BIOCHAR

Black Gold that Enriches the Soil Fertility

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"DON'T BURN crop residues
CONVERT IT INTO BIOCHAR FOR BETTER SOIL HEALTH"

Dedicated to...

(1920 -1993)
Founder President
Dr. Manibhai Desai
BAIF Development Research Foundation
Central Research Station, Uralikanchan
Taluka Haveli, District Pune - 412 202
Maharashtra

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Soil health is the overall quality and functionality of soil as a living ecosystem. It reflects the soil's ability to sustain plants, animals, and humans. Healthy soil has a balanced structure, rich organic matter, active microorganisms, and proper nutrient and water retention. It supports plant growth, reduces erosion, improves water quality, and helps combat climate change by storing carbon. Maintaining soil health is essential for sustainable agriculture, food security, and environmental protection.

Acknowledgement

We are pleased to present this booklet, "Biochar: Black Gold that Enriches Soil Fertility," to our valued farmers. The use of Biochar can significantly improve soil texture, enhance crop growth and yield, and ultimately contribute to better soil health. In the current context of sustainable agriculture, Biochar stands out as one of the most practical and effective options for enhancing soil fertility.

We believe this booklet will be highly beneficial to farmers. It is designed to help reduce crop production costs by lowering the dependency on chemical fertilizers while maintaining long-term soil productivity.

We extend our heartfelt gratitude to the Nature Positive Solutions (NPS) project team for their cooperation and financial support in making this publication available for widespread use.

We are also thankful to the BAIF office at Warje, Pune, for facilitating the printing of this booklet through support from the NPS project. Special thanks to Dr. Rajshree Joshi, Shri Mahesh Lade, and Shri Vishwadev for their valuable contributions. The authors deeply appreciate the guidance as well as the scientists and staff at the BAIF Central Research Station, Urulikanchan, Pune.

Soil conservation is a critical practice that is essential for the future generations and sustainable agriculture. Soil conservation has many benefits, including the preservation of soil fertility, the prevention of soil erosion, and the reduction of land degradation. According to the Food and Agriculture Organization (FAO), 3 principles of Conservation Agriculture are: (a) Minimum mechanical soil disturbance, (b) Permanent soil organic cover, (c) Species diversification.

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What is Biochar

Biochar is a charcoal produced by heating biomass in the absence of oxygen—a process known as pyrolysis. Various agricultural residues such as stalks of mulberry, pigeon pea (tur), cotton, maize straw, and corn husks (after grain removal) can be used as feedstock. During pyrolysis, components like cellulose, lignin, and other non-carbon materials in the biomass are broken down, leaving behind carbon-rich Biochar.

Biochar is also made through the controlled combustion of plant materials such as leaves, field weeds, and fire wood under low-oxygen conditions. The resulting product retains carbon that was originally present in the biomass.

Biochar is primarily used to enhance soil fertility. It increases water retention, and boosts nutrient uptake by crops, thereby promoting plant growth and increasing yields. Additionally, Biochar can store significant amounts of carbon in the soil, playing a crucial role in climate change mitigation. It also enhances soil texture and Soil health.

Soil fertility status

1. Soil Fertility Under Threat

The uncontrolled use of chemical fertilizers and pesticides is gradually degrading soil fertility across farming landscapes.

2. Ideal Organic Carbon Levels

Soil to be considered fertile, with more than 1% organic carbon in the top soil or the crop's root zone.

3. Current Alarming Situation

In modern farming systems, organic carbon levels have dropped drastically to 0.30% to 0.40%. This is an alarming indicator of declining soil health and a warning sign for the future of sustainable agriculture.

4. Need for More Organic Carbon

For optimal crop growth and productivity, organic carbon levels must exceed 1%. Without this, soil struggles to support healthy plant development.

5. Decline in Organic Inputs

The reduction in the use of traditional organic inputs like cow dung and compost has led to a significant decrease in organic carbon content in the soil—now often falling below the critical 1% level.

