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Influence of Biochar on Medicinal Plant-Rice Intercropping Systems in the Subtropical Monsoon Climate of Nepal

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Abstract
Rice remains the cornerstone of food security in South Asia, while medicinal and aromatic plants (MAPs) are gaining importance in global markets for pharmaceuticals, nutraceuticals, and aromatherapy. Integrating medicinal plants into rice-based systems through intercropping provides opportunities for income diversification and resource-use efficiency, but challenges arise from nutrient competition, soil acidity, and variable water availability. Biochar—stable carbon-rich material derived from pyrolysis—offers a promising amendment to improve soil fertility, water retention, and carbon sequestration.
This study was conducted at the Institute of Agriculture and Animal Science (IAAS), Rampur Campus, Chitwan District, Nepal (27.63°N, 84.35°E), representing a subtropical monsoon climate with ~2000 mm annual rainfall and alluvial sandy loam soils. A two-factor field experiment tested biochar rates (0, 5, 10, and 15 t ha^{-1}) and intercropping arrangements (sole rice, rice-Tulsi, rice-mint, rice-lemongrass, rice-turmeric). Biochar was pre-charged with compost before application.
Results indicated significant improvements in soil organic carbon (+0.4% over baseline), cation exchange capacity (up to +25%), and water retention (10-15%) at 10 t ha^{-1} biochar. Rice yield increased by 8-15% under biochar-amended intercrops, while medicinal plants showed higher biomass (12-25%) and enhanced phytochemical quality (e.g., menthol in mint +18%). Greenhouse gas intensity per ton of rice equivalent yield (REY) decreased by 12-20% under biochar with alternate wetting and drying.
The findings demonstrate that biochar is a viable amendment for rice-MAP intercropping in Nepal's Terai region, supporting both food security and high-value herbal production under subtropical monsoon climates.

Keywords: Deepan, pachan, jatharagni, cephalic phase, gastric phase, GI Tract

1. Introduction
Rice is cultivated on over 1.5 million hectares in Nepal, with the Terai region serving as the country's primary rice bowl. In parallel, the demand for medicinal plants such as Ocimum sanctum (Tulsi), Mentha arvensis (Mint), Cymbopogon citratus (Lemongrass), and Curcuma longa (Turmeric) is rising in both domestic and export markets. Integrating MAPs into rice-based systems offers a dual advantage: enhancing farmer income and promoting biodiversity. However, resource competition, soil degradation, and climatic stresses—particularly under the subtropical monsoon climate—constrain productivity.
The Terai soils are predominantly alluvial sandy loams, acidic to neutral in reaction, and prone to nutrient leaching under heavy monsoon rains. Rice monocultures intensify soil organic matter depletion and greenhouse gas (GHG) emissions. Medicinal plants, often sensitive to nutrient imbalance, may show reduced phytochemical quality when intercropped with rice in such environments.
Biochar has emerged as a potential solution. It improves soil structure, retains nutrients, enhances microbial colonization, and sequesters carbon for decades. Studies in South Asia have reported yield increases of 5-20% and improved soil resilience with biochar use [1-4]. For MAPs, biochar may enhance essential oil content and bioactive compounds by improving nutrient supply and moderating abiotic stress [5, 6]. Despite promising evidence, few studies have examined biochar in rice-MAP intercropping systems under Nepal's monsoon conditions.
This study aims to:
1. Evaluate the impact of biochar on soil properties in rice-MAP intercrops in Chitwan, Nepal.
2. Quantify rice yield, medicinal plant biomass, and phytochemical quality.

3. Assess system-level productivity through rice equivalent yield (REY) and economic returns.
4. Examine water-use efficiency and GHG intensity in biochar-amended systems.

2. Materials and Methods
2.1 Site Description
The experiment was conducted at the IAAS Rampur Campus, Chitwan, Nepal (27.63°N, 84.35°E; altitude 228 m). The climate is subtropical monsoon, characterized by ~2000 mm annual rainfall (80% between June-September) and summer mean temperatures of 28-34 °C. Soils are sandy loam Inceptisols, pH 5.8, organic carbon 0.62%, low available N (210 kg ha^{-1}), medium P (18 kg ha^{-1}), and K (165 kg ha^{-1}).

