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Impact of Biochar Application on Soil Health and Nitrogen Dynamics

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Introduction:

In changing climate conditions, soil organic matter is depleting, and soil nutrients are being lost, threatening agricultural sustainability. Most Indian soils do not contain enough soil organic carbon, i.e., 0.5% organic carbon. A decline in soil fertility is caused by the degradation of soil organic carbon, which leads to a decline in agricultural productivity. Organic matter and manure are applied to the soil in order to increase its organic carbon content. Among organic materials, the biochar as soil amendments is used to improve soil health. Biochar is a fine-grained, carbon-rich, porous product remaining after plant biomass has been subjected to thermo-chemical conversion process (pyrolysis) at low temperatures (~350–600°C) in an environment with little or no oxygen (Amonette and Joseph, 2009). Biochar is not a pure carbon, but rather mix of carbon (C), hydrogen (H), oxygen (O), nitrogen (N), sulphur (S) and ash in different proportions (Masek, 2009). The fundamental quality of biochar that makes it attractive as a soil amendment is its highly porous structure, potentially responsible for improved water retention and increased soil surface area. Biochar, a soil conditioner that is environmentally friendly, is produced using several thermochemical processes. It has unique characteristics such as high surface area, porosity, and surface charges.

Biochar can influence nutrients in soil in several ways: (1) as a source of nutrients for plants and soil microorganisms (2) as a nutrient sink, thereby impacting the mobility and bioavailability of nutrients and (3) as a soil conditioner, thereby altering soil properties that influence the reactions and cycling of nutrients in the soil. As a source, biochar can supply nutrients such as nitrogen (N), phosphorus (P), potassium (K), and other trace elements inherently present in the original feedstock used for biochar production. Biochar derived from manure and biosolid-based feedstock materials generally contain higher levels of N and P than those derived from wood and straw-based feedstock materials. While the N content decreases with increasing pyrolytic temperature through gaseous emission, the P and K contents increase due to an increase in ash content. As a nutrient sink, biochar can retain nutrients, thereby reducing their losses through leaching and gaseous emission. The nutrient retention capacity of biochar depends on its porosity and surface charge (cation and anion exchange capacity).

Biochar application reduces the loss of N, P and K through leaching, and N through nitrous oxide emission. Biochar application influences various soil properties including pH, bulk density, cation exchange capacity, water retention, and biological activity. Upon application to the soil, biochar improves soil fertility and crop productivity by increasing the soil nutrient contents and the mobility of nutrients. It enhances microbial activity, improves aeration and water retention, buffers soil reactions, reduces bulk density, and maintains soil aggregate structure. Moreover, biochar reduces nutrient leaching and loss of nutrients by volatilization through altering the soil pH and by enhancing the ion exchange capacity. Biochar can change the soil microbial community composition, and thus, it impacts nutrient cycling and uptake by plants. Biochar decreases nitrification in soil resulting in reduced nitrate leaching.

Methods of biochar production

Biochar can be produced by several methods as follows:

- **Heap Method:** In this traditional method, a heap of pyramid like structure (earth kiln) is prepared by keeping wood logs and roots of plants for making biochar. To allow the combustion products to escape, vents are opened starting from the top. When smoke production is stopped, the cooling process is started by covering stack with a layer of moist earth. The cooling process takes several days before the earth is removed and the biochar produced is separated from the surrounding carbonized portions. Generally, people use the heap method of charcoal production as it is easy and cost involved in char production is very low. Mostly fibre wastes of coconut, paddy straw or any available agriculture waste are used to prepare paste mixed with clay soil to cover the heap structure containing wood logs. Finally, it is covered with sand from