6. Sustainable Waste Management

Instead of burning plant residues, leaves, and weeds indiscriminately, farmers are encouraged to: Compost organic materials during the monsoon or produce Biochar in a controlled, scientific manner during winter and summer. This provides a rich source of stable organic matter for the soil.

7. Carbon Sequestration for Soil and Climate

By converting atmospheric carbon dioxide into stable organic carbon and integrating it into the soil, we can address two major issues simultaneously like Soil fertility restoration and Climate change mitigation

Importance of Biochar for soil fertility improvement

The concept of Biochar is not new. In fact, its use dates back to traditional practices. For example, in many households years back, especially in rural areas, our grandmothers used the ash and charcoal left behind after cooking on a chulha (traditional mud stove) to enrich the soil of backyard garden. This reflects their deep-rooted understanding of soil health an intuitive form of Biochar use passed down through generations. Despite being illiterate, they possessed remarkable wisdom in making use of natural resources to improve the soil.

The green revolution began in India in 1967, aiming to increase food grain production to meet the demands of the rapidly growing population. During this period, chemical fertilizers and pesticides played a significant role in boosting yields. However, over time, their excessive use led to: Soil fertility degradation, Environmental pollution, Decline in microbial life in the soil. While these chemical interventions were necessary for the time, they eventually contributed to long-term soil exhaustion.

Recognizing these adverse effects, many individuals and institutional thoughts began seeking alternative solutions that were eco-friendlier and more sustainable. This prompted a renewed focus on organic, traditional, and natural farming practices. Scientists emphasized that maintaining a high level of organic matter in soil is key to increasing beneficial microorganisms, improving nutrient cycling, enhancing crop nutrition and yield.

Biochar is a sustainable solution that not only builds on our traditional knowledge but also incorporates scientific innovation. Its advantages include:

- Utilizing abundant biomass waste after harvest of the crops
- Capturing and storing carbon in the soil
- Improving soil texture, moisture retention, and nutrient availability

Importantly, Biochar helps to mitigate climate change by preventing the release of greenhouse gases into the atmospheric gases that contribute to global warming.

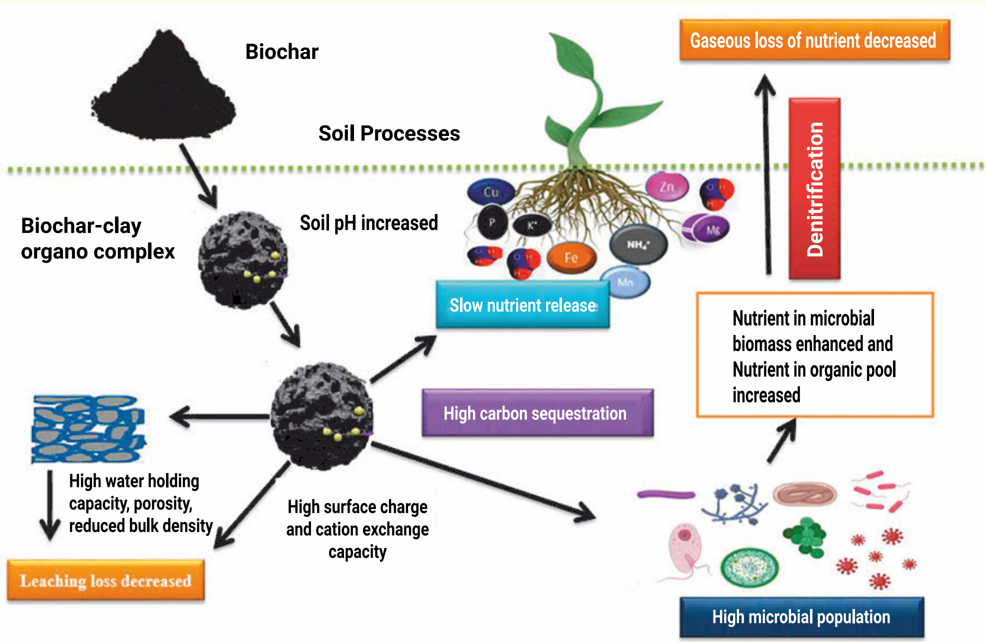
In essence, Biochar brings together the wisdom of the past and the technology of the present to secure a greener, more fertile, and sustainable future for Indian agriculture.

