving soil quality. This chapter details the role of biochar in mitigating nutrients stress, sequestering carbon and improving crop yield.

Keywords Biochar · Climate change · Crop yield · Food security · Nutrients stress

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5.1 Introduction

Among major challenges, poor soil fertility is one of the key problems around the globe which is directly linked to low productivity (FAO 2011). Soils in arid region are often characterized by poor physical properties, water scarcity, low organic matter and nutrients deficiency for plants (Khalifa and Yousef 2015; Ullah et al. 2022).

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Similarly, tropical climates of the world also face such types of problems for practicing sustainable agriculture. Because, the major plant nutrients are washed out from the root zone due to extreme weather such as high rainfall and temperature and presence of decomposers which results in improved soil organic matter mineralization (Bruun et al. 2015). Moreover, the decline in soil organic matter have undesirable affects soil fertility by affecting physico-chemical properties of the soil (Annabi et al. 2011), and ultimately threaten soil productivity (Lal 2015).

During 1960s (Era of Green Revolution), the application of sole mineral fertilizer was the main cause of increasing food production (Bationo and Waswa 2011). Though, sole application of mineral fertilizer is not the most appropriate remedy (Usman et al. 2015; Saleem et al. 2021). Therefore, the world needs sustainable and economical soil amendments. Biochar is a carbon rich material produced by the pyrolysis of organic solids (Lehmann et al. 2006). Its application might recover degraded and poor fertile soil and ultimately improve crop productivity. Improving soil quality through application of organic soil amendments is the key objective of this chapter, having specific emphasis on biochar.

5.2 Biochar Versus Other Organic Amendments

In nature the stability in carbon cycle is sustained by the production/evolution of CO_2 from the breakdown of the organic materials such as plant debris, which is a much quicker process (Wang et al. 2016). Therefore, the primary purpose of the introduction of wood biochar technology decreases the flow of carbon, deter the rapid degradation of plant materials, and store carbon in biochar, which is highly more stable compared to any other form of organic matter and strongly resilient to degradation (Beesley et al. 2011). Wood biochar reduces the return of CO_2 from soil to air and store carbon in a long-term soil carbon pool.

Higher probabilities of adopting biochar are observed in countries having huge farming, agricultural or forestry industries that generate greater quantity of waste materials for feedstock (Khan et al. 2020). Furthermore, El-Naggar et al. (2019) found that the influence of wood biochar on soil properties as well as on crop production is mainly determined by the feed stock used in production of wood biochar and temperature during pyrolysis. Moreover wood biochar of similar nature might have a different effect on both Alkaline and acidic soil (Peake et al. 2014; Mian et al. 2021).

The most differentiating property of biochar is its stable nature when compared to other organic materials (Beesley et al. 2011). Organic materials have a comparatively short life in the soil however wood biochar is highly stable (Hansen et al. 2016). Once practiced wood biochar has life span of 100–1000s of years in soil (Duku et al. 2011; Mehmood et al. 2021) which is much greater than any other organic substance. Lehmann and Joseph (2015) described that the total life of wood biochar in soil is ten to thousand times greater than other organic materials; therefore the addition of wood biochar to soil is a possible sink for carbon. Furthermore, stability of the wood biochar can be set by the particular feed stocks (materials used for production of biochar), the type of soil used and pyrolysis temperature.

5.3 Biochar Effects on Soil Properties

In general, various agricultural benefits has been recorded for biochar due to its uses as a soil amendment, these benefits mainly consists of high soil sorption capacity, minimizes nutrient leaching with groundwater or loss with surface water, and a slow nutrients release to crop plants (Salim 2016; Mensah and Frimpong 2018). It increases the nutrient stocks in the rooting zone, hence increased nutrients uptake and improve crop yield (Muhammad et al. 2017; Khan et al. 2022). The presence of plant nutrients in the biochar and its greater specific area, high porosity and its ability to create a favorable environment for microorganisms are the key causes for the enhancement in soil properties and improve plants nutrients uptake in soil amended with biochar (Nigussie et al. 2012).

