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The Pharma Innovation

ISSN (E): 2277-7695
ISSN (P): 2349-8242
NAAS Rating: 5.23
TPI 2023; 12(5): 569-577

www.thepharmajournal.com
Received: 18-04-2023
Accepted: 19-05-2023

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Impact of biochar in sustainable crop production and soil health management: A review

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Abstract
Sustainable agricultural approaches emphasize soil health and crop production conservation. Organic matter is essential for soil health and agricultural productivity in the future. It can boost agricultural output while also reducing greenhouse gas emissions from agricultural soils. This has rekindled the interest of agricultural exports in the production of biochar from bio residues, which is used as a soil amendment. Biochar is a material made from the carbonization of charcoal or biomass. Pyrolysis is the most widely used process for producing biochar. Biochar has a lot of potential for reclaiming soil characteristics and increasing nutrient availability, which immediately boosts crop output. Apart from raising agricultural yields, biochar has a wide range of applications in improving soil microflora and may also be used for reclamation. As a result, the current review focuses on and offers future research prospects. Furthermore, because biochar has the potential to improve agricultural productivity in soils under a variety of biotic and abiotic conditions, thereby contributing to global food security, it might be an important and accessible resource for sustainable agriculture. The addition of biochar to soil can have a considerable impact on nutrient dynamics, soil pollutants, and microbial activities; this can be helpful in the sustainable management of the agroecosystem and future food security.

Keywords: Biochar, sustainability, soil health, agroecosystem, soil microflora

1. Introduction
Biochar is a word derived from the Greek language, where *bios* means life and *char* means "charcoal obtained by the carbonization of the biomass). Biochar is a pyrogenetic substance derived from the heat and chemical transformation of biomass under oxygen-exhausted conditions with a high capability to foster soil carbon sequestration (Jindo *et al*., 2020) [11]. Biochar is generated with the help of pyrolysis. This process signifies the long-forgotten process of treating biomass. The use of this method dates back to Egyptian times (Mohan *et al.,* 2006). In this process, considerations are primarily accountable for defining the composition of the biomass. The considerations incorporate temperature, categories of biomasses, residence time, heating rate, stress, etc. Here, the temperature is an important consideration influencing the quality of biochar (Yashikaa *et al*., 2020) [37]. It is a carbon-rich substance. A few important possible effects of biochar on topsoil include: soil carbon sequestration (Lal, 2015; Brassard *et al*., 2016) [3], green-house gas discharges (Brassard *et al*., 2016), land potency (Ding *et al*., 2016) [6], crop-production capability (Biederman and Harpole, 2013), soil biology (Lehmann *et al*., 2011), soil and chemical capabilities (Brassard *et al*., 2016; Ding *et al*., 2016; Mukherjee and Lal, 2017) [3, 6], and remedy for contaminated soils (Safaei Khorram *et al*. 2016) [32]; Biochar has obtained collective interest due to its exclusive characteristics, such as its high level of C substance and EC capability, its larger specific exterior space, and its constant composition. (Yang *et al*., 2019) [38] Biochar is also a multi-factor player because it deals with energy, agriculture, and the environment.

The most common materials are wood chunks, tree grafts, bagasse, distilled food grains, oil cakes, and rice husks and other leftovers from juice factories (Parmar *et al*., 2014) [26]. Yet, manufacturing can also be based on bio-mass products other than lignocellulose, such as sewage waste, poultry litter, bones, poultry manure, etc. (Kumar *et al*. 2016). With increasing human populations and rapidly mounting industrialization, the production of waste has greatly increased over the past decade. Agriculture, like every other system, is a major source of organic waste, which contributes to global warming by releasing greenhouse gases like methane, carbon dioxide, etc. Here, this organic waste and other by-products of industry can be used to make biochar, which reduces waste and helps us follow the principles of sustainable agriculture.

In this article, various aspects of biochar are discussed, such as its various sources, different procedures for producing it, its application in agriculture, and the scope of biochar at the national and international level. Finally, this article describes the impacts of biochar on yield production and soil fertility and its mode of action. In addition to all the above-mentioned topics, the constancy of biochar and the application of biochar for biological and non-biological pollutants removal are considered in this paper.

1. Resources of Biochar

There are different resources of bio-mass in various areas of our day-to-day lives, such as plant waste like straw, coconut shells, and also dry leaves. Biochar production has been tested with energy crops like switchgrass and corn, but most research has been done with biomass production from sources like animal waste, forestry, etc. (Figure I).

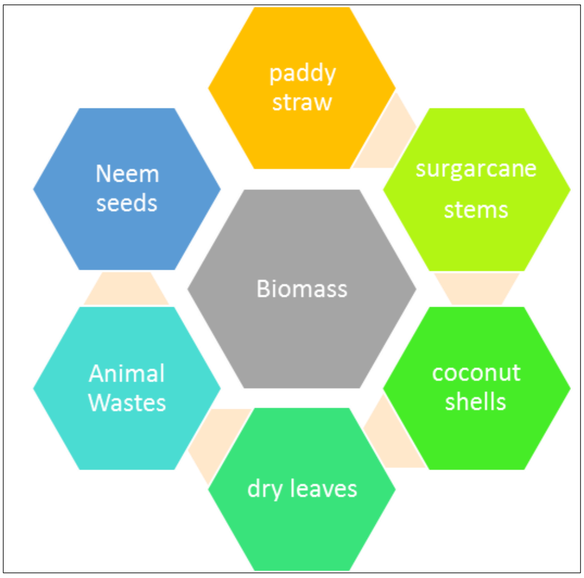

Fig 1: Image showing various types of Biomasses that can be utilised in effective production of biochar.

