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Black Treasure: Unlocking the Key Potential Effects of Biochar as Organic Input for Restoring Healthy Soil and Carbon Credit for Next-Gen Agriculture in Soil

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A B S T R A C T

With a human population of eight billion which is destined to exceed 11.4 Billion by 2100, soil degradation is a global issue which is a risk multiplier in aggravating food and nutritional insecurity. Soil is the foundation for all crop production and to scavenge food security in future. Normally, soil health is consider as a basic functionality test or indicator which has a direct contact with the environmental ecosystem. Soil carbon is a key player which augment the soil health that includes physical, chemical and biological properties. It's also a critical component of climate change offsets. Suitable measures should be adopted to trade the carbon upon soil and for soil sustainability. Incorporation of carbonaceous material like Biochar will definitely improves the status of fertility in soil and can mitigate adverse climate situation to agriculture system. Generally, the bichar are thermally stabilized one and becomes a final product called "char" which exist as an organic material for current system of practices and its fine nature is definitely helpful for both physical and chemical properties of the soil and sure it helps to maintain carbon stock in soil and sustainability of soil. Here, addition of biochar enhances soil organic carbon, availability of other nutrient and its mobilization pattern. Hence it acts as an organic source for improving carbon status to the soil and keeping soil healthier.

Introduction

The production environment and natural resources are continuously shrinking and deteriorating globally and the food demand is expected to be doubled by 2050. There are findings which indicates the need for food grains production in India which will rise up from 192 MT by 2000 to 348 MT in 2050. Therefore, projecting the upcoming 20 years, the production of food grains will definitely to be increased by the rate of 6 MT annually. Now a days high value commodities getting more demand and gets faster increasing needs than food grain crops (Bandumula, 2018). For future food grain needs and raising population growth, the present solution is to make large production from the limited land resources. By the last three decades, it has notable that fertilizer consumption in India has increased significantly. The NPK requirement for per hectare has become imbalanced ratio of (4.8:2.3:2 against an optimum ratio of 4:2:1) and even many cases, the recommended application of fertilizers resulted in depletion of soil nutrients as it was resulting in less yield in case of intensification cropping

system. Reduced land area to function soil system for sustainability will definitely results in the major gap between potential and actual yield among the farmers farming systems (Das *et al.,* 2022). The major cause in depletion of soil organic carbon range in soil is due to reduced application of organic amendments with intensive cultivation of crops. The fall down range of soil organic carbon content among Indian soils is mainly because of intensive cultivation of crops, in SOC content of Indian soil is due to intensive cultivation of crops, less usage of organic manures, use of high analysis fertilizers and also burning of crop residues. Apart from this, human activities viz., deforestation, biomass burning, land use changes and environmental pollution results in SOC depletion. The role of organic manure is improving soil quality is reported by many authors, but the problem is unavailability of organic manures due to burning of crop residues and reduced cattle population.

The problem is overcome by addition of 'Biochar', a relatively new green technology management tool, through the process of pyrolysis wherein the organic material is thermally decomposed under limited supply of O_2 and at relatively low temperature (Amonette and Joseph, 2009). Biochar are single grained powdered char material, which is rich in organic carbon and it strongly resist to decomposition. As a soil input, by producing a carbon-negative recalcitrant soil carbon pool, Biochar acts as a net removal of atmospheric carbon dioxide that has been stored in extremely refractory soil carbon stocks. Incorporation of Biochar as a direct input to soil will alters the soil physical properties like Porosity, structure, texture, density, soil aeration, and finally soil workability (Bruun *et al.,* 2011).

What is "*Biochar*"

Biochar, an organic rich compound of carbon material that can be produced by the process called "Thermal decomposition" by utilizing some organic material or agricultural wastes that can be used as soil amendment (Osayi *et al.,* 2014). The chief composition pertaining towards Biochar are C, H, O, N and S. Lehmann and Joseph in 2009 reported that this carbon compound will enhance nutrient properties in soil and catch carbon from atmospheric environment. The physical appearance of Biochar and field application is illustrated in Fig. 1. Due to its high porous nature, when it was incorporated into soil it will improves the water holding capacity by increase in the surface area of the (Srinivasarao *et al.,* 2013).

