Journal Homepage: -www.journalijar.com

INTERNATIONAL JOURNAL OF ADVANCED RESEARCH (IJAR)

Article DOI:10.21474/IJAR01/24574
DOI URL: http://dx.doi.org/10.21474/IJAR01/24574

ISSN (O): 2320-5407
ISSN (P): 3107-4928

RESEARCH ARTICLE

SAL LEAF BIOCHAR: EVALUATING ITS POTENTIAL FOR FOREST WASTE MANAGEMENT, SOIL AMENDMENT AND ENVIRONMENTAL REMEDIATION

Pranab Sahoo[1,2,3,4]

1.Associate Professor, Dept. of Geography Seva Bharati Mahavidyalaya (Under VU), Kapgari- Jhargram, WB, India.
2.Visiting Professor, PG Dept. of Geography, Sadhu Ramchand Murmu University of Jhargram Jitushole- Jhargram, WB, India.
3. Geo- Environmental Scientist, UN SDGs-2030 Forest Restoration & Carbon credit Programme, West Africa.
4. Geo- Environmental Scientist, Nirvana Carbon Foundation, USA Associated with Princeton University, USA.

Manuscript Info

Manuscript History
Received: 12 September 2026
Final Accepted: 14 October 2026
Published: November 2026

Abstract

Charcoal is created both naturally as a result of vegetation fires and intentionally by humans in burn pits and hand-made structures. When charcoal is made for the purpose of adding it to soil as an amendment, it's called Biochar. Despite the good things that Biochar can do for soils, making charcoal in the traditional method is not an environmentally friendly practice. The first evidence of charcoal made by humans being used as a soil amendment was in the Amazon Basin of South America over 2,500 years ago. Archaeological evidence suggests that ancient people piled and covered wood in earthen pits, then burned it slowly with limited air.Biochar is a carbon rich organic matter that remains after heating of organic material in the absence of oxygen, a process called pyrolysis. The International Biochar Initiative standards for Biochar define Biochar as the solid byproduct of a thermochemical conversion process containing greater than 10% organic carbon. Carbon in Biochar is extremely stable which takes more than 100 years to break down, so amending soils with Biochar is an effective way to sequester carbon. Biochar is used as a substrate for soilless media and soil amendments to improve soil quality. The high surface area of Biochar contributes to the soil's ability to hold water and reduces nitrogen leaching and dissolved organic carbon. Application of organic matter along with Biochar reduces nutrient leaching, thus enhancing nutrient use efficienc y of the crop instead of organic matter alone.Biochar can be produced f rom dry Sal leaves using thermochemical conversion processes, primari ly pyrolysis.

"© 2026 by the Author(s). Published by IJAR under CC BY 4.0. Unrestricted use allowed with credit to the author."

Corresponding Author:-Pranab Sahoo
Address:-Associate Professor, Dept. of Geography Seva Bharati Mahavidyalaya(Under VU), Kapgari- Jhargram, WB, India.

This process involves heating biomass (like paddy straw) in an oxygen-limited environment at temperatures between 350^0C and 650°C. The resulting Biochar is a high carbon-rich solid that can be used as a soil amendment, a smokeless fuel, or in various industrial applications. **Sal (*Shorea robusta*)**is the tropical dry deciduous tree of south AsiaAsia. This forest area has been dominating vegetated trees by Sal in India, especially Chhatonagpur plateau, Dandakaranya plateau,Easternghat region and Lateritic area of West Bengal.The Jhargram Forest area has been covered with sal trees, about 80% trees has been dominating by Sals. About 62,000 hectors area is under the forest region in Jhargram District. Where, about 49.6million first generation Sal trees live in the forest area and age of the trees more than 10 yrs which are mature trees in this area. Dry Sal leaves have been produced by defoliation in winter season, which amount is about 396800 ton per year. The Biochar component may be produced 277760 ton (wet component) and 138880 ton (dry component).Air pollution caused by man-made forest fires has become an alarming issue in this region in recent times, resulting in a severe loss of biodiversity. Utilizing dry Sal leaves from 30% of the forest area could produce approximately 83,328 tons of wet biochar annually.The total agricultural land in the Jhargram District spans about 268,249 hectares, 60% of which consists of lateritic soil. This soil type is characterized by low fertility, poor moisture retention, acidity, and low organic carbon content. Biochar derived from Sal leaves contains roughly 57.7% organic carbon, making it significantly higher in quality than biochar made from paddy straw, wheat straw, or other agricultural residues. Therefore, applying Sal-leaf biochar as a soil amendment can substantially boost crop production in this area.While the biochar demand for 60% of Jhargram's agricultural land is estimated at 201,187 tons, converting dry Sal leaves into biochar can help bridge this gap. Ultimately, this practice would benefit local farmers, restore the ecological balance of lateritic soils, improve environmental quality, mitigate greenhouse gas (GHG) emissions and climate change, and build resilience against environmental degradation.

1. Introduction:-

Archaeological evidence suggests that ancient people piled and covered wood in earthen pits, then burned it slowly with limited air. This method, still used today in developing countries, creates considerable smoke and releases half the carbon dioxide (CO_2) in the original biomass along with other greenhouse gasses (GHG's). That's not healthy for people or the atmosphere and all that heat (energy) is wasted.Charcoal is created both naturally as a result of vegetation fires and intentionally by humans in burn pits and hand-made structures. When charcoal is made for the purpose of adding it to soil as an amendment, it's called Biochar. Despite the good things that Biochar can do for soils, making charcoal in the traditional method is not an environmentally friendly practice. The first evidence of charcoal made by humans being used as a soil amendment was in the Amazon Basin of South America over 2,500 years ago.Biochar is a carbon rich organic matter that remains after heating of organic material in the absence of oxygen, a process called pyrolysis. Carbon in Biochar is extremely stable which takes more than 100 years to break down, so amending soils with Biochar is an effective way to sequester carbon. Biochar is used as a substrate for soilless media and soil amendments to improve soil quality.