Application of biochar is important and valuable because it cleans the polluted soils through adsorption and immobilization (Deng et al. 2017). In addition to the above biochar has also the ability to absorb pesticides contamination from the soils and subsequently decrease the overwhelming effect on the local environment (Rawat et al. 2019). To counter the conceivably of inaccessible nirogen, it has been discovered that utilization of biochar alongside nitrogen fertilizer can have beneficial outcomes, thus improve the effectiveness of mineral nitrogen fertilizer by decreasing the use of inorganic fertilizers and hence the cost as well (Sarfraz et al. 2017; Khalid et al. 2019).

It has been demonstrated previously that biochar application modifies the nitrogen dynamics in the soil (Lim et al. 2018) and decomposition of biochar in soil can prompt nitrogen immobilization in soil (Singh et al. 2010). Typically biochar has higher adsorption ability for nitrate and ammonium (Fidel et al. 2018), thus enhances the amount of ammonium-nitrogen in the soil (Clough and Condron 2010). Hence induces higher nitrogen uptake in plants (Cao et al. 2019). Reports are available that biochar application without nitrogen fertilizer does not improve crop yield; however, application of biochar at different levels 10, 50 and 100 t ha^{-1} and nitrogen at 100 kg ha^{-1} enhances yield as a result of enhancing use efficiency of nitrogen of crop plants (Ding et al. 2010).

Frequent and consistent applications of biochar to soil are not needed since biochar is not warranted as a fertilizer (Lehmann and Joseph, 2009; Fahad et al. 2020). Enhanced soil fertility status through wood biochar application is a renowned fact though the response of crop to biochar addition mainly depends on the type of materials used for preparation of biochar, its production process, soil properties and the nutritional composition of biochar (Schulz et al. 2013) (Fig. 5.1).

Chemical properties of the soil like such as electrical conductivity, pH, Soil nitrogen, phosphorus and potassium and physical properties like soil bulk density, soil structure, water holding capacity and pore spaces of the soil are greatly responsive to addition of wood biochar into agricultural soils. As a result adequate availability of water to crops is enhanced and soil erosion is reduced (Steiner et al. 2007). Furthermore biochar enhances/improves biological properties of the soil as well,

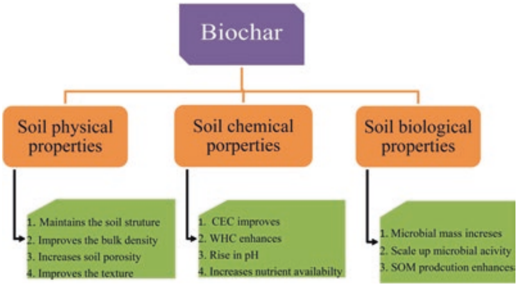

Fig. 5.1 Impact of biochar addition on different soil properties. The above figure showed summary about modifications in soil physical, chemical and biological properties in response of biochar application. CEC, WHC and SOM stands for cation exchange capacity, water holding capacity and soil organic matter respectively. (Modified and reprinted with permission from Murtaza et al. 2021)

which results in better growth of the crop plants that ultimately leads to improved crop productivity (Habtegebrial et al. 2007; Dawar et al. 2021).

The soil physical properties depend upon the interactive effect of the biochar with the physico-chemical properties of the soil. In contrast to the findings of Lehman (2007) wood biochar responses positively in acidic soils, and Van et al. (2010) who observed increased pH due to biochar, reduced micronutrient concentration in soil, which ultimately reduced crop growth and yield. Mohammad and Alamgir (2013) expressed a persuading impact regarding wood biochar on productivity of maize in alkaline soils. Biochar made from the waste of the pine forest was utilized to assess plant growth using two levels 2 and 4% wt/wt amended with alkaline, loamy sand soil. Similarly, Major (2010) also observed that incorporation of wood biochar results in reduce or high soil pH depends upon on the kind of feed stocks used to make biochar and also on the soil type.