Overview on Biochar production

Different sources of Biological waste in agriculture sector can be utilize in preparation of Biochar that includes, manures from livestock unit, sewage sludge, solid waste collected from municipality, waste from paper industry, waste from food processing sector, forest waste, and crop residues (Cantrell *et al.,* 2012; Ahmad *et al.,* 2014). Renewable sources of gas compounds like (CO, H_2, CH_4, and CO_2) and oil were produced from the production of Biochar (Windeatt *et al.,* 2014). Many methods, such as conventional carbonization, torrefaction, hydrothermal carbonization, gasification, and pyrolysis, can be used to produce gaseous products and oil during the thermal degradation of waste biomass and feedstock into Biochar (Van Der Stelt *et al.,* 2011; Yuan *et al.,* 2017). Gasification and pyrolysis are two very different processes for producing Biochar (Ahmad *et al.,* 2014). Biomass and fuel are transformed into gases rich in CO and H at a high temperature (700 °C) under regulated conditions in order to produce Biochar by gasification (Mohan *et al.,* 2014). However, because of the poor yield of Biochar produced by gasification, this method is not advised for use in commercial settings (Yuan *et al.,* 2019).

Sources of Biochar in Indian Scenario

Biomass waste fabrics are appropriate for Biochar result which involve crop residues, in addition to patio, fare and forestry wastes, and animal manures. Large amounts of land, concerning cities, and silviculture biomass are currently charred or abandoned to disintegrate, surrendering carbon and poison gas into the air. The readiness of Biochar does not include use of harmful chemical compound. It may be willing by utilizing any biography-waste as a natural resources. Thus, as Biochar is came from green sources, it maybe thought-out as a green adsorbent. In current age, Biochar has attracted much consideration by way of allure request and the wide chance of natural resources that can symbolize raw material. Any material that is to say rich in element beginning maybe serve as a feedstock for Biochar result. It may be acquired from agricultural and silviculture waste, feed, and texture, refine industry waste, meadow, etc., as proved in Fig 2.

Prevalence of *Prosopis* species

On the other side, the prevalence of weed species i.e.

Prosopis juliflora is a massive invading species causing the underground water depletion. In allure native range, densities of *P. juliflora* maybe high concerning different leguminous shrubs and timbers, but allure canopies can have much more forceful facilitative effects on neighbours than additional leguminous wood species (Alcázar and Soriano, 2008).

Many different Prosopis class, in their native ranges, create "system islands" with larger concentrations of natural resources, nitrogen, planet seen at dawn and potassium beneath their canopies and behave as forceful facilitators of added species.

Accordingly, *Prosopis cineraria*, an indigenous native species of North-Western India, which forms a dense bilateral branches and sucks the groundwater level thereby depleting the underground water table storage. The prevalence of *Prosopis Juliflora* in waste land ecosystem is depicted in Fig. 3.

The preparation of Biochar under the process of Pyrolysis is represented in Fig. 4. Under extreme heat, it gets converted into powdered form.

Soil organic carbon status

SOC acts as a principle component of the soil organic matter that facilitates water-retention capacity, structure, and fertility. The Soil Organic Carbon (SOC) content in India has been depleted from 1 percent to 0.3 % for the past 70 years that causes a major concern in sector of agriculture (National Rainfed Area Authority of India, 2022).

The depletion of SOC content in scenario of Indian soil is because of intensive cultivation of field crops, reduced addition in organic manures, and use of high analysis fertilizers and also burning of crop residues.

The important benefits of Biochar are powerful cause as it reduces draining of soil foods, increases the soil pH and thus lowering the need for lime application, improves nutrient requirement for plants, reduces toxicity of aluminium to plant roots, increases water status of drainage or runoff, reduces dependency on fertilisers to crops, reduces bioavailability of burdensome metals and so everything as bioremediation, decreases N O and CH diffusions from 2 4 soils, accordingly further lowering GHG issuances (Mate *et al.,* 2015). The different factors of soil and its impact on soil properties is given in Table. 1.

