

Biochar Production from Cotton Stalks



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Introduction

The management and disposal of crop residues left in the field after harvesting is a significant challenge across various agricultural sectors. In many countries, residue burning is commonly practiced as a consequence, resulting in nutrient loss, soil degradation and increase in CO₂ emissions into the atmosphere, which contributes to air pollution (Kranti & Kranti, 2023). Crop residue burning is a significant source of greenhouse gases (GHGs) such as CH₄, CO and N₂O along with other hydrocarbons. It also releases a large amount of particulate matter consisting of a wide range of organic and inorganic compounds (NPMCR, Government of India, 2014). Instead of burning those residues, farmers can utilize them as feedstock for biochar, biogas, ethanol, or other biofuels production. Biochar is a cost-effective material for challenging the world's issues like global climate change mitigation, reducing the emissions of greenhouse gases to minimize the global warming potential by improving soil quality and promoting the food safety.

1.1 What is Biochar?

Biochar is a fine-grained, carbon-rich, porous charcoal produced by heating organic matter (biomass) in a low-oxygen environment—a process known as pyrolysis (Amonette and Joseph, 2009). Due to multiple high value benefits for soil, crops, environment and climate biochar is also known as "Black Gold" of agriculture. This form of biochar comprises highly stable aromatic fixed carbon (80-95%), differing significantly in chemical properties from biomass, yet sharing similar physical attributes, featuring structured (S), tubular or through (T) and restricted (R) micro and mesopores. Biochar improves soil fertility, retains moisture, enhances microbial activity and sequesters carbon, making it a valuable tool for regenerative agriculture and climate change mitigation.

Biochar has a porous structure that can serve as a habitat for beneficial microorganisms and help retain nutrients in the soil, reducing leaching and enhancing nutrient uptake by cotton plants. Incorporating biochar into soil can enhance soil structure, improve water retention, and increase nutrient availability, which can be particularly beneficial in calcareous soils where water holding capacity and nutrient availability might be limited.

1.2 What is pyrolysis?

- 1) The process where organic material is heated in an environment with little or no oxygen called as pyrolysis.
- 2) Pyrolysis is the thermo-chemical conversion or decomposition of organic material /biomass into simpler chemical compounds.
- 3) Heating of biomass in an environment where cellulose & lignin are broken down from long to short carbon structure.

Pyrolysis process occurs in three main stages

Drying stage: Moisture and some light volatile compounds are removed from the biomass when it is heated.

Decomposition stage: The untreated biomass breaks down into volatile compounds, gases and biochar due to thermal degradation.

Biochar formation stage: A slow chemical rearrangement of the remaining material occurs, leading to the formation and stabilization of biochar.

Pyrolysis process to be carried out normally between **300–700 °C**

(Avoid temperature **above 700 °C**, as the biochar may further degrade and turn into ash).

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Properties of Biochar

Surface area: Biochar generally has a large specific surface area which depends on the pyrolysis temperature and the biomass. Increasing pyrolysis temperature typically increases surface area of biochar due to decomposition of cellulose and hemicellulose and the formation of micro pores during the pyrolysis.

Porosity: Biochar produced from bamboo biomass has high porosity, with longitudinal pores ranging from micro to macro pores i.e., 10-200 μm . The pore structure also facilitates the retention of nutrients and water, making biochar an effective soil conditioner.

Aromatic Carbon Structure: Biochar prepared at high temperatures (600–700 $^{\circ}\text{C}$) leads to the formation of stable rings like aromatic carbon structure due to formation of micro pores and the degree of organic matter decomposition.

Functional Groups: The evaporation of moisture during pyrolysis process results in breakage of bonds and formation of various functional groups like hydroperoxide, $-\text{COOH}$ and $-\text{CO}$. Slow pyrolysis biochar contains labile hydroxyl, carbonyl and carboxyl groups while fast pyrolysis biochar contains ethers and quinines groups.

Volatile Matter: Increased in the pyrolysis temperature decreased the volatile matter content in biochar due to the cracking of volatile fractions into low-molecular-weight liquids and gases.

pH: Due to the formation of carbonates and inorganic alkali group biochar has alkaline pH nature. Higher amount of carboxyl groups in the biochar makes alkalization of acidic groups to the conjugated bases which resulted in more alkaline pH.

Cation Exchange Capacity: Biochar has high CEC due to high content of ash in biomass. The decrease in CEC is due to formation of aromatic carbon and the removal of surface functional groups and increasing pyrolysis temperature.

Ash and Carbon Content: Increase in pyrolysis temperature increases the ash contents from 5.7 to 18.7% and the carbon content from 62.2 to 92.4% due to the higher degree of polymerization and higher lignin content in the plant biomass.

Factors Influencing Biochar Properties

Feedstock Type: Different feedstock (wood, agricultural residues, manure etc.) contain varying levels of lignin, cellulose, and hemicellulose, which affect the thermal degradation process and the resulting biochar properties.

Moisture Content: High moisture content in the feedstock can lower the efficiency of the pyrolysis process and affect the quality of the biochar produced.

Heating Rate: Faster heating rates can lead to a more fragmented and less stable biochar structure, while slower heating rates promote a more ordered and stable structure.

Chemical Composition of Biochar

Biochar exhibits higher amount of total and organic carbon, optimum concentrations of micro and macro nutrients like N, P, K, Na, Mg, Ca, Cu, Zn etc. Biochar prepared from hardwood biomass contains 9.86% ash, 53.96% carbon, 1.83% hydrogen 1.24% nitrogen and 42.98% oxygen. Higher contents of P (4.3 g/kg), K (9.9 g/kg) and Mg (2.8 g/kg) were observed in the biochar produced at 500 $^{\circ}\text{C}$, while maximum contents of carbon (73.6%) and nitrogen (1.9%) were observed in biochar produced at 400 $^{\circ}\text{C}$ (Saletnik et al., 2016).

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Typical average nutrient content per 1 kg of biochar

N: 0.2–0.8% → 2–8 g/kg

P□O□: 0.1–0.4% → 1–4 g/kg

K□O: 0.5–2.5% → 5–25 g/kg

C: 60–80% → 600–800 g/kg

This nutrient concentration is mainly varied with pyrolysis temperature and feedstock (biomass)

Biomass/ feedstocks materials used for biochar production

Crop residue remaining after the harvest or any organic biomass can be used for conversion into biochar. The primary sources of biomass used for biochar production include agricultural wastes (such as maize cobs, corn stalks, wheat straw, rice straw, and cotton stalks ([Prabha et al., 2015](#)), wood biomass, municipal waste, animal waste, and other organic materials.