Separate biomass production units for the sole purpose of making biochar are, at present prices, not likely to be beneficial. From a life-cycle point of view, biochar made by cleaning up native forests doesn't change the net reduction of emissions, and it can also be dangerous for managing biodiversity. There exists a contest among bio-mass sources. That is why present biochar setups are used in particular for various streams that are economically pleasing.

Plant remains and animal waste that are left in the area are very important for storing carbon, taking care of soil and water, promoting bacterial growth, and growing crops. By using them, you don't have to add any more of the artificial fertilizers that are now sold as fertilizers. Additionally, some plant leftovers are utilized to feed cattle. Thus, plant leftovers and animal manure symbolize zero waste in agriculture, and everything from the soil to producing biochar must be done very carefully. The required quantity of feedstock exclusion must be planned, and subsequent biochar can also be used on similar land where feedstock is produced.

Bio-char made from sewage waste during the treatment of household and municipal waste contains heavy metals that could pollute the top soil instead of helping it. Because of this possibility, more research is needed to figure out how different kinds of sewage sludge behave in different situations since the amount of pollution they cause is likely to be different in different places and at different times. Also, as the amount of wet feedstock (like sewage sludge and animal waste) increases, questions about the best way to carbonize it come up. This is because it takes a lot of power to make the feedstock warm and dry so that slow pyrolysis can happen. Biochar enhances the potency of topsoil, which promotes crop development. Healthy crops consume and transform more carbon dioxide, thus improving the air quality.

2. Advantages and Disadvantages

Advantages

Biochar can keep nutrients in the soil for a long time, so it cuts down on the need for chemical stimulants. It also lowers the acidity of the soil, which means less liming is needed to make the soil the right way. The enormous proximity and massive porosity of biochar offer a protected environment for microbes. This boosts the growth of soil microorganisms, which may facilitate greater nutrient acceptance by crops. Recycling agricultural garbage and other organic raw materials into biochar can inhibit CO2 and methane productions caused by bio-mass fuel disintegration. Biochar provides a great way to discard the huge amounts of manure produced by livestock.

- increased fertilizer efficiency rate.
- increase in water quality due to the preservation of contaminants, such as pesticides, herbicides, etc.
- Climate change will be less severe if carbon is stored in a stable form, emissions of strong greenhouse gases like nitrous oxide and methane are cut, renewable energy sources are used, etc.
- lowering ammonium production.
- Clearance of bio-waste from agriculture and forestry

A few more benefits, in addition to the above-mentioned ones, are:

- increase in the EC capacity of the soil.
- increase in the moisture of the soil.
- Improved soil pH level (i.e., less acidic)
- increase in soil microbial biomass.

Disadvantages

Few dis-advantages found are:

- In some cases, production may go down because biochar soaks up water and nutrients, making them harder for plants to get to. Biochar can sometimes also prevent sprouting.
- Sorption of insecticides and weedkillers by biochar can lower their effectiveness.
- Biochar may act as a source of pollutants like heavy metals, PAHs (polycyclic aromatic hydrocarbons), DOC (dissolved organic carbon), etc.
- A decline in nitrous oxide release isn’t common, and some releases also boost levels.
- Fine ash evolved from biochar can also be the primary cause of dust and lead to breathing disorders.
- Long-term removal of crop remains, such as stems, leaves, and so on, to make biochar can weaken the soil by reducing the number of soil microbes and messing up the way nutrients cycle inside the soil. The increase in cation exchange capacity depends on what's in the topsoil. If the topsoil has a lot of clay or organic matter, the effect isn't

very noticeable, especially when the right amount of biochar is added.

- Higher pH (basic) soils don't need their pH to go up because plants can only grow in a certain pH range.

Biochar preparation is easy. In biochar preparation, the feedstock is added to the pyrolysis apparatus with the required heating and gas flow frequency, duration period, and temperature, and then biochar is formed. During this procedure, a few co-products are formed, like gas and bio-oil. Yet, when biochar is used within the agricultural land area, earlier revisions listed a few disadvantages of biochar application: (i) damage to land by erosion; (ii) compaction of soil during application; (iii) hazards of pollution; (iv) elimination of plant remains; and (vii) decrease in insect life rates.

In earlier case experiments, it evaluated the bio-gas application under top soil supervision. For example, soil fertility within the Amazon zone isn’t simply due to the biochar application and other input. Even so, the biochar utilized had a fairly consistent material source and production method. A different case was that bio-char application would inappropriately cause soil compaction, and heavy metals are often noticed, which are very high in sewage bio-char. Besides, biochar from plant waste will negatively affect the soil surface, e.g., through erosion caused by water and/or wind (Bridle and Pritchard 2004).

3. Methods of Biochar Preparation

General preparation of biochar is generally categorized into 1. Pyrolysis (Zwieten, L. V. *et al*., 2010) [40], 2. hydrothermal carbonization (HTC) (Liu, Z. *et al*., 2013) [18], microwave-carbonization (Yu, F.; Deng, *et al*., 2007), gasification and reductive oxidation (S. Pang *et al*., 2010), and flash Here, different preparation methods and different biomasses affect the biochar in different ways, such as yield, ash, cation exchange properties, the structure of the pore, and the effect on the functional group (Sabio *et al*., 2016) [31].

But, unlike pyrolysis, hydrothermal carbonization doesn't need any steps for drying, but it makes more biochar (Yang *et al*., 2019) [38]. But Afolabi *et al*. (2017) [1] say that microwave carbonization is the best way to save energy and get rid of hysteresis.

