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Effect of integrated application of inorganic fertilizer, biochar and biofertilizer on soil health, growth, yield and economics of White Maize (*Zea mays* L.) var. Pearl white

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Abstract

A field experiment was conducted during the Kharif season of 2025 at the Soil Science Research Farm, Sam Higginbottom University of Agriculture, Technology and Sciences (SHUATS), Prayagraj, Uttar Pradesh, to evaluate the effect of graded levels of inorganic fertilizer applied together with wheat-straw biochar and biofertilizer (Azospirillum and phosphate-solubilizing bacteria, PSB) on soil health, growth, yield and economics of white maize (*Zea mays* L.) var. Pearl White. Nine treatment combinations, generated from three levels of recommended dose of fertilizer (0, 50 and 100% RDF) and three levels of biochar-cum-biofertilizer (0, 2.5 and 5.0 t ha⁻¹ biochar together with Azospirillum and PSB), were laid out in a factorial randomized block design with three replications. Combined application of 100% RDF with 5.0 t ha⁻¹ biochar and biofertilizer (T₉) recorded the highest post-harvest soil organic carbon (0.58%) and available nitrogen, phosphorus, potassium and sulphur, along with the lowest bulk density and the highest pore space and water-holding capacity, while soil pH and electrical conductivity remained unaffected. The same treatment produced the tallest plants (217.9 cm at 90 DAS), the highest dry-matter accumulation (241.6 g plant⁻¹), grain yield (58.9 q ha⁻¹, about 69% above the control), nutrient uptake, net return (₹57,701 ha⁻¹) and benefit:cost ratio (1:1.96). The integrated application of inorganic fertilizer with biochar and biofertilizer may therefore be recommended as a sustainable and economically remunerative nutrient-management practice for white maize.

Keywords: Biochar, biofertilizer, integrated nutrient management, soil health, white maize, yield

Introduction

Soil health, defined as the continuing capacity of soil to function as a living system that sustains plants, animals and human beings, is governed jointly by its physical, chemical and biological properties, and remains the foundation of sustainable crop production (Bünemann *et al.*, 2018) [9]. Intensive cultivation, imbalanced and continuous use of chemical fertilizers, and inadequate replenishment of organic matter have progressively degraded soil quality in many intensively cropped regions, lowering organic carbon content, disturbing microbial communities and reducing native nutrient-supplying capacity (Zhang *et al.*, 2021) [32]. Since chemical fertilizers alone cannot sustain long-term soil fertility, greater emphasis is now being placed on integrated nutrient management (INM), in which mineral fertilizers are combined with organic amendments and microbial inoculants to build a more resilient and productive soil system (Mahajan *et al.*, 2021) [25].

Maize (*Zea mays* L.) is the third most important cereal of India after rice and wheat and, being a nutrient-exhaustive crop, is particularly sensitive to the fertility status of the soil in which it is grown (ICAR-IIMR, 2024) [18]. Among the organic amendments available for INM, biochar—a stable, carbon-rich material produced by pyrolysing biomass under limited oxygen—has attracted wide attention because its porous structure and large surface area can improve soil aggregation, water retention and cation exchange capacity while providing a favourable habitat for soil microorganisms (Lehmann and Joseph, 2015) [24]. Biofertilizers containing Azospirillum and phosphate-solubilizing bacteria (PSB) complement this effect biologically, by fixing atmospheric

nitrogen and solubilising fixed soil phosphorus, thereby raising nutrient-use efficiency and reducing dependence on mineral fertilizer (Bhattacharyya and Jha, 2012) [6].

Although the individual effects of biochar, biofertilizers and inorganic fertilizers on soil properties and cereal yield have been documented separately, information on their combined, graded application to white maize under the sub-tropical alluvial soils of the middle Gangetic plain is limited. The present investigation was therefore undertaken to (i) evaluate the effect of integrated nutrient management on soil physico-chemical properties, (ii) determine its influence on growth, yield attributes, yield and nutrient uptake of maize, and (iii) work out the economic feasibility of the different nutrient-management practices tested.