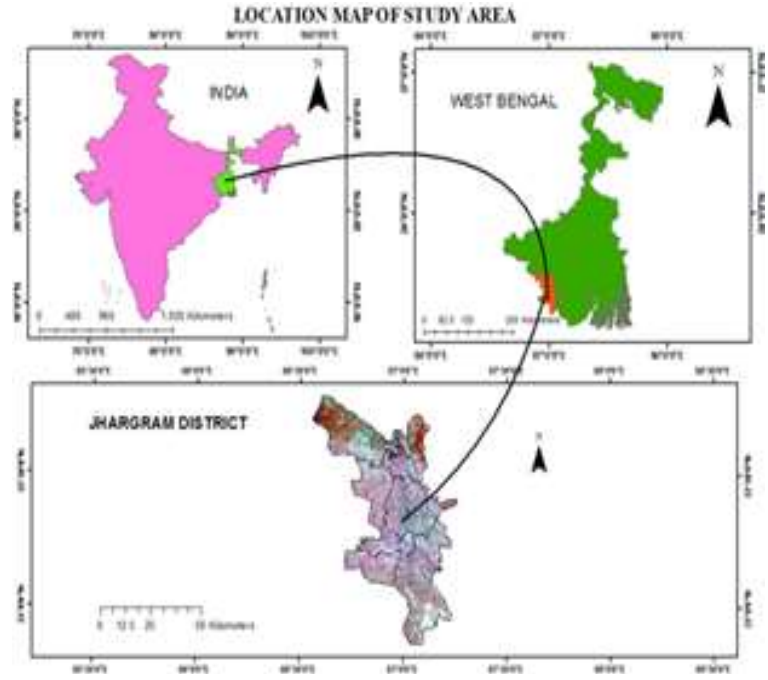
The high surface area of Biochar contributes to the soil's ability to hold water and reduces nitrogen leaching and dissolved organic carbon. Application of organic matter along with Biochar reduces nutrient leaching, thus enhancing nutrient use efficiency of the crop instead of organic matter alone. This process drives off volatile gases, leaving behind the Biochar. Biochar is often used as a soil amendment, improving soil structure and fertility. Soil properties such as physical and biological properties could be improved by using biochar and it is used as preventive against heavy metal stress of soil. Biochar can be produced from dry Sal (***Shorea robusta*)**leaves using thermochemical conversion processes, primarily pyrolysis. This process involves heating biomass (like paddy straw) in an oxygen-limited environment at temperatures between 350ºC and 650°C. The resulting Biochar is a high carbon-rich solid that can be used as a soil amendment, a smokeless fuel, or in various industrial applications. Sal(***Shorearobusta***) is the tropical dry deciduous tree of south Asia. This forest area has been dominating vegetated trees by Sal in India, especiallyChhatonagpur plateau, Dandakaranyaplateau,Easternghat region and Lateritic area of West Bengal.

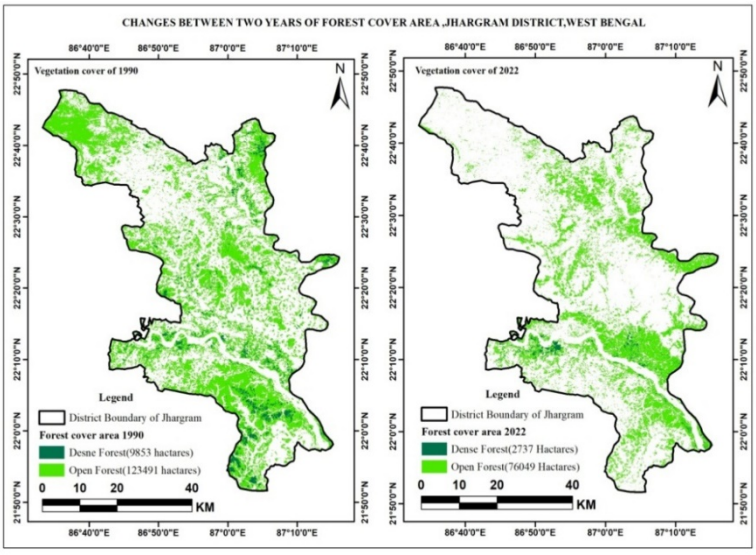
The Jhargram Forest area has been covered with Sal (***Shorearobusta***)trees, about 80% trees has been dominating by Sals. About 62,000 hectors area is under the forest region in Jhargram District. Where, about 49.6million first generation sal trees live in the forest area and age of the trees more than 10 yrs which are mature trees in this area. Dry sal leaves have been produced by defoliation in winter season, which amount is about 396800 ton per year. The Biochar component may be produced 277760 ton (wet component) and 138880 ton (dry component). The Jhargram forest region has been damaged by man- made forest fire during the defoliation season in winter, about 12% to 15 % sal forest area has been damaged by the forest fire as result huge amount of Co2 and CO have been

emission. Air pollution caused by man-made forest fires has become an alarming issue in this region in recent times, resulting in a severe loss of biodiversity. Utilizing dry Sal leaves from 30% of the forest area could produce approximately 83,328 tons of wet Biochar annually.

The total agricultural land in the Jhargram District spans about 268,249 hectares, 60% of which consists of lateritic soil. This soil type is characterized by low fertility, poor moisture retention, acidity, and low organic carbon content. Biochar derived from Sal leaves contains roughly 57.7% organic carbon, making it significantly higher in quality than Biochar made from paddy straw, wheat straw, or other agricultural residues. Therefore, applying Sal-leaves Biochar as a soil amendment can substantially boost crop production in this area.

While the Biochar demand for 60% of Jhargram's agricultural land is estimated at 201,187 tons, converting dry Sal leaves into Biochar can help bridge this gap. Ultimately, this practice would benefit local farmers, restore the ecological balance of lateritic soils, improve environmental quality, mitigate greenhouse gas (GHG) emissions and climate change, and build resilience against environmental degradation. Therefore, dry Sal leaves can be utilized to produce Biochar as a soil amendment for agricultural land. This approach would benefit local farmers in the Jhargram District, maintain the ecological balance of lateritic soils, improve environmental quality, minimize greenhouse gas (GHG) emissions, and build regional resilience against climate change and environmental degradation.