Each feedstock type imparts distinct chemical and physical properties to the resultant biochar. Various research studies have found that feedstock from different sources as well as pyrolysis temperature shows variation in different physicochemical properties of biochar ([Sohi, 2012](#)).

The biomass used to produce biochar must be sustainable and renewable. Most of the feedstocks are moist with 95 % moisture by weight.

Biomass containing more than 30% moisture must be dried before pyrolysis, as high moisture content reduces thermal efficiency and affects the quality of the resulting biochar ([Ha and Lee, 2020](#)).

Hardwood feedstock materials such as eucalyptus, bamboo, and nut shells (e.g., coconut shell) generally produce higher biochar yield and fixed carbon content due to their high lignin composition, which converts into stable aromatic carbon structures during pyrolysis.

Low-density biomass like rice husk, wheat straw, corn cobs have low lignin content, high volatile matter and higher cellulose so it burns more carbon as volatilisation losses during pyrolysis, leading to lower biochar recovery, which resulted to biochar with low fixed carbon and high ash content.

In general, biochar produced from high-lignin, woody or fibrous materials have the highest organic carbon content and the most stable carbon structures.

Here we will consider cotton stalks as a biomass because cotton stalks serve as an excellent source of feedstock for biochar production ([Kranti & Kranti, 2023](#)) which content fixed carbon ranges from 41.15% to 47.05% ([Venkatesh et al., 2013](#)).

Biochar derived from cotton residues exhibits alkaline properties (pH 8.0-9.0) with high surface area (150-300 m² g⁻¹), moderate water retention capacity (50-60%) and low bulk density ([Kranti & Kranti, 2023](#)).

Biochar Production from Cotton Stalks

Cotton biomass for biochar production

In cotton-growing areas, after harvesting an estimated 3-5 metric tons of cotton biomass residue per hectare is left in the field. The left-over stalks are either uprooted or cut above ground level. Depending on their thickness these stalks should be grouped into different batches. (Fig 1 & 2)

These residues are rich in lignin (15-30%) decomposes slowly-taking 5 to 20 months under natural conditions. Additionally, in the off-season, it can serve as a habitat for bollworms, increasing the risk of pest infestations in subsequent crops. Thus, converting this biomass into biochar through pyrolysis is viable solution to make waste management more effective and to reduce residual pest infestation (Kranti & Kranti, 2023).

When cotton stalks are pyrolyzed at 350-400°C, about 20.4 to 46.5% recovery is obtained, which means that 1 tone of dry cotton stalks typically produces about 200 to 465 kg of biochar by weight which could contain approximately 130 to 302 kg of carbon. Reasonably it can be assumed that converting one ton of cotton stalks into biochar could sequester approximately 500 to 1000 kg CO₂.

Methods biochar production

After cotton harvesting at ICAR–CICR, Nagpur, the cotton stalks were collected and left in the field for natural drying in order to reduce their moisture content. Once adequately dried, the stalks were separated into root and stem portions and tied into bundles for further processing. Biochar was produced from different cotton stalk residues, including root biomass, stalk biomass, and middle stem biomass. The production of biochar was carried out using different pyrolysis methods such as the cone-pit open earth kiln, Kon-Tiki kiln, and a furnace pyrolysis machine. These methods were adopted with the objective of reducing crop residue burning, enhancing carbon retention in the biomass and minimizing ash content in the produced biochar.

- 1) Open Earth -Cone-Pit kiln
- 2) Kon Tiki method
- 3) Furnace pyrolysis machine method

Open Earth -Cone-Pit kiln : A low-cost technology for biochar production

The soil cone pit method of biochar, originally invented by our ancestors over 2,500 years ago and was modified by a young American agriculturist, Mr. Josiah Hunt in 2008. It is a traditional method of biochar production used by ancient farmers for converting biomass into biochar under limited oxygen conditions without any additional cost, machinery and infrastructure.

Dig a conical pit in the ground with dimensions of 2 meters in diameter and 1.5 meters deep.

The pit should look like an English 'V' (v) or ice cream cone shape (Fig 3) which makes it easier to add biomass continuously at the bottom and to enhances the pyrolysis efficiency.

Site selection for setting up a cone pit

Location

Avoid areas near buildings, trees, steep slopes, rocks, or water bodies. Maintain a distance of 20–30 meter from water sources and avoid windy areas. Choose a well-drained, unused portion of a field. (Ensure that the pit should be completely dry before the biochar production process)

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Materials required (Fig 4)

Dried cotton stalks or branches exceeding 500 kg to 1000 kg.

Shovel, spade or any other digging tool.

Measurement tape for digging of cone pit.

Match box to ignite fire.

Water drum, bucket/mug or pipe for quenching.

Steps for biochar production by cone pit method (As presented in the images below)

1. Dry cotton biomass collection after harvesting

Air-dry uprooted cotton stalks and roots for 2 weeks. Heap them 20–30 meter from the pit.

Avoid green or wet biomass, which increases smoke and reduces yield.

2. Ignite Chimney

Create a small chimney (25–30 cm height) at the bottom of the pit and ignite from the top.

The chimney should be ignited with light-density biomass like dry leaves, straw, or small twigs that catches fire easily.

3. Layering

Heating of biomass of short size (30–45 cm) with subsequent layering until the pit is 75% full (This takes ~30–45 minutes)

First layer

Allow the chimney to initiate pyrolysis, once red-hot char or ash appears, slowly adding the first layer of stalks, one by one, around the perimeter of the pit next to the chimney.

Second layer

Keep adding stalks continuously until the second layer reaches a thickness of approximately 20 cm and fully covers the first layer. Repeat the process of adding biomass layers above the lower layer in the pit until it is completely filled. By the third layer you will find a deep, hot bed of biochar.

4. Quenching

When the top stems turn red and a layer of ash settles around them, at this point, sprinkle water or soil (if water is not available) on the smoke to extinguish the fire and halt combustion. Avoid over wetting, which affects next batch of production.