Soil Fertility and Organic Matter

The soul of the soil is organic matter. The physical, biological and chemical properties of the soil depend on the use of organic matter. Organic matter gives the soil the power to keep it alive and productive. That is why it is necessary to preserve organic matter. There are many methods in the modern agriculture practices. As a result, the organic matter in the soil, which has been preserved for thousands of years, has been brought to a very low level in the last 60-70 years. Scientists have found terra preta, a very fertile soil in some places in the Amazon basin. More than 1% organic matter was found there. This land was created by local farmers hundreds of years ago. However, the lands around it are barren. This fertile soil was mainly found to contain charcoal, fish and animal bones, fragments of pottery, compost manure, etc. This attracted the attention of scientists around the world to Biochar.

Properties of Biochar

1. Biochar is porous, so any liquid fertilizer is absorbed into it and it is good habitat for microbes.
2. Biochar is alkaline in nature. Therefore, it shows good results in acidic and red clayey soils. It shows better results in other types of soils to a lesser extent for example pure black cotton soil.
3. Biochar absorbs water like a sponge. It can be used well in loamy soils that do not retain water. However, in black soils that retain water, therefore we need to use it in a limited way in stages.
4. It is rich in organic carbon, the soil carbon can be maintained in the soil by using Biochar.
5. High surface charge and cation exchange capacity
6. The Biochar decomposes slowly in the soil and it will be remain in the soil for long period.



Crop residues and their availability for Biochar production

India generates a vast amount of crop residues every year—an estimated 500 million tons annually. However, around 150 million tons of these residues remain unused or underutilized, often ending up as waste or being burned in open fields, contributing to environmental pollution. (Ref:NPMCR,2019)

A huge opportunity for sustainable Biochar Production

The unused biomass, it is possible to produce approximately 25 to 35 million tons of Biochar every year. This represents a significant opportunity to:

- Convert agricultural waste into a valuable soil amendment
- Reduce air pollution from residue burning
- Enhance soil organic carbon levels
- Support climate-resilient farming

Side effects of burning various crop residues:

1. CO_2 in the atmosphere increases.
2. Global temperatures are rising.
3. The number of microorganisms on the soil surface decreases.
4. Soil productivity decreases.

Different methods of preparing Biochar

Biochar is created through a process called pyrolysis, where organic matter—such as crop residues—is burned in a controlled, low-oxygen environment. This is typically done using a furnace or an airtight chamber (kiln) at high temperatures ranging from 500°C to 650°C.

1. Iron drum

Biochar is produced through pyrolysis using farm waste and fire woods with locally available drums.

Materials required :

a. Iron drum (50 kg)

b. Residue or stalks of any crop such as Maize, Mulberry, Cotton, Wheat the Corn cob of maize left after threshing the grains.

c. 5-6 bricks

Preparation method:

1. Take a 200-liter iron drum and drill 18 to 20 holes of 5 centimeters in diameter in its bottom as shown in the photo.
2. Make a 1 square foot lid for the top of the drum with a 1ft pipe on each side to hold the drum. Place a drum on the bricks and keep the air space below the drum.
3. The lid open will make it easier to fill the crop residues into the drum. The holes in the bottom will allow the crop residues to burn slowly with little oxygen.
4. Fill the drum completely with selected crop residue such as mulberry, cotton, maize, etc., or the husks of maize left after harvesting the grains. If the crop residues are large, chop them into pieces before loading the drum.
5. Once the drum is filled, place it on chulha made from bricks and light the chulha at the bottom of the drum and automatically it will start firing in side the drum.
6. After lighting the fire, initially white smoke will be seen then the smoke will gradually turn slight brownish colour. In this stage close the drum and apply moist soil on all sides of the lid to prevent the smoke leakages.