2.Research Project Area and Background:-

Presently the forests of Jhargram Division are situated in the Civil Sub-division of Jhargram of PaschimMedinipur District and cover the Civil Blocks viz. Binpur-I (the portion on the West of the Kangsabati river), Binpur-II, Jhargram, Jamboni, Gopiballavpur-I &Gopiballavpur-II and police stations of Belpahari, Binpur, Jamboni, Jhargram, GopiballavpurandBeliyabera. The Jhargram Forest Division lies between 21° -52′ and 22° -48′ North latitudesand 86° -34′ and 87° -20′ East longitude approximately. On the North it is bordered with the civil districts of Purulia and Bankura and on the East it is bordered by the river Kangsabati (from the western border of Midnapore Division) and partly by the river Subarnarekha from the western border of Kharagpur Division. It is having common borders with the State of Orissa on the Southand on the West with the Jharkhand State. That the Jhargram Geographical area has characterized by laterite surface with the upland tract, the younger alluvium surface of modern flood plain faces, with metamorphosed rocks of iron ore series , quartzite , mica schist and basalts which contain ferro-magnesium minerals in the region . Subarnarekha, Kangasabati and Dulung rivers and stream are non-perennials runoff. And also high annual rainfall about 130 cm. to 160 cm. and Avg. temperature is (27ºc-35ºc) throughout the year. The JhargramGeographical area is an abundant

source of flora & fauna. Jhargram biodiversity canvas has numerous rare and endangered species in its surroundings. The forest area has covered by 62,000 Hectors.

An inseparable part of West Bengal state has a combination of a variety of tribes and occupational artisan castes. The tribes include linguistic groups: the mundari linguistic group including the Santhal, Lodha -Sobar and Munda; some primitive tribes are still present in Jhargram who are totally dependent on forest and hunting. Dancing and singing is the base of tribal community of the area. Tribals say that to speak is music and to walk is dance. Jhargram has many famous tribal writers. Tribals have good knowledge of herbal medicines.Tribal society has some specific cultural identity. There have happened many cultural movements in tribal society in the area. The longstanding demand for a separate District in West Bengal has underlined the distinctive tribal education in alchiki language, heritage art and culture of the region as the primary reason for alternative administrative and political arrangements. From the assessment, it is clear, that the all information and evidences, ST people are motivated towards education and also modern medical science remarkable during last 10 years in Jhargram geographical area. The Geographical studies of Human Ecology can help in development of proper perception. The study is related with ecosystem of the Jhargram forest area and their inhabitant, economy and society, degradation of environment and Environmental management as well as future planning. This Paper has been fined and introduced that the relationship in between Environment-livelihood, environment-folk culture, environment-religious culture, environment-behavior and environment-psychology of ancient past people in Jhargram Geographical area (Sahoo,P).

3. Location and Identification of the Study Area:-

The study focuses on nine blocks of the Jhargram district, West Bengal: Binpur-I, Binpur-II, Jamboni, Jhargram, Gopiballavpur-I, Gopiballavpur- II, Sankrail and Nayagram .These blocks are situated in a region characterized by its proximity to forests, rivers, and laterite areas. The local population predominantly comprises lower caste communities, including the Santal, Lodha, and Mahata(Kurmi).

Geographic and Socio-economic Context:-

The villages are located in an area where the natural environment plays a crucial role in the livelihoods of the residents. The dense forests and fertile lands have traditionally supported a range of economic activities, including agriculture, agroforestry, labor, and muram (laterite) mining. These activities are not only economic but are deeply intertwined with the social and cultural fabric of the communities.

Livelihoods and Economic Activities:-

- **Forestry and Agroforestry**: The forests provide a variety of resources such as fuelwood, fodder, and non-timber forest products, which are essential for the daily sustenance of the local population.
- **Agriculture**: Farming is a primary occupation, with the fertile lands supporting crops that sustain the local economy.
- **Labor**: Many villagers work as laborers in nearby towns or within the village, contributing to the household income.
- **Lateritic Soils Mining**: The extraction of laterite (muram) is another significant economic activity, although it often contributes to environmental degradation.

Socio-economic Challenges:-

- **Low Literacy Rates**: The villages have low levels of literacy, which hampers the ability of the residents to access better employment opportunities and improves their living standards.
- **Poverty**: A significant portion of the population lives below the poverty line (BPL), indicating widespread economic hardship.
- **Remoteness**: The villages are remote, with limited access to market areas and cities, making it difficult for residents to sell their produce or access essential services.

4. Research and Innovation on Sal Forest, Dry Sal Leaves and Yield Biochar:-

The Jhargram Forest area has been covered with sal trees, about 80% trees has been dominating by sals. About 62,000 hectors area is under the forest region in Jhargram District. Where, about 49.6million first generation sal trees live in the forest area and age of the trees more than 10 yrs which are mature trees in this area. Dry sal leaves have been produced by defoliation in winter season, which amount is about 396800 ton per year.

Model of equivalent for Number of Sal Trees in Jhargram District:*TpSt ≈Fah. Nt*
Where; TpSt (Total population of Sal Trees)≈ Forest area in Hectors x No of Trees
So, TpSt≈62,000x800≈4, 96, 00,000
Total Population of Sal Tree in Jhargram District≈4, 96, 00,000

Amount of Dry Sal leaves by defoliation in every winter season:
Step -I for Dry Leaves Biomass from Sal trees:*TaDL≈TpSt. IaDL*
Where; TaDL (Total amount of Dry Leaves) ≈TpSt (Total population of Sal trees) x IaDL (individual amount of Dry Leaves).
So, TaDL≈49600000 x 8kg ≈ 396800 ton
iii) Estimation of Yield Wet Biochar in Jhargram District:
Step-2 for Potentiality of Yield Wet Biochar: *ptYWB≈TaDL.aYWB/t*
Where; ptYWB(Potentiality of Yield Wet Biochar≈TaDL(Total amount of Dry Leaves) x aYWB/t (amount of Yield Wet Biochar per ton)
So, ptYWB≈396800ton x 700kg ≈277760 ton.
If we can be used 30% of Dry Leaves, we may be produced of Yield Wet Biochar from Dry Sal leaves in Jhargram District which amount is about 83328 ton every year.