5. Cooling Drying and Storage

Let the pit cool overnight. Scooping the biochar from pit, crush it (<10 mm) with moist conditions, sun-dry for 2 days, and store for soil application.

Safety measures

1. Line the perimeter with stones to prevent access by children or animals.
2. Wet the surrounding area to prevent fire spread.
3. Wear protective clothing, gloves, masks, and safety goggles to prevent burns and inhalation of smoke or dust.

Biochar Production from Cotton Stalks



1. Collect cotton biomass material after harvesting.
 2. at the bottom of the pit, ignite the chimney from the top
 3. Add biomass in thin layers
 4. Once red-hot char or ash appears, add subsequent layers of biomass
 5. Water quenching & allow overnight cooling
 6. Scooping out the Biochar from pit
 7. Biochar dried for 2 days & storage
- (Step by step procedure of cone pit biochar production at ICAR-CICR, Nagpur)

Biochar Production from Cotton Stalks

Advantages of cone pit method of biochar

1. The open earth cone-pit method yields ~25-30% of biochar by weight of original biomass with production cost of Rs. 5 per kg.
2. It is a low-tech, simple, affordable and effective approach for biochar production using on-farm cotton residues. Best for small to medium farmers with low capital cost and easy to operate.
3. With proper training, this method can help farmers reduce residue burning, enhance soil health, and build resilience in soil and cotton production through improved soil carbon and nutrient management.
4. The conical shape of the pit promotes optimal airflow and efficient heat distribution which allows for more complete pyrolysis of biomass, increasing biochar yield.
5. The method helps to reduce emissions of pollutants and other gases than open burning.

Limitations:

1. During water-quenching and cooling process, there is a high risk of mixing of soil in biochar that can increase the biomass to biochar conversion efficiency (%).
2. additional sieving or winnowing process to be carried out to separate the soil from biochar.
3. Can reduce the fixed carbon content due to excess moisture at the bottom of pit.

2) Kon Tiki method of biochar production

The Kon-Tiki pyrolysis reactor was invented by Dr. Hans Peter Schmidt and Dr. Paul Taylor (2014) at Ithaca institute (Kranti & Kranti, 2023). It is a simple, low-cost technology used for producing high-quality biochar through an open flame-curtain pyrolysis. Recently, this method is popular among the small-scale farmers because it is a low cost, clean, fast and produces excellent quality of biochar with low carbon emissions.

The conical metal designed is inspired by the traditional cone-pit method, somewhat similar to cone pit method having similar steps instead soil pit there is a metal machine (Fig 5) with deep cone having top diameter of 100 cm, a height of 90 cm and a wall slope of 63.50° with total capacity of 827 liters (Maulana et al., 2021). In this modified design, small tube attachments at the bottom helps to control vapours & removing excess moisture during pyrolysis (Fig. 6). The steel walls reflect the heat during pyrolysis and combustion back into the kiln, resulting in a more uniform temperature distribution which ensures more consistent charring conditions and improves the overall quality and homogeneity of resulting biochar.

Before pyrolysis ensure that the kiln is clean and in a safe outdoor location with ventilation.

Materials required

Metal Kon-tiki kiln

Dried cotton stalks or branches exceeding 500 kg to 1000 kg

Ignition material (small twigs, paper, dry leaves)

Water hose or buckets for quenching

Long stick or metal rod for stirring.

Shovel, spade for scooping.

Safety gear: gloves, goggles, mask and fire extinguish.

Biochar Production from Cotton Stalks

Steps for biochar production by Kon-tiki method (Same as followed for cone pit method)

1. **Dry cotton biomass collection after harvesting:** Collect the uprooted cotton stalks and allowed them for sun drying for 2 weeks to remove the excess moisture present in stalks.
2. **Ignite Chimney:** Place dried light density cotton biomass at the bottom. Ignite the chimney (25–30 cm height) from the top. Light the fire and wait until you have a stable flame. This initial fire serves to generate enough heat for pyrolysis to begin.
3. **Layering:** Heating of biomass of short size (30-45 cm) one by one, around the perimeter next to the chimney with subsequent layering.

First layer: Allow the chimney to initiate pyrolysis, once red-hot char or ash appears, slowly adding the first layer

Second layer: Keep adding stalks continuously until the second layer reaches a thickness of approximately 20 cm and fully covers the first layer. Repeat the process of adding biomass layer after layer until it is completely filled.

Maintain a visible flame cap-that protecting lower layers from complete combustion.

4. Quenching

When the top portion of stalk turns red and a layer of ash settles around them, at this point, quiche water carefully at the end of the burn to stop the fire and protect the biochar from excess burning.

Stir thoroughly to stop further combustion and ensure that all hot spots are fully cooled.

After quenching, open the small tubes fixed at the bottom of the Kon-tiki kiln to remove excess water and to avoid moisture present in biochar (Fig 6).

5. Scooping out the Biochar

After quenching, allow the biochar to cool down for several hours or overnight so that excess heat and moisture can dissipate, scoop out the biochar from kiln.