Soil Carbon: Nitrogen ratio

The balance ratio of C to N i.e. carbon-to-nitrogen ratio of Biochar will ranges from 6.5 to 640, that depend solely on input materials like type of feedstock and situation of conducting pyrolysis at definite temperature. The Carbon to nitrogen ratio of soil can be modified by adding materials like compost, manure, and mulch. The C: N ratio with different treatment which was conducted by Dey and Mavi in 2021 is illustrated as bar diagram in Fig. 5.

Nutrient cycling of soil health

Soil is a fundamental few favorable farming, and allure character has expected upgraded to blow up crop yield and soil productivity. To increase crop production and soil fertility, Biochar can be incorporated into the soil. The increase in pH of soil will alter the nature and availability of phosphorous and potassium by the application of Biochar material (Atkinson *et al.,* 2010). When the Biochar is applied over the soil, oxidation process is observed on the surface of soil particles due to high CEC (Liang *et al.,* 2006). When CEC gets increased, nutrients will remain attached to the soil opposing the leaching process.

When highly oxidized organic matter when comes to attach with the surface, it will definitely create a pool of negative charge on the outer surface. As a result, certain charge on these sites gets reduced. However, the results from the studies revealed that the effect of Biochar is more anticipated on the soils bearing larger pores (Tryon, 1948). The soil health and its relation with Physical and chemical constituent of Biochar are given in Fig. 6.

Soil microbial properties

Biochar is small porous material compound which helps to improve soil microbial biomass and nutrient mineralization. It elevates the function on agricultural ecosystem especially soil microorganism thereby directly affects the microbial properties of soil. The pores that is present in Biochar which specifies an acceptable residence for many microorganisms by assuring bureaucracy from predation and drying while providing many of their various element (C), strength and not organic nutrient needs. The chief characteristics of Biochar and its ability to form complex nature accompanying various soil type, can have an direct affect on soil-plant bacteria interrelationship.

Thus, modifications in the soil microbial property can influence changes in mineral mobilizing and crop growth in Biochar incorporated soil. Biochar will increase Co (Cobalt) adsorption that bring about increase in local mineral concentrations for microbial pool and water retension. By Biochar application, the activities of Dehydrogenase enzyme and microbial biomass carbon are significantly enhanced (Windeatt *et al.,* 2014).

Carbon source for soil

Biochar will be acting organic conditioner which helps in improving crop production and carbon sequestration (Woolf and Lehmann, 2012). By regular application of Biochar into the soil, it will increase the carbon credit and it was benefitted by the farmers.

Carbon incorporated into the fields in the form of Biochar manage present growers of C credits that will pursued C credit display for supplementary income for the farmers. Incorporation of carbon sink into the soil will minimize emission of CO_2, CH_4, and N_2O.

When comparing with different other approaches of carbon capture like tree growing, silvipasture, agroforestry, the Biochar application is better and it increases the carbon storage in soil for long term basis. Compared with other terrestrial sequestration strategies, such as afforestation or re-forestation, carbon sequestration in Biochar increases its storage time. The fundamental approaches is that when soil is mixed with carbon material like Biochar, then the residence time in soil gets increased due to interaction between outer surface of mineral compound and other relevant substrate (Wang *et al.,* 2012).

Effect of Biochar on Carbon status

Soil carbon sequestration is the phenomenal process of removing atmospheric carbon dioxide by natural or artificially and getting incorporated into the soil for prolonged condition. When converting available resource of organic matter into highly stabilised form of Biochar will definitely reduce CO_2 emission in the soil by minimizing the decomposition rate (Sohi *et al.,* 2009). The CO_2 emission from the process of pyrolysis and will affect by the range of temperature it produced (Lehmann *et al.,* 2011; Gaunt and Lehmann, 2008). Thus, it can therefore strongly state that Biochar production and deposition on soil are getting promising one and important method for carbon storage in soil (Shaaban *et al.,* 2018). Soil refractory organic carbon reservoir gets steady increase by the application of Biochar because of its relative fineness (Matovic, 2011; Bruun *et al.,* 2011).