5. Methods of SL Biochar Production:-

The developing interest in utilizing Biochar for various applications has led to increased conversion of biomass to Biochar. Thermochemical conversion is a common technique for Biochar production. Thermochemical conversion method includes pyrolysis, hydrothermal carbonization and flash Carbonization .For a maximum yield of Biochar, the technique chosen for production must be appropriate depending on the biomass type and also the process conditions such as heating rate, temperature, residence time, etc must be optimum. These conditions are crucial since they may affect the physical and chemical states of Biochar during the production process. The morphology of Biochar derived from plant biomass varies based on the process conditions since it involves weight loss of the biomass. Initially, the weight loss because of water loss around 100 ºC continued by cellulose, hemicellulose and lignin degradation occurring above 300 ºC. Finally, loss of weight occurs due to the burning of carbonaceous residues.

a) 'Basutirtha Methods' for Dry Sal Leaves Yield Biochar :

$\propto$ **i)** ***DSLyBchpyrop****DSL*$|$*mc-tr-rt*$|$ **…….Formula-I**

Where , DSL-Dry Sal Leaves
yBch- Yield Biochar
Pyrop- pyrolysis process

DSL- Dry Sal Leaves
mc- moisture content
tr- temperature required
rt- Residence time

$\propto$ **ii)** ***DSLyBchhydrcarbp****DSL*$|$*mc-tr-rt*$|$ **……..Formula -II**

Where , DSL-Dry Sal Leaves
yBch- YieldBiochar
hydrcarp - Hydrothermal Carbonizationprocess

DSL- Dry Sal Leaves
mc- moisture content
tr-temperature required
rt-Residence time

$\propto$ iii) ***DSLyBchflcarbp****DSL*│*mc-tr-rt*│……**Formula-III**

Where , DSL-Dry Sal Leaves
yBch- YieldBiochar
flcarp - Flash Carbonizationprocess

DSL- Dry Sal Leaves
mc- moisture content
tr-temperature required
rt-Residence time

b) The 'Basutirtha'thermochemical conversion techniques and their process conditions for Sal leaves biomass are given in Table 1.

Techniques/ Methods	Moisture (%)/ Dryness (mc)	Required Temperature (°C) (tr)	Residence time (rt)	Yield of Biochar (%)
Formula –*I* *DSLyBchpyro*p**(Pyrolysis)**	10-15	350−650 (slow)	< 3 s (slow)	45-55 (slow)
	8-12	450−950(fast)	Hour-day (fast)	35-55 (fast)
Formula-*II* *DSLyBchhydrcarbp***(Hydrothermal carbonization)**	6-12	200−320	1−16 h	70−80
Formula-*III* *DSLyBchflcarbp***(Flash carbonization)**	8-16	350−650	< 30 min	50-70

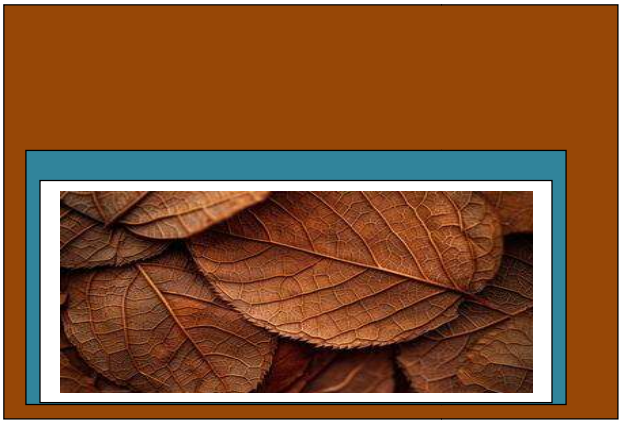
Biochar Process From Sal Leaves:-
Pyrolysis:-
Biochar is primarily produced through pyrolysis, a thermochemical process that breaks down organic matter in the absence or presence of limited oxygen.

Types of Pyrolysis:-
Different pyrolysis methods, including slow pyrolysis, fast pyrolysis, and hydrothermal carbonization, can be employed to produce Biochar from Sal leaves.

Controlled Heating:-
The process involves controlled heating of the biomass, typically at temperatures ranging from 350ºC-650°C, in a closed environment.

Yield:-
The yield of Biochar depends on factors like the type of biomass, pyrolysis temperature, and time.

The size of Earthen Pit/ Concrete Chamber for producing theBiochar:
Length -3m , Width- 2m and depth-1.5m





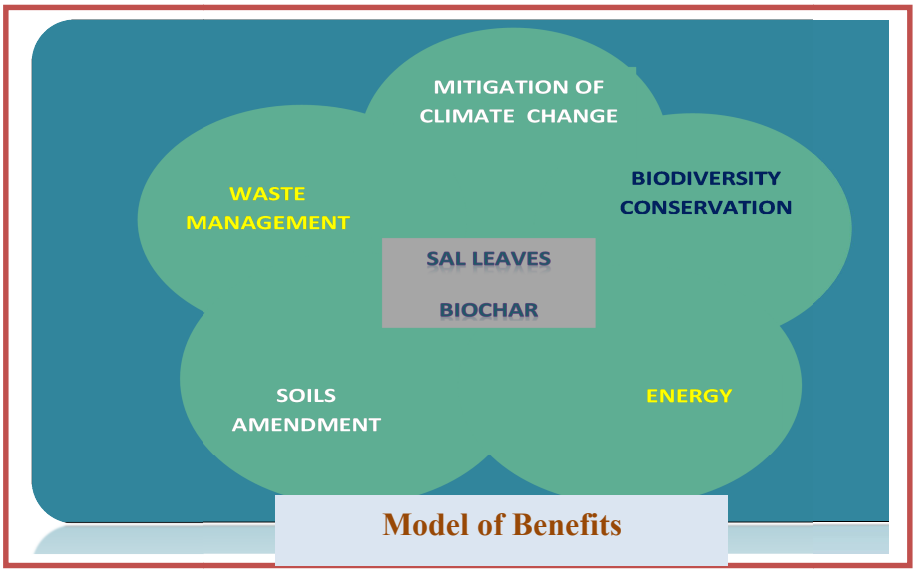
6. Characteristics of Sal Leaves Biochar:-

a. It produces a high yield of wet Biochar, weighing 600–700 g/kg.
b. It has a very high carbon content of 57.6%.
c. It features a well-developed and prominent porous structure.
d. It possesses a high ability to retain nutrients.
e. The nitrogen content of the Sal Biochar is approximately 1.06%.
f. The pH of the Biochar is 8.27.
g. The sulfur content of the Biochar is about 0.5%, and the hydrogen content is 3.14%.
h. These properties make it suitable for soil amendment.
i. It demonstrates strong carbon sequestration potential.