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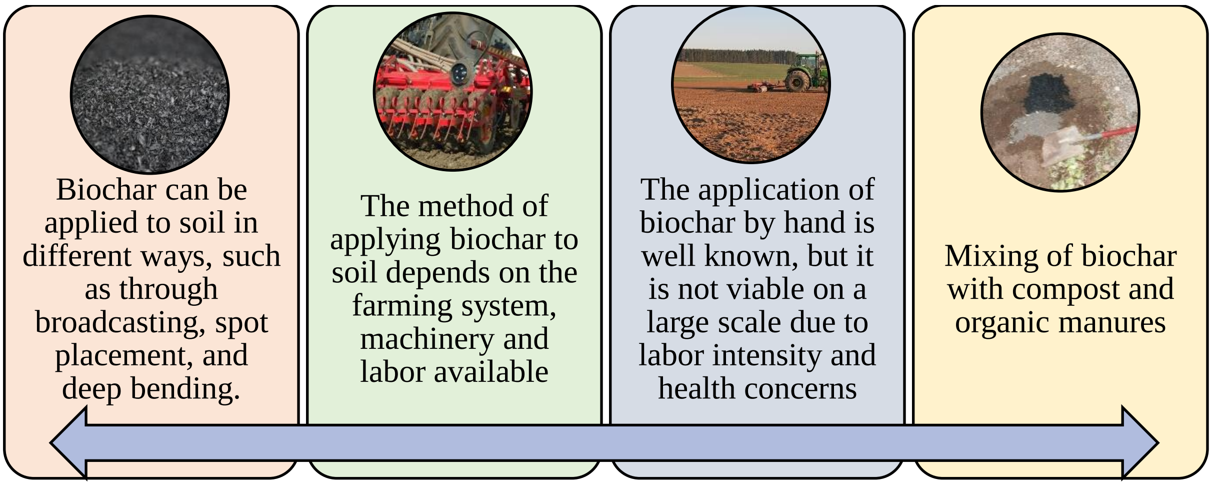
outside and water is applied over it. Entire wood logs are converted into biochar after burning inside the heap for 3-4 days.

- **Drum Method:-** Purakayastha *et al*. (2012) developed a cylindrical low-cost pyrolysis kiln made from fire brick at IARI, New Delhi. The gap between the two-fire brick wall is filled with perlite which acts as insulator to check the heat loss through dissipation. The used oil drum was placed on a stand inside the brick kiln for heating. The drum is filled with agricultural residues with not too tight packing and the drum is closed from the top with a metal lid having provision for escape of syngas. Heating is provided by wood log externally at the bottom of the drum until the desired temperature (300–400^{o}C) is reached. This method requires two hours for complete preparation of good quality biochar with biochar yield of approximately 50%.
- **Biochar Stove:-** There are two basic types of stoves that can be used to produce biochar, the Top-Lit Updraft Gasifier (TLUD) and the Anila stove. The TLUD operates as a gasifier by creating a stratified pyrolysis/combustion regime with four basic zones: raw biomass, flaming pyrolysis, gas combustion and biochar combustion. Biomass fuel is placed between the two cylinders and a fire is ignited in the centre. Heat from the central fire pyrolyzes the concentric ring of fuel. The gases escape to the centre where they add to the cooking flame as the ring of biomass turns to biochar.



The modern Anila stove was developed by U.N. Ravikumar, an environmentalist and engineer with the Centre for Appropriate Rural Technology (CART) at India's National Institute of Engineering. The engineering principle the underlines the Anila stove is top lit updraft gasification, which essentially means that the hardwood fuel burns from the top down and simultaneously combusts the syngas that is released by the biomass. The stove is made from steel and weighs about 10 kg.

Application methods of biochar:

Effect of biochar on soil health: The changes in soil properties resulting from biochar application are likely to impact nutrient reactions and microbial transformation of nutrients.

- **Physical properties:** Addition of biochar has been shown to increase the ability of soil to hold water. Biochar reduced the tensile strength and cracks of a surface soil and suppressed soil shrinkage by increasing the ability of the soil to hold water, thus, soil structure has improved. Application of biochar improved soil water retention, reduced bulk density, and stabilized soil organic matter. Additionally, it has hydrophilic functional groups on the surface and pores of biochar with a high affinity for water, biochar application has shown to increase soil water retention more in a sandy soil than a loamy soil or a clay soil. Biochar also shows a positive impact on surface area of soil which varied with biochar types. Therefore, irrespective of soil types, experimental conditions, biochar types, pyrolytic temperatures, and application rates, biochar has positive impacts on soil physical properties.

    1. Chemical properties: Biochar application shows impact on soil chemical properties such as pH, electrical conductivity (EC), and cation exchange capacity (CEC). These soil chemical properties influence nutrient interactions in soil. Soil pH can be altered by incorporation of biochar into soil, thereby contributing to alterations in nutrient availability. Biochar also generates organic acids during pyrolysis of biomasses that influence the pH of the final product. Biochar generally has a pH range of 6.52–12.64 and the pH values positively correlate with the pyrolytic temperature. Application of alkaline biochar tends to increase the pH of acidic and neutral soils. Availability of soluble nutrient ions such as $NO3^{-}$, K+, and Ca2+ could be directly related to the soluble salt content and, hence, the EC of biochar when applied to soil. The CEC of most biochar's is higher than that of typical agricultural soils.
    2. Biological properties: Owing to its porous system, biochar can be a favourable habitat for soil microorganisms including bacteria, mycorrhizal fungi and

