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Biochar: The Black Gold of Agriculture

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Background

The world's population is increasing day by day and is expected to reach 9.8 billion by 2050 (United Nations Department of Economics and Social Affairs, New York, NY, USA), which will put the world's agricultural system under an increasing threat. Thus, to feed the increasing population and fulfil the constantly growing demand for food grains, which increases pressure on agriculture sector. So, this crisis affects the management practices like effective management of farm residues. According to the World Bank, the world generates at least 1.3 billion metric tons of agricultural waste annually, and the number is expected to increase as the population grows. The four most commonly grown crops worldwide are maize, sugarcane, cereals, and rice, which together weigh more than 16.5 billion kilograms annually. On average, 80% of the plant consists of agricultural waste, which includes stems, branches, and leaves. Usually, the farm residues are either left unmanaged or burnt in the field. In India, around 87.0 Mt of crop residue is burnt annually, which is much larger than the entire agricultural waste production in other Asian countries like Bangladesh (72.0 Mt), Indonesia (55.0 Mt), and Myanmar (19.0 Mt) (Deshpande *et al.*, 2023). In order to manage the farm residues in an ecofriendly and sustainable manner, the concept of 'Biochar' came into existence.

Introduction

Biochar is a carbonaceous solid derived from the pyrolysis of agricultural and forest residual biomass. Pyrolysis is the thermal decomposition of materials at elevated temperatures (300 - 800° C) in an inert atmosphere. The word pyrolysis is coined from the Greek-derived elements pyro 'fire' and lysis 'separating'.To mitigate global climate change and simultaneously increase soil productivity, the use of biochar in agriculture can be a modern agro-technology that can helps in reducing the greenhouse gas emissions from onsite farm residues burning, enhancing soil carbon sequestration capacity, and ultimately increasing crop yield. Adding biochar converted from organic residues is an environmentally sound agronomic practice and acts as an ecological risk-free soil conditioner globally.

Agricultural and forestry residues are a potential source of biomass for fuels, but there is concern that removing these residues will adversely affect soil organic carbon stores and soil fertility. Pyrolysis, or the thermal breakdown of wastes in the absence of oxygen at high temperatures, may provide a different way to generate energy and replenish the soil with nutrients and carbon. Pyrolysis produces gases, bio-oil and biochar, all of which can be used as fuel sources. The potential for minimizing the possible detrimental effects of removing biomass for energy production on soil quality has sparked interest in using biochar as a soil conditioner. Biochar from pyrolysis is an amorphous form of carbon that consists of numerous carbon compounds and ash. Biochar is utilized as an amendment that can recoup soil fertility and richness, plant development, improve carbon sequestration just as waste administration and immobilization of contamination. It can be used to enhance plants' growth and increase the yield of crops by increasing a significant amount of soil carbon.

Importance of Biochar in agriculture

Biochar has gained attention in agriculture due to its potential benefits in soil health, plant growth, and environmental sustainability. Here are some key roles of biochar in agriculture:

- **Soil Amendment:** Biochar improves soil structure by increasing porosity, water retention, and aeration. Its porous nature provides habitat for beneficial microorganisms and enhances soil fertility by retaining nutrients and preventing leaching.

- **Nutrient Management:** Biochar can serve as a nutrient reservoir, holding onto nutrients like nitrogen, phosphorus, and potassium, and releasing them slowly over time, thus reducing the need for frequent fertilization. This can help in mitigating nutrient runoff and pollution of water bodies.
- **Carbon Sequestration:** Biochar is a stable form of carbon, which means it can remain in the soil for hundreds to thousands of years, effectively sequestering carbon and mitigating climate change by reducing atmospheric carbon dioxide levels.
- **Alleviation of Soil Acidity:** Some types of biochar, especially those derived from alkaline feedstocks, can help neutralize soil acidity, making it suitable for crops that prefer neutral to slightly acidic pH levels.
- **Reduced Greenhouse Gas Emissions:** By enhancing soil fertility and reducing the need for chemical fertilizers, biochar can indirectly contribute to reducing greenhouse gas emissions associated with fertilizer production and application.
- **Enhanced Crop Productivity:** Studies have shown that biochar application can lead to increased crop yields, improved plant growth, and enhanced resistance to certain diseases and pests, although the effects may vary depending on soil type, biochar properties, and crop species.
- **Waste Management:** Biochar production offers a way to recycle organic waste materials that would otherwise decompose and release greenhouse gases into the atmosphere, thus providing a sustainable solution for waste management.
- **Remediation of Contaminated Soils:** Biochar has been used to remediate soils contaminated with heavy metals and organic pollutants by adsorbing and immobilizing these contaminants, thereby reducing their bioavailability and environmental impact.
- **Improvement of Soil Water Retention and Drainage:** The porous structure of biochar enhances soil water retention by increasing water-holding capacity and reducing soil compaction.