7. During pyrolysis, it is important to carefully monitor the heating process. While the process is ongoing, occasionally open the lid to check the material. Ensure that the crop residues are not burning completely, as this would result in ash instead of the desired Biochar.
8. While the process is ongoing, ensure that no air enters the drum. If air leaks inside, the residues will burn instead of undergoing proper pyrolysis, and the desired quality of charcoal will not be obtained.
9. The time required for charcoal formation depends on the type of crop residue used.
10. Once the charcoal is ready, carefully remove the drum from the brick chulha. Since hot charcoal can ignite when it contact with air and quickly turn into ash, immediately sprinkle water over it to prevent burning.
11. After the drum has cooled completely, remove the charcoal. Separate and set aside any unburned residues, which can be reused in the next batch.

2. Iron Kiln

Biochar kiln is a new method that has been developed in recent times. The kiln should be prepared using iron sheets or buy a kiln from the market. This costs about 1 lakh rupees. A good quality charcoal can be produced under this method.

Materials required:

Iron kiln with a capacity of 200 kg, any type of crop residues

Preparation method:

1. Make a circular kiln of 12 ft in diameter and 3 feet in height.
2. Prepare a lid of 12.5 ft in diameter to cover the kiln.
3. Fix a 3 ft round pipe (4 inches in diameter) at the center of the lid to act as a chimney.
4. This chimney will ensure proper burning and result in good-quality charcoal.
5. Use 18-gauge thick plain iron sheet for the kiln walls. Drill 0.5-inch circular holes in the middle section of the kiln.
6. This controlled airflow ensures a smooth pyrolysis process.
7. On both sides of the kiln, erect two 15 ft square pipes (3 inches × 5 mm in size).

8. Place a 15 ft horizontal pipe on top of them with attach pulleys, iron wire, and circular rotating handles to lift the lid easily.
9. Alternatively, an old-fashioned pulley with a 500 kg lifting capacity can also be used.
10. Fill the kiln completely with available crop residues and press the crop residue manually and place dried grass or straw in the middle to help ignite the fire quickly.
11. Ensure that no air enters in the kiln during the process. If air leaks in, the residues will burn instead of undergoing pyrolysis, resulting in

poor-quality charcoal.
12. After lighting, white smoke from chimney will appear initially and gradually, the smoke will turn light brown colour. It indicates the phyrolisis process is taking properly.
13. During pyrolysis, open the lid occasionally to check that the residues are not burning to ash.
14. The readiness of charcoal is indicated when the smoke changes from white to brownish in color. At this stage, stop the pyrolysis by spraying water inside the drum to cool down the hot Biochar. Leave it undisturbed for 2–3 hours, then remove the pyrolyzed Biochar from the drum.

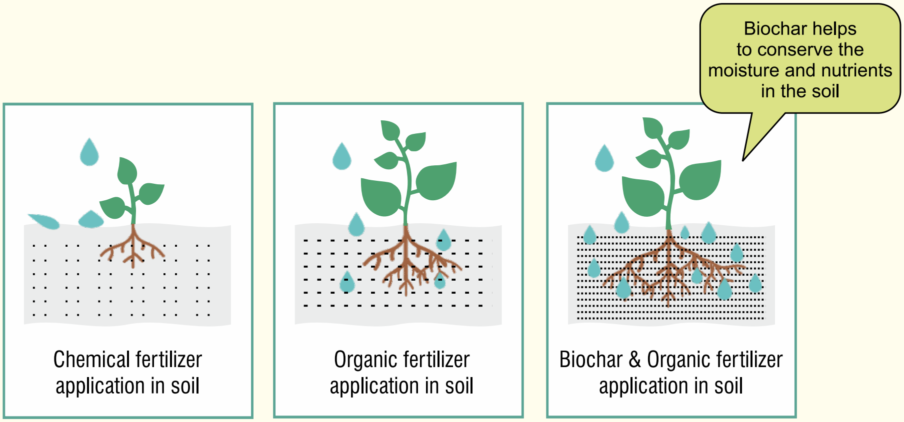
3. Mud based Chulha

The method of making biochar under a mud-based chulha has been in use since ancient times. This is a low-cost technique, as the chulha can be constructed easily with locally available materials such as mud and bricks.