3.1 Pyrolysis

Here, the thermal decomposition of the biomass takes place under anaerobic conditions (oxygen-free conditions). Most procedures are followed to produce the biochar. Here, electric heating keeps organic waste materials heated to temperatures above 400 degrees Celsius in inert environments. This process is highly influenced based on various physicochemical properties of biochar, for example, residence time, temperature, and type and nature of the mass used. This process is a substitute for transforming waste (biomass) into value-added products like biogas and other useful oils and biofuel. Here, cellulose, hemicellulose, and other substances, under various processes such as depolymerization, fragmentation, and cross-linking at different temperatures, give rise to various types of materialistic foams such as solids, liquids, and gases. The inverse relationship can be seen in the production of biochar yield and syngas production due to an increase in temperature during the pyrolysis method (Figure. II). Based on the rate of heating, temperature, time of residence, and pressure, pyrolysis is of two types: (i) fast pyrolysis and (ii) slow pyrolysis. Here, fast pyrolysis is an immediate thermochemical procedure that can dissolve hard biomass. In this method, fumes from pyrolysis are present along with the biomass as the temperature rises to about 100 Celsius per minute. However, the name "slow pyrolysis" itself signifies that here the rate of heating is low, around 5 to 7 degrees Celsius per minute, and requires a longer residence time when compared to fast pyrolysis, but the quality and yield of the biochar are higher in this process.

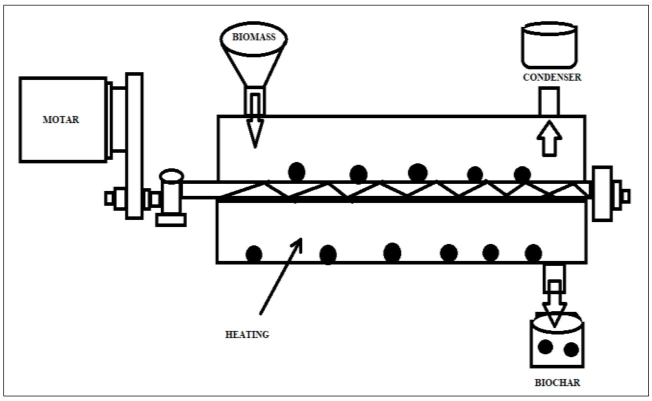

Fig 2: Image showing the process of simple pyrolysis**.**

3.2 Hydrothermal carbonization

HTC is an abbreviation for the hydrothermal process, which is a thermochemical process that happens in subcritical water with mild consequences. Usually, the temperature is kept between 180 and 250 Celsius, and the pressure is kept between 10 and 50 bar. Here, water in the form of foam is used as a solvent for the biomass, where different chemical reactions take place in different places. Here, the hydrolysed product goes through more steps of reactions, such as dehydration, fragmentation, and isomerization, to make an intermediate product between 5-hydroxymethylfurfural and its products. The resultant biochar is called a hydro char. This hydro char has a high nutrient value and has a broad scope of uses in agriculture. The HTC process performs a major role in enhancing the quality of biomass. As it occurs in moist conditions, it is highly advantageous compared to other biomasses (Ischia & Fiori, 2021) [10].

3.3 Microwave carbonization

The U.K.-based company Tech-En Ltd., which is where this method first originated, developed it in Hainault (Holland, 1994) [9]. In this process, the molecules are heated quickly, the temperature is made more uniform, and this method is easier to control, which saves money and energy. This method can be deployed as a replacement for traditional heating methods. (Mubarak *et al*., 2016) [22] The microwave method is highly useful because the heat is produced in the bulk of the material, where microwave energy is transformed into internal energy. Based on the efficiency of the microwave, the efficiency of biochar production varies from 80 to 85%. The time taken to produce the biochar is less, and the quality is also superior (Nizamuddin *et al*., 2018) [25].

3.4 Gasification

The thermochemical decomposition method, which is a partial oxidation process, is used to turn solids into gaseous foam. One of the main ways to make biogas, which is also called "syngas" and is made up of different carbon molecules like CO, CO2, CH4, etc., is to use gasification agents like steam, oxygen, etc. Here, the temperature determines the production of the syngas. Temperature is directly proportional to the production of CO and methane and is indirectly proportional to the production of hydrocarbons. This process is primarily concerned with the production of syngas from biomass, and biochar is a by-product of this process, although the biochar yield is also very low. This process occurs in two phases:

- Drying is a passive process that doesn't use any energy and gets rid of all the water. The rate of speed is mainly based on the biomass material's moisture content. This phase is mainly used when the moisture percentage is high in the given biomass material.
- Combustion: This part of the gasification process is very important because it is the main source of energy for it. Here, a few agents react with combustible species that are available in the gasifier to produce carbon dioxide and water (Cha *et al*., 2016) [5].

3.5 Torrefaction

In this process, the heart rate is very low, temperatures around 300 degrees Celsius are maintained, and this process mainly occurs under inert conditions using various decomposition processes, which can also be defined as an incomplete pyrolysis process (Fig. 3). The residence time is less than 50 oC/min and under the influence of anaerobic conditions. This procedure can be categorized into different parts, such as:

- Drying: This section is mostly about getting the water out of the biomass by evaporation.
- Pre-heating is the stage when the temperature is around 100 ^{o} Cand all the water has been evaporated.
- Post-drying is when the temperature goes up to 200ºC At this point, all of the water has evaporated, and the temperature is directly related to the amount of mass lost.
- Torrefaction: at this phase, 200ºC is maintained as a stable temperature. Crucial phase for the torrefaction process.
- Cooling: The obtained product is made to cool below room temperature.

3.6 Flash carbonization

With a high pressure of 1-2 MPa on top of the bio-mass bed, a fire is started in the foam, which is then exposed to foam gas and solid phase products. (Cha *et al*., 2016) [5]. Here, around 40 percent of the subjected biomass is transformed into solid products, which are considered biochar at low pressure, i.e., 1 MPa (Mochidzuki *et al*., 2003) [20]. This process is not widely followed (Yang *et al*., 2019) [38].