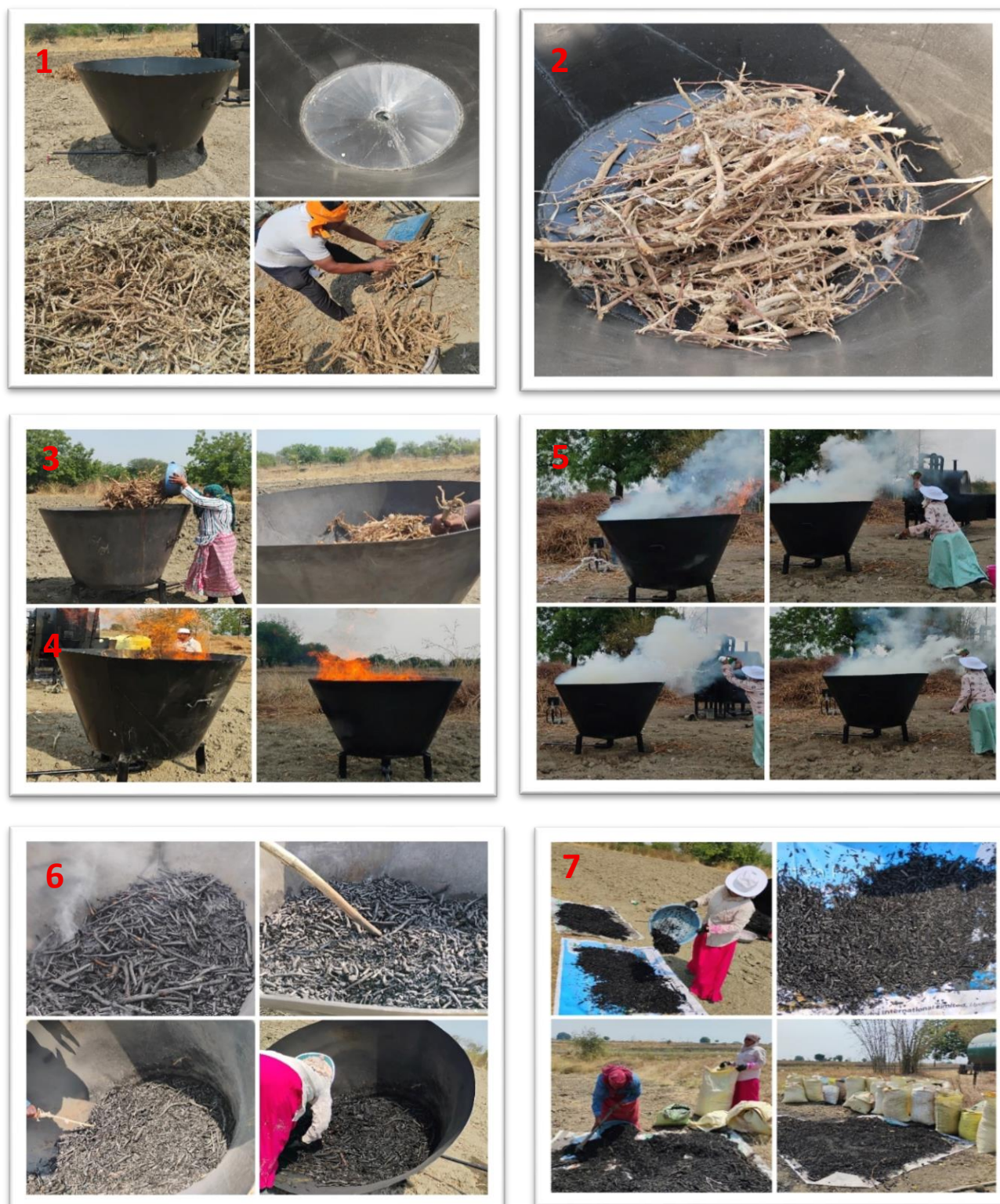
6. Cooling Drying & Storage

Once it is completely cool, spread the biochar on a tarpaulin, banner, or any suitable sheet to dry. Leave it exposed for 1–2 days to confirm that no steam or moisture is still present, after the biochar is completely dry, store it in burlap or breathable paper bags and keep it in a cool, dry place to prevent moisture absorption and contamination. crush biochar into granule or finely powder form before application to ensure minimal dust volatilization and improved soil–biochar interaction.

Safety measures

1. Avoid pyrolysis during high wind or strong airflow conditions, as it can increase flame intensity and spread fire.
2. Use safety tools such as metal rods or shovels instead of bare hands while burning of biomass and quenching of biochar from kiln.
3. Keep a water source or fire extinguisher nearby to quickly control any accidental fire.

Biochar Production from Cotton Stalks



- 1) Collect dried cotton biomass
 - 2) Preparation of chimney at the bottom
 - 3) Add biomass in thin layers
 - 4) Once red-hot char or ash appears, add subsequent layers of biomass
 - 5) Water quenching & allow for cooling
 - 6) Scooping out the Biochar
 - 7) Biochar dried for 2 days & storage
- (Step by step Biochar production by Kon Tiki method at ICAR-CICR, Nagpur)

Biochar Production from Cotton Stalks

Benefit	Details
Low Cost	Made from readily available materials like steel drums or concrete.
High Efficiency	Large amount of biomass can burn at a single time which gives more biochar yield (Converts up to 50% of biomass carbon into stable biochar)
Clean Burning	Flame curtain reduces smoke and harmful gases. Low ash content (compared to traditional pit methods).
Scalable	Can be sized for small gardens or smallholder farms.
Environmental impact	The method helps to reduce residue burning, emissions of pollutants and other gases than open burning.
Agricultural impact	Can enhance soil health, and build resilience in soil and cotton production through improved soil carbon and nutrient management. Stable carbon that persists in soil for hundreds to thousands of years.

Limitations

1. **Initial investment required:** Small scale to medium farmers need to spend more cost initially to construct or purchase the kiln.
2. Due to unstable pyrolysis temperature, it may create a chance of releasing smoke and particulate matter.

3) Biochar Production by furnace- pyrolysis machine

A furnace-based biochar pyrolysis machine, designed and modified by Sanjivani Terra Innovation, Nagpur, was used to produce biochar with the aim of higher carbon content and lower ash content. The furnace operates on the principle of fast pyrolysis at high temperature, involves a rapid heating rate (10-1000°C/s) and short residence times under controlled oxygen which produces lower yields of biochar (around 20-30%) due to extensive de-volatilization. Excessive heating and shorter residence time during pyrolysis can lead to the formation of bio-oil as a by-product, which may account for nearly 30% of the total biomass weight. (Fig. 7). The high temperature and limited oxygen conditions resulted in the production of completely dry (moisture-free) biochar with high stable fixed carbon and low ash content. Before initiating pyrolysis, ensure that all doors and ventilators are tightly closed to minimize carbon emissions and maintain proper furnace operation. Clear the surrounding area of biochar unit by removing dry grass, leaves, wood, anything that can catch fire during pyrolysis.

Steps for Biochar Production (Follow the steps 1-6 below)

1) Weight dried cotton biomass and placed at furnace jar

Cotton biomass was collected and dried properly to remove moisture content before the pyrolysis process. The dried cotton biomass was weighed and placed into furnace jar using a weighing balance to determine the recovery % of biomass to biochar.

2) Layering of biomass by filling the jar at once

Allow all the biomass to jar at once and placed inside the furnace chamber.

Keep adding stalks continuously until it completely fills.