Materials required: Soil bricks, soil for plastering and any crop residues.

Preparation Method:

1. Build a round mud-based chulha about 12 ft in diameter and 3 feet in height from the base.
2. Prepare a dome-shaped lid of about 13.5 ft in diameter. Place a 3-foot round pipe (4 inches in diameter) in the center as a chimney. This chimney helps gases escape and ensures smooth burning.
3. On both sides of the chulha, erect two iron poles made from 15 ftsquare pipes. Place a 15 ft horizontal pipe across the top of these poles.
4. Fix a pulley and wire system with circular rotating handles to lift and lower the lid easily.
5. Fill the chulha completely with crop residues and press them down firmly. Place dried grass or straw in the middle to help ignite the fire quickly.
6. After lighting, white smoke will begin to come out of the chimney. As the process continues, the smoke will gradually turn light brown.
7. During the process, open the lid occasionally to ensure the residues are not burning to ash.
8. Ensure that no air enters in the chulha during pyrolysis. If excess air enters, the residues will turn to ash instead of forming high-quality charcoal. Again the time required for charcoal preparation depends on the type of crop residue used.
9. The charcoal is ready when the smoke changes from white to brownish in color. At this stage, stop pyrolysis by spraying water inside the chulha to cool down the hot Biochar.
10. Leave it undisturbed for 3–4 hours. Once cooled, remove the Biochar from the chulha and collect the good-quality Biochar separately.
11. Keep aside any unburned residues, which can be reused in the next batch.


Biochar helps to conserve the moisture and nutrients in the soil
Chemical fertilizer application in soil
Organic fertilizer application in soil
Biochar & Organic fertilizer application in soil

4. Heap Method

The heap method is one of the oldest traditional practices for making charcoal. The Katkari community in particular is well-known for using this technique. In this method, wood from *Prosopis juliflora* is mainly used to produce charcoal in large quantities, resulting in very good quality charcoal.

Important points:

- Only wood should be used for this method; crop residues cannot be used.
- Small twigs or pruned branches from trees are suitable.
- Cutting down whole trees for charcoal is not advised—only waste wood, branches, or twigs should be used.

Materials required :

Pruned twigs, small wood, wet grass, moist soil for covering the heap

Preparation method:

1. Arrange hole with bricks on six sides at the bottom of the heap. This allows a small amount of air to enter, ensuring smooth burning.
2. Stack the wood in a uniform, compact pile, avoiding large gaps between logs or poles.
3. Place green grass on the top and all around the heap to cover it and leave a small open space in the middle of the heap to allow for firing.
4. Moisten soil and spread it evenly over the grass-covered on the heap. This seals the air, helping for proper pyrolysis.
5. Keep a small opening on one side for lighting the heap.
6. Once the heap is well ignited, close the central open space by adding green grass and moist soil.
7. Check the heap regularly, day and night. Watch carefully for unexpected any holes at the top and in this stage the wood may catch fire suddenly and turn into ash. If holes appear, immediately cover them with green grass and moist soil, pressing firmly to seal the gap immediately.
8. Conversion of wood to Biochar in this method takes a minimum of 4–5 days. Hardwoods require more time, while softwoods convert faster.




9. Once the process is complete, carefully remove surface soil from all sides with a shovel.

10. Spray water around the heap to fully to see that no extinguish any remaining fire.

11. After the heap has cooled down, collect the charcoal and set it aside for further process.

5. Pit method

Materials required :

Prosopis juliflora wood or other pruned branched of trees can be used for Biochar production under pit method.

Preparation method:

1. Layer with the dried grass in the base of the pit , this will help to fire the wood.
2. The wood should be piled with compact one on top of the other.
3. After keeping the wood, place green grass on top and cover with moist soil.
4. Light it on all four sides from the bottom and wait for 4-5 minutes to get fire properly in all the sides.
5. Once the fire is consistent, then close the sides with green grass and moist soil.
6. Slowly the ignition will continue for 2-3 days.
7. Check the pit regularly, day and night. Watch carefully for holes at the top. If air enters, the wood may catch fire suddenly and turn into ash. If holes appear, immediately cover them with green grass and moist soil, pressing firmly to seal the gap.
8. This method is not suitable for large-scale Biochar production, as both the quality and quantity are much lower compared to other methods. It is generally practiced in shifting cultivation, where only a small amount of Biochar mixed with ash is obtained.

