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7. Biochar: Importance in Sustainable Agriculture

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Abstract:

Biochar, a carbon-dense solid developed through the pyrolysis of organic waste, can be utilized to improve soil quality. Biochar is made up of polycondensed aromatic compounds and ion exchange functional groups after dehydration and decarboxylation. Biochar pyrolysis produces volatile molecules such as hydrogen (H), methane (CH4), and carbon monoxide (CO), which are then converted into bio-oil and ash. Biochar is an effective soil amendment for managing nutrient content, pH, EC, aeration, porosity, and water retention capacity because to its very porous structure, increased surface area, and mostly alkaline pH. Biochar properties vary based on the feedstock used and the pyrolysis conditions, such as temperature, residence time, heating rate, and oxygen supply. Biochar is made from a variety of feedstocks, including ordinary garbage, agricultural leftovers, biomass crops, manure, and sludge. Pyrolysis, gasification, hydrothermal carbonization, and torrefaction are all used to convert feedstocks into biochar. Biochar has been shown to provide considerable benefits when added to agricultural soils in conjunction with certain fertilizers. The use of biochar in conjunction with chemical fertilizers has been shown to increase crop yields by 45-250%. The use of biochar improved soil water retention, saturated hydraulic conductivity, and nutrient availability.

Keywords:

Biochar, Agriculture, Soil health, Nutrients dynamics, Water availability.

7.1 Introduction:

Biochar, a carbon-dense solid produced through pyrolysis of organic materials, can be used to improve soil quality (Lehmann and Joseph, 2015). During thermal decomposition, carbonaceous materials are converted into aromatic compounds that are highly resistant to degradation. Biochar is composed of polycondensed aromatic compounds and ion exchange functional groups after dehydration and decarboxylation. According to Spokas *et al.* (2012), terra preta soils in Amazonian Brazil are more fertile than surrounding soils due to the automatic addition of biochar during "slash and char" farming operations. This was identified by Late Wim Sombroek. Pyrolysis of biochar releases volatile chemicals such as hydrogen (H), methane (CH_4), and carbon monoxide (CO), resulting in the formation of bio-oil and ash. Biochar is an appropriate soil amendment for controlling nutrient content, pH, EC, aeration, porosity, and water retention capacity due to its extremely porous structure, increased surface area, and primarily alkaline pH (Abewa *et al*., 2013; Steiner *et al.,* 2007; Chan *et al.,* 2008; Asai *et al.,* 2009, Smider and Singh, 2014; Purakayastha *et al.,* 2013). Biochar qualities vary depending on the feedstock utilized and pyrolysis circumstances, including temperature, residence time, heating rate, and oxygen supply (Sohi *et al*., 2010). Biochar's excellent adsorption properties make it an effective instrument for retaining nutrient ions, leading to increased plant efficiency and agricultural yield (Ding *et al*., 2010; Yao *et al*., 2012). Thus, biochar improves both soil and crops. Biochar added to soil at <30 t ha^{-1} boosted crop productivity by around 11% (Liu *et al*., 2013). Crop productivity and returns vary significantly depending on soil, crop, and biochar conditions. Biochar could also be used to restore the microbial population and eventually make the soil biologically productive. This increase in microbial biomass and occupancy in soil could be attributed to increased surface area that serves as a habitat for microorganisms present in soil, hence improving soil nutrient status.

Indian agriculture experienced a massive rise in crop output during and after the green revolution by utilizing the yield potential of high yielding cultivars and applying fertilizers in extremely high dosages. Fertilizer application in significant amounts was effective in the past, but has not resulted in further output increases. The need to increase production has rendered fertilizer use in Indian agriculture an unguided practice.

Fertilizer recommendations might be excessive, leading to high production costs and residue accumulation in the soil. Only a small portion of the applied fertilizer is available to the plant for usage, therefore the remainder is unavailable. Many soils have low fertilizer use efficiency due to nitrogen loss and nutrient fixation. Biochar with high surface area and adsorption capability can improve nutrient availability for plants by lowering losses and boosting soil cation exchange capacity (Liang *et al*., 2006). Organic amendments do not significantly impact soil organic carbon concentration because they disintegrate quickly, unlike biochar, which is highly persistent. Using biochar instead of conventional organic manures can boost soil fertility and increase agricultural yields.