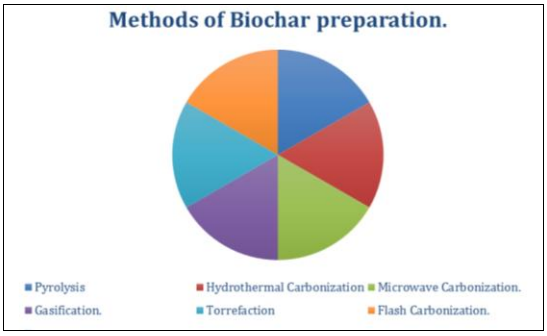

Fig 3: Methods of Biochar preparation.

4. Production of biochar under lab conditions

Under lab conditions, for the sake of biochar production, the biomass can be selected as woody feedstocks: black pine and willow woods, which are around 15 cm in length and 2 centimetres in diameter, were peeled, milled, and sieved. Here, the pyrolysis method is very useful for producing biochar. This process can be achieved through macro TGA (LECO TGA 701) in the presence of nitrogen (10 L/min) with a rate of heating of 20 ºC/min and ensuring that the thermal plateau is around 2 h following the temperatures of 400 º C, 550 º C, or 650 ºC, 2 +/- 0. 1 g is the starting rate of biochar production for all the samples. Further, these samples are characterized based on elemental analysis, pore space, and operational units to verify the capacity of retaining and releasing ions via CEC (Ferraro *et al*., 2021) [7].

5. Production of biochar on a large scale (industrial level)

At the industrial level, there are a lot of different kinds of biomass that can be used. These include crop waste and agricultural waste like human and animal manure. Here, crop waste and other types of manure can be used to make biogas, which can be used as a source of heat energy in the next step of the pyrolysis process. Large-scale production of biochar can be good for the environment and will also be a good choice from an economic point of view. The biomass with a high moisture content can be used as raw material for biogas with the help of a marsh gas tank. Also, animal and human manure, which is high in carbon and nitrogen and good for microbial growth, can be used to make biogas, and the leftovers from biogas can be used as manure to make the topsoil more useful. Biomass with a high bulk density requires a special, large-volume kiln. Alternatively, a spiral conveyor can be used to cut down the substances into smaller pieces, but this task requires additional labor and energy. Here the pilot continuous biogas energy pyrolysis system can be deployed, which includes a continuous rollaway bed kiln for torrefaction and pyrolysis and other auxiliary facilities for cooling the biochar and reducing the atmospheric emissions. As earlier discussed, biogas is the source of energy used for both torrefaction and pyrolysis (Wang *et al*., 2013) [36].

6. Scope of Biochar Worldwide

According to the International Biochar Initiative (IBI) and Cornell University's collaborative project with the World Bank, whose primary objective was to identify promising biochar systems in developing nations, thus helping to direct funding for the development of the required infrastructure for the production of the biochar, in December 2010, this survey was sent to developing nations requesting information, and more than 150 responses from 43 countries were reported. The primary objective of the IBI is to improve the soil nutrition value with the application of biochar, make use of the potential resources of biomass to produce biochar, and provide an additional economic source for the local people in the developing nations. IBI has recognized the nine best-performing nations in the developing nations, and IBI is also working with these nine nations to achieve the following objectives:

(i) Put biochar and pyrolysis technologies, like biochar ovens and small-scale manufacturing units, into villages.

1. Build on a general evaluation system to calculate the implementation and production of these things.
2. Figure out common procedures to analyse and monitor

the treatment and crop development.
3. Build a way to keep track of the business and community costs of biochar technology and study its benefits and effects on topsoil.

Countries included are Belize, Cameroon, Chile, Costa Rica, Egypt, India, Kenya, Mongolia, and Vietnam.

Belize: Carbon Gold, operational along with Toledo Carbon and a sub-enterprise of Toledo Cacao Growers Association (TCGA), is supervising trails with five units. Among these 5 units, 2 are in the Golden Stream Preserve. The Natural Reserve has a total biomass availability of 100,00 metric tons with an estimated value of 30,000 metric tons of carbon. Her studies are primarily concerned with the usage of bio-mass from cacao cultivation, rice husks, and citrus fruit peels. The crops selected were corn, beans, etc.

Cameroon: The Biochar Fund from Belgium and key farmers in Cameroon are working together on sustainable soil management approaches in agricultural lands in Cameroon. This change was mostly about how biochar buffers could be used to protect the forest and ecosystem.

Chile: The University of Tarapaca and Convenio de Desempeno are working with other government agencies to improve degraded desert soil by adding biochar. This will stabilize and buffer the salinity of the soil and help it hold more water. These groups have also been trying to get the word out about biochar as an innovative and environmentally friendly substance that could change the way farming is done, solve the region's farming problems, and create new opportunities.

Costa Rica: On the Osa Peninsula of Costa Rica, the world's most biodiverse region, Forest Trends and an NGO based in Washington, DC, are working with the Business Development Facility (BDF) to integrate various national and international parameters intended to evaluate the social, economic, and practical viability of utilizing biochar, which includes: 1. evaluating the nutrition value of existing biochar; and 2. accessing the technologies to produce and transport biochar. 3. Implementing small and medium-scale biochar production units 4. Set up research stations to analyse the quality and other parameters of the biochar. 5. To determine the potential of the biochar-related revenues.

Egypt: Scholars from the University of Mansura in Egypt and the University of Copenhagen are working on the rice straw, which is produced at around 2.8 metric tons and is used to produce syngas from a rice straw gasifier, which also produces biochar, which helps reduce the price of fossil fuels. They are also working on oven-based biochar production and are also assigned to test the oven and the performance of the biochar.