Characteristics of Biochar

- **Heavy metal remediation:** To regulate the amount of organic and inorganic contaminants in the environment, biochar is essential. Biochar has a big surface area and a strong ability to absorb organic contaminants and heavy metals. Biochar has the potential to mitigate the bioavailability and leachability of organic contaminants and heavy metals (Fig. 1) in soils by means of adsorption and other physicochemical processes. Generally, biochar is an alkaline substance that can raise soil pH and help stabilize heavy metal levels.
- **Green-house Gas mitigation:** Applying biochar as a soil amendment may be a useful tactic for reducing greenhouse gas emissions and raising crop yields (Fig. 1). A lower ratio of methanogenic to methanotrophic archaea and enzymatic activity may be linked to the beneficial effects of biochar application on lowering soil CH_4 and CO_2 emissions. After adding biochar, there was a rise in soil pH that may have encouraged the activity of the N_2O reductase enzyme (Simek *et al.*, 2002) and served as a significant mechanism for denitrification decrease in soils supplemented with biochar. Most of the C present in biochar is of recalcitrant in nature cannot be mineralized easily hence reduces the CO2 emission. Nonetheless, soil GHG emissions and crop productivity are significantly influenced by biochar qualities and soil attributes.
- **Improve soil physical properties:** The very porous structure of biochar is one of its primary characteristics, and it is believed to be the cause of its improved capacity to retain soil moisture. The physical characteristics of biochar indicate that it may change the distribution of soil pore sizes, water retention, percolation patterns, and flow pathways. Biochar has the potential to enhance crop yield by modifying the chemical or physical characteristics of the soil. This can lead to improvements in root growth, water and nutrient retention, and acquisition (Fig. 1). The physical

characteristics of soil, including its texture, structure, porosity, surface area, and distribution of pore sizes, can be improved by the application of biochar. Because the physical characteristics of the soil play a major role in determining the depth of roots and the availability of air and water within the root zone, these changes will subsequently affect plant growth.

- **Improve soil chemical Properties:** The application of biochar is promising for improving the chemical properties of soil (Fig. 1). Addition of biochar to soil can influence soil pH, usually the biochar will be alkaline in nature and hence increases the pH of the soil, but the biochar produced at lower temperature (200° C) will be acidic in nature and hence decreases the pH of the soil. Presence of carbonates of alkali and alkaline earth metals in the ash residues of biochar helps to increase the Electrical Conductivity (EC) of soil. The amount of soil organic carbon content will be almost equal to the amount of C added through biochar, because most of the carbon present in biochar is of recalcitrant, and cannot be easily mineralized. Biochar increases the total nitrogen content in the soil and increases the available phosphorous and potassium contents irrespective of the pH of soil. Acidic biochar increases the micronutrient availability when added to alkaline soil.

Factors affecting biochar properties

1. **Pyrolysis temperature:** Low-temperature biochar’s chemical makeup is comparable to that of the biomass used in pyrolysis, but high-temperature biochar's characteristics diverge significantly from those of the feedstock. As compared to its high-temperature equivalent, biochar produced at a low temperature is expected to have more volatiles, less fixed carbon, and less ash (Rafiq *et al.*, 2016).
2. **Feedstock used:** In comparison to biochar made from lignocellulosic feedstocks like wood, biochar made from non-woody feedstocks like manures and plant leftovers is more nutrient-rich, has a higher pH, and contains less stable carbon (Mukherjee and Zimmerman, 2013).
3. **Rate of Pyrolysis process:** Studies on pyrolysis length indicates that slow pyrolysis results in a significant increase in surface area, while fast pyrolysis has little to no influence on the C:O ratio of biochar (Chintala *et al.*, 2014).
4. **Age of Biochar:** When compared to fresh biochar, aged biochar has a higher concentration of oxidized functional groups, Cation Exchange Capacity and Anion Exchange Capacity and hence may produce different results in soils.