Crop production in India generates a large amount of plant residue and garbage. According to research by the Ministry of New and Renewable Energy (MNRE), our country burns around 92 million tons of crop residue each year, out of a total of 500 million tons. Crop leftovers are often burned due to a lack of appropriate disposal methods. Some remnants can be used as animal food, whereas others, such as weeds, are unsuitable and typically discarded. Farmers typically choose to burn plant wastes instead of incorporating them into soil due to a lack of available technology. In addition to crop residues, forests produce a significant amount of plant waste, including leaf fall and dried plant components that cannot be used commercially or as fodder or compost. Producing biochar from agricultural and forest leftovers is a viable option for disposing of inappropriate materials for animal feeding or composting.

Biochar production can reduce CO2, methane, and nitrous oxide emissions by around 12% of anthropogenic CO2-C emissions annually (Woolf *et al*., 2010). Biochar is a long-lasting molecule that can sequester carbon over time, perhaps accumulating in soil as useful terrestrial carbon. Adding biochar to soil, whether farmed or not, has been shown to reduce greenhouse gas emissions (Karhu *et al*., 2011; Zhang *et al*., 2012). Biochar manufacturing can minimize environmental contaminants such pesticides, heavy metals, and inorganic compounds (Ahmad *et al*., 2014). Biochar can enhance nutrient availability while also improving soil conditions.

Despite its numerous benefits, biochar has not been widely used in Indian agriculture. There is limited study on the usage of biochar, including production, characterisation, and impact on soil and crop yields.

7.2 Preparation of Biochar:

In general, common wastes include agricultural residues, biomass crops, manures, and sludge. In China alone, sludge production reached 6.25 million tons in 2013 (Yang *et al*., 2015), and converting these wastes to biochar could be an option for environmental sustainability. For example, straw-derived biochar has higher potassium content (961mg/kg) and pH (9.5) than wood biochar (349mg/kg, pH 8.0) (Vaughn *et al*., 2013). Furthermore, straw-derived biochar had a higher volatile component, which was easier to extract during the pyrolysis process. As a result, feedstocks with a high volatile content may produce low biochar yields. Kołodynska *et al.* (2012) found that manure from pigs and cows had varied element compositions. As a result, it is concluded that feedstock types have a considerable effect on biochar's physiochemical properties (Suliman *et al*., 2016; Shi *et al*., 2018). The amount of carbon in the biochar is a significant factor. Table 1 lists the feedstock used in prior experiments, as well as the carbon concentration of each.

Feedstock can be transformed into char using carbonization techniques such as pyrolysis, gasification, and hydrothermal carbonization. Pyrolysis is the most frequent carbonization procedure for producing biochar, whereas gasification and hydrothermal carbonization produce char that does not fulfil the definition of biochar. Pyrolysis occurs in oxygen-free environments at temperatures ranging from 300 to 900 ^{0}C (Jin *et al*., 2016). During the pyrolysis process, solid, liquid, and gas products are created. The solid and liquid were commonly referred to as biochar and bio-oil, respectively, while the gasses were known as syngas, which typically contained carbon dioxide, hydrogen, and nitric oxide. Pyrolysis frequently comprises both fast and slow pyrolysis. Fast pyrolysis is distinguished by the addition of feedstock to the reactor after the temperature has reached a desired level, with a residence duration of several seconds. For slow pyrolysis, the feedstock is introduced into the reactor at the start of the process, and the residence duration ranges from half to several hours. Slow pyrolysis typically produces more charcoal than quick pyrolysis. Compared to traditional techniques of preparing carbon compounds such as graphene, pyrolysis-based biochar production is simple and inexpensive, contributing to environmental sustainability. Gasification uses gasification agents (such as air, oxygen, and steam) to partially oxidize the fuel. Gasification, unlike pyrolysis, necessitates a high temperature (often greater than 700 degrees Celsius) as well as a tiny amount of oxygen and steam. Similar to the pyrolysis process, gasification produces solid, liquid, and gas products. However, biochar yields from the gasification process are often lower than those from the pyrolysis process since the gaseous products are the desired products in the gasification process. Typically, pyrolysis and gasification required a dry process. The feedstock was combined with water in a reactor before being carbonized hydrothermally. Then, the temperature and pressure were increased. The temperature of hydrothermal carbonization was less than 250 degrees Celsius. The resulting biochar has a higher carbon content than the pyrolysis and gasification processes (Funke and Ziegler, 2010). It should be noted that, in addition to the aforementioned biochar preparation processes, flash carbonization and torrefaction were utilized to make biochar (Benavente and Fullana, 2015; Chen *et al*., 2015; Nunoura *et al*., 2006; Wade *et al*., 2006). Flash carbonization is the conversion of feedstock into solid and gas products at a pressure of 1-2 Mpa, temperatures ranging from 300 to 600 ^{0}C, and a residence duration of approximately 30 minutes. Torrefaction occurs under inert conditions, and the feedstock is transformed into hydrophobic solid products while moisture and oxygen are removed. The temperature employed in this technique is between 200 and 300 degrees Celsius. Torrefaction-produced solids typically have a low oxygen to carbon ratio (Jin *et al*., 2016). Furthermore, the biochar has a limited adsorption capability due to the partial oxidation of the feedstock during the torrefaction process.

