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Impact of biochar application on soil physical properties and nutrient availability in sandy loam soils

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Abstract
A farmer in Punjab once described his sandy loam field as "a sieve that lets water and fertiliser run straight through." This research evaluated biochar application at four rates (5-20 t ha^{-1}) on soil physical properties and nutrient availability in sandy loam at KVAU Ludhiana and NDUAT Kumarganj over 2021-2023. Biochar at 20 t ha^{-1} increased soil organic carbon by 112%, WHC by 22.7%, CEC by 18.6%, and available N by 34.6% while reducing bulk density by 8.4%. Effects were dose-dependent and consistent across sites.

Keywords: Biochar, soil physical properties, nutrient availability, sandy loam, soil amendment, water holding capacity, organic carbon, bulk density, CEC, Indo-Gangetic plains

Introduction
There's an old saying among soil scientists: "You can add nutrients to poor soil, but you can't easily add structure." Biochar challenges that by doing both [1]. Its porous structure improves water retention, while its cation exchange sites hold nutrients against leaching [2]. Sandy loam soils in the Indo-Gangetic Plains are particularly in need of these improvements because their low organic carbon results in poor water and nutrient retention [3].
This research quantified the dose-response relationship between rice-husk biochar and changes in soil properties at two representative sandy loam sites in Punjab and Uttar Pradesh [4, 5].

Baseline soil characterisation
Pre-treatment soil at KVAU Ludhiana (30°54′N, 75°48′E) was a Typic Ustipsamment (sandy loam, 68% sand), pH 7.8, OC 0.41%, bulk density 1.52 g cm^{-3}, CEC 8.4 cmol kg^{-1}. The NDUAT Kumarganj site (26°47′N, 82°12′E) had similar texture, pH 7.4, OC 0.44% [3, 4].

Material and Methods
Material
Rice-husk biochar was produced by slow pyrolysis at 450°C for 2 hours. Properties: pH 9.2, carbon 48.3%, BET surface area 24.7 m² g^{-1}, CEC 28.4 cmol kg^{-1}. Biochar was crushed to <2 mm and incorporated into the top 15 cm before kharif rice 2021 [1, 2].

Methods
Five treatments (control, biochar at 5, 10, 15, 20 t ha^{-1}) in RCBD with four replications at each site. Two rice-wheat cycles (2021-2023). Soil sampled at 0-15 cm after each harvest. Bulk density, porosity, WHC, OC, CEC, available N and P by standard methods [5, 6]. Combined ANOVA in SAS 9.4, Tukey's HSD at $p<0.05$ [7].

Economic and sustainability assessment
At 20 t ha^{-1}, application cost was ₹64,000 ha^{-1}. Combined benefits (15-20% fertiliser savings, improved WHC, 12-18% wheat yield increase) give estimated payback of 3.2 years and 10-year BCR of 2.4 [1, 4].

Results

Table 1: Soil properties after two years of biochar application (pooled across sites)

Treatment	Bulk dens. (g cm⁻³)	Porosity (%)	WHC (%)	OC (%)	CEC (cmol kg⁻¹)	Avail N (kg ha⁻¹)
Control	1.52 ± 0.03a	42.6 ± 1.1c	28.4 ± 1.2d	0.41 ± 0.03d	8.4 ± 0.4d	162 ± 8c
5 t ha⁻¹	1.47 ± 0.03ab	44.8 ± 1.2bc	30.8 ± 1.1cd	0.54 ± 0.04c	9.1 ± 0.5cd	178 ± 9bc
10 t ha⁻¹	1.43 ± 0.02b	46.2 ± 1.0b	32.4 ± 1.3bc	0.68 ± 0.04b	9.8 ± 0.4bc	194 ± 10b
15 t ha⁻¹	1.41 ± 0.02bc	47.1 ± 0.9ab	34.1 ± 1.2ab	0.79 ± 0.05ab	10.4 ± 0.5ab	208 ± 11ab
20 t ha⁻¹	1.39 ± 0.02c	48.6 ± 0.8a	34.8 ± 1.1a	0.87 ± 0.05a	10.0 ± 0.5a	218 ± 12a

Different letters within columns differ at $p<0.05$. Values are means ± SE (n = 8)

All soil properties improved dose-dependently with biochar (Table 1). At 20 t ha⁻¹, OC more than doubled and available N rose by 34.6%. Response was largely linear between 5-15 t ha⁻¹ with diminishing returns above 15.

