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Biochar: Turning Farm Waste into Soil Wealth

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SUMMARY

Biochar is a carbon-rich, stable material produced from organic biomass through pyrolysis. Different preparation methods influence its quality and effectiveness. When applied to soil, biochar improves soil structure, water retention, nutrient availability, and microbial activity, leading to better crop growth and sustainability. Its ability to sequester carbon makes it an important tool in climate-smart agriculture.

INTRODUCTION

Sustainable management of soil and agricultural residues has become a major challenge in modern agriculture due to declining soil fertility, increasing input costs, and climate change concerns. Large quantities of crop residues and organic wastes are generated every year, which are often burnt or improperly disposed of, leading to environmental pollution. In this context, biochar has emerged as a promising, eco-friendly soil amendment that not only improves soil health and crop productivity but also contributes to carbon sequestration and environmental protection. Biochar is a carbon-rich material produced by heating organic biomass under limited or no oxygen conditions, a process known as pyrolysis. Its use in agriculture is gaining importance due to its long-term benefits and sustainability.

Huge quantities of unused and excess crop and agroforestry residues in India are becoming an issue of concern due to inefficient crop residue management practices (Fig 1 and 2). The annual surplus crop residues of cotton stalk and pigeonpea stalk are estimated to be 11.8 Mt and 9.0 Mt, respectively. India ranks first in castor bean production in the world, a typical rainfed crop which generate 18.0 Mt of residues annually. These residues are either partially utilized or unutilized due to various constraints.

Fig. 1 : Agroforestry residue 1. *Eucalyptus* twigs 2. *Eucalyptus* barks 3. *Pongamia* shells

Fig. 2 : Crop residue 1. Pigeonpea stalk 2. Cotton stalk 3. Castor stalk 4. Maize stalk