After the addition of biochar, decomposition of the small organic molecules by the action of microbes get stared which liberate CO_2, organic acids and release initial ammonia content that cause reduction in soil pH, furthermore this reduction in pH might be different due to the nature of the applied wood biochar. While the rise in pH, might be due to the bacterial hydrolysis of protein that liberate $NH4^+$. The bulk density of wood biochar is considerably lesser when compared to soil bulk density; therefore incorporation of wood biochar decreases the soil bulk density (Ulyett et al. 2014). Substantial improvement in bulk density is possible in certain situations. At the point when the soil pores space is not absolutely filled by the biochar particles, it will bring about decline of the soil bulk density. Otherwise; wood biochar incorporation might improve soil bulk density if the applied biochar disintegrates rapidly into little particles and occupy the soil pores (Verheijen et al. 2010; Arif et al. 2021).

Khan et al. (2013) revealed considerable reduction in soil bulk density through the addition of wood biochar. Furthermore incorporation of wood biochar declined the soil bulk density and enhanced the soil water content both under field as well as pot moisture capacity conditions (Artiola et al. 2012). Chan et al. (2008) described that application of biochar decrease the threat of soil compaction through reduction in tensile strength. The incorporation of wood biochar decreases soil total nitrogen after 1st year of its application whereas no or significant effect were noted on soil total nitrogen content after 2nd years of field trial (Arif et al. 2012).

Generally alone application of wood biochar promote nitrogen immobilization in the soil (Gao and Deluca 2016) thus, causes deficiency of nitrogen in plants and decrease crop yield primarily because of higher C:N ratios (Lehman and Joseph, 2009). Incorporation of organic materials having higher C:N ratios (>20) results in immobilization of nitrogen (through microbes) and change inorganic nitrogen to organic form (Kizewski et al. 2019). When both wood biochar and mineral fertilizer particularly nitrogenous, are applied to soil in integrated form than the process of mineralization dominant over immobilization. Hence, soil nitrogen content is enhanced. Though, the exact quantity of easily biodegradable organic substances present in biochar is not the single choice for microorganisms to encourage immobilization of the available nitrogen.

Ameloot et al. (2015) are of the opinion that biochar can potentially enhance nitrogen mineralization by sorting organic molecule from the soil solution when applied to the field. Likewise, Oladele et al. (2019) revealed that the use efficiency of nitrogenous fertilizer possibly be improved if the soil is amended with a certain quantity of wood biochar. Various woods biochar may positively alter soil biology due to their potential to increase the microbial biomass with considerable changes in microbial community composition (Lehmann et al. 2011; Amanullah et al. 2022). Wood biochar as soil amendments results in improved colonization of mycorrhizal fungi (Solaiman et al. 2011). The enhanced biological nitrogen fixation potential by legumes was observed following biochar application (Mia et al. 2014).

Similarly, Wu et al. (2016) observed an improved production of soil total nitrogen content through application of wood biochar. Sohi et al. (2009) indicated that cation exchange capacity is the capability of the soil to store and release cations of essential nutrients in a form which is easily available to plants and to decrease loses due to leaching. Biochar improve soil fertility and the concentration of the cation in soil when treated with soil. In case of high leaching situations, anthrosols amended with biochar has a greater ability to adsorb and retain greater cations (Lima and Marshall 2005), thus considerably increases the availability of all major cations (Topoliantz et al. 2005).

Glasaer et al. believe that the formation of carboxyl groups could be the main reason for greater cation exchange capacity of the soil amended with biochar. Zornoza et al. (2016) observed improved cation exchange capacity in biochar applied soil might be clarified by the presence of several chemical functional groups that render the biochar as an active chemical exchange surface. Nigussie et al. (2012) stated that the inherent cation exchange capacity of wood biochar is steadily greater than that of soil and soil organic matter.

The cation exchange capacity of biochar is greatly variable which mostly depends upon the pyrolysis conditions. Cation exchange capacity is lower at low pyrolysis temperatures and considerably higher when produced under high temperatures

(Lehmann 2007). Newly made biochar have minimum potential to hold cations in soil causing lower cation exchange capacity (Cheng et al. 2008; Amanullah et al. 2021), but considerably increase with the passage of time in soil with surface oxidation (Cheng et al. 2006). However, Mukherjee and Zimmerman quoted that fresh biochar had more power to release reasonable amounts of nitrogen and phosphorus.