Closed all the furnace doors and ventilators tightly to restrict oxygen supply and avoid carbon emissions.

Biochar Production from Cotton Stalks

3) Allow the heating from the bottom

Initiate the heating from the bottom of the furnace by wood or any biomass.

The biomass inside the jars was heated gradually to reach the required pyrolysis temperature.

4) Note pyrolysis temperature and allow for cooling

Throughout the process, the pyrolysis temperature was monitored, maintaining a range between 350°C and 700°C. After completion of pyrolysis, the furnace was allowed to cool overnight to avoid fire hazards since the biochar is produced at high temperatures and without moisture.

5) Scooping out the Biochar

After cooling, open the door of furnace and allow to cooling for sometimes.

Scoop out biochar after cooling process due to excessive heating within the furnace.

6) drying & storage

Once it is completely cool, spread the biochar on a tarpaulin, banner, or any suitable sheet to dry.

Leave it exposed for 1–2 days to confirm that no steam or moisture is still present.

After the biochar is completely dry, store it in burlap or breathable paper bags and keep it in a cool, dry place to prevent moisture absorption and contamination.

Safety measures

1. Do not pack the biochar immediately after production. Allow it to cool overnight because it is produced at high temperature and without moisture, which can pose a high risk of fire.
2. clear the surrounding area of biochar unit by removing dry grass, leaves, wood, anything that can catch fire during pyrolysis.

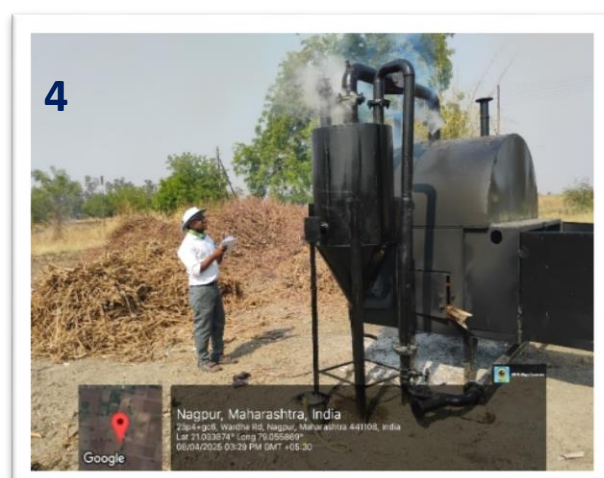
Advantages

1. Due to controlled temperature and lack of oxygen it produced moisture free biochar with high stable carbon and other biochar properties.
2. Yields uniform biochar with consistent organic carbon, making it suitable for farmers at the farm level.
3. Pyrolysis process produced additional bio-oil, which can be used for controlling sucking pests in crops.

Limitations

1. Required trained person to operate the machine safely and efficiently.
2. Required extra (external) biomass to initiate and maintain the pyrolysis at the bottom.
3. Can operate limited amount of biomass at a single time.
4. Its higher capital and operating costs make it less affordable for small and marginal farmers.
5. Extra transportation cost: The machine needs to be transported to the biochar production unit.

Biochar Production from Cotton Stalks



- 1) Weight dried cotton biomass and placed at furnace jar
 - 2) Layering of biomass by filling the jar at once and tightly pack the machine
 - 3) Allow the heating from the bottom
 - 4) Note pyrolysis temp. and allow for cooling
 - 5) Scooping out the Biochar
 - 6) Biochar allow for drying & storage
- (step by step Biochar production by Furnace pyrolysis machine at ICAR-CICR, Nagpur)**

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Recovery (%) of cotton biomass to biochar (Table 4)

Biochar was produced from different types of cotton biomass i.e. cotton stalk (root + stem), cotton root (remains after shredding), and cotton mid stem, using different methods like cone-pit, Kon-Tiki, and furnace pyrolysis machine method.

Based on the results presented in table, biochar recovery ranged from 32.20 to 43.12%. Across all methods, the cone-pit method produced the highest recovery, followed by Kon-Tiki and the furnace pyrolysis machine.

Recovery was highest in cotton stalk (root + stem) and cotton root biomass due to higher lignin content, which produces more stable biomass. Slightly lower recovery was observed in cotton mid stem biomass.

The cone-pit method is the most efficient and low-cost method for maximizing biochar yield due to limited oxygen entry and slow pyrolysis.

The furnace pyrolysis method produced lower biochar yield because higher temperatures increase carbon volatilization; however, it produced good-quality biochar with higher carbon purity and low moisture content.

In practice, the Kon-Tiki method offers the best balance between yield, carbon quality, and affordability for on-farm biochar production.

Methods of biochar application in soil

Biochar is highly susceptible to wind and water erosion. Proper incorporation into the soil helps to reduce losses through surface runoff during heavy rainfall and to reduce wind erosion (Venkatesh et al., 2015). During land preparation, biochar should be incorporated into the soil by different methods like spot placement, deep banding, mixing of biochar with other soil amendments such as manure, compost or lime before soil application can improve efficiency by reducing the number of field operations required.

At ICAR-CICR, Nagpur, biochar was mixed with vermicompost in a 1:1 ratio (Fig 8). With the help of tractor- drawn implement, 10-15 cm depth furrow was opened with 90 cm spacing between rows in each plot (Fig 9). Biochar as per the recommended dose (approx. 0.5–1 kg/m²) was applied through the deep banding method during land preparation (Fig 9) in respective treatments 30 days prior to sowing. The banding method enables biochar to be applied within the soil with minimal disturbance, allowing its use after crop establishment.