Basics of Biochar Production & Co-Products

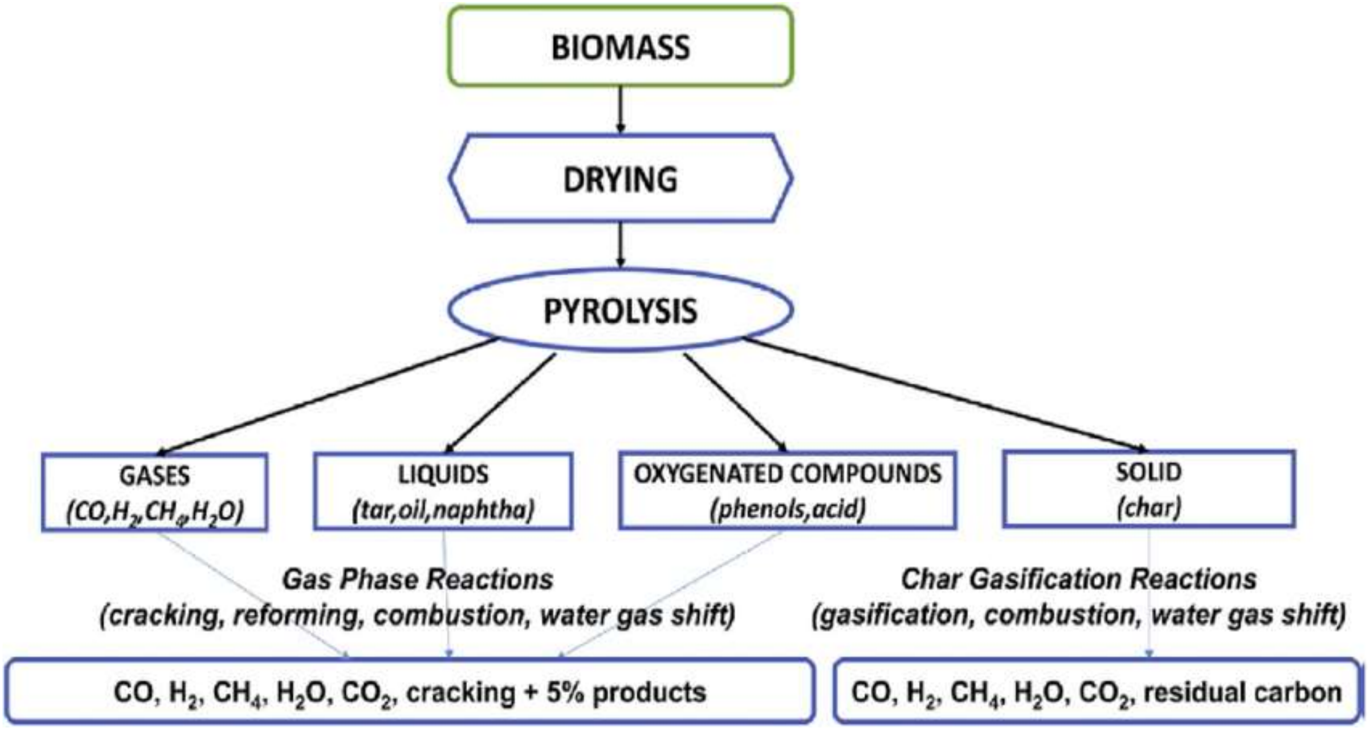

Fig 3: Basics of Biochar Production & Co-Products

In production of biochar, thermochemical processes that can be used to treat biomass include pyrolysis, gasification, hydrothermal processing, and combus tion. Each of these processes is defined by specific operating conditions (e.g., temperature, presence of oxygen) and feedstock requirements for optimal conversion to the product of primary interest. Each process results in varying fractions of gaseous, liquid, and solid products.

Thermochemical Conversion of Biomass to Biochar

	Slow Pyrolysis	Fast Pyrolysis	Gasification	Combustion
Time required for reaction	minutes - hours	seconds	seconds	seconds
Typical particle size for operation	wood chips - logs	saw dust - milled wood	milled wood – wood chips	wood chips
Temperature (°C)	300-800	400-700	750-1,000	1,000-1,200
Main product	biochar	bio-oil	syngas	heat
Biochar yield (wt. %)	35-50	15-30	5-10	<2

Table 1. General conditions of pyrolysis, Gasification, Combustion

The progression from biomass to the resulting products is shown in fig 3. Biomass moves from drying to pyrolysis, which is a thermal decomposition process in the absence of oxygen that separates com ponents of biomass into gases, liquids, oxygenated compounds (e.g., wood vinegar), and solid (biochar). Biochar recovery occurs at this stage. Some systems capture the gases, liquids, and oxygenated compounds for making other products, while in other systems these products undergo gasification (further thermo chemical conversion in the presence of oxygen).

Pyrolysis

Depending on the particle heat transfer rate achieved, it is possible to identify two types of pyrolysis reactors: slow and fast pyrolysis. Table 1 shows a comparison of these two processes with gasification and combustion, while Figure 4 offers a comparison of the distribution of resulting products.

Slow Pyrolysis

Slow pyrolysis, also called conventional carboniza tion, produces biochar by heating biomass at a low heating rate (around 5-7 °C per minute) for a relatively long residence time and typically uses large particles like wood chips or even whole logs. These conditions produce less liquid (30-50 by weight [wt. %]) and more biochar (35-50 wt. %) than fast pyrolysis.

Fast Pyrolysis

With fast pyrolysis, the process of heating biomass is rapid (heating rates of over 300 °C/min). Fast pyrolysis is typically used to obtain high yields of single-phase bio-oil. Fast pyrolysis uses small particles, generally smaller than 5 mm in diameter, due to the low thermal conductivity of lignocellulosic materials. High-rate heating of lignocellulosic materials typically yields 60-75% bio-oil, 15-30% biochar, and 10-20% non-condensable gas, and can be done in seconds. Most fast pyrolysis systems currently in commercial use consume the biochar that they make rather than recovering the biochar.

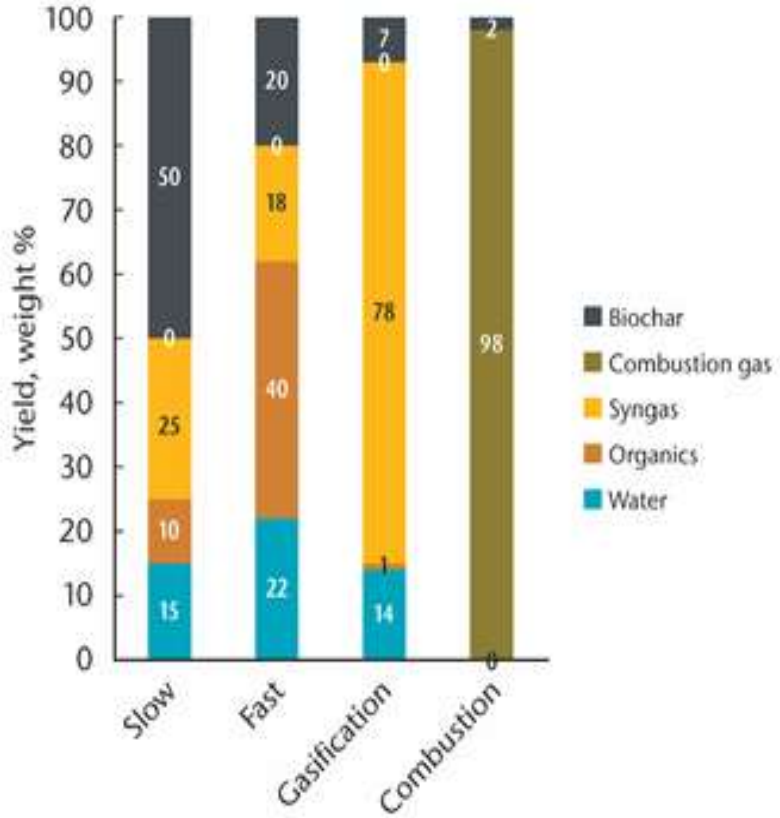

Fig 4: Typical distribution of products from the three main thermochem ical conversion technologies used to process low-moisture biomass feedstocks: slow pyrolysis, fast pyrolysis, and gasification.