Table 7.1: Various Feedstocks and Methods for Biochar Production.

Feedstock	Production Technique	Percentage of C	References
Bamboo	Pyrolysis,500 ^{0}C	83.6%	Wang *et al*. (2017)
Loblolly pine	Pyrolysis,1000 ^{0}C,15min	92.9%	Yoo *et al*. (2018)
Wheat husk	Pyrolysis,500 ^{0}C,20min	50.5%	Kalderis *et al*. (2017)
Maize	Pyrolysis,1200 ^{0}C,40min	56.1%	Lydia *et al*. (2017)
Straw	Gasification700-750 ^{0}C	48.4%	Hansen *et al*. (2016)
Sugarcane bagasse	Pyrolysis,350,450and550 ^{0}C,	45.31-63.3%	Cross and Sohi (2011)
Rice straw	Pyrolysis,250-450 ^{0}C, 2,4,8h	57.2-72%	Peng *et al*. (2011)
Safflower seed	Pyrolysis, 400-600 ^{0}C,0.5h	68.22-73.75%	Angin (2013)
Pig manure	Pyrolysis,400 ^{0}C,1h	44.13%	Kołodynska *et al*. (2012)
Sludge	Pyrolysis,550 ^{0}C,2h	-	Lu *et al*. (2012)
Coconut fibre	Hydrothermal carbonization,375 ^{0}C,0.5h	78.2%	Liu *et al*. (2013)
Banana peels	Hydrothermal carbonization,230 ^{0}C,2h	71.38%	Zhou *et al*. (2017)
Wood	Gasfication,750 ^{0}C,0.25h	48.4%	Wu *et al*. (2009)

7.3 Properties of Biochar:

A. Physio-Chemical Properties:

Novak *et al*. (2009) studied various designer biochars generated from peanut hull, pecan shell, chicken litter, and switchgrass (*Panicum virgatum* L.) pyrolyzed at temperatures ranging from 250 to 700 °C. Their investigation found that as the pyrolyzing temperature increased, so did the pH and surface area of the biochar. The pH ranged from 5.9 to 10.3, while the surface area varied between 0.40 and 222 m^2 g^{-1}. Ding *et al*. (2010) studied the effect of bamboo biochar pyrolyzed at 600 °C on nitrogen retention and leaching in multi-layered soil columns by adding 0.5% BC to the top layer. Their findings found that the pH of the biochar was 8.15 and the C% was 68.1%. The density and specific surface area of bamboo biochar were determined to be 0.75 g cm^{-3} and 330 m^2 g^{-1}, respectively. Yao *et al*. (2011) investigated the properties and phosphate removal potential of biochar made from anaerobically digested sugar beet tailings at 600°C. The pH of biochar produced from raw sugar beet tailings (STC) and anaerobically digested sugar beet tailings (DSTC) was 9.45 and 9.95, respectively. The CO2 surface area measurements revealed that DSTC (449 m^2 g^{-1}) had a significantly larger surface area than STC (351 m^2 g^{-1}). The SEM imaging of the STC (500X) revealed that the undigested sugar beet tailing biochar had smooth surfaces, whereas the DSTC (500X) revealed knaggy surfaces due to the presence of nano-sized or colloidal magnesium crystal. The reported C content of biochar derived from raw sugar beet tailings and anaerobically digested sugar beet tailings was 50.78 and 30.81%, respectively.

Cantrell *et al*. (2012) investigated the effects of pyrolysis temperature and manure source on the physicochemical properties of biochars made from paved-feedlot manure (FL), dairy manure (MD), poultry litter (PL), and turkey litter (TL), and separated swine solids (SW) at 350 and 700°C. All biochars made at 700°C had higher pH and EC (µS cm-1) values than those prepared at 350°C. The pH ranged from 8 to 9.2 at 350°C and 9.5 to 10.3 at 700°C. The EC ranged from 216 to 1405 µS cm-1 at 350°C and 702 to 2217 µS cm-1 at 700°C, except for SW, which had EC 194 µS cm-1 at 700°C. As the pyrolysis temperature increased, the BET surface area (m2 g-1) of the biochars increased significantly, ranging from 0.92 to 3.93 m2 g-1 at 350°C and 4.1 to 186.5 m2 g-1 at 700°C.