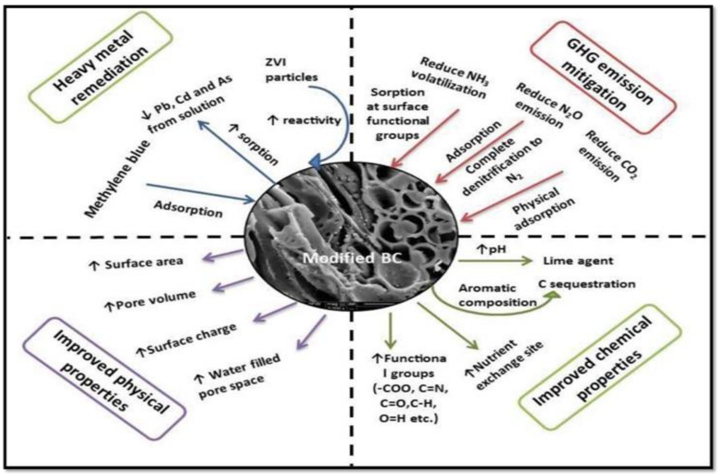

Fig. 1: Schematic diagram showing characteristics of Biochar

It is essential to consider these properties when selecting farm residues for biochar production, as they can impact the effectiveness of biochar as a soil amendment and its suitability for specific agricultural applications. Additionally, biochar production methods and process parameters can also influence its properties, so it is important to consider both feedstock characteristics and production techniques when assessing biochar quality and suitability for agricultural use. The details of physical and chemical properties of biochar produced from different feedstocks is given in the Table 1.

Conclusion

Given its numerous advantages and capacity for transformation, biochar embodies the essence of "black gold" in agriculture. It is a useful instrument for boosting sustainable farming methods, decreasing climate change, and increasing soil fertility. It is indispensable for boosting crop yields, preserving resources, and reducing environmental degradation because of its capacity to sequester carbon from the atmosphere while also improving soils physical (surface area, porosity, water-holding capacity, surface charge density, and soil structure) and chemical (nutrient addition, retention and recycling, pH, EC, CEC, organic carbon, and nutrient availability) properties and microbial activity. Biochar is aptly referred to as the "black gold" of agriculture because, like the highly esteemed material to which it is compared, it has enormous value as a catalyst for promoting agricultural sustainability, resilience, and prosperity.

Table 1. Physical and chemical properties of different biochar's synthesized from different feedstocks through various pyrolysis production methods. (Vijayaraghavan, 2019)

Biochar feedstock	Temp (°C)	C	N	H	O	Yield (%)	Ash (%)	VM (%)	pH	SA (m^2/g)	CEC (cmol/kg)
Algae residues	300–700	50.5	10.5	7.54	30.8	40–90	4.8	–	–	–	–
Bamboo	600	80.9	0.15	2.43	16.5	–	–	–	7.9	470.4	–
Corn Stover	600	70.6	–	–	–	–	16.7	23.5	9.42	527	252.1
Cow manure	500	43.7	–	–	–	57.2	67.5	17.2	10.2	21.9	149
Domestic wastewater sludge	400	42.7	8.1	3.4	8.1	–	37.1	34.5	7.3	–	–
Grass (*Festuca arundinacea*)	400	77.3	1.24	4.70	16.7	37.2	16.3	26.8	–	8.7	–
Hickory wood	600	81.8	0.73	2.16	15.3	–	–	–	8.4	401.0	–
Japanese cedar	400	72.0	1.6	4.2	22.1	–	0.1	57.7	7.7	–	–
Municipal sludge	500	17.5	1.54	0.7	10.5	63.1	74.2		8.8		76.8
Oak wood	600	87.5	–	–	–	–	1.30	27.5	7.9	642	75.7
Peanut hull	600	86.4	0.94	1.36	11.3	–	–	–	6.9	27.1	–
Pig manure	500	42.7				38.5	48.4	11.0	10.5	47.4	82.8
Pinewood	450	81.4	0.3	3.0	15.3	41–44	4.6	8.2		166	
Poultry litter	600	23.6					55.8	44.1	10.3	94	58.7
Poultry manure	400	34.3	5.1	1.5	10.7	–	48.4	28.3	10.8	–	–
Rice (*Oryza sativa* husk)	400	37.2	1.3	1.2	12.4	–	47.9	38.2	6.7	–	–
Sugarcane bagasse	600	76.5	3.03	2.93	19.8	–	–	–	7.5	557.4	–
Timothy grass	450	67.5	1.9	2.3	28.2	41–44	3.5	7.5		179	
Turkey litter	700–800	15.6	0.78	0.83	4.4	–	64	–	10.9	21.8	24.4
Walnut shell	900	55.3	0.47	0.89	1.6	–	40.4	–	9.7	227.1	33.4
Wheat straw	450	65.2	0.9	2.3	31.5	41–44	3.9	7.2		184	–
Wheat straw	500	62.9	–	–	–	29.8	18.0	17.6	10.2	33.2	95.5
Wood (*Pinus ponderosa*)	400	74.1	0.06	4.95	20.9	35.3	1.4	36.4	–	28.7	–

[a]Temp, pyrolysis temperature; VM, volatile matter (%, dry basis); SA, BET-N_2 surface area; CEC, cation exchange capacity.

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