India: Ra Ga LLC works with two other NGOs, ARTI and Jalandhar, to make a new kind of biochar called "modular pyrolysis kilns." These kilns are used in villages to turn organic materials, other manures, and waste from sewage plants into biochar. At first, in ARTI technology, locally constructed kilns are used to produce the biochar, and at Jalandhar, municipal waste is used for biochar production and to maintain the day-to-day operations. Here, tests are also carried out on various strains of marijuana and in field experiments.

Kenya: The project was mostly about making a pyrolysis cook stove that could be used for farming in the countryside. So that it is easy to make biochar, research was done in Nandi districts, which are in the highlands of western Kenya.

Mongolia: tests are done on how to use small-scale herders, vegetable growers, etc. to make biochar and use it to fight global warming. For making biochar, it is expected that around 200 biochar manufacturing stoves and 25 biochar ovens will be set up. The Mongolian Biochar Initiative (MoBI) is also working on a number of low- to moderate-tech pyrolysis units for communities. MoBI is jointly working with various NGOs, such as People-Centred Conservation in Mongolia (PCC). The Mongolian Women Farmers' Association (MWFA) for the same purpose.

Vietnam: The Soil & Fertilizer Institute in Hanoi, Vietnam, is working to address poor soil health for agricultural production. Here, it's projected that 1.2 million ha of the area is under slash-and-burn type cultivation practices, which are leading to large emissions of carbon and leaving a lot of crop residue. There is a lot of scope to produce biochar using these crop residues and other organic materials. So, this group is trying to teach people and increase the production of biochar, which is seen as both good for the environment and an extra source of economic activity.

7. Scope of Biochar Production in an Indian Scenario

India is one of the most populated countries, and 70% of its people work in agriculture. Just like any other industry, even the agriculture sector produces a large number of waste materials. Apart from the agriculture waste, even municipal and other sewage waste is produced in large amounts. Using this as an advantage, biochar production has a wide range of uses and can even be used as an alternative to landfilling and burning as a way to get rid of waste. Especially this biochar production has a lot of potential as an alternative to burning stubble in places where slash-and-burn farming is done or where corn and groundnuts are the only crops grown.

Some estimates say that between 72 and 127 metric tons of crop waste are burned in India every year. Most fields in India are burned in the open, which causes huge amounts of carbon dioxide to be released into the air and destroys nutrients like N and S, as well as carbon-based matter and bacterial action, which are important for keeping the soil healthy (IARI, 2012). The Central Research Institute for Dryland Agriculture (CRIDA) and the Indian Council of Agricultural Research (ICAR) are two large organizations that work on all organic biomass in the agricultural sector. This includes crop residues like pigeon pea, cotton stalks, and maize stalks, as well as agroforestry residues like Eucalyptus twigs, barks, Pongamia shells, etc.

In the Indian scenario, there are the major states of Punjab, Haryana, and Delhi in the north and north-eastern states such as Assam, Nagaland, Tripura, and other states; and in the south, Andhra Pradesh, Telangana, Karnataka, and other states, where there is a large scope to produce biochar and also to store and utilize this biochar for crop production and to mitigate the soil conditions. Moreover, the production of biochar also helps in the better management of waste, both organic and municipal, to make an extra source of revenue for farmers and even decrease inputs for farming. These organizations are trying to achieve the principles and goals of sustainable agriculture and are also trying to educate farmers and people and even provide essential knowledge through various extension programs. However, there are still a few constraints regarding implementing this project, converting this biochar production into an income-generating source, and taking this to the level of industrial production, like a lack of interest, a lack of knowledge, and insufficient economic resources to take this as an entrepreneurship opportunity. So, government as well as NGOs should work together for the successful implementation of this biochar production program and educate the youth and farmers about the advantages and the optimistic properties of biochar on soil and crop development when used in agriculture, and also recognize the scope of biochar production from various biomass and employment and entrepreneurship opportunities in this area.

8. Applications of biochar

One of the major issues facing agricultural activities is the management of large amounts of organic waste; these must be properly treated to avoid the risks of contamination in the atmosphere, soil erosion, eutrophication of water, and the release of greenhouse gases. As a result, various technologies for biochar applications are currently being used.

The most important thing about BC is its ability to absorb inorganic substances like heavy metals (like lead, chromium, etc.) that come from drilling operations in soil and water. In addition, BC has been described as a stimulating choice for maintaining agrochemical-polluted soils. Many toxic substances have accumulated in the soil because of the enormous use of herbicides and other toxic molecules. For example, it is detected that the quantity of atrazine in the soil was reduced by animal manure. Absorption of biochar In addition, Biochar's better surface and nano-permeability promoted the adsorption of pesticides based on chlorpyrifos and carbofuran, as well as lower amounts of an insecticide such as pentachlorophenol. In the long run, biochar has reduced the polluting effects of substances including diclofenac, naproxen, and sulfamethazine.

Less attention has been paid to how biochar affects the bacteria in the soil than to how it affects the soil's physical and chemical properties. Scientists found that biochar increases the number of bacteria families like Streptosporangineae (6%), Thermomonosporaceae (8%), Bradyrhizobiaceae (8%), and Hyphomicrobiaceae (close to 14%) by changing the way carbon moves through the soil. (The last two families make a big difference in the nitrogen cycle, especially in the process of turning NO3 into N2.) These results show that biochar increases phosphate-solubilizing bacteria, which changes the way carbon moves through the soil and raises the number of microbes that may get rid of extra carbon molecules that are hard to get rid of while lowering the number of bacteria that hurt plants. The microbial biomass has been the subject of numerous studies.

