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Biochar Amendment in Paddy Field: A Sustainable Way for Enhancing Crop Productivity

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ABSTRACT

Biochar, carbon-rich residue from pyrolyzed biomass, is emerging as a promising soil amendment in paddy cultivation. It improves soil physical structure, enhances nutrient retention, boosts microbial activity, and contributes to carbon sequestration, while potentially mitigating greenhouse gas emissions. This review explores mechanisms by which biochar influences soil health and rice yield, examines its impact on methane (CH_4) and nitrous oxide (N_2O), and discusses optimal application strategies and challenges. The evidence supports biochar's role in achieving sustainable intensification of rice systems in India and beyond. Studies by Haefele *et al*. (2011), Lehmann & Joseph (2009), and Ali *et al*. (2022) substantiate the positive outcomes of biochar integration in paddy fields.

INTRODUCTION

Turning Waste into Wealth

Paddy fields in Asia face issues of declining productivity due to soil nutrient depletion and climate stress. In this scenario, biochar, a carbon-rich product obtained through pyrolysis can offer a sustainable intervention. It converts agricultural residues into stable organic matter that enhances soil fertility (Lehmann & Joseph, 2009). Moreover, the growing interest in nature-based solutions for climate change mitigation has placed biochar at the forefront of sustainable agriculture (Jeffery *et al*., 2011).

PRODUCTION & PROPERTIES OF BIOCHAR

Biochar can be produced from a variety of feedstocks including rice husk, straw, poultry litter, and wood chips under limited oxygen conditions. It has high porosity, surface area, and cation exchange capacity, which makes it effective in retaining nutrients and water (Abel *et al.*, 2013). The properties vary with temperature and feedstock used, which in turn influence its effect on the soil ecosystem (Spokas *et al.*, 2012).

MECHANISMS OF BIOCHAR IN PADDY FIELDS

- **Enhancing soil health**

Biochar enhances paddy soil health by improving physical (bulk density, porosity), chemical (pH, nutrient availability), and biological (microbial biomass) attributes (Ali *et al.*, 2022). In acidic soils, it acts as a liming agent, increasing pH and availability of phosphorus. Its porous nature provides habitat for microbes which play a crucial role in nutrient cycling (Cornelissen *et al.*, 2013).

- **Boosting rice productivity**

The positive impact of biochar on rice yield has been well documented. Biederman & Stanley (2013) in a meta-analysis reported an average yield increase of 10-15%. Field trials in China and India also observed improved nitrogen use efficiency and enhanced root development (Wang *et al.*, 2010; Yangtze Region Study, 2024).

- **Carbon sequestration**

Biochar acts as a stable carbon sink, reducing greenhouse gas emissions from paddy soils.

- **Microbial activity**

It supports beneficial soil microorganisms, enhancing nutrient cycling and soil health.

IMPACTS ON GREENHOUSE GAS EMISSIONS

Rice fields are a major source of CH_4 emissions. Biochar suppresses methanogenesis by improving aeration and promoting methanotrophs (Haefele *et al.*, 2011). It also reduces N_2O by enhancing nitrogen retention and lowering denitrification (Jeffery *et al.*, 2011). However, effects vary with soil type and management (Snyder *et al.*, 2009).

MECHANISMS AT WORK

Biochar affects soil via multiple pathways: it stabilizes organic matter, increases microbial efficiency, and moderates water flux. These changes help reduce GHGs and improve nutrient dynamics (Lehmann & Joseph, 2009; Spokas *et al.*, 2012). Moreover, it enhances nutrient sorption and reduces leaching losses (Abel *et al.*, 2013).

APPLICATION RATES & BEST PRACTICES

Effective biochar application depends on local soil conditions. Recommended rates range from 5–20 t/ha (Jeffery *et al.*, 2011). Combining biochar with compost or chemical fertilizers often yields better results. Slow pyrolysis-derived biochar is generally more effective in paddy fields (Ali *et al.*, 2022).

LIMITATIONS & CONSIDERATIONS

Despite its benefits, biochar application is limited by production cost, scalability, soil type variability, optimal application rates, economic variability and lack of field-level standardization. Field variability and inconsistent results across trials have also raised concerns (Spokas *et al.*, 2012). Therefore, integrated nutrient management with site-specific trials is essential (Cornelissen *et al.*, 2013).

POLICY & FUTURE DIRECTIONS

- To mainstream biochar, supportive policies such as subsidies for pyrolysis units, carbon credits, and farmer training are needed. Research on long-term impacts and lifecycle assessments is crucial (Vijay *et al*., 2021).
- With international frameworks pushing for carbon-negative agriculture, biochar offers a promising pathway for climate-resilient rice farming.
- Research on Biochar variants.
- Integration with other sustainable practices.

CONCLUSION

Biochar represents a viable strategy for improving soil health, enhancing rice yields, and mitigating GHG emissions in paddy ecosystems. When used judiciously with other inputs, it can transform rice cultivation into a more sustainable and climate-smart practice. Scaling biochar adoption requires synergy among researchers, policymakers, and farmers (Lehmann & Joseph, 2009; Vijay *et al*., 2021).

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