The basic consideration is that the application or incorporation of Biochar is consider as an effective and promising approach to capture more carbon when compared to other conventional methods which immediately directs mineral dissolution and CO_2 capture (Crombie and Masek, 2015). Even when Biochar are applied now, it will remain in soil for many decades, which directs to capture carbon for long term carbon (Bashir *et al.,* 2018). The total soil carbon which gets increased from 41% to 69% which was identified by incubation method of analysing carbon at the year-end in Inceptisols soil order which when soil gets deposited with Biochar in Indian condition (Purakayastha *et al.,* 2015).

Amount of soil organic carbon sequestrated by the application of Biochar may be around of 1 Pg C $year^{-1}$ (annual mean of carbon budget) or more than that (Lehmann *et al.,* 2006; Sohi *et al.,* 2010). Biochar has an equivalency of ≥ 60%-80% carbon composition which is equal to ≥ 2.20-2.94 tonnes of CO_2 sequestered per ton of Biochar. Biochar application at the rate of 13.5 t ha^{-1} will increase space which would last for 200 years ahead (Sohi *et al.,* 2010). Biochar addition is best way and eco-friendly method for C sequestration at present situation. The overall biomass reserves appear expected adequate to fulfil the sequestrations need and still supply different substitutions for non-renewable energy use (Ding *et al.,* 2016; Yuan *et al.,* 2019). The Key overall frame function involving application of Biochar and its impact on climate change in agriculture is understood and depicted in Fig. 7.

Recent trend that Biochar, an organic carbon source material receiving different scientific approaches in various industries to solve most of the problem relating towards ecological system. Recent threat is that climate ad weather pattern are getting changed now a days which directly affects food security and environmental quality, hence a task of reducing bio waste is required.

Table.1 Biochar – A Source of Organic amendment and effects on soil properties

Sr. No.	Soil factors	Impact on soil properties
1.	BD (Bulk density)	Brings optimum of 1.33
2.	Retention of soil moisture scale	Up to 50% increase in soil
3.	Liming addition	pH increases by 1 to neutral situation
4.	CEC	50% increase
5.	Crop production	50-100% increase
6.	CH_4direct emission	95% decrease
7.	N_2O emission	50% decrease
8.	Biological nitrogen fixation	50% increase
9.	Mycorrhizal fungi	30% increase

(Das *et al*., 2017)

Figure.1 The physical appearance of Solid Biochar and its application over field

(Madhurya Bandara, 2022)

Figure.2 Production of Biochars from different sources.

(Jha *et al.*, 2023)