5.4 Biochar for Carbon Sequestration

Soil carbon sequestration is the capture of air CO_2 into the soil carbon pool through addition of plant and animal residues. Decreasing soil fertility of cultivated lands due to running down of soil organic carbon content is a serious issue for the farming community. Soil organic carbon being the foundation stone to soil quality and key indicator of agricultural sustainability (Lal 2004). Restoring soil carbon is significant for food security, ecosystem functioning, and environmental health, particularly in light of global climate change (Majumder et al. 2019). There are many recommended management practices which under suitable environments improve soil organic carbon sequestration. One among these management practices is the addition of organic material into the soil that is moderately resistant to microbial decomposition such as biochar (Lal 2016).

Biochar amendment to soil have been suggested as a means of reducing greenhouse gas emission and abating climate change by improving soil quality, protecting natural resource and sequestering carbon into the soil (Zheng et al. 2010; Fidel et al. 2019), so the burden of additional atmospheric CO_2 will be diminished (Lehmann et al. 2006). Biochar in soil not only leads to a net carbon sequestration and mitigation of atmospheric CO_2 emission, but as a one potential strategy to reduce the release of other gases like N_2O and CH_4 (Harter et al. 2014).

In order to achieve the purpose of carbon sequestration under different climates first we need to address the farming community to grow the appropriate crop plants as they are being used to make biochar hence the first phase of CO_2 sequestration and with the help of biochar is exclusively be determined by photosynthesis in plants. It is generally revealed that the overall plant biomass produced through the process of photosynthesis can release their carbon quickly due to fast decomposition. The decomposition of plant biomass contrary to the biochar process plays a crucial role in climate change as it releases the heap of carbon into the atmosphere which is fixed by the plant through photosynthesis.

However, unlike decomposition when the same biomass is converted to biochar, it decomposes gradually (Lehmann 2007). Secondly, the biochar is highly stable when compared with original plant biomass. Since the stability level of biochar is the key parameter that can generally be achieved through the process of pyrolysis and can be used to assess its carbon sequestration potential. Furthermore, the pyrolysis process has significant consequences on the stability of biochar. Because during the process of pyrolysis most of the cellulose and lignin are completely destroyed and the appearance of aromatic structures in the biochar leads to a significant change in the composition.

To gauge the carbon sequestration potential and measure the amount of atmospheric CO_2 carbon sequestrated through biochar several methods have been documented. These methods are considered to be a preliminary estimate of the large-scale potential of biochar sequestration and subsequently its benefit in the form of greater crop productivity (Laird 2008); however these methods need must be refined against economic as well as ecological constraints and extended to a complete carbon emission balance. Furthermore, the overall balance of carbon emission must be compared with a baseline scenario and simultaneously it must be shown that what emission of carbon has been reduced by changing of the product from plant material that utilizes biochar.

We therefore need more studies that clearly demonstrate the potential of carbon sequestration with biochar. Many studies have found that the earth's soil is stored about 4 times higher organic carbon when compared to atmospheric CO_2 (Stockmann et al. 2013; Ahmad et al. 2022a, b). Likewise, the annual CO_2 absorbed by the plants during photosynthesis is about eight times higher as compared to today's anthropogenic emissions of CO_2 into the atmosphere. Therefore, there is strong evidence that a substantial quantity of CO_2 flow between the plants and atmosphere while soil is one of the best source where most of the organic carbon is already stored.

Thus, if we are trying to transfer a small fraction of this massive quantity of cycling carbon into the soil through biochar. It will have a large impact on the concentrations of atmospheric CO_2 but on the other hand it will have a small impact on the global soil carbon storage. It was previously projected/estimated that by diverting almost 1% of the annual net plant uptake into biochar perhaps it may reduce nearly 10% of current anthropogenic carbon emissions into the atmosphere (Laird 2008). The biochar stability define that how long carbon remains sequestered in the soil in the form. The conversion of plant biomass to biochar through pyrolysis and its application to the soil has been shown to increase the life of carbon in the soil compared to the same organic materials application (Nachenius et al. 2013).