2.2 Experimental design
A **split-plot design** with three replicates:

- **Main factor (biochar rate):** B_0 = 0, B_1 = 5 t ha^{-1}, B_2 = 10 t ha^{-1}, B_3 = 15 t ha^{-1}.
- **Sub-factor (intercropping arrangement)**

a) I_1 = sole rice
b) I_2 = rice + Tulsi (bund)
c) I_3 = rice + Mint (row; 4:2)
d) I_4 = rice + Lemongrass (bund)
e) I_5 = rice + Turmeric (relay intercropping)

Biochar was prepared from rice husk and bamboo residues at 550 °C, surface area ~160 m² g^{-1}, pH 8.2, CEC 32 cmolc kg^{-1}. It was pre-charged with farmyard manure and urea (C:N ~25:1) for 14 days before application.

2.3 Crop management
Rice variety: **Sabitri** (130 days). MAPs transplanted at recommended spacings. Rice was grown under alternate wetting and drying (AWD) irrigation. Fertilizers applied: 120:60:40 kg ha^{-1} N:P_2O_5:K_2O (adjusted for intercrops).

2.4 Measurements
- **Soil:** pH, organic carbon, CEC, bulk density, available NPK, water retention, microbial biomass C.
- **Rice:** tillers m^{-2}, grain yield, 1000-grain weight, N uptake.
- **MAPs:** biomass, essential oil content (hydrodistillation), phytochemicals (HPLC/GC-MS for menthol, citral, curcumin, eugenol).
- **Environmental:** irrigation water use, GHG fluxes (CH_4, N_2O by static chamber).
- **Economics:** gross returns, net returns, benefit-cost ratio.

2.5 Data analysis
Two-way ANOVA (biochar × intercropping). Tukey's test at $p < 0.05$. Rice equivalent yield (REY) calculated based on market prices of MAP products.

3. Results
3.1 Soil properties

Table 1: Changes in soil properties after harvest (mean of 2 years)

Treatment	SOC (%)	pH	CEC (cmolc kg^{-1})	Water retention (%)
B_0	0.62	5.8	10.2	25.1
B_1	0.78	6.1	12.8	27.4
B_2	0.98	6.4	14.9	29.1
B_3	1.01	6.5	15.2	29.4

Biochar significantly increased SOC (+58% at 10 t ha^{-1}), raised pH toward neutrality, and improved CEC and water retention.

3.2 Rice yield and intercrop performance

Table 2: Rice yield and MAP performance (selected).

Treatment	Rice yield (t ha^{-1})	Mint biomass (t ha^{-1})	Menthol (%)	REY (t ha^{-1})
B_0I_3	4.6	8.5	0.82	6.1
B_1I_3	5.1	9.6	0.89	6.9
B_2I_3	5.4	10.2	0.97	7.6
B_3I_3	5.5	10.3	0.98	7.7

Rice yields improved by 10-15% under B_2 compared to B_0. Mint biomass rose by 20%, and menthol content by 18%. Similar positive trends were observed for Tulsi (eugenol +15%), lemongrass (citral +17%), and turmeric (curcumin +12%).

3.3 Environmental indicators
- Irrigation water use decreased by ~18% under AWD with biochar.
- N_2O emissions per unit REY declined by 15-20% under B_2 treatments.
- CH_4 emissions showed modest reductions (~10%) under AWD with biochar.

4. Discussion
Biochar proved effective in enhancing soil fertility in the sandy loam soils of Chitwan. The liming effect raised soil pH, crucial in alleviating acid stress common in the Terai. Higher SOC and CEC improved nutrient retention, benefiting both rice and MAPs. Similar findings have been reported in Nepalese and Indian soils [7-10].

MAP quality improvements (menthol, citral, curcumin, eugenol) suggest that biochar-mediated nutrient balance and moderate stress favored secondary metabolite synthesis. This aligns with earlier work showing higher oil yields of basil and lemongrass under biochar treatments [11, 12].

From an environmental standpoint, biochar reduced irrigation requirements and GHG intensity, consistent with global meta-analyses [1, 4]. The synergy of AWD and biochar offers a pathway for climate-smart agriculture in Nepal.

Economically, intercrops with MAPs produced 20-30% higher returns than sole rice, with biochar amplifying the advantage by boosting yields and quality. This supports diversification policies for smallholders in Nepal's Terai.

5. Conclusion
The field experiment in Chitwan, Nepal demonstrates that biochar is a multifunctional amendment that enhances soil fertility, crop yield, medicinal plant quality, and environmental performance in rice-based intercropping under subtropical monsoon conditions. Application of 10 t ha^{-1} pre-charged biochar is optimal, balancing benefits with cost. The integration of MAPs such as mint, tulsi, lemongrass, and turmeric with rice presents a resilient, profitable, and climate-smart farming model for Nepal's Terai region.

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