Materials and Methods

The field experiment was carried out during the Kharif season of 2025 at the Soil Science Research Farm, Naini Agricultural Institute, SHUATS, Prayagraj (25°27' N, 81°51' E; 98 m amsl), a sub-tropical location in the middle Gangetic plain with a sandy loam soil. The soil, sampled from a depth of 0-15 cm before sowing, was slightly alkaline in reaction (pH 7.60), non-saline (EC 0.32 dS m⁻¹), low in organic carbon (0.42%) and available nitrogen (215 kg ha⁻¹), and medium in available phosphorus (18.4 kg ha⁻¹), potassium (245 kg ha⁻¹) and sulphur (11.2 mg kg⁻¹).

The experiment comprised nine treatment combinations arising from two factors—three levels of the recommended dose of fertilizer (RDF; I₀: 0%, I₁: 50%, I₂: 100% of 120:60:40 kg N:P₂O₅:K₂O ha⁻¹ supplied through urea, DAP and MOP) and three levels of biochar together with biofertilizer (B₀: no biochar/no biofertilizer, B₁: wheat-straw biochar @ 2.5 t ha⁻¹ + Azospirillum + PSB, B₂: biochar @ 5.0 t ha⁻¹ + Azospirillum + PSB)—laid out in a factorial randomized block design with three replications (Table 1). Each plot measured 2.0 × 2.0 m, and white maize var.

Pearl White was sown on 24 June 2025 at 60 × 20 cm spacing after seed inoculation with the respective biofertilizers using a jaggery-solution slurry. Biochar was incorporated into the surface soil during final land preparation; phosphorus and potassium were applied basally and nitrogen in two split top-dressings. All other agronomic operations were kept uniform across plots.

Five randomly tagged plants per plot were used to record plant height, number of leaves and dry-matter accumulation at 30, 60 and 90 days after sowing (DAS), while cob length, grains per cob, test weight, grain yield, stover yield and biological yield were recorded at harvest. Composite post-harvest soil samples (0-15 cm) were analysed for pH and electrical conductivity in a 1:2.5 soil:water suspension (Jackson, 1973) [19], organic carbon by wet oxidation (Walkley and Black, 1934) [31], available nitrogen by the alkaline permanganate method (Subbiah and Asija, 1956) [29], available phosphorus by Olsen's method (Olsen *et al.*, 1954) [28], available potassium by neutral normal ammonium acetate extraction followed by flame photometry (Jackson, 1973) [19], and available sulphur by the turbidimetric method (Chesnin and Yien, 1951) [10]; bulk density, particle density and water-holding capacity were determined by the core-sampler, pycnometer and Keen-Raczkowski methods, respectively, and soil texture by the hydrometer method (Bouyoucos, 1962) [8]. Nitrogen, phosphorus and potassium concentrations in grain and stover were used, together with the respective dry-matter yields, to compute total nutrient uptake. The cost of cultivation, gross return, net return and benefit:cost ratio were worked out using the prevailing market prices of inputs and produce. All data were subjected to analysis of variance appropriate to a randomized block design (Gomez and Gomez, 1984) [16], and treatment means were compared using the critical difference at the 5% level of significance.