It is mainly responsible for adsorption and is very useful for using a certain type of char based on its physical and chemical properties, even though the link between char properties and these products is not very clear. X-ray photoelectron spectroscopy, X-rays, solid-state nuclear resonance spectroscopy, Fourier transform infrared spectroscopy, etc. are some of the new methods that have been used a lot and are important for biochar classification. In the modern era, people are using the high concentration of biochar for many environmental uses, such as getting rid of pollution in the air, storing carbon, and making soil better. Biochar has unique qualities that make it effective, economically useful, and environmentally friendly enough to get rid of a wide range of pollutants. The differences in physico-chemical properties (e.g., higher surface area, microporosity, and pH) provide a path for biochar to make the best use of its efficacy in targeted applications. Diffraction, thermogravimetric investigation, near-edge X-ray absorption, fine structure spectroscopy, etc. Consumption of these contemporary methods delivers the quantitative and qualitative data, i.e., determination of sizes, shapes, and physico-chemical features of biochar, which is dependable to keep track of pathway changes in the carbon arrangement over response time and temperature, and it's very beneficial for effective production of biochar and application. It is helpful in providing the information to the scientists to this extent and is useful not only for effective biochar production but also for potential utilization for environmental and agricultural purposes.

8.1 Impacts of Biochar in Agroecosystems

8.1.1 Impact of biochar on soil health

Soil health is the ability of the soil to do its different jobs in an ecosystem in a way that is good for the environment. The physical environment, the biological environment, the chemical environment of the soil, and the amount of organic matter in the soil all show how healthy the soil is. Soil health is necessary for desirable crop growth and yield. It is the soil that plays a major role in the development of a crop, as it is a precious source of nutrients and water supplementation for the plants. To meet the increased demands of the food supply, many synthetic fertilizers, pesticides, and herbicides are used injudiciously, which gradually leads to the deterioration of soil fertility. Fertility of the Indian soils has been noticed to have declined tremendously due to these practices over a long period of time. Thus, there is an urgent need for a novel approach to improving the soil's health. Our paper describes the impact of biochar on soil health.

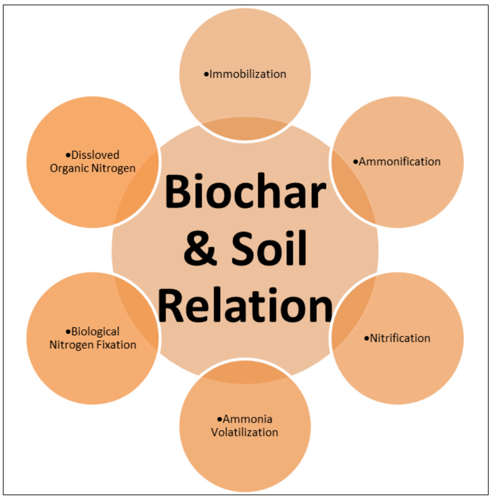

Fig 4: Image showing the various process that are influenced by the accumulation of bio-char to the soil.

Biochar application restores soil health sustainably. However, the efficiency of biochar on crop growth and development depends on factors like the feedstock of biochar, the process of making biochar, time, and rate of application of biochar. Biochar ameliorates the soils as it is rich in organic matter content (Jindo *et al*., 2020) [11]. In the case of acidic soils, it enhances the PH content of the topsoil directly due to the existence of carbonized mixtures. The porous nature of biochar has added to the increased water-holding capability of soil. The nutrient content of biochar is the highest when compared to biomass. Overall improvement of the soil health due to the application of biochar is long-lasting (Figure 4).

Biochar	Physical effect	Improves soil aggregation, water holding capacity,bulk density.
	Chemical effect	Improves fertility,PH, soil acidity,supply of nutrients ,restoration.
	Biological effect	Improves Microbial activity and diversity.

Plant biochar element size can be used to increase the field's capacity, permanent wilting point, and amount of water that can be reached (Zuolin Liu *et al*., 2017) [17]. As the temperature of pyrolysis goes up, the amount of nutrients in biochar goes up to some degree.It has been found that the biochar made from plant waste has more nutrients than biochar made from other plant materials.

8.1.2 Influences of Biochar on Crops

The use of biochar results in enhanced availability of nutrients for the crop. Biochar acts as a soil amendment and decreases the plant's need for water and fertilizers. Biochar increases the porosity and thus increases the moisture retention capacity, which protects the crop from drought. Biochar increases soil fertility as it combines nutrients with the soil; this ultimately indicates the growth and yield of the crop (Fig. 5). Biochar similarly plays a vital role in stimulating the microflora of the soil. Biochar similarly plays a vital role in stimulating the microflora of the soil. It provides a habitat for the growth of microorganisms like bacteria, actinomycetes, and fungi. The availability of nutrients in the soil and its solution, as well as an evaluation of plants' capacity, greatly exaggerate plant development. Growth and development can be greatly decreased if the nutrients are unavailable to the plant. In such cases, biochar does a major job of supplying the required amount of nutrients, e.g., C, N, Ca, Mg, K, etc., to plants (Rodrguez *et al*., 2016). Moreover, the biochar releases the nutrients in a slow and steady manner, which helps increase the nutrient use efficiency. Many studies have proved their potential has increased the growth potential among the plant species (Seleiman *et al*., 2019). The incorporation of poultry waste in biochar has increased the nutrient availability in the biomass and produced an excellent yield in cucumber (Solaiman *et al*., 2020) [34]. Even mustard has seen a 49% increase in growth (Khan *et al*., 2017) [14]. In maize, the yield increased from 46 to 58 percent due to the application of 50 mg ha1 (Rabion *et al*., 2016). The use of biochar enhanced the stomatal conductance of maize, which indirectly augmented the production of TSS—total soluble sugar—in soybean (Qian *et al*., 2019) [27]. In alternative research, crops grown on a biochar-modified soil exhibited a great intensity of nutrients in leaves, augmented protein matter (44%), and inferior production of reactive oxygen species under pressure (Kamran *et al*., 2019) [12]. In additional studies, biochar addition has amplified the starch and ascorbic acid content (Ramzani *et al*., 2017) [30] and the starch and soluble sugars.