7. Benefits of Sal Leaf Biochar:-

a. Waste Management:-

Biochar production transforms Sal Leaves Waste, reducing its environmental impact and creating a resource from what was previously considered a problem. Mainly Jhargram town has been bounded by oldest and heritage sal trees. The huge dry leaves have been defoliated in winter as result leaves waste has scattered everywhere in the town. There are not any initiatives to sal leaves waste management by the municipality. So, we can be management for Biochar yield.



b. Environment management: The Jhargram forest region has been damaged by man- made forest fire during the Sal leaves defoliation season in winter, about 12% to 15 % Sal forest area has been damaged by the forest fire as result huge amount of Co2 and CO have been produced. Air pollution is the alarming issues of this area in recent

time and also loss of biodiversity is the other environmental crisis of this Geographical area. Biochar process can be applied for 30% forest area, Wet Yield Biochar may be produced 83,328 ton every year.

c. Soil Improvement:-

Biochar enhances soil properties, including water retention, aeration, and nutrient availability, promoting healthier plant growth. The total area of agricultural land in the Jhargram District is about 268249 hectors and also 60% land under the lateritic soils which characterized by infertile soils, humidity and water holding capacity low, acidic soil, low organic carbon content. So, may be used the Biochar component in agricultural land for soils amendment and crops production in this area

d. Carbon Sequestration:-

Sal's Biochar high carbon content contributes to carbon sequestration, helping to improve the soils and environmental quality and also minimize the Global warming GHGs and to mitigation of climate change.

e. Resilience to Environmental degradation:-

Biochar can be used for environmental resilience, including the absorption of pollutants in soil and water.

f) Sustainable Agriculture:-

Biochar production supports sustainable agriculture by reducing reliance on synthetic fertilizers and improving soil health. We can be used of dry Sal leaves to produce the Biochar for soils amendment of agricultural land and would be benefited host farmers in the Jhargram District and maintain the ecological balance of Lateritic soils.

f. Extra benefit of Sal leaves Biochar than other Biochar:-

High carbon content Biochar and maximum amount of Wet Yield Biochar, near about balancing P^H, and also others are enrich component than others Biochar.

8. Laboratory Assessment:-

Paddy Straw Biochar (Test Parameter)						Sal leaves Biochar(Test Parameter)					
Moisture (%)	**Carbon (%)**	**Hydrogen (%)**	**Nitrogen (%)**	**P^H (%)**	**Sulphur (%)**	**Moisture (%)**	**Carbon (%)**	**Hydrogen (%)**	**Nitrogen (%)**	**P^H (%)**	**Sulphur (%)**
82.06	34.6	2.20	0.65	9.16	0.12	78.15	**57.6**	**3.14**	**1.06**	**8.27**	**0.5**

1. **PROPSED SYMBOLIC DESIGN :**

BSLB: ABCDE

BSLB (Basutirtha Sal Leaves Biochar):

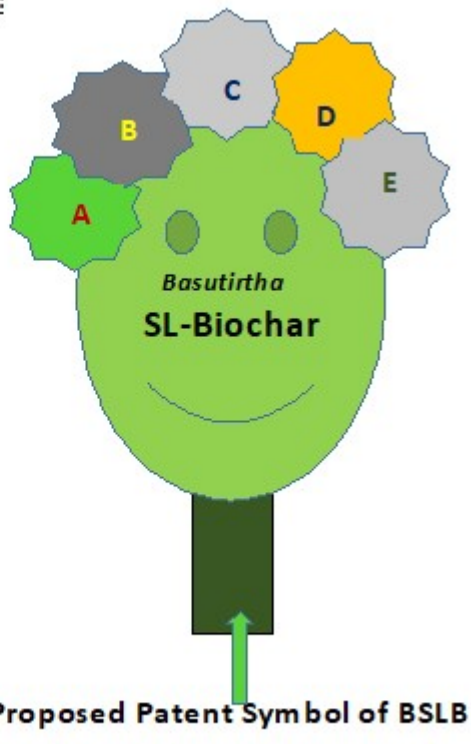
A: Raw Materials

B: Moisture

C.: Temperature

D: Time

E: SL-Biochar



Proposed Patent Symbol of BSLB

10. Area of Application:-

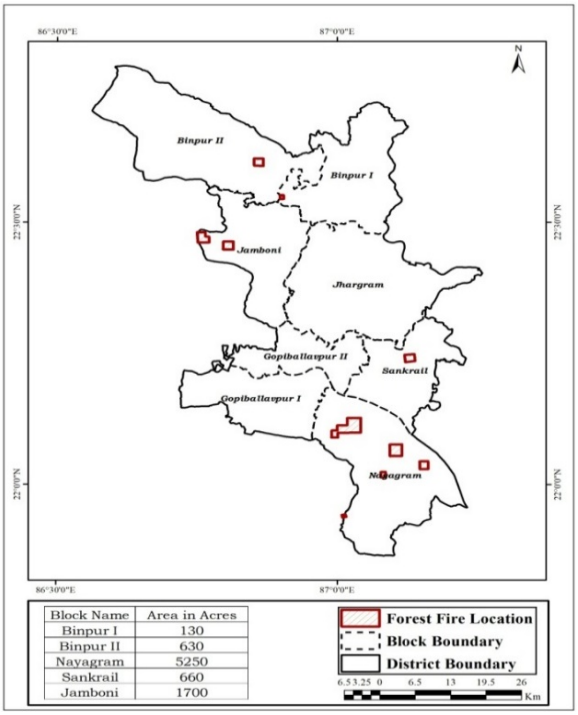
Sal Leaves Biochar can be used for various applications, including:-