The encouraging effect of carbon sequestration through addition of biochar can be better observed in soils having lower amount of carbon compared to soils having higher amount of carbon. Research data revealed that the selection of appropriate biochar technology can address the emerging challenges of agricultural sector and improve environmental quality (Yadav et al. 2017).

5.5 Biochar Role in Nitrogen Availability

Nitrogen is one among the essential macro nutrients which decreased wheat yield if not supplied in appropriate quantity as it is required for vigorous growth of the plants and ultimately for higher production (Grant et al. 2016). It play significant role in all the metabolic processes occurring in plants (Bloom 2015; Ahmad et al. 2022a, b). All the biochemical processes going in plants are mostly governed by nitrogen and its related compounds which make it crucial for the growth and development of wheat (Khan et al. 2015). Thus, it is compulsory to apply nitrogen fertilizer to the soil in order to get maximum wheat yield (Ahmad et al. 2008). The varieties which have greater genetic yield potential needs high amount of nitrogen to produce higher production (Emam 2011).

In order to get the higher wheat yield, application of nitrogen in sufficient quantity is measured as an important key to success (Fageria 2014). Use of inorganic nitrogen at 120 kg enhanced wheat yield and yield attributes while non-significant influence on soil carbon, phosphorus and potassium concentration (Ali et al. 2015b). Among the essential nutrients, nitrogen plays a vital role in sustaining vegetative growth of the crop (Kibe et al. 2006). Visually high stature plants and more grains ear^{-1} of maize was obtained from plots where only mineral nitrogen was used (Arif et al. 2012). Ullah et al. (2018) observed highest fertile tillers, maximum plant height, 1000 grain weight and biological yield where nitrogen was applied at 203 kg ha^{-1}.

Improved physiological parameters such as plant height, leaf area plant, leaf number at 120 kg nitrogen ha^{-1} (Ayub et al. 2003). Increasing nitrogen rates (up to 69 kg ha^{-1}) on durum wheat had improved yield, yield components, nitrogen uptake parameters and protein content (Woyema et al. 2012). Similarly maximum plant height, more grains spike^{-1}, single spike grain and thousand grain weight, more biological and grain yield were produce by nitrogen and P_2O_5 by 120 and 90 kg ha^{-1} (Khan et al. 2007). Patra and Ray (2018) listed that plant height, leaf area index, crop growth rate, number of tillers, grain yield and biological yield and all other yield attributes except 1000 grain weight were considerably improved with increase the nitrogen level up to 150 kg.

More tillers m^{-2}, maximum plant height, spike's length, yield and its components of wheat were considerably improved by increasing the levels of nitrogen from 0, 80, 130 & 180 kg ha^{-1} over control (Ali et al. 2011). Furthermore, application of 120 kg nitrogen produced greater tiller m^{-2} which further improves productivity of wheat (Shahzad et al. 2013). Iqbal et al. (2012) attained considerably maximum plant height, grain yield, biological yield and harvest index at 125 kg nitrogen when compared to control. Higher dose of nitrogen improved grain yield of wheat by 30% (Dang et al. 2006). Kousar et al. (2015) observed that 120 and 150 kg nitrogen considerably enhanced fertile tillers, plant height, spike length, number of spikelet per spike, number of grains per spike, 1000 grain weight, grain yield per plot and grain yield of wheat.

Shere et al. had noticed maximum days to anthesis, maturity, leaf area tiller^{-1}, leaf area index, plant height and biological yield by 150 kg nitrogen. Ullah et al. (2013) experienced considerable improvement in wheat phenology, growth and physiological attributes when nitrogen was applied by 210 kg. Ali et al. (2015b) also observed delayed booting, anthesis and maturity stage in wheat plots treated with 120 kg nitrogen. Similarly application of 100 kg nitrogen improves grain protein content (Maqsood et al. 2000). Moreover, Ali et al. (2015a) observed higher wheat leaf nitrogen content, stem nitrogen content, grain nitrogen content, grain protein content, grain nitrogen uptake, total nitrogen uptake in those plots where nitrogen was treated by 120 kg (Fig. 5.2).