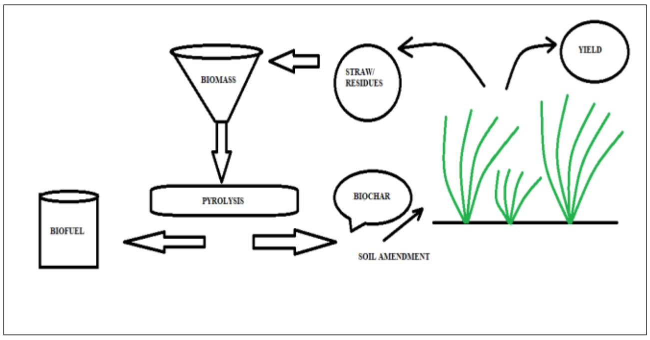

Fig 5: Image showing the soil fertility supervision & Plant produce enhancement by application of bio-char.

9. Mode of Action of Biochar

Biochar is used in soil to make it more habitable and to add nutrients. Treatment can also help lower the number of contaminated elements in the soil. Existing studies have demonstrated that biochar is also capable of adsorbing heavy metals (such as lead, cadmium, etc.) and organic pollutants that contaminate land and are toxic to the environment. For that reason, biochar acts as an additive for soil. It improves its total adsorption capability, affecting toxicity because there is a reduction in transportability and a reduction in the existence of metal or organic complexes. Because of its low price and lower ecological effect, biochar would be a hopeful approach to remediating contaminated ecosystems. Modern experiments have revealed that biochar, in association with stimulation, has equivalent adsorption and absorption capabilities, which play a crucial role in the elimination of pollutants from the soil ecosystem.

In terms of how research is done now, results have shown that metal ions are effectively adsorbed onto certain functional sites on the outside of biochar that have phenolic and carboxyl functions. When biochar is used to handle wastewater, impurities like heavy metals (like lead) replace ions that might already be on the biochar with metallic ions in the solution system. This could mean that the content of the biochar is related to its ability to clean up metals. Although soils with biochar. Even though biochar-rich soils will make pollutants less bio-accessible and, therefore, less harmful, they may also slow down the rate at which organic mixtures are broken down in the ecosystem because of this decrement studies have shown that biochar makes it less likely that organic insecticides and other organic pollutants will be used up. This should be thought about when the soil has biochar, especially if the top layer had organic complexes that would break down faster. In the same way, this reduced bio accessibility can be bad because it can lower the effectiveness of herbicides, leading to the need for higher treatment rates for these substances. In some cases, biochar has been found to hurt residues and soil creatures, especially those that live close together and eat a lot of residue and topsoil.

10. Conclusion

Biochar production is an important part of achieving the goals of sustainable agriculture. It can be used to improve waste management that isn't working well and lower the cost of agricultural inputs. By making biochar, a wide range of biomasses can be used, and it can be an important way to deal with the organic waste that comes from farming. The type of biomass and the pyrolysis conditions have a significant impact on the final product, biochar. But new, more promising ways to make biochar need to be found, and biochar with great refining properties needs to be processed. As we've already talked about, biochar is seen as one of the most promising ways to get rid of pollutants. Financial effects and recyclability must also be considered when developing novel biochar production methods. This review paper has condensed the state-of-the-art knowledge that would be beneficial for the discovery of novel prospects in systematic modernization within the subject of biochar exploration.