Figure.3 Prevalence of Prosopis juliflora in waste land ecosystem

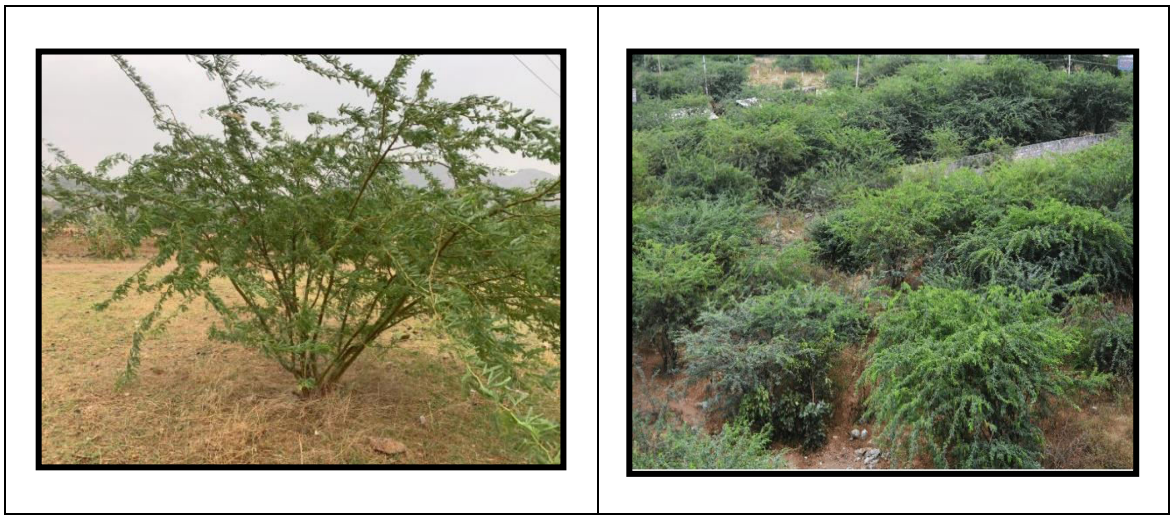
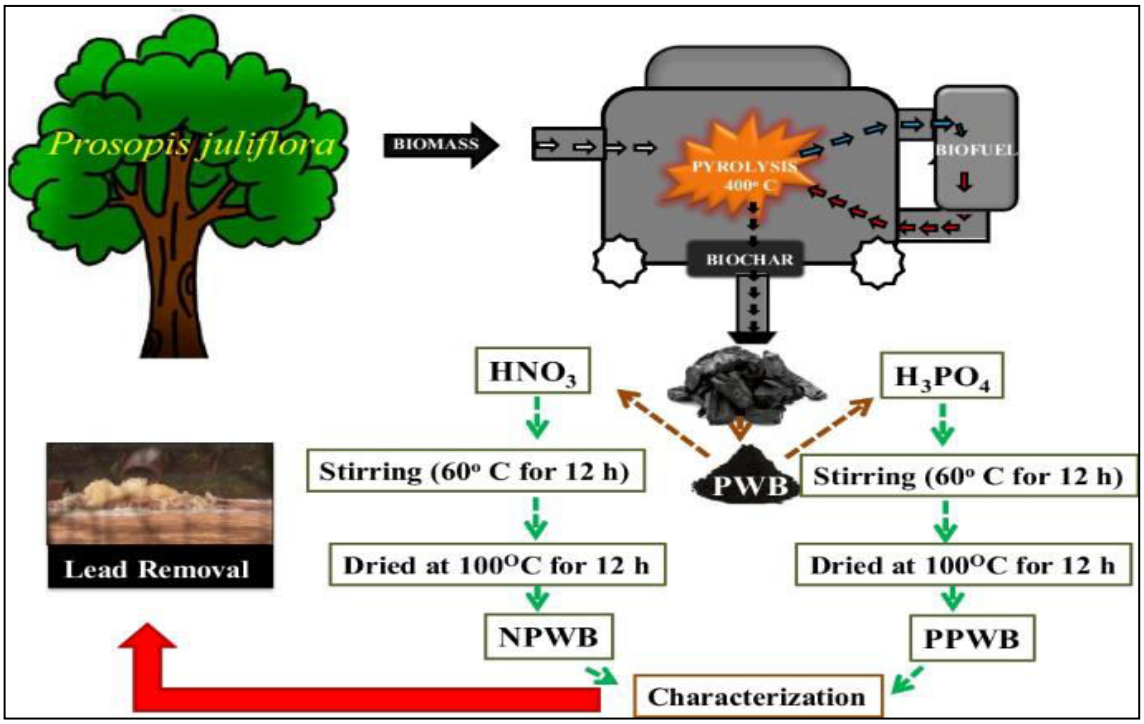
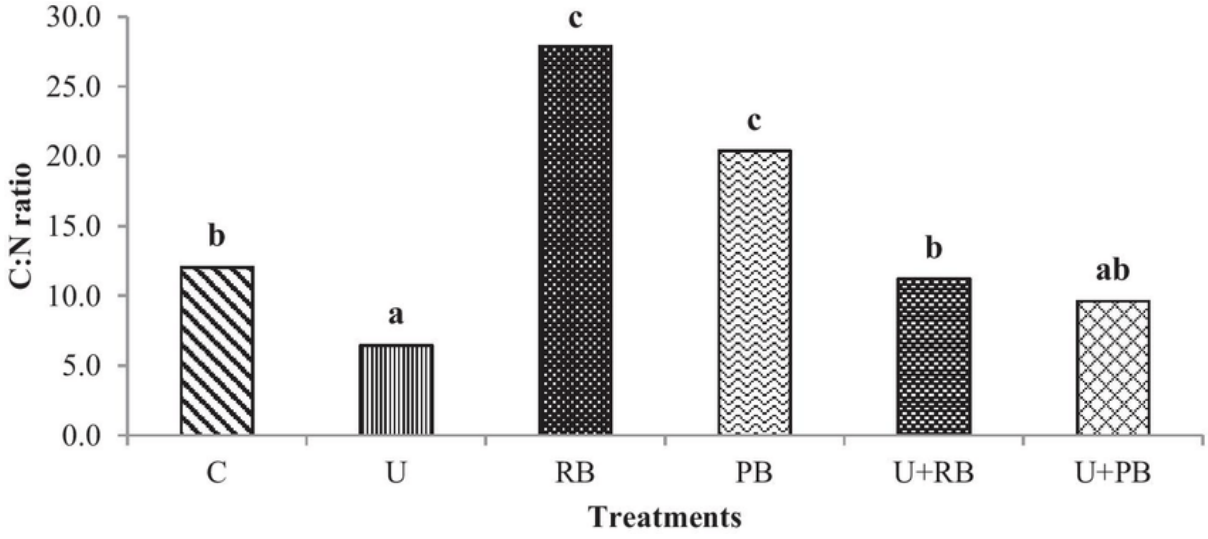