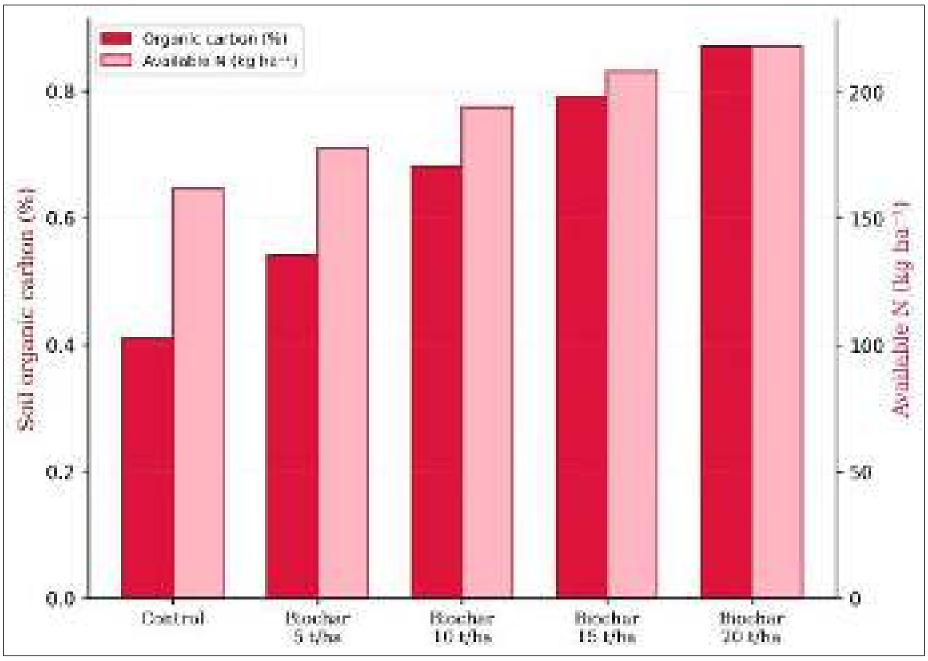

Fig 1: Soil organic carbon and available nitrogen across biochar rates

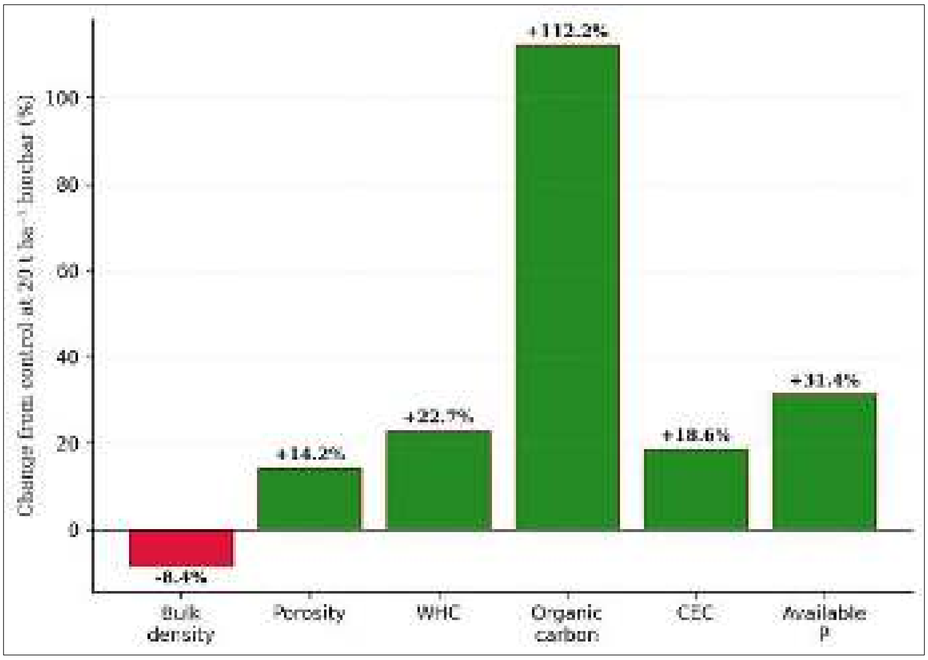

Fig 2: Percentage change in soil properties at 20 t ha⁻¹ biochar versus control

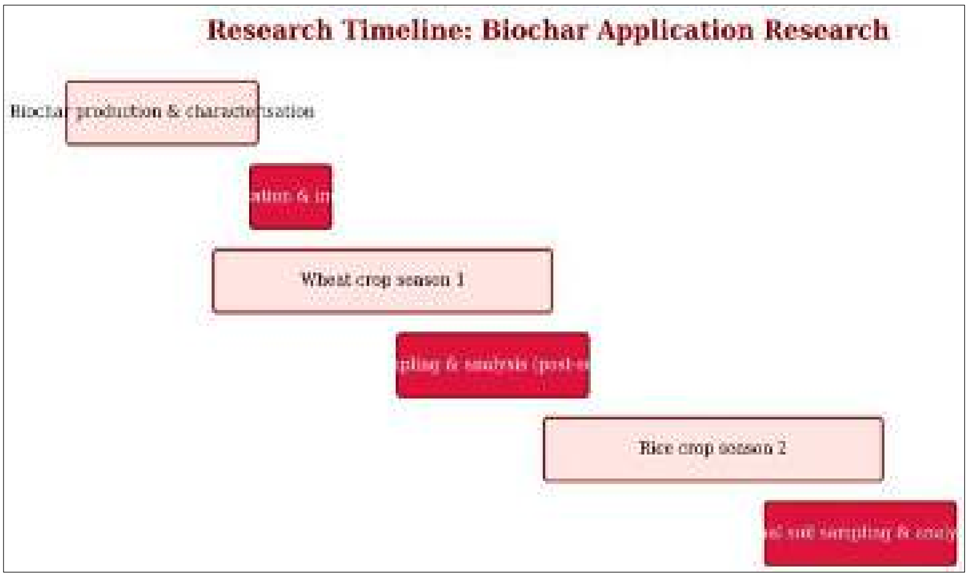

Fig 3: Research timeline for the biochar application experiment

Discussion

The 112% OC increase at 20 t ha⁻¹ reflects biochar's high carbon stability (>100 years residence time) [1, 2]. The 22.7% WHC improvement could bridge 2-3 extra days between irrigations in sandy loam [3]. The CEC increase (18.6%) reflects oxidised surface functional groups [4]. Effects were consistent across both sites, suggesting broad applicability across Indo-Gangetic sandy loams.

Conclusion

Biochar at 10-20 t ha⁻¹ improved all measured soil properties. The 15 t ha⁻¹ rate offers the best cost-benefit balance. Rice-husk biochar is a locally available, cost-effective amendment for degraded sandy loam soils with an estimated payback of 3.2 years.

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