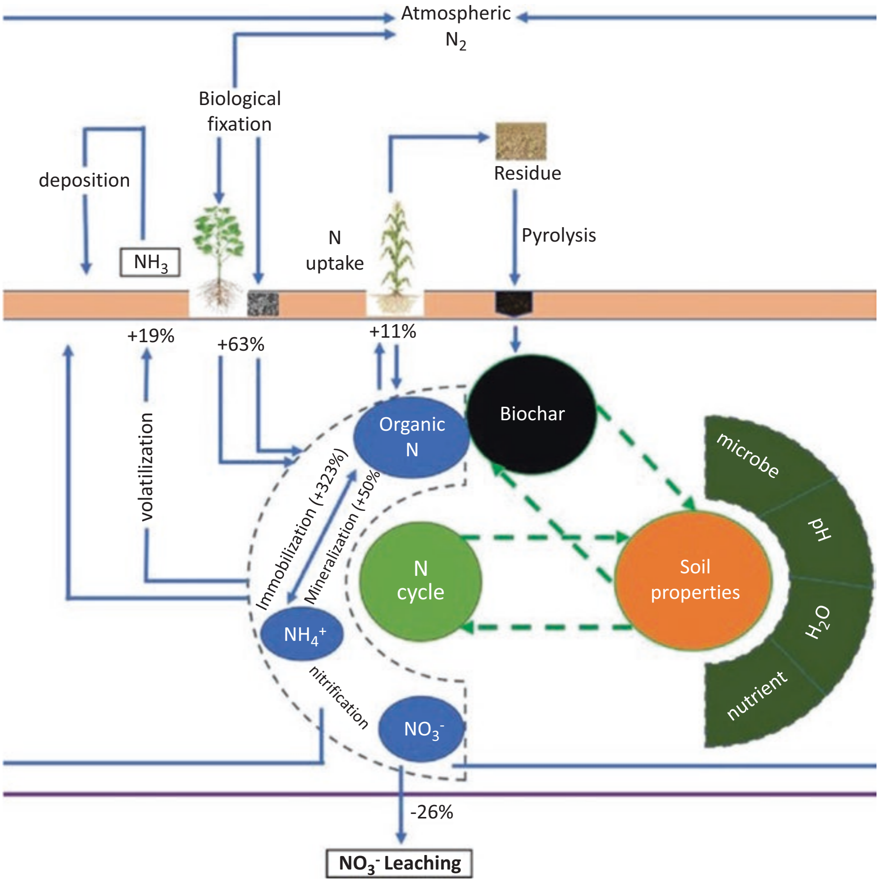

Fig 5.2 Biochar-mediated nitrogen cycle. Summary about nitrogen cycle in response of biochar application showed that the application of biochar reduced NO_3^- leaching by 26%. However, biochar could temporarily increase volatilization of nitrogen by 19% as NH_3, which will be ultimately deposited into the soil. Similarly application of biochar has been shown to improve nitrogen uptake by 11%. N stands for nitrogen. (Modified and reprinted with permission from Liu et al. 2018)

5.6 Biochar and Phosphorus Availability

Phosphorus is major plant nutrient which is required for crop growth and yield. Many soils around the globe are facing phosphorus deficiency, particularly in both tropical and subtropical areas due to both high rainfall and phosphorus fixation (Blake et al. 2000). To fulfill plant phosphorus requirements, globally about 15 million tons of phosphorus based fertilizer is applied every year (Wang et al. 2012). Under best condition only 5–30% of the applied fertilizer phosphorus is utilize by crop (Price 2006). The remaining quantity of the applied phosphorus is lost due to runoff.