Figure.4 Preparation of Biochar under process of Pyrolysis from *Prosopis Sp*.



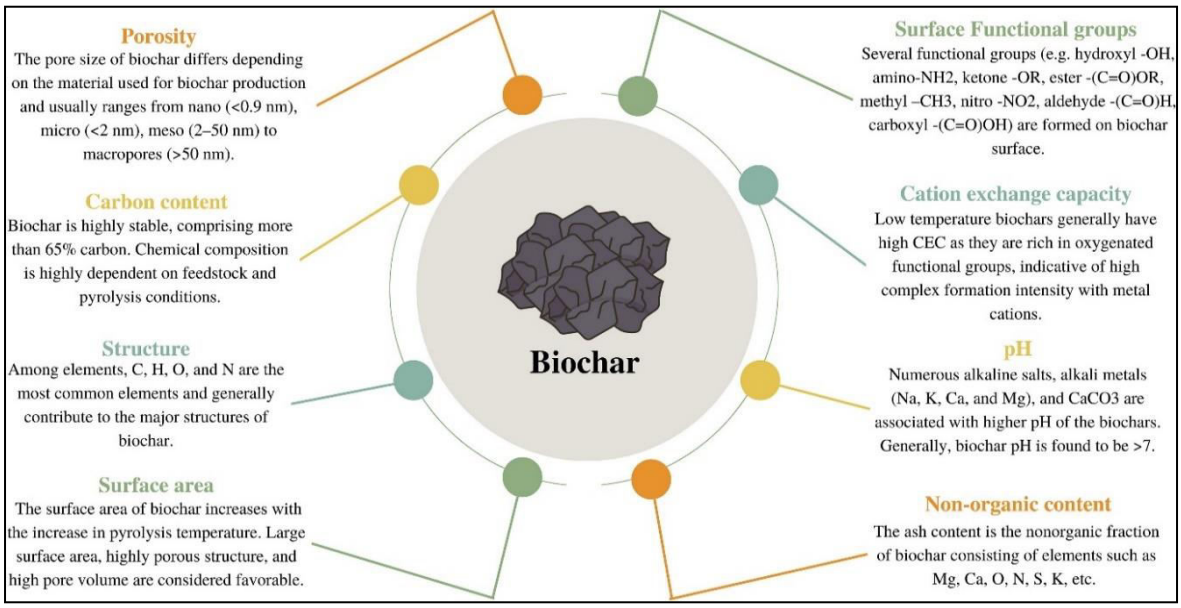
(Subramanian *et al*., 2024)