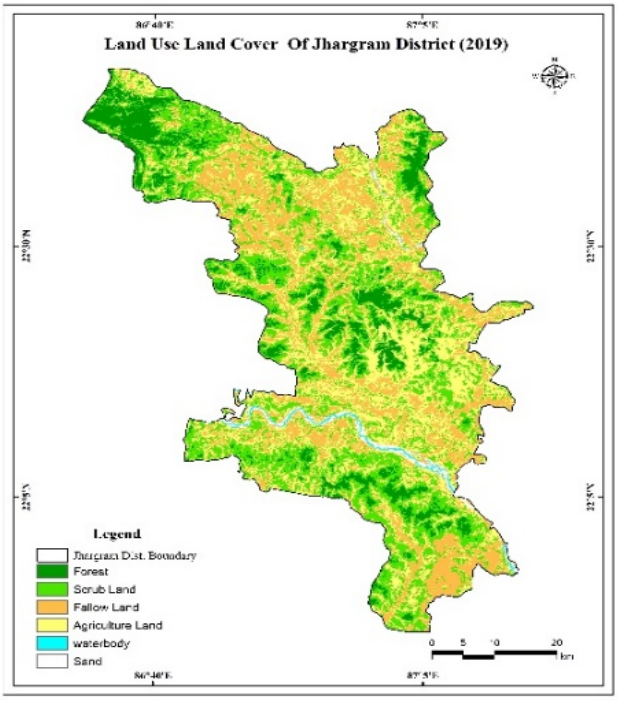
- **Soil amendment:** Biochar can be Improved thesoil structure, fertility, and water retention.
- Heavy metal removal: Biochar can effectively remove heavy metals like arsenic and manganese from water.
- **Other applications:** Biochar can also be used as an adsorbent for other pollutants, such as Pb and Zn.
- **Cost-effectiveness:** Biochar production from Sal leaves is a relatively cost-effective way to utilize forest waste and produce a valuable material.
- **Abundant Sal leaves :** The region has a large amount of Sal leaves available as a raw material for biochar production.
- **Potential for soil improvement:** The application of Biochar in the region could improve soil health and address issues like heavy metal contamination. The agricultural area has been covered in Jhargram District is about 2, 69,000 hectors and infertile laterite soils has been covered is about 1,40,000 hectors area. So, If we can be used of 30% Dry Sal Leaves for yield of Biochar, it may be produced 83,328 ton and to be changed the soil fertility and amendment the soils.
- **Economic benefits:** Biochar production could create jobs and generate revenue for local ancient host communities.
- **Sustainable Rural Development:** about 44% host ancient people of the Jhargram District have been directly and indirectly depended on Sal Forest and 55% host communities are depending of agriculture. Forest based villagers will be involved to collect the dry leaves, making the yield Biochar, packing the Biochar and distribution the Biochar in agricultural field. So, Village employees will be generated and may be attached to this project.

11.Key Points To Remember:-

- The properties of Biochar produced from Sal Leaves depend on the pyrolysis conditions.
- Biochar is a versatile material with various applications in agriculture, environmental remediation, smoke less fuel and other industries.
- Sal leaves is a readily available and sustainable resource for Biochar production.