Preparation of microbial enriched biochar

An electric machine for producing charcoal powder is readily available in the market, equipped with sieves of different sizes such as 8 mm, 10 mm, and 12 mm. For agricultural applications, the 8 mm sieve is recommended, as it produces Biochar powder most suitable for enhancing crop yield.

The advantages of using 8 mm Biochar powder include:

- It mixes thoroughly with the soil.
- It has minimal chances of floating on the water during flood irrigation. It remains in the soil even after watering, reducing the risk of beingwashed away.

Preparation of microbial enriched Biochar

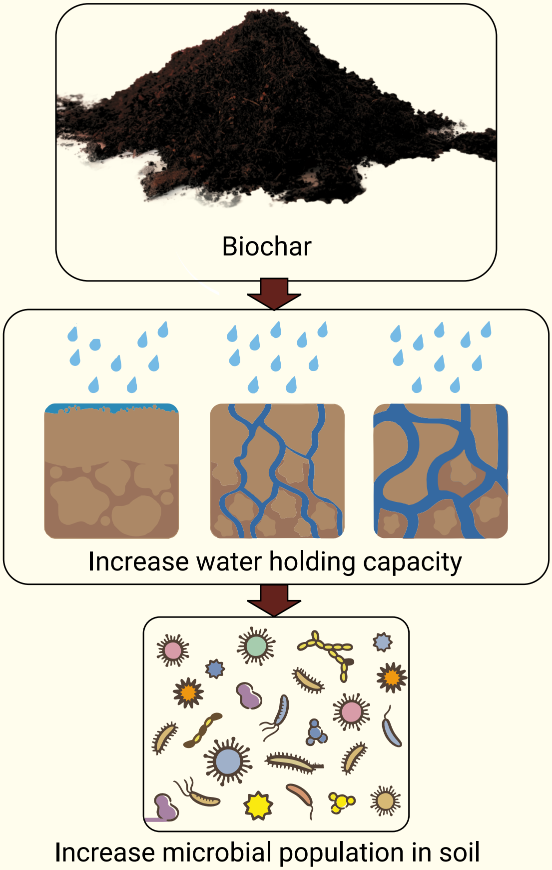
- After preparing the charcoal, spread it on the ground and spray a 10% solution of microorganisms such as *Rhizobium, Azotobacter*, *Phosphate Solubilizing Bacteria (PSB),* and *Potash Solubilizing Bacteria (KSB)* over it.
- Immediately powder the charcoal with the help of a machine, then pack the prepared powder for soil application.
- This Biochar, enriched with beneficial microbes, is highly effective in enhancing soil fertility. Care should be taken to store this material at room temperature or under shade to maintain the microbial population in the Biochar

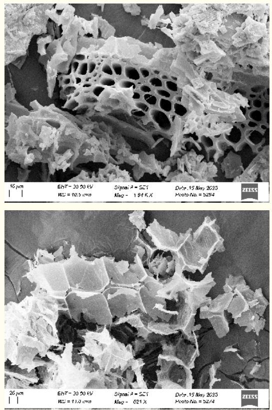
Process of making extended organic fertilizer

- The crop-specific extended organic fertilizers can also be prepared at the village level.
- To prepare an extended solution, take 7 liters of water, 1 kg of jaggery, and 1 kg of gram flour, and add 1 liter of Rhizobium solution.
- Mix the ingredients properly and keep the mixture in a closed drum for 10 days.
- After fermentation, add 90 liters of water to prepare the extended Rhizobium solution for legume crops.
- For cereal crops, use Azotobacter along with PSB and KSB.
- A total of 100 liters of the extended solution should be sprayed or sprinkled over 1 metric ton of Biochar.
- Finally, apply the microbial-enriched Biochar to the soil before sowing the crop.