Taghizadeh *et al*. (2012) investigated the effect of adsorbed ammonia on biochar by adsorbing ammonia at 6.7 mg/g and reported an increase in pH of biochar manufactured from Monterey Pine (*Pinus radiata* L.) wood chips at pyrolysis temperatures of 300, 350, and 500°C. The pH was observed to increase from 5.15 at 300°C to 7.77 at 350°C and then decrease to 6.64 at 500°C. A similar variation in EC values was seen with temperature, with values of 0.01, 0.53, and 0.02 dS m-1 at 300, 350, and 500°C. Biochar pyrolyzed at 350°C had the highest bulk density and specific surface area (as measured by iodine adsorption (mg g-1), followed by 500°C and 300°C. The C content (mg g-1) was likewise shown to increase with temperature, reaching 622, 772, and 826 mg g-1 at 300, 350, and 500°C respectively. Wu *et al*. (2012) studied rice straw-derived biochars produced at various temperatures (300, 400, 500, 600, and 700 °C) and residence times (1, 2, 3, and 5 h), and found that the pH increased from 9.19 to 10.77 as the charring temperature climbed from 300°C to 700°C. The CEC of the biochars was seen to decrease with increasing temperature, with values ranging from 56.9 cmol/kg at 300°C to 23.1 cmol/kg at 700°C. The C content (wt.%) was likewise shown to increase with increasing pyrolysis temperature. The values of all metrics, including pH, CEC, and C content, were seen to change with the biochars' residence time.

Cybulak *et al*. (2019) investigated the physicochemical properties of wood-derived biochar pyrolyzed at 650°C and found a very low-density value of 1.46 g cm-3, which was comparable to the value discovered by Brewer *et al*. (2014). The OC content of the biochar was 15.4%, and its nature was alkaline with a pH of 8.25. The specific surface area of the biochar was determined to be 69.9 m2g-1. Faloye *et al*. (2019) investigated the effects of biochar on key maize growth metrics. The biochar was made from maize-cob scraps that were pyrolyzed at 500°C with a heating rate of 2.08 °C/min. The biochar was found to have a pH of 9.42, CEC of 16.26 cmol/kg, total organic carbon of 690 g/kg, and bulk density of 0.4 g/cm3. Yadav *et al*. (2019) examined the advantages of biochar over other organic amendments in terms of crop productivity and nutrient loss. The biochar utilized in the study was created by pyrolyzing *Cymbopogon winterianus* J. chaff at 450°C for 60 minutes.

They stated that the biochar had a pH of 8, a water holding capacity of 45%, a CEC of 125.2 cmol/kg, a bulk density of 0.58 g cm 3, and 58.39% total carbon content.

B. Nutrient Value of Biochar:

Yao *et al*. (2011) investigated the properties of biochar made from anaerobically digested sugar beet tailings at 600 degrees Celsius. Their findings revealed that biochar made from raw sugar beet tailing included 1.83% N, 0.35% P, and 1.04% K, whereas digested sugar beet tailing biochar contained 2.74% N, 2.18% P, and 1.97% K. Cantrell *et al.* (2012) studied the impact of pyrolysis temperature and source on physicochemical characteristics of biochars obtained from paved-feedlot manure (FL); dairy manure (MD); poultry litter (PL); and turkey litter (TL); separated swine solids (SW) at 350 and 700 °C and noted the elemental N content (wt.% oven dry basis) to be lower at 700 °C (1.51 to 2.61% N) than at 350°C (2.60 to 4.45% N), while the contents of P were 10.0 to 38.9 g kg-1. Peterson *et al.* (2012) evaluated the characteristics of corn stover biochar (CSB) and switchgrass biochar (SB), finding that the N% in SB was 0.78% and only 0.44% in CSB. Wu *et al.* (2012) characterized rice straw-derived biochars produced at various temperatures (300, 400, 500, 600, and 700 °C) and residence times (1, 2, 3, and 5 h), and found that 0.5 M NaHCO3 extractable P decreased from 376.6 mg/kg to 138.2 mg/kg as the charring temperature increased from 300 °C to 700 °C. The trends observed for elemental N (dry ash free basis) and extractable K (cmol/kg) varied with temperature and residence duration, but no consistent pattern of change was detected in these parameters.