Process: Thermo-chemical conversion of residue to biochar

The steps involved in preparation of biochar (Fig 5) from different crop / agroforestry residues by using the CRIDA biochar kiln are as under:

- Š Prior to loading, a metal pole (110 cm height and 2.0 cm radius) was inserted through top hole and fixed to central bottom vent of the kiln to create a central vent through the packed residues
- Š Pre-configured and shade dried residues were loaded through kiln top vent into the kiln chamber
- Š Depending upon the residue load, stalk fragments were manually packed and arranged parallel to bottom in as many voids as possible in the kiln chamber by gentle shaking
- Š The loaded kiln was lifted and placed over hearth of three flat stones (minimum of about 20 cm height) on level surface to facilitate primary air flow through the bottom vents
- Š Before initiating the conversion process, the metal pole was carefully removed leaving a central vent through the loaded residues to ensure efficient flow of hot gases from bottom to top for continuous heat transfer through the residues
- Š Locally available dry twigs can be used as combustible source at firing point of the kiln base vents to raise the temperature for spontaneous ignition under open atmospheric conditions
- Š Exposed residues at concentric base vents were flamed for 3-4 min. for partial direct combustion to develop sufficient exothermic temperature to trigger thermal bio-carbonization in the remaining residues
- Š Primary airflow through the concentric staggered base vents was used as carrier medium for rapid heat development through partial oxidation and flow of hot volatiles toward cooler fragments for uniform thermal exchange in kiln chamber and subsequently for upward thermal buoyancy of the released water vapor and volatiles
- Š The target end stage of bio-carbonization was indicated by distinctive thin blue hot gases with puff of flame

- Š At this stage, the kiln was ready to be sealed with clay and sand sealing mixture to restrict the flow of carrier medium through the kiln for significant yield realization
- Š The metal lid was placed over the top vent to block the upward movement of hot exhaust gases
- Š The kiln was then transferred to a leveled surface to ensure that no significant primary air ingression occurs in order to cut off totally the partial combustion process
- Š A sealing mixture of clay can be used to seal the circumferential edges of the drum and also along the edges of the metal lid used for covering the top hole for development of gas pressure in the enclosed space of kiln
- Š During the cooling cycle, it should be ensured that no volatiles escape from the kiln by sealing all possible air-entry points
- Š Biochar samples in the kiln should be left for cooling for 3-4 h by heat loss through natural convection and radiation
- Š After cooling, the sealed mixture was removed thoroughly and the biochar was taken out

Fig 5: Biochar kiln operational process
1. Residue loading 2. Central vent 3. Target end stage 4. sealing

The recommended practices for use of biochar in agriculture

1. Use freshly harvested and under-utilized dry crop and agroforestry residue for biochar production
2. Avoid use of crop residue grown on toxic chemical and heavy metal contaminated site
3. Co-locate the kiln unit to crop and agroforestry residue generating locations to provide a management solution and minimize handling and transportation costs
4. Operate the CRIDA biochar kiln unit in an open area with lots of atmospheric air circulation ideally away from any structures
5. Keep sufficient water source close by and do not open the kiln unit during cooling period
6. Let fresh biochar be 'cured' overnight by exposure to open air
7. Store as whole biochar outside under shelter, away from buildings, in a cool, dry wellventilated open spot and grind to powder just before its use

8. Transfer the biochar to application site in a sealed container or in a closed plastic bag
9. To avoid biochar loss by wind, apply biochar as close to ground as possible on mild windy day to avoid drift or on a day with a mild precipitation to dampen and lay on the soil surface until following tillage operations
10. Use protective clothing such as insulated gloves or gunny rags, masks or cloths whenever possible while handling kiln and biochar

CONCLUSION

Biochar represents a sustainable and environmentally sound approach for managing agricultural residues while improving soil health and productivity. Although biochar alone may not supply sufficient nutrients, its integration with organic and inorganic nutrient sources significantly enhances its effectiveness. With proper production methods and application strategies, biochar can play a vital role in sustainable agriculture, resource conservation, and climate change mitigation. Wider adoption of biochar technology, especially at the farm level, can contribute to long-term soil fertility and environmental sustainability.

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