Figure.5 C:N ratio of soils amended with urea and biochar (RB or PB) either alone or in combination on day 60 of incubation. Bars with same letter are not significantly different (P < 0.05). The different letters are represented as follows: C=Control, U=Urea, RB=Rice-residue biochar, PB=Poultry manure biochar



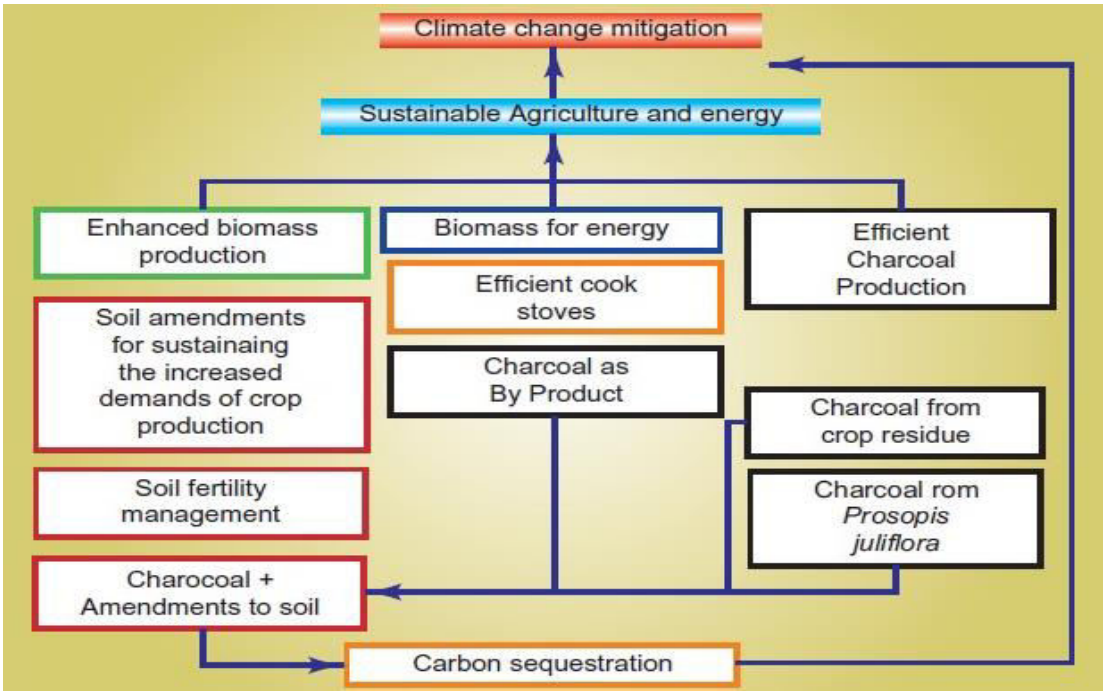
Dey and Mavi (2021)

Figure.6 Physical and chemical constituent of Biocharand relation of soil health.



(Yadav *et al*., 2023)

Figure.7 Biochar overall Framework



Das (2015)

To combat this, biological conversion of biomass material to Biochar compound is highly efficient as it has many versatile, unique properties, including functionality, non-toxicity, porous structure, and others. Hence the future research proposal, finding may include to combat soil health and to credit the use of carbon towards soil that helps to build a future sustainable agriculture.

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Disclaimer (Artificial intelligence)

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Statement of AI used while preparing this article

No Al had been used in this preparation of this article

Author Contributions

G. Muhilan: Investigation, formal analysis, writing—original draft. U. Bagavathi Ammal: Validation, methodology, writing—reviewing. R. Rajakumar:—Formal analysis, writing—review and editing. V. G. Venkatesan: Investigation, writing—reviewing.

Data Availability

The datasets generated during and/or analyzed during the

current study are available from the corresponding author on reasonable request.

Declarations

Ethical Approval Not applicable.

Consent to Participate Not applicable.

Consent to Publish Not applicable.

Conflict of Interest The authors finally declared that there are no conflict of interest with the present publication.

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