The temperature at which the biochar was pyrolyzed had no effect on its nutritional content. Huang *et al.* (2019) studied the short-term impacts of organic amendments on soil fertility and root growth in rubber plants on Hainan Island, China, and characterized them. These researchers found 10.38 g total N/kg, 1.97 g total P/kg, and 28.75 g total K/kg in the peanut shell biochar.

7.4 Effects of Biochar:

A. Effects on Soil Properties:

Cybulak *et al*. (2019) investigated the effects of wood-derived biochar amendment on soil characteristics in both fallow and grassland conditions. The biochar doses were 1, 2, and 3 kg m-2 as soil amendment. Although Pranagal *et al.* (2017) reported a slight reduction in soil bulk density, their study found no significant changes in soil bulk density as a result of the addition of biochar, which was attributed to the biochar's low dose in comparison to soil mass. Khan *et al*. (2019) investigated how mesquite biochar, FYM, and chemical fertilizers affected soil fertility and onion crop growth. Mesquite biochar was made by slowly heating mesquite at 575 °C for three hours. A dosage of biochar at 10 t/ha reduced the BD from 1.23 to 1.10 g cm-3 while increasing the WHC from 0.46 to 0.55 ml water per gram dry soil.

Abewa *et al*. (2013) investigated the role of Eucalyptus biochar in the reclamation of acidic soil. The application of 4, 8, and 12 t ha-1 biochar resulted in higher pH values of 5.67, 5.69, and 5.9, respectively, compared to the control with the lowest pH (5.38).

Higher organic carbon (1.84%) was observed after 12 t ha-1 biochar treatment compared to the lowest amount (1.66%) observed in the control plot. With the application of 4, 8, and 12 t ha-1 of biochar, soil CEC increased by 6.13%, 11.25%, and 29.68% compared to the control. Agegnehu *et al.* (2019) investigated the effects of coffee husk and bagasse-derived biochars application at 5, 10, 15, and 20 t ha-1 on plant growth and oil yield of Lemon Grass (*Cymbopogon citratuc* L.). They found that soil pH improved from 6.4 to 6.8 and soil organic carbon (OC) increased from 1.8 to 2.0%. Huang *et al*. (2019) studied the short-term impacts of organic amendments such as bagasse, coconut husk, and biochar on soil fertility and root growth in rubber trees. According to their findings, applying biochar to soil at a 9:1 soil-amendment ratio on mass basis increased soil organic matter (SOM) from 10.04 g/kg to 46.35 g/kg and soil pH from 4.73 to 6.20. Khan *et al.* (2019) examined the effects of mesquite biochar, FYM, and chemical fertilizers on soil fertility and onion crop growth. Mesquite biochar was made by slowly heating mesquite at 575 °C for three hours. A dosage of biochar at 10 t/ha raised soil pH from 7.69 to 8.68, EC from 1.33 to 1.47 dS/m, and SOM from 0.25 to 0.58%.

Kamau *et al*. (2019) studied the impact of biochar alone at 5 and 10 Mg ha−1 on soil nutrients, fauna, and maize growth. They also applied three fertilizer types separately (di-ammonium phosphate (18:46:0), urea (46:0:0), and composite NPK (23:23:0), as well as six fertilizers + biochar blends of the three fertilizer types and two biochar rates (0.05 and 0.1 Mg ha−1). The study found that soils treated with biochar or fertilizer + biochar had greater levels of total C and N, with over 15.0 g C and 1.9 g N kg−1, compared to 10.4 g C and 1.0 g N kg−1 in control plots. Khan *et al*. (2019) investigated how mesquite biochar, FYM, and chemical fertilizers affected soil fertility and onion crop growth. Mesquite biochar was made by slowly heating mesquite at 575 °C for three hours. A treatment of biochar at 10 t/ha increased Nitrate-N concentration from 0.73 to 2.02 mg/kg, Olsen-P from 5.25 to 5.35 mg/kg, and extractable K from 13.8 to 17.1 mg/kg.