At present, most of the phosphorus fertilizer is obtained from mined rock phosphate, which is a non-renewable resource. Streubel et al. (2012) predicted that the availability of rock phosphate may be reduced because of the ever increasing demand of phosphorus on global basis. Therefore, we need to discover new strategies on urgent basis which can provide phosphorus in plants available forms, which can be used as alternate source to traditional phosphorus fertilizer and further minimizes the loss of phosphorus from the soil. Many studies around the world have now shown that biochar can be utilized as phosphorus source for soils and reasonable amount of this phosphorus is available for plant use. However, the type of feedstock used and pyrolysis conditions of biochar are the key parameters which determine the amount of phosphorus in biochar.

Siebers and Leinweber (2013) stated that phosphorus in biochar prepared from animal bone was 152 and extractable phosphorus was almost 7 g kg^{-1}. Uzoma et al. (2011) described that Olsen- phosphorus was 23 g kg^{-1} in wood biochar prepared at 500 °C, while the amount of Olsen- phosphorus was found 1.2 g kg^{-1} when biochar was made from the same material at 300 °C. Naeem et al. (2014) noticed that raising temperature during pyrolysis (300–500 °C), the amount of phosphorus in biochar did volatilize. This is because of the loss of hydrogen and oxygen ions. The use of biochar in acidic soil, the released phosphorus is easily available for plants uptake. Yao et al. (2013) stated that biochar can retain phosphorus applied as fertilizer in soil. Though, data regarding retention of phosphorus in soil due to biochar application is limited.

5.7 Biochar and Micronutrients Availability

Micronutrients are important for plant growth and play crucial role in balanced crop nutrition. The availability of micronutrients is mainly determined by soil pH. The concentration of micronutrients declines with raising soil pH except molybdenum. In high alkaline soil the availability of zinc, iron and boron, is of great concern. During the pyrolysis process not all micronutrients are volatilized until 1000 °C temperature. Amonette and Joseph (2009) found that iron and manganese are mainly retained in biochar during biochar preparation.

Naeem et al. (2014) observed that raising pyrolysis temperature upto 500 °C increase the total micronutrient contents of biochar. At different temperatures, total zinc were 46 to 68 mg kg^{-1} and 66 to 96 mg kg^{-1} in wheat and rice straw biochar respectively. While Fe were 156 to 419 mg kg^{-1}, and 193 to 517 mg kg^{-1} respectively. However, manganese was 104 and 393 mg kg^{-1} for biochar prepared from the above sources. Except manganese, plant available micronutrients contents e.g. iron and zinc decline in both wheat and rice straw biochar with raising temperature. Gaskin et al. (2008) prepared biochar from poultry manure, peanut hull and pine chips at 400 and 500 °C.

Maximum zinc, copper, manganese and iron contents of 0.75, 1.03, 0.73 and 8.03 g kg^{-1} were found in case of poultry litter biochar produced at 500 °C when compared to biochar made from the same feedstock's at 400 or 500 °C. It must be worth noted that the nutrient concentration change from feedstock to feedstock. Moreover the pyrolysis conditions also alter the plant available concentration of micronutrients. Biochar has also the ability to hold nutrients like those have positive charges on it. Moreover, biochar having high pH may decline the concentration of micronutrients in the soil. Care must be exercise to select those Biochar having acidic or neutral pH. Greater nutrient concentration is desirable characteristic of biochar but greater concentration of basic cations may cause several issues, like high pH and high electrical conductivity of produced biochar. To keep soil quality good, we have to select suitable biochar feedstocks and pyrolysis conditions.

5.8 Conclusion

Poor soil fertility is the major constrains in ensuring food security around the globe. Biochar contributes to soil fertility either by acting as a direct nutrient source or by altering the physiochemical properties in the soil. Biochar not only improves soil fertility and crop productivity but also promotes soil carbon sequestration. It has high soil sorption and cation exchange capacity thus minimizes nutrient losses with surface/ground water, and promotes timely nutrients release to crop plants. It also increases the nutrient stocks in the root zone, hence increased nutrients uptake and improve crop yield. Therefore, biochar shall be applied as soil conditioner to improve soil health and crop yield by mitigate nutrients deficiency.

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