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Field overview of different biochar formulations in rainfed Bt cotton



Biochar Production from Cotton Stalks

Advantages of biochar

- 1) Biochar has higher amount of stable carbon and porosity and has multiple benefits (Lehmann, 2007) which improves the soil physical, chemical and biological properties (Joseph *et al.*, 2010) than the other organic sources.
- 2) **Biochar has the potential to retain more water in soil** (Gururaj and Krishna, 2016): Due to the porous nature, biochar can improve soil water retention which can reduce irrigation needs and increase crop resilience to drought stress, particularly beneficial in calcareous soils where water holding capacity and nutrient availability might be limited (maintaining moisture levels during dry spells).
- 3) **Biochar as a stable carbon sink**: Helps to remove and store a carbon dioxide in the atmosphere and can reduce emissions of potent greenhouse gases like methane (CH₄) and nitrous oxide (N₂O) from soil, fighting against the global climate change by capturing and storing the CO₂ back in the earth atmosphere (Lorenz and Lal, 2014)
- 4) **Biochar as a soil amendment and soil conditioner**: Due to the domination of carbonates of alkali and alkaline earth metals, biochar increased the soil pH in acid soils. It means that biochar can be used as soil amendment for reclaiming acid soils due to its higher pH.
- 5) **Biochar as a tool for soil fertility management**: Biochar can serve as a source of nutrients that enhances soil fertility through the initial release of soluble nutrients present in the biochar and through the mineralization of organically bound nutrients contained within it. Improvement of soil properties (increased aggregation capacity, pH, and CEC) could increase soil fertility by increasing nutrient contents and availability and increasing nutrient leaching.
- 6) **Influence of biochar on soil physical parameters**: Improve water infiltration, water retention, macro-aggregation & soil stability which enhance groundwater quality.
- 7) **Influence of biochar on soil chemical properties**: Highly application of biochar observed significant changes in soil quality including increase in pH and organic carbon.
- 8) **Increases the soil microbial activity**: The high porosity of biochar, along with its ability to retain water and nutrients, creates a protective environment for soil microbes, helping them to survive through fallow and drought periods.
- 9) **Decreased fertilizer dependency**: Due to greater nutrient retention capacity, biochar increases the nutrient use efficiency of fertilizers by reducing nutrient leaching and volatilization. The combined application of biochar with inorganic fertilizer has the potential to increase crop productivity thus, providing additional income and reducing the quantity of inorganic fertilizer use.

Biochar Production from Cotton Stalks

Biochar as a carbon sequestration component

- 1) Soil carbon sequestration is the process of removal of carbon dioxide (CO₂) from the atmosphere and stored into soil as lived stable carbon pools in such a manner that it is not re-emitted into the atmosphere in near future ([R. Lal, 2004](#)).
- 2) Carbon Sequestration is a function of photosynthesis as plant displaces CO₂ from the atmosphere to soils by the process of photosynthesis.
- 3) The long-term stability of biochar in soil is one of the major factors which reduces the emissions of CO₂ into the atmosphere ([Cheng et al., 2008](#)) and the most important property for the carbon sequestration potential of biochar.
- 4) Biochar can persist in soils for hundred to thousand years, which can be more resistant to decomposition than the organic matter for long term carbon storage.
- 5) Due to an aromatic structure biochar is highly resistant to the microbial decomposition which is helpful for the carbon sequestration.
- 6) Application of Biochar to soils has been suggested to reduce the emission of atmospheric carbon dioxide (CO₂) and mitigation of global climate change ([Lorenz and Lal, 2014](#)).
- 7) Biochar can potentially play an important role in long term storage of carbon and has the ability to reduce emissions of harmful gases into the atmosphere and because of its potential applications it reduces nutrient losses in soils useful for carbon sequestration in soils which improves soil structure, microbial activity and improving the soil health ([Yadav et al., 2023](#)).
- 8) The conversion of biomass carbon to biochar leads to sequestration of about 50% of the initial carbon compared to the low amounts retained after burning (3%).
- 9) Raw material of cotton stalk biochar content 46.0% carbon which increases to 83.2% after pyrolysis, shows a carbon sequestration potential of 23.8% which indicates that cotton stalk biochar has a stronger carbon sequestration potential as compared to straw biochar.

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Dr. Mangi Lal Jat, Secretary, DARE & Director General, ICAR along with Dr. D.K. Yadava, DDG Crop Science Visited the Biochar Production Unit, ICAR-CICR, Nagpur.



Ms. Vrunda M. Desai, Textile Commissioner, Mumbai, visited the Biochar Production Unit, ICAR-CICR, Nagpur.

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Preventive/safety measures during biochar production and application (Venkatesh *et al.*, 2015)

- 1) Use freshly harvested and under-utilized dry crop residue for biochar production. (Avoid wet materials because it smokes a lot and does not burn well).
- 2) Biochar should be prepared from a single biomass at a time to ensure uniform burning, high carbon content, and consistent biochar quality. Don't mix light and heavy density biomass at a single time because mixing may create a problem like uneven burning, more ash, poor quality biochar and difficult to manage the fire due to heavy oxygen supply from light biomass.
- 3) Moisture content in biomass for efficient burning should be < 15–20%.
- 4) Once the biochar sample dries, crush it into granule or finely powder form and applied it at a desired depth (15-20 cm) to ensure minimal dust volatilization and improved soil–biochar interaction.
- 5) Maintain proper temperature control by quenching water (if excess fire) to prevent accidental fires or explosions.
- 6) Soil testing is recommended prior to large-scale application (Biochar is often alkaline so avoid over-application in already alkaline soils).
- 7) Store biochar in a cool, dry well-ventilated open spot away from open flames.
- 8) Biochar contains up to 60-80% carbon, significantly increasing the soil's carbon content and C:N ratio when applied. application of large quantities of biochar to soil without proper assessment can excessively raise the C:N ratio, causing nutrient lockup, crop yellowing, and ultimately negative impact on crop yields.

Conclusion

In many countries, crop residue burning is commonly practiced, resulting in nutrient loss, soil degradation and increase in CO₂ emissions into the atmosphere, which contributes to air pollution. To achieve more effective management and disposal of these residues, their conversion into biochar through a thermochemical process such as slow pyrolysis is emerging as an innovative and economically viable solution for efficient waste management. Therefore, it is necessary to develop low-cost biochar production methods to make this technology affordable for small and marginal farmers. The brief research conducted at ICAR-Central Institute for Cotton Research, Nagpur resulted in the development of a farmer-friendly soil cone-pit open earth kiln method for the effective utilization of cotton stalk residues to produce biochar. However, the low-cost biochar production method developed in this study does not include any mechanism to capture the exhaust gases released during the biochar preparation process. Furthermore, interdisciplinary and location-specific research should be undertaken to evaluate the long-term effects of residual biochar on different soil types, nutrient availability, soil microbial activity, carbon sequestration potential, crop productivity and greenhouse gas mitigation. The field trial experiment provides a good platform to demonstrate the conversion of cotton stalk residues into biochar using different methods through pyrolysis and also aims to address the complex issues related to the soil fertility management by integrating organic waste recycling with sustainable agricultural

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practices. In conclusion, biochar represents a promising and multifaceted approach to addressing some of the most pressing environmental challenges of our time. By sequestering carbon and improving soil health, biochar offers a sustainable solution for climate mitigation and agricultural resilience. However, realizing its full potential will require coordinated efforts across research, industry, and policy.