Forest Fire Location and Lulc of Jhargram:-

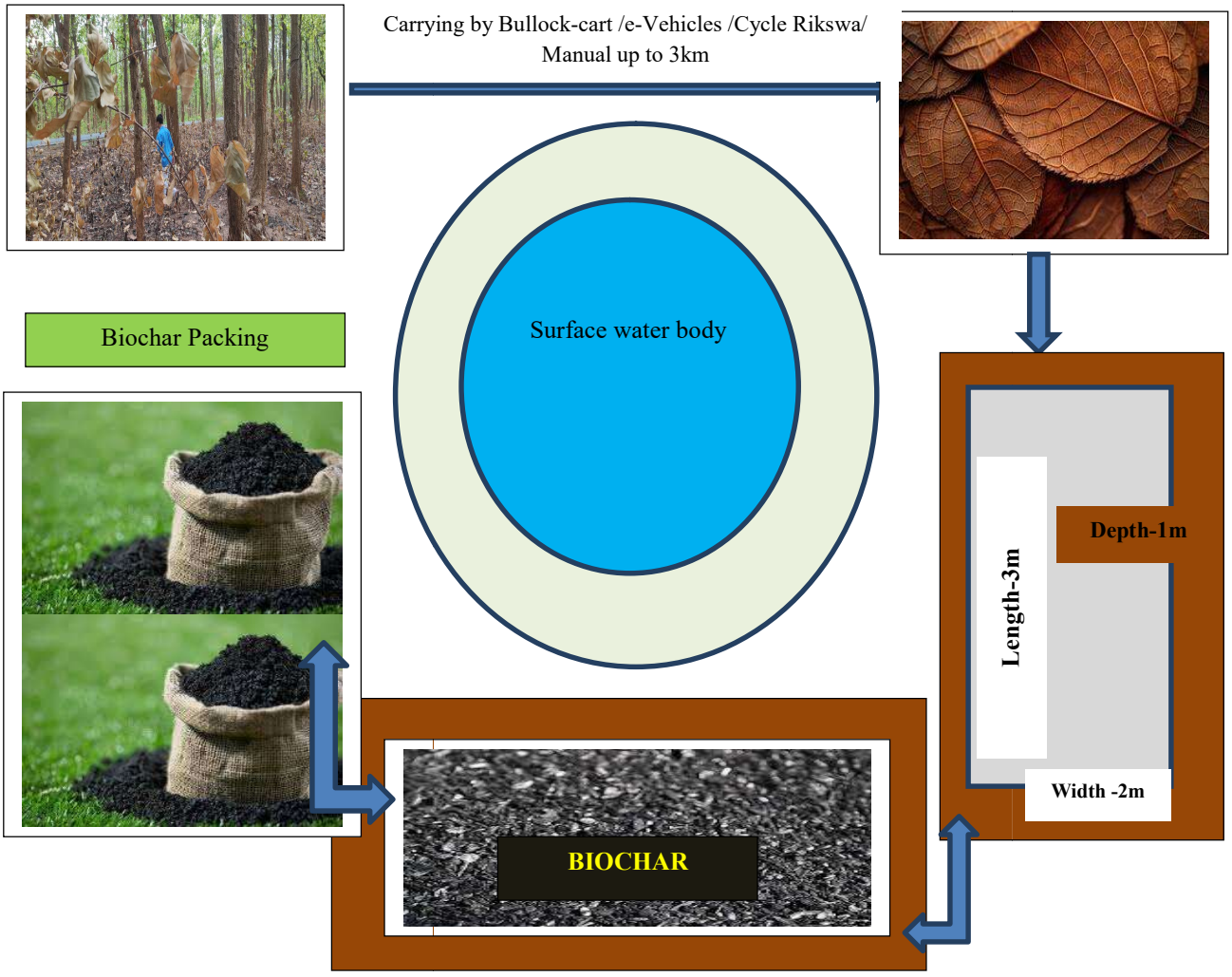








11. Flowchart of Implementation Methods:-



References:-

1. Abbas T, Rizwan M, Ali S, Zia-ur-Rehman M, Qayyum MF, Abbas F, Hannan F, Rinklebe J, Ok YS. 2017. Effect of biochar on cadmium bioavailability and uptake in wheat (Triticumaestivum L.) grown in a soil with aged contamination. Ecotoxicol Environ Safety. 140:37–47. doi:10.1016/j.ecoenv.2017.02.028.
2. Adekiya AO, Ayorinde BB, Ogunbode T. 2024. Combined lime and biochar application enhances cowpea growth and yield in tropical Alfisol. Sci Rep. 14(1):1–12. doi:10.1038/s41598-023-50600-8.
3. Akhtar SS, Andersen MN, Liu F. 2015. Biochar mitigates salinity stress in potato. J Agron Crop Sci. 201:368–378. doi:10.1111/jac.12132.
4. Andersen MN, Liu F. 2014. Biochar enhances yield and quality of tomato under reduced irrigation. Agricul Water Manag. 138:37–44. doi:10.1016/j.agwat.2014.02.016.
5. Amezketa E. 1999. Soil aggregate stability: a review. J Sustain Agric. 14:83–151. doi:10.1300/J064v14n02_08.
6. Antonangelo JA, Sun X, Zhang H. 2021. The roles of co-composted biochar (COMBI) in improving soil quality, crop productivity, and toxic metal amelioration. J Environ Manag. 277:111443. doi:10.1016/j.jenvman.2020.111443.
7. Atkinson CJ, Fitzgerald JD, Hipps NA. 2010. Potential mechanisms for achieving agricultural benefits from biochar application to temperate soils: a review. Plant Soil. 337:1–18. doi:10.1007/s11104-010-0464-5.
8. Agriculture contingency plan for district: PaschimMedinipur. (2011). ICAR-Central Research Institute for Dryland Agriculture.
9. Banerjee, H., Dhara, P. K., &Mazumdar, D. (2009). Bamboo (Bambusa spp.) based agroforestry systems under rainfed upland ecosystem. Journal of Crop and Weed, 5(1), 286–290.
10. Bashir S, Hussain Q, Shaaban M, Hu H. 2018. Efficiency and surface characterization of different plant derived biochar for cadmium (Cd) mobility, bioaccessibility and bioavailability to Chinese cabbage in highly contaminated soil. Chemosphere. 211:632–639. doi:10.1016/j.chemosphere.2018.07.168.
11. Compensatory Afforestation Fund Act, 2016, Act No. 38 of 2016 (India).
12. Chang Y, Rossi L, Zotarelli L, Gao B, Shahid MA, Sarkhosh A. 2021. Biochar improves soil physical characteristics and strengthens root architecture in Muscadine grape (Vitisrotundifolia L.). ChemBiolTechnolAgricul. 8(1):1–11. doi:10.1186/s40538-020-00199-z.
13. Cheng CH, Lehmann J, Thies JE, Burton SD, Engelhard MH. 2006. Oxidation of black carbon by biotic and abiotic processes. Org Geochem. 37:1477–1488. doi:10.1016/j.orggeochem.2006.06.022.
14. Claudio J, Missau J, Anshu K, Siakpebru OK, Thengane SK, Morais AR, Tanabe EH, Bertuol DA. 2023. Review on biomass pyrolysis with a focus on bio-oil upgrading techniques. Analytica. 4(2):182–205. doi:10.3390/analytica4020015.
15. Department of Land Resources & National Remote Sensing Centre. (2019). Wastelands atlas of India 2019: Change analysis based on temporal satellite data of 2008-09 and 2015-16 [West Bengal chapter]. Ministry of Rural Development; Indian Space Research Organisation.
16. Elliott DC. 2007. Historical developments in hydroprocessing bio-oils. Energy Fuels. 21:1792–1815. doi:10.1021/ef070044u..
17. Fahad S, Hussain S, Saud S, Hassan S, Tanveer M, Ihsan MZ, Shah AN, Ullah A, Nasrullah, Khan F, et al. 2016. A combined application of biochar and phosphorus alleviates heat-induced adversities on physiological, agronomical and quality attributes of rice. Plant PhysiolBiochem. 103:191–198. doi:10.1016/j.plaphy.2016.03.001.
18. Forest Survey of India. (1985). Report on forest resources of Midnapore district of West Bengal. Ministry of Environment and Forests, Department of Forests and Wildlife.
19. Forest Survey of India. (2024). India state of forest report 2023 (Vol. 2). Ministry of Environment, Forest and Climate Change.
20. FAO, IFAD, UNICEF, WFP, WHO. 2020. The state of food security and nutrition in the world 2020. Transforming food systems for affordable healthy diets. Rome: FAO. doi:10.4060/ca9692en.
21. Japan International Cooperation Agency & Oriental Consultants Co., Ltd. (2011). The preparatory survey on West Bengal Integrated Forestry Development and Biodiversity Conservation Project: Final report. Jhargram District Administration. (n.d.-a). About district. Government of West Bengal
22. Jhargram District Administration. (n.d.-b). History. Government of West Bengal. JhargramKrishiVigyan Kendra. (n.d.). District profile.
23. Gao Y, Fang Z, Van Zwieten L, Bolan N, Dong D, Quin BF, Meng J, Li F, Wu F, Wang H, Chen W. 2022. A critical review of biochar-based nitrogen fertilizers and their effects on crop production and the environment. Biochar. 4(1):36. doi:10.1007/s42773-022-00160-3.