B. Effect of Biochar on Plant Nutrition:

Ding *et al*. (2010) studied the effect of biochar on nitrogen retention and leaching in multi-layered soil columns by adding 0.5% BC to the top layer. Their findings demonstrated a 15.2% reduction in overall cumulative NH4+-N losses from leaching at 20 cm. Yao *et al.* (2012) investigated the effect of a 600°C biochar amendment derived from Brazilian pepperwood and peanut husk (PH600 and BP600, respectively) on nitrate, ammonium, and phosphate sorption and leaching in a sandy soil using a column leaching experiment. Their findings showed that the BP600 biochar efficiently reduced the overall amount of nitrate, ammonium, and phosphate in the leachates by 34.0%, 34.7%, and 20.6%, respectively, when compared to the soil alone. The PH600 biochar also reduced nitrate and ammonium leaching by 34% and 14%, respectively, but increased phosphate release from soil columns, indicating that the effect of biochar on agricultural nutrient leaching in soils is not uniform and varies depending on the biochar and nutrient type. Badu *et al.* (2019) conducted a field experiment to assess the synergistic effect of biochar and inorganic fertilizer on nitrogen uptake, nitrogen usage efficiency, and maize yield. Biochar was treated at 0, 5, 10, 15, and 20 t ha-1, while fertilizer N was applied at 0, 45, and 90 kg ha-1. Their findings showed that biochar applied at 10 t ha^{-1} and coupled with 45 kg N ha-1 boosted N absorption by 200% compared to the control.

Dong *et al*. (2019) conducted an experiment to investigate the dynamic reactions of ammonia volatilization to various rates of fresh and 3 years field-aged biochar treatments in a rice-wheat rotation system. Using aged biochar at a low N rate (250 kg N ha−1 per crop, 20 t ha−1 biochar) reduced ammonia volatilization by 13.3% to 36.8% in wheat and 17.6% to 20.8% in rice, respectively. Mandal *et al*. (2019) studied the impact of biochar amendment on NH_3 volatilization and plant N uptake in calcareous soil. They used well-characterized biochars made from poultry manure (PM-BC) and green waste compost (GW-BC) applied at 0, 7.5, 15, 22, and 30 t ha−1. The wheat crop (*Triticum aestivum* L., variety: Calingiri) was grown for 30 days. Their findings showed that both PM-BC and GW-BC reduced NH_3 volatilization in the soil-plant system to a similar extent (by 47 and 38%, respectively) as compared to the unamended control. With the addition of biochar, plant biomass output rose by up to 70%, while plant N uptake improved by up to 58%.

C. Effect on Growth and Yields:

Major *et al*. (2010) found that applying wood biochar at 0, 8, and 20 t ha−1 to a Colombian savanna Oxisol for four years (2003-2006) in a maize soybean rotation resulted in a significant increase in maize grain yield, with increases of 28, 30, and 140% in 2004, 2005, and 2006, respectively, compared to the control. Husk and Major (2010) investigated the effect of applying biochar produced by fast pyrolysis of wood waste in their commercial scale biochar on crop production of several crops in a field trial experiment. The study found that applying biochar at 5.6 t/ha doubled the fresh weight of the oat crop and increased the yield of the soybean crop by 20% when compared to the control. Schulz *et al*. (2013) found that applying a mixture of biochar made from beech wood at 350-450 °C and compost made from 50% sewage sludge, 25% freshly chaffed lop, and 25% sieve residues from previous composting improved Oat crop plant development. Composted biochar significantly improved plant height, above-ground biomass ($p<0.01$), and grain yield ($p<0.001$) when compared to the control. This rise was only due to the addition of biochar; compost had no meaningful contribution to this impact.

Concilco *et al*. (2018) investigated the effect of biochar treatment combined with conventional fertilization on fodder oat yield and quality parameters. The results showed that applying 2.25 Mg biochar ha-1 along with conventional fertilization resulted in a statistically significant increase of 33 and 102% in plant height and green matter of the forage oat crop, respectively, when compared to the control group that did not receive biochar or fertilizers. Agegnehu *et al*. (2019) investigated the effect of coffee husk and bagasse-derived biochars on plant growth and oil yield in Lemon Grass (Cymbopogon citratuc L.) at 5, 10, 15, and 20 t ha-1. They found that applying 15 t ha-1 of coffee husk biochar and the same rate of bagasse biochar resulted in the highest mean fresh biomass (7996 and 7898 kg/ha), total dry matter (2033 and 2050 kg/ha), and moisture content (75.3 and 75.2%). Badu *et al*. (2019) investigated the synergistic effect of biochar and inorganic fertilizer on nitrogen uptake, nitrogen usage efficiency, and maize production in a field experiment using biochar at 0, 5, 10, 15, and 20 t ha-1 and fertilizer N at 0, 45, and 90 kg ha-1.

The results showed that applying 10 t ha-1 of biochar coupled with 45 kg N ha-1 enhanced grain yield by 213% and 160% compared to the control in the minor and major wet seasons, respectively.

Kaur and Sharma (2020) investigated the impact of mixed wood biochar treatment on the growth characteristics of the berseem crop. Their study found that applying 5% biochar boosted plant height by 28-50% and biomass by 30-60% over a 180-day period compared to not applying biochar.