Benefits of Biochar

1. The water retention capacity of the soil increases significantly due to the high pore spaces.
2. The chemical, physical and biological properties of the soil improves.
3. The soil bacteria count increases.
4. The efficiency of plants to absorb nutrients from the soil increases. The crops get the required amount of nutrients and the fertility and productivity of the soil are well maintained.





Pore Space images of Biochar under Scanning Electron Microscope (SEM)

Nutrient content in Biochar

Organic carbon	30 %
Nitrogen	0.79 %,
Phosphorus	0.15 %
Potash	0.88 %
Cation Exchange Capacity (CEC)	8.34 (M.eq/100gm)

Benefits of using Biochar to the soil

1. Improves soil moisture retention: Biochar enhances the soil's ability to retain water, reducing the need for frequent irrigation.
2. Boosts microbial activity: It supports the growth and diversity of beneficial microorganisms in the soil.
3. Reduces nutrient leaching and improves nutrient use efficiency: Biochar helps in retaining essential nutrients and making them more accessible to crops.
4. Improves soil texture: Its porous structure improves aeration, drainage, and overall soil structure.
5. Enriches the Rhizosphere: Biochar creates a favorable environment in the root zone (rhizosphere), promoting root health and microbial symbiosis.
6. Increases Soil Organic Carbon (SOC): By adding stable carbon to the soil, biochar contributes to long-term soil fertility and carbon sequestration.
7. Provides a habitat for beneficial microorganisms: The biochar is having pores and large surface area. It is good habitat for multiplication of micro organisms.
8. Enhances seed germination and crop yield: Traditionally, the biochar is used to enhance the germination of hard coated seeds.
9. Reduces dependency on chemical fertilizers: It holds the nutrients for longer period of time and releases the nutrient as and when required to the plant.
10. Improves soil aeration and root development: It lowers the soil bulk density and it will be remain in the soil for more than 11 years.
11. Acts as a long-term carbon sink : reducing greenhouse gas emissions.
12. The microbial enriched Biochar effectively helps for enriching the soil fertility.

Biochar usage for best results

1. **Incorporate Biochar** into the soil before sowing crops to ensure even distribution and effective soil integration.
2. **For fruit trees:** Apply 200 grams of microbial-enriched Biochar in a ring pattern around the tree, maintaining at least 1 foot distance from the main trunk.
3. **Application frequency:** Use Biochar only once every 7 to 8 years, as its benefits last long in the soil.
4. **Recommended dosage:** Apply Biochar at a rate of 2.5 to 7.5 MT ha^{-1} for agricultural crops. The amount of Biochar can be increased or decreased depending on soil type and cropping system requirements.
5. **Research findings:** Research findings indicate that in soybean–wheat cropping systems, the application of 7.5 metric tons per hectare of microbial-enriched Biochar combined with a 25% reduction in chemical fertilizers significantly increased grain yields:

   Soybean: 25.89 q ha^{-1} and Wheat: 43.19 q ha^{-1} .

Biochar’s Untapped Potential: Scope for Further Research

1. **Addressing current limitations.**
   Despite its potential, Biochar still has certain limitations. Continued research is essential to overcome these challenges and optimize its use.
2. **High production costs & long-term effects.**
   Biochar production remains costly, and since it does not readily decompose in soil, long-term studies are needed to assess its sustained impact on crop yields across different cropping systems.
3. **Nutrient stabilization and sustainable agriculture.**
   Further investigation is required to explore how Biochar can support nutrient retention and contribute to sustainable farming practices.
4. **Soil-specific applications.**
   Biochar's alkaline nature makes it suitable for acidic red soils. However, more research is needed on its effects in black soils, including appropriate application rates and long-term impact.
5. **Evaluating microbial enriched biochar.**
   To maximize benefits and minimize risks, systematic experiments are essential to fully understand the advantages and any potential disadvantages of microbial-enriched Biochar.
6. **Studies on the right dosage,** crop-specific benefits, long-term effects, and how it interacts with fertilizers and microbes.


Biochar
Production Unit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