24. Gross A, Bromm T, Glaser B. 2021. Soil organic carbon sequestration after biochar application: a global meta-analysis. Agronomy. 11:2474. doi:10.3390/agronomy11122474.
25. Haider I, Raza MAS, Iqbal R, Aslam MU, Habib-ur-Rahman M, Raja S, Khan MT, Aslam MM, Waqas M, Ahmad S. 2020. Potential effects of biochar application on mitigating the drought stress implications on wheat (Triticumaestivum L.) under various growth stages. J Saudi Chem Society. 24:974–981. doi:10.1016/j.jscs.2020.10.005.
26. Harrison BP, Gao S, Gonzales M, Thao T, Bischak E, Ghezzehei TA, Berhe AA, Diaz G, Ryals RA. 2022. Dairy manure co-composting with wood biochar plays a critical role in meeting global methane goals. Environ Sci Technol. 56(15):10987–10996. doi:10.1021/acs.est.2c03467.
27. Huang M, Zhang Z, Zhai Y, Lu P, Zhu C. 2019. Effect of straw biochar on soil properties and wheat production under saline water irrigation. Agronomy. 9:457. doi:10.3390/agronomy9080457.
28. Jeffery S, Verheijen FGA, Van Der Velde M, Bastos AC. 2011. A quantitative review of the effects of biochar application to soils on crop productivity using meta-analysis. AgricEcosyst Environ. 144:175–187. doi:10.1016/j.agee.2011.08.015.
29. Joseph S, Cowie AL, Van Zwieten L, Bolan N, Budai A, Buss W, Cayuela ML, Graber ER, Ippolito JA, Kuzyakov Y, et al. 2021. How biochar works, and when it doesn't: a review of mechanisms controlling soil and plant responses to biochar. GCB Bioenergy. 13:1731–1764. doi:10.1111/gcbb.12885.
30. Kamran M, Malik Z, Parveen A, Huang L, Riaz M, Bashir S. 2020. Ameliorative effects of biochar on rapeseed (Brassica napus L.) growth and heavy metal immobilization in soil irrigated with untreated wastewater. J Plant Growth Regul. 39:266–281. doi:10.1007/s00344-019-09980-3.
31. Kumari A, Lakshmi GA, Krishna GK, Patni B, Prakash S, Bhattacharyya M, Singh SK, Verma KK. 2022. Climate change and its impact on crops: a comprehensive investigation for sustainable agriculture. Agronomy. 12:3008. doi:10.3390/agronomy12123008.
32. Lai W-Y, Lai C-M, Ke G-R, Chung R-S, Chen C-T, Cheng C-H, Pai CW, Chen SY, Chen CC 2013. The effects of woodchip biochar application on crop yield, carbon sequestration and greenhouse gas emissions from soils planted with rice or leaf beet. J Taiwan InstChem Eng. 44:1039–1044. doi:10.1016/j.jtice.2013.06.028.
33. Liu S, Zhang Y, Zong Y, Hu Z, Wu S, Zhou J, Jin Y, Zou J 2016. Response of soil carbon dioxidefluxes, soil organic carbon and microbial biomass carbon to biochar amendment: a meta-analysis. GCB Bioenergy. 8:392–406. doi:10.1111/gcbb.12265.
34. Lorenz K, Lal R. 2014. Biochar application to soil for climate change mitigation by soil organic carbon sequestration. J Plant Nutr Soil Sci. 177: 651–670. doi:10.1002/jpln.201400058.
35. Mona S, Malyan SK, Saini N, Deepak B, Pugazhendhi A, Kumar SS. 2021. Towards sustainable agriculture with carbon sequestration, and greenhouse gas mitigation using algal biochar. Chemosphere. 275:129856. doi:10.1016/j.chemosphere.2021.129856.
36. Ministry of Environment and Forests. (2014). National working plan code 2014: For sustainable management of forests and biodiversity in India. Forest Research Institute, Indian Council of Forestry Research and Education. https://icfre.gov.in/UserFiles/File/Institute-FRI-2011/2014/NWPCode-2014_21May14.pdf
37. National Bamboo Mission. (2025). Operational guidelines of National Bamboo Mission (2025). https://nbm.da.gov.in/Documents/pdf/NBM_Guideline_2025.pdf
38. Rajput VD, Minkina T, Ahmed B, Singh VP, Mandzhieva SS, Sushkova SN, Bauer TV, Verma KK, Shan S, Hullebusch EDV, Wang B. 2022. Nano-biochar: a novel solution for sustainable agriculture and environmental remediation. Environ Res. 210:112891. doi:10.1016/j.envres.2022.112891.
39. Sahoo, P: Sal Leaves Biochar and Carbon credit project in South Asia under UN SDGS -2030 framing; Nirvana Carbon Solutions Pvt. Ltd, USA(2025).
40. Singh R, Kumari T, Verma P, Singh BP, Raghubanshi AS. 2022. Compatible package-based agriculture systems: an urgent need for agro-ecological balance and climate change adaptation. Soil EcolLett. 4(3):187–212. doi:10.1007/s42832-021-0087-1.
41. Thammasom N, Vityakon P, Lawongsa P, Saenjan P. 2016. Biochar and rice straw have different effects on soil productivity, greenhouse gas emission and carbon sequestration in Northeast Thailand paddy soil. Agric Nat Resour. 50:192–198. doi:10.1016/j.anres.2016.01.003.
42. Tripathi, S. K., & Singh, K. P. (1996). Culm recruitment, dry matter dynamics and carbon flux in recently harvested and mature bamboo savannas in the Indian dry tropics. Ecological Research, 11(2), 149–164. https://doi.org/10.1007/BF02347681
43. Viksit Bharat—Guarantee for Rozgar and Ajeevika Mission (Gramin): VB—G RAM G Act, 2025, Act No. 36 of 2025 (India). https://www.indiacode.nic.in/bitstream/123456789/22478/1/a2025-36.pdf

44. Wildlife Institute of India & Project Elephant Division. (2023). Elephant reserves of India: An atlas (Version 2; WII-TR No. 2023/19). Ministry of Environment, Forest and Climate Change. https://moef.gov.in/uploads/2023/11/PE-Elephant-Reserve-of-India-an-atlas.pdf
45. Verma KK, Song XP, Budeguer F, Nikpay A, Enrique R, Singh M, Zhang B, Wu JM, Li YR. 2022b. Genetic engineering: an efficient approach to mitigating biotic and abiotic stresses in sugarcane cultivation. Plant SignalingBehavior. 17(1):e2108253. doi:10.1080/15592324.2022.2108253.
46. Verma KK, Song XP, Yadav G, Degu HD, Parvaiz A, Singh M, Huang HR, Mustafa G, Xu L, Li YR. 2022a. Impact of agroclimatic variables on proteo-genomics in sugarcane (Saccharum spp.) plant productivity. ACS Omega. 7:22997–23008. doi:10.1021/acsomega.2c01395.