7.5 Use of Biochar in Agriculture:

Various forms of biochar have advantages and play a role in agricultural soil improvement, climate change mitigation, and future biochar applications in agriculture. Biochar application significantly improves soil physical health, which includes structure, texture, air, water temperature, density, and other factors. Biochar addition to soil increased aggregate stiffness in sandy clay soil, and it may eventually be effective in improving such soil's water retention capacity, particularly during drought conditions. Charcoal addition reduced the bulk density of sandy soil while increasing water holding capacity and total pore space at the permanent wilting point (Jha *et al*., 2010).

Biochar inclusion can significantly improve soil integrity since soils require a particular level of aggregates, solids, and organic matter (or humus) to offer an optimal growing medium for plants. Furthermore, WHC requires a diversity of particle sizes as well as a particular level of aeration. Biochar can improve the physical structure of poor soils. If soil is overly compacted, biochar addition may improve aeration due to its changing porosity. Biochar has a substantially bigger surface area and porosity than fine, sandy soils. There are other advantages to using biomass compost in conjunction with biochar produced from that biomass (Li *et al*., 2018).

The mixture of compost and biochar showed to be just as beneficial to plant yields as biochar alone because the faster decomposing biomass provided a consistent supply of nutrients for plant uptake until the gradual release of nutrients from the biochar occurred. When soils are modified with biochar, more oxidation-reduction processes occur inside the soil matrix. Another advantage of biochar is its ability to stay in the environment and soils over time, which can occur in fields for several years (Jha *et al*., 2010).

As a result, biochar may not require reapplication every year, making it a cost-effective solution. The amount of organic matter in soil decreases over time. Weathering, agricultural practices, and other human-caused activities all contribute to this. Biochar's crystalline form makes it exceptionally stable and long-lasting in soils. Another noteworthy impact is that adding biochar to soils increases the amount of ethylene, an important plant hormone that regulates plant development and ripening. Crop yields will rise as the amount of ethylene produced through biochar amendment increases.

A. Nutrients and pH:

Biochar has the ability to retain and deliver bioavailable nutrients for plant absorption. For example, the potassium in charcoal is available for plant absorption. Biochar can also affect soil pH in a variety of ways, the extent of which varies depending on the feedstock and production conditions. Soils include a variety of microbes, including actinobacteria, nematodes, and fungi like mycorrhizae. Biochar has the potential to assist remedy deficiencies identified in "problem soils," which include characteristics such as poor aggregate stability, high salt, abnormal pH values (too high or too low), or a lack of nutrients. Problem soils are those with poor qualities (biological, physical, or chemical) that inhibit plant growth. Even a single application of biochar can boost soil health over time (Ramzani *et al.*, 2017).

Biochar can improve soil health, leading to increased crop output. One approach to accomplish this is to increase microbial population diversity. The refuge afforded by charcoal pores allows populations to reproduce while simultaneously fixing nitrogen for plant uptake. This is especially critical for crops that can't fix their own nitrogen (such as non-legumes). It is also significant to note that the potassium in charcoal is already in forms that are available for plant uptake. Biochar also increases the availability of nitrogen for plant uptake in crops that cannot fix their own nitrogen. Furthermore, the carbon content of the soil rose, momentarily lowering the pH level, despite the fact that alkaline soils are best suited for common cash crops like maize. Using solid forms of carbon also allows soils to improve nutrient availability and retention (Das *et al.*, 2020).

B. Water Holding Capacity:

One of the most important ways biochar can help mitigate the effects of climate change-induced drought is its ability to retain water. Biochar is an efficient way to counteract dry soils in Sub-Saharan Africa. Soils in this region are often poor due to higher sand concentrations from the granite-rock parent material. These soils are not only naturally dry, but also acidic (typically with a pH of less than 4), resulting in low plant production. The soils in this area are also strained due to the repeated drought. The combination of these two impacts causes widespread food shortages in the area (Li *et al*., 2018).

Biochar's WHC is reported to be most heavily influenced by its porosity level. This porosity consists of macro and micro pores. This porosity is critical for increasing soil water capacity; biochar combined with fertilizer increased water content by up to 14.6%. Water is the principal channel via which plants absorb nutrients; lowering WHC and boosting soil health further enhances the favorable benefits. When soils lose a substantial amount of water, the plants that live there suffer from salt stress. The inclusion of biochar results in an average increase of approximately 18% WHC (Li *et al*., 2018).