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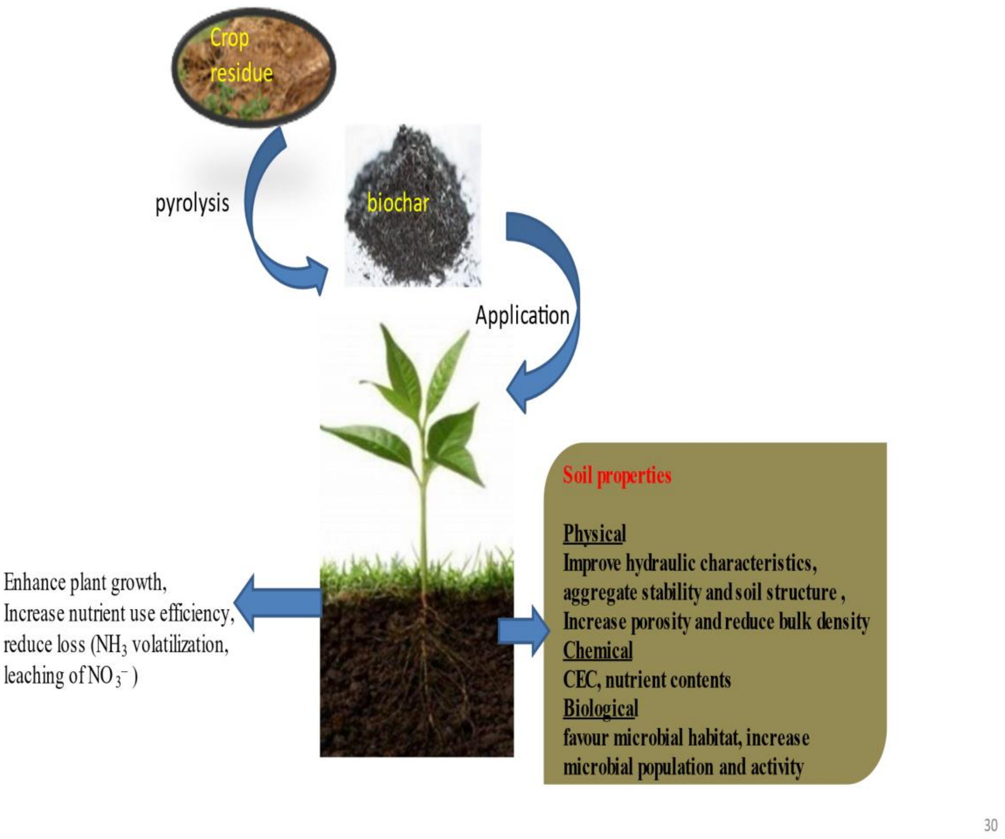
actinomyces. Biochar also increased P-solubilizing bacterial populations such as *Burkholderia–Paraburkholderia*, *Planctomyces*, *Sphingomonas*, and *Singulisphaera*, which contributed to improving P availability in soil. Biochar creates positive effect on soil microbial community structure and N-cycling bacteria so its application increases biological N fixation by 63%.



Effect of biochar on nitrogen dynamics

Biochar can be a potential source of N for plants. Biochar can manipulate inorganic N dynamics in soil through affecting the rate of BNF, mineralization, nitrification, retention of available N forms, N_2O and NO emissions, NH_3 volatilization, N losses in runoff and leaching. Biochar can increase N mineralization rate due to its high specific surface area and microstructure, it provides favourable habitat to nitrogen mineralizing microbes. Biochar amendment soil can reduce N_2O emission. Biochar contains acidic surface groups, which can protonate NH_3 gas to NH_4 ions. Application of biochar also enhances NO_3^- -N and NH4 $^+$-N retention by increasing the soil pH and soil organic matter. Biochar has two important mechanisms for N retention in soil: (1) adsorption of NH4 $^+$-N due to the high CEC of biochar, (2) reduced leaching of NO_3^- -N due to increased ability of the soil to hold water. Biochar can contribute to nitrogen use efficiency in plants, both directly through increased nitrogen uptake and indirectly by decreasing the loss of nitrogen through leaching and gaseous emission.

Conclusion

- Using biochar to improve soil quality and agricultural productivity on agricultural land.
- Studies have shown that it improves soil parameters such as pH, cation exchange capacity, and water holding capacity.
- It is possible to improve the efficiency of nitrogen use and crop productivity by using biochar.
- In addition to reducing greenhouse gas emissions through carbon sequestration, biochar has the potential to reduce soil methane and nitrous oxide emissions.
- Biochar can be an important source of plant nutrients and can supply macro-nutrients, secondary nutrients, and micronutrients to plants.
- Biochar can retain N and other nutrients in soil by decreasing their leaching loss.

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