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Queries asked by the farmers during biochar unit visit

If we use biochar, is it mandatory to apply other fertilizers?

biochar does not fully replace chemical fertilizers because it is used as a soil improver/conditioner (Improves soil structure, aeration, and nutrient retention) not a complete fertilizer. Biochar itself contains very low available N, P, K, so plants can't rely on it alone. It works best when combined with fertilizer.

By applying biochar which nutrients we get available?

Nitrogen in NH_4^+ (Ammonium) form 2) Phosphorus in H_2PO_4^- / HPO_4^{2-} (phosphate ions) 3) K^+ Ca^{2+} Mg^{2+} exchangeable form 4) Sulphur: SO_4^{2-} Sulphate form 5) Chelated or exchangeable ionic forms micronutrients 6) Stable Carbon.

Nutrient content in 1 kg of biochar (Results are reported on a dry weight basis)

Nitrogen (N): 0.2–0.8% → 2–8 g/kg Phosphorus (P_2O_5): 0.1–0.4% → 1–4 g/kg

Potassium (K_2O): 0.5–2.5% → 5–25 g/kg OC: 60–80% → 600–800 g/kg

Raw biochar content very low nutrients as compared to saturated biochar?

Raw (freshly produced) biochar has mostly fixed carbon and has very poor N, P, K due to loss of nutrients during pyrolysis, can actually temporarily lock up nutrients, making them unavailable to plants (especially nitrogen). Saturated biochar is nutrient-rich because of its high porosity and CEC. Biochar when pre-loaded with nutrients by charging external nutrients to biochar from organic sources like compost, cow urine, vermicompost etc fill the pores of biochar with nutrients and microbes which gets available to plants in a slow-release form.

Fixed carbon content?

Fixed carbon content varies with the type of feedstock (biomass used) and pyrolysis temperature. Higher pyrolysis temperature has higher fixed carbon. Fixed carbon content is reported on a dry weight basis, while it gets reduced with high moisture content. Raw biochar contains about 50–80% fixed carbon on a dry basis.

Expected soil organic carbon increase in 1 year after application?

Soil organic carbon is a stable pool which builds up slowly. Even with biochar, soil needs time for mixing and stabilization. Hence, instant increase is not realistic under field conditions. Biochar maintains SOC, but does not keep increasing it rapidly every year. Application of biochar increases soil organic carbon gradually, and a measurable increase of about 0.1–0.2%. generally, requires a minimum of 3–5 years under field conditions.

Recommended dose of biochar?

Depending on the crop and soil type, the generally recommended application rate of saturated biochar is 1.5–2.5 t ha⁻¹ (approximately 500 kg to 1 tonne per acre) for field crops, 2–5 kg per tree for orchards, 10–15% for potting media. 2–5 tons per hectare (≈800–2000 kg per acre) for vegetables / horticulture crops. Do not exceed 0.5 kg/m² in clay or alkaline soils. Higher doses may cause: 1) excessive moisture retention and temporary pH increase which is good for acidic soils and risk in alkaline soil.

When and how to apply biochar?

3–4 weeks (1–1.5 months) before sowing or transplanting. Incorporate it into soil at 10–15 cm depth which allows nutrient stabilization and better microbial activity. (Avoid deep placement in very heavy black soil)

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How much fertilizer can be reduced by biochar application?

With proper use we can reduce Nitrogen by ~10–30% Phosphorus by ~15–25% and Potassium by ~25–30%. So, it reduces total NPK dose by 20-25%. Biochar already holds nutrients, do not apply full doses of fertilizer at once. Apply only 75-80% of the recommended NPK dose (Depends on soil and crop).

How much expected yield increases after saturated biochar application?

Biochar alone does not give a high yield increase. Yield increase mainly depends on soil, crop, fertilizers and nutrient management. biochar is a soil conditioner not just a yield booster. Biochar does not replace fertilizers; it makes fertilizers work better and longer. Saturated biochar alone expected yield increase is ~0- 5% and average expected increase ~5–15% (During 1st year) when biochar is properly saturated and fertilizers are managed correctly ≈ 10–25 % yield increase (After first year)

From which location will transportation be arranged and managed for the biochar market?"

Transportation will be arranged and managed from the designated biochar production units located within selected villages or cluster. Appropriate transport vehicles will be arranged and managed from the designated collection and storage point where the biochar is produced and packed (responsible market logistics team, based on market demand and delivery timelines). The overall responsibility for transportation and logistics will rest with the project management team, in coordination with local stakeholders such as, Self Help Group (SHG's,) Farmers producing Organisation (FPO) and Non-Governmental Organizations (NGO's).

Can biochar be used for soil drenching or fertigation?

No, we can't use biochar through drip or fertigation line because, fully saturated or finely powdered, biochar is insoluble water which may clog drip emitters, filters and pipes. Even if the biochar is fully saturated and very fine, it does not stay evenly suspended in water and non-uniform distribution to crops.

Which biomass feedstock is most suitable for biochar production to achieve a high organic carbon content?

In general, biochar made from high-lignin, woody or fibrous materials have the highest organic carbon content and the most stable carbon structures. Less ash means a higher percentage of pure carbon in the final biochar. Woody biomass and coconut shells are rich in lignin (20–35% or more). More lignin means more stable carbon in biochar. Low-density biomass produces biochar with lower fixed carbon because it contains more volatile matter and less lignin, causing greater carbon loss as volatilisation loss during pyrolysis.

For which soil biochar is preferred and why?

Biochar is mainly preferred for sandy, acidic and degraded soils.

In sandy soils, biochar improves water-holding capacity, nutrient retention, and cation exchange capacity, thereby reducing nutrient leaching.

In acidic soils, biochar acts as a liming material, increases soil pH, reduces aluminium toxicity and improves the availability of essential nutrients such as phosphorus, calcium and magnesium.