Biochar is known to improve water-holding capacity by increasing surface area and porosity. Biochar amendment improves WHC across all soil types. With merely 9% biochar (yellow pine wood pyrolyzed at 400 °C), WHC increases by 100%. This means that the WHC has doubled.

C. Microbiome:

Many aspects of biochar influence microbial populations, including feedstock, pyrolysis conditions, particle size, and soil characteristics. There is evidence that biochar enrichment can improve mycorrhizal and rhizobial populations at the root level. With these microbial communities present, a number of processes occur inside the soil matrix. These occur at the interface of root hairs and bacteria in soil.

The plant can employ a variety of organic chemicals attached to biochar structures via sorption. The addition of organic stuff often benefits microbial organisms. When examining the health and quantity of mycorrhizal communities, biochar amendment has been proven to assist them in the following ways: they provide a sanctuary for species via porosity, they detoxify heavy metals from soils, and they can change the soil's physicochemical qualities. More bacteria (both gram negative and gram positive) were found in soils treated with pyrolyzed biochar at 350 °C than in soils amended with biochars produced at lower or higher temperatures. Furthermore, increased aeration and soil pores produce the soil-water interface, where these bacteria thrive (Chan *et al*., 2007).

Microbial populations can also aid in the breakdown of fertilizers, reducing nutrient leaching. Their presence in soils is critical to the health of food crops. In general, the prognosis for increasing the variety and number of bacterial genes in biochar-amended soils is promising.

Biochar can affect microbial diversity through the following mechanisms:

- Increasing nutrient levels to increase plant development and recruiting helpful microorganisms that promote fungal growth.
- Changing the rhizosphere environment to improve soil physicochemical characteristics.
- Establishing a safe environment for helpful fungus and bacteria.
- Preventing or reducing the hazardous effects of allelochemicals, soil-permanent agrochemicals, and other soil confinement methods.
- Enhancing signaling during plant-fungal interactions.

Incubation with fresh pyrolyzed biochar significantly improved many sorts of enzyme behaviour. It has been widely observed that heavy metals have a negative impact on soil biological and biochemical parameters such as soil enzyme activity. However, it has been claimed that the addition of biochar to soil can reduce the toxic effect of heavy metals, allowing it to change soil enzymes.

D. Role of Biochar in Disease Suppression:

Intensive agriculture contributes significantly to soil organic matter degradation and microbial diversity, as well as an increase in soil-borne plant diseases. Chemicals commonly used to combat disease pathogens might cause soil contamination if not applied properly. Biochar has been found to effectively control plant diseases caused by both soil and foliar pathogens. The nutrients provided by biochar, or the enhanced availability of soil nutrients in the presence of biochar, increases plant vigour and reduces the pathogen's capacity to infect the plant.

By increasing the morphological, histological, and functional characteristics of plant tissues and maintaining larger levels of inhibitory chemicals in tissues, biochar treatment allows plants to respond quickly to pathogen attacks. Biochar application may affect root architecture, thereby increasing vulnerability to soil-borne diseases. Biochar also influences soil pH, resulting in alterations in the Eh-pH system.

Biochar-induced alterations at the rhizosphere can significantly impact pathogen survival, as many diseases thrive in specific Eh-pH ranges.

Thus, the soil Eh-pH system has a significant impact on microbial community growth, diversity, structure, and disease virulence (Harel *et al*., 2012).

Biochar has a significant role in systemic acquired resistance. The optimal application rates for disease suppression vary depending on the type of biochar. There is no "one concentration fits all" approach for incorporating biochar into soilless systems.

Arbuscular mycorrhizal fungi combined with biochar can boost lettuce biomass in salt-stressed conditions. Biochar treatment promoted root colonization as well as mycorrhizal fungus spore germination, which was caused by improved soil physical and chemical properties as a result of increased nutrient availability.

7.6 Conclusion:

Biochar has drawn attention for its ability to improve agricultural yield, reduce greenhouse gas emissions, and sequester carbon in soil. Using biochar in environmental and agricultural systems can improve soil quality, boost carbon sequestration, and reduce farm waste. Biochar can be used to restore damaged landforms, providing long-term benefits to the environment, agriculture, and economy. Research on biochar synthesis and application is crucial for promoting its use as a developing amendment.

While there are conflicting reports on the effectiveness of biochar in agriculture, it has the potential to reduce CO2 levels in the environment with proper application and mechanism of action. Long-term use of biochar requires monitoring of soil's physical, chemical, hydrological, and ecological conditions. It's important to determine how different crops respond to biochar application throughout agro-ecological zones.

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