11. Conflicts of interest
The authors declare that they have no conflicts of interest in relation to this article.

12. References

1. Afolabi, Oluwasola OD, Sohail M, Thomas CLP. Characterization of solid fuel chars recovered from microwave hydrothermal carbonization of human biowaste. Energy. 2017;134:74-89.
2. Alkharabsheh Hiba M. *et al*. Biochar and its broad impacts in soil quality and fertility, nutrient leaching and crop productivity: A review. Agronomy. 2021;11(5):993.
3. Brassard, Patrick, Stéphane Godbout, and Vijaya Raghavan. Soil biochar amendment as a climate change mitigation tool: Key parameters and mechanisms involved. Journal of environmental management. 2016;181:484-497.
4. Biederman, Lori A, Stanley Harpole W. Biochar and its effects on plant productivity and nutrient cycling: a meta-analysis. GCB bioenergy. 2013;5(2):202-214.
5. Cha, Jin Sun, *et al*. Production and utilization of biochar: A review. Journal of Industrial and Engineering Chemistry. 2016;40:1-15.
6. Ding Yang, *et al*. Biochar to improve soil fertility. A review. Agronomy for sustainable development 2016: 36.2:1-18.
7. Ferraro, Giovanni, *et al*. Biochar from lab-scale pyrolysis: influence of feedstock and operational temperature. Biomass Conversion and Biorefinery, 2021, 1-11.
8. Guo, Mingxin. Application of biochar for soil physical improvement. Madison, WI, USA: Soil Science Society of America, 2016.
9. Holland KM. U.S. Patent No. 5,330,623. Washington, DC: U.S. Patent and Trademark Office, 1994.
10. Ischia, Giulia, Luca Fiori. Hydrothermal carbonization of organic waste and biomass: a review on process, reactor, and plant modeling. Waste and Biomass Valorization. 2021;12.6:2797-2824.
11. Jindo Keiji, *et al*. Role of biochar in promoting circular economy in the agriculture sector. Part 1: A review of the biochar roles in soil N, P and K cycles. Chemical and Biological Technologies in Agriculture. 2020;7.1:1-12.
12. Kamran, Muhammad, *et al*. Biochar alleviates Cd phytotoxicity by minimizing bioavailability and oxidative stress in pak choi (*Brassica chinensis* L.) cultivated in Cd-polluted soil. Journal of environmental management. 2019;250:109500.
13. Kleber Markus, William Hockaday, Peter S. Nico. Characteristics of biochar: macro-molecular properties. Biochar for environmental management: Science, technology and implementation, 2015, 111-137.
14. Khan, Kiran Yasmin, *et al*. Impact of different feedstocks derived biochar amendment with cadmium low uptake affinity cultivar of pak choi (*Brassica rapa* ssb. chinensis L.) on phytoavoidation of Cd to reduce potential dietary toxicity. Ecotoxicology and environmental safety. 2017;141:129-138.
15. Lal Rattan. Biochar and soil carbon sequestration. Agricultural and environmental applications of biochar: Advances and barriers. 2016;63:175-197.
16. Lehmann, Johannes, *et al*. Biochar effects on soil biota–a review. Soil biology and biochemistry. 2011;43(9):1812-1836.
17. Liu Zuolin, *et al*. Biochar particle size, shape, and porosity act together to influence soil water properties. Plos one. 2017;12(6):e0179079.
18. Liu, Zhengang, *et al*. Production of solid biochar fuel from waste biomass by hydrothermal carbonization. Fuel. 2013:103:943-949.
19. Chan, K. Y卌, *et al*. Agronomic values of greenwaste biochar as a soil amendment. Soil Research. 2007;45.8,, 629-634.
20. Mochidzuki, Kazuhiro, *et al*. Electrical and physical properties of carbonized charcoals. Industrial & Engineering Chemistry Research 2003, 42.21, 5140-5151.
21. Wu, Min, *et al*. The sorption of organic contaminants on biochars derived from sediments with high organic carbon content." Chemosphere 2013, 90.2, 782-788.
22. Mubarak, N. M., *et al*. Plam oil empty fruit bunch based magnetic biochar composite comparison for synthesis by microwave-assisted and conventional heating. Journal of Analytical and Applied Pyrolysis. 2016; 120:521-528.
23. Mukherjee, Atanu, and Rattan Lal. Biochar and soil characteristics. Encyclopedia of soil science, 3rd edn. CRC Press, Boca Raton, FL, 2017, 184-188.
24. Derakhshan Nejad, Zahra, and Myung Chae Jung. The effects of biochar and inorganic amendments on soil remediation in the presence of hyperaccumulator plant." International Journal of Energy and Environmental Engineering 2017, 8.4, 317-329.
25. Nizamuddin, Sabzoi, *et al*. An overview of microwave hydrothermal carbonization and microwave pyrolysis of biomass. Reviews in Environmental Science and Bio/Technology 2018, 17.4, 813-837.
26. Parmar Aditya, Prabhat K Nema, Tripti Agarwal. "Biochar production from agro-food industry residues: A sustainable approach for soil and environmental management. Current Science 2014, 107.10, 1673-1682.
27. Qian ZHU, *et al*. Effect of biochar on grain yield and leaf photosynthetic physiology of soybean cultivars with different phosphorus efficiencies." Journal of Integrative Agriculture 2019, 18.10, 2242-2254.
28. Raboin, Louis-Marie, *et al*. Improving the fertility of tropical acid soils: Liming versus biochar application? A long-term comparison in the highlands of Madagascar. Field Crops Research. 2016, 199, 99-108.
29. Rodríguez, Lylian, Patricia Salazar, Preston TR. Effect of biochar and biodigester effluent on growth of maize in acid soils, Integrated Farming Systems for Food and Energy in a Warming, Resource-depleting World, 2009, 84.
30. Ramzani, Pia Muhammad Adnan, *et al*. Improved quinoa growth, physiological response, and seed nutritional

quality in three soils having different stresses by the application of acidified biochar and compost." Plant physiology and biochemistry. 2017;116:127-138.
31. Sabio E, *et al*. Conversion of tomato-peel waste into solid fuel by hydrothermal carbonization: Influence of the processing variables. Waste management. 2016;47:122-132.
32. Khorram, Mahdi Safaei, *et al*. Biochar: A review of its impact on pesticide behavior in soil environments and its potential applications. Journal of environmental sciences. 2016; 44:269-279.
33. Seleiman Mahmoud F, *et al*. Effects of ZnO nanoparticles and biochar of rice straw and cow manure on characteristics of contaminated soil and sunflower productivity, oil quality, and heavy metals uptake. Agronomy. 2020, 10.6, 790.
34. Solaiman Zakaria M, *et al*. Poultry litter biochar increases mycorrhizal colonisation, soil fertility and cucumber yield in a fertigation system on sandy soil. Agriculture. 2020, 10.10, 480.
35. Kumar, Sandeep, *et al*. An assessment of U (VI) removal from groundwater using biochar produced from hydrothermal carbonization. Journal of environmental management. 2011, 92.10, 2504-2512.
36. Wang, Shenqiang, *et al*. Large-scale biochar production from crop residue: A new idea and the biogas-energy pyrolysis system. Bio Resources. 2013, 8.1, 8-11.
37. Yaashikaa PR, *et al*. A critical review on the biochar production techniques, characterization, stability and applications for circular bioeconomy. Biotechnology Reports. 2020, 28, e00570.
38. Yang, Xue, *et al*. Preparation and modification of biochar materials and their application in soil remediation. Applied Sciences 2019, 9.7, 1365.
39. Yu, Fei, *et al*. Physical and chemical properties of bio-oils from microwave pyrolysis of corn stover. Applied biochemistry and Biotecnology. Humana Press, 2007, 957-970.
40. Van Zwieten, Lukas, *et al*. Effects of biochar from slow pyrolysis of papermill waste on agronomic performance and soil fertility. Plant and soil 327.1, 2010, 235-246.`