In degraded soils, biochar enhances soil organic carbon, microbial activity and long-term soil fertility. Thus, biochar improves soil physical, chemical and biological properties and contributes to sustainable soil management. Useful in red and lateritic soils common in parts of India.

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Table 1. Chemical composition of different biochar samples (Tested at ICAR-CICR, Nagpur)

Sr No	saturated biochar samples	Moisture %	Volatile matter %	Ash %	Fixed carbon %
1	Pyrolysis ash	6.58	11.70	40.25	41.47
2	Cotton stalk Biochar	11.24	16.60	33.05	39.11
3	Bamboo Biochar	9.42	17.05	25.30	48.23
4	SB (Biochar + Cow urine)	13.52	13.15	26.95	46.38
5	SB (Biochar + Vermicompost)	18.54	17.00	30.40	34.06
6	SB (Biochar + cow dung)	10.02	23.30	30.50	36.18
7	Bio oil (Vinegar)	ND	ND	ND	ND

Table2. Proximate characteristics of different biochar samples (ASTM standards on dry weight basis)

Sr No	Saturated biochar samples	pH	EC (ms ⁻¹ cm)	N (%)	P (%)	K (%)	Micronutrient mg/l			
		1:20 Extract		Diacid extract (3:1)			Fe	Mn	Zn	Cu
1	Pyrolysis ash	11.21	9.34	0.42	0.10	2.53	0.40	0.37	0.52	0.22
2	Cotton stalk Biochar	8.12	1.52	0.77	0.10	1.70	0.63	1.31	0.79	0.55
3	Bamboo Biochar	10.14	3.06	0.91	0.12	1.96	0.42	1.34	0.88	0.35
4	SB (Biochar + Cow urine)	8.28	5.12	0.94	0.13	2.20	0.60	1.43	1.41	0.69
5	SB (Biochar + Vermicompost)	8.11	2.54	0.78	0.14	2.03	0.33	0.68	0.84	0.29
6	SB (Biochar + cow dung)	8.23	1.52	0.88	0.15	2.07	0.26	0.55	0.67	0.31
7	Bio oil	4.91	1.54	0.60	0.08	1.05	0.38	0.79	0.65	1.42

Table 3. Laboratory protocols followed for biochar analysis.

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Parameters	Method / Technique	Standard / Instrument	Reference
Chemical composition			
pH	Suspension method (biochar: water 1:20)	Glass electrode pH meter	Jackson (1973)
Electrical Conductivity (EC)	1:20 biochar-water extract	Conductivity meter	Jackson (1973)
Nitrogen (%)	Acid digestion	Micro-Kjeldahl's method	Piper (1966)
Phosphorus (%)	Acid digestion Diacid extract (3:1)	Vanado-molybdate yellow color solution using spectrophotometer	Jackson (1973)
Potassium (%)		Flame photometer	Piper (1966)
Micronutrient Fe, Mn, Zn & Cu (mg/l)	Acid digestion (Diacid extract 3:1)	Atomic Absorption Spectrophotometry (AAS)	R. A. Isaac and W. C. Johnson (1975)
Proximate analysis			
Moisture Content	Oven drying	105 °C oven (gravimetric)	ASTM D1762-84
Ash Content	Muffle furnace combustion	550–750 °C	
Volatile Matter	Thermal decomposition	Furnace at ~950 °C	
Fixed Carbon	(100 – % (moisture + ash + volatile matter))	Proximate analysis	

Table 4. Recovery (%) of cotton feedstocks biochar produced at ICAR-CICR Nagpur

Cotton stalk (Root+ stem) biomass			
Biochar Production Method	Biomass Used (kg)	Biochar obtained (kg)	Recovery (%)
Cone Pit	50	21.5	43.12
Kon Tiki	50	18.4	36.74
Furnace pyrolysis machine	50	16.9	33.88
Cotton root biomass			
Cone Pit	400	165.2	41.30
Kon Tiki	300	108.2	36.07
Furnace pyrolysis machine	300	98.4	32.80
Cotton mid stem biomass			
Cone Pit	50	19.8	39.60
Kon Tiki	50	17.7	35.40
Furnace pyrolysis machine	50	16.1	32.20

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Fig 1. Cotton root biomass to biochar



Fig 2. Cotton mid Stem biomass to biochar

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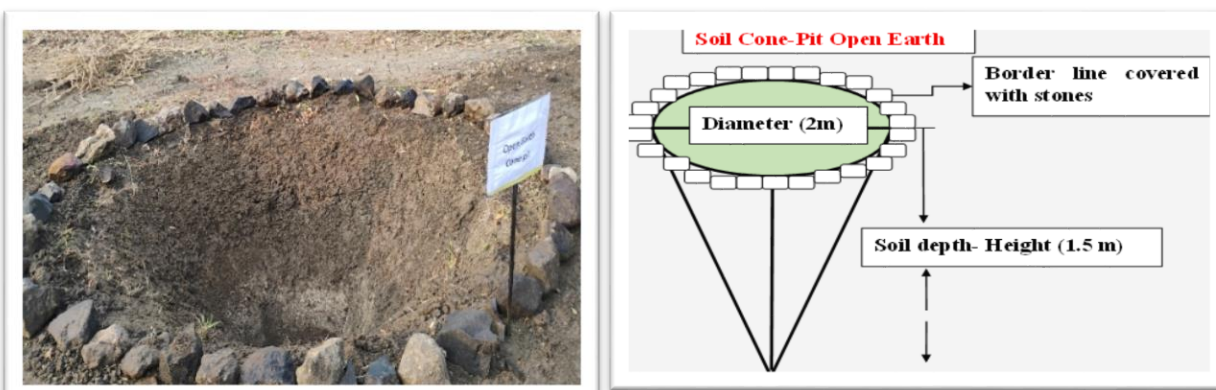


Fig 3. Soil Cone-Pit Open Earth Kiln



Fig 4. Materials required for cone pit method



Fig. 5 Modified Kon-Tiki pyrolysis Kiln

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Fig. 6 Small tube attachments at the bottom of Kon-tiki to drain out excess water



Fig. 7. Biochar production by furnace- pyrolysis machine



Fig 8. Saturation of biochar with vermicompost



Fig. 9. Deep Banding method of biochar application (10-15 cm soil depth)