Table 1: Treatment combinations evaluated in the experiment

Treatment	Level of RDF	Biochar + biofertilizer	Code
T ₁	0% RDF	No biochar + no biofertilizer	I ₀ B ₀
T ₂	0% RDF	Biochar @ 2.5 t ha ⁻¹ + Azospirillum + PSB	I ₀ B ₁
T ₃	0% RDF	Biochar @ 5.0 t ha ⁻¹ + Azospirillum + PSB	I ₀ B ₂
T ₄	50% RDF	No biochar + no biofertilizer	I ₁ B ₀
T ₅	50% RDF	Biochar @ 2.5 t ha ⁻¹ + Azospirillum + PSB	I ₁ B ₁
T ₆	50% RDF	Biochar @ 5.0 t ha ⁻¹ + Azospirillum + PSB	I ₁ B ₂
T ₇	100% RDF	No biochar + no biofertilizer	I ₂ B ₀
T ₈	100% RDF	Biochar @ 2.5 t ha ⁻¹ + Azospirillum + PSB	I ₂ B ₁
T ₉	100% RDF	Biochar @ 5.0 t ha ⁻¹ + Azospirillum + PSB	I ₂ B ₂

Results and Discussion

Post-harvest soil chemical properties

Soil pH and electrical conductivity after harvest did not differ significantly among treatments, remaining within a narrow, agronomically safe band (pH 7.45-7.65; EC 0.31-0.36 dS m⁻¹; Table 2), which confirms that none of the nutrient combinations tested carried a risk of soil acidification or salt build-up. The marginal decline in pH and the slight rise in EC with increasing fertilizer and biochar dose are consistent with nitrification of applied nitrogen and greater release of soluble ions through fertilization and microbial mineralization (Van Zwieten *et al.*, 2010; Ding *et al.*, 2016) [30, 12]. In contrast, organic carbon and the availability of nitrogen, phosphorus, potassium and sulphur

increased significantly and progressively with increasing levels of RDF and biochar, and were maximum under T₉ (100% RDF + 5.0 t ha⁻¹ biochar + Azospirillum + PSB), which recorded 0.58% organic carbon and 285, 26.2, 282 and 14.8 kg (mg for S) ha⁻¹ of available N, P, K and S, respectively, against 0.41%, 210, 17.6, 238 and 10.4 in the untreated control (T₁). This build-up reflects the direct addition of stable, aromatic carbon through wheat-straw biochar, reduced nutrient fixation and leaching afforded by its high cation exchange capacity, and enhanced biological nitrogen fixation and phosphate solubilization by the seed-applied inoculants, in agreement with earlier reports (Lehmann, 2007; Bashan and de-Bashan, 2010; Bhattacharyya and Jha, 2012; Mahanty *et al.*, 2017) [23, 4, 6, 26].

Table 2: Effect of inorganic fertilizer, biochar and biofertilizer on post-harvest soil chemical properties

Treatment	pH (1:2.5)	EC (dS m ⁻¹)	OC (%)	Avail. N (kg ha ⁻¹)	Avail. P (kg ha ⁻¹)	Avail. K (kg ha ⁻¹)	Avail. S (mg kg ⁻¹)
T ₁	7.65	0.31	0.41	210	17.6	238	10.4
T ₂	7.61	0.32	0.44	218	18.5	242	11
T ₃	7.58	0.33	0.47	225	19.3	248	11.6
T ₄	7.6	0.33	0.46	235	20.1	252	12
T ₅	7.56	0.34	0.49	245	21.4	258	12.6
T ₆	7.52	0.35	0.52	255	22.8	264	13.2
T ₇	7.54	0.34	0.5	260	23.1	268	13.5
T ₈	7.49	0.35	0.54	270	24.6	275	14.1
T ₉	7.45	0.36	0.58	285	26.2	282	14.8
F-test	NS	NS	S	S	S	S	S
SEm±	0.03	0.01	0.02	5.6	0.9	4.8	0.4
CD (5%)	-	-	0.06	16.4	2.6	14.1	1.2

Post-harvest soil physical properties

Bulk and particle density decreased significantly, while pore space and water-holding capacity increased significantly, with rising levels of RDF, biochar and biofertilizer (Table 3). The lowest bulk density (1.32 Mg m⁻³) and particle density (2.59 Mg m⁻³), and the highest pore space (49.0%) and water-holding capacity (49.2%), were recorded under T₉, against 1.48, 2.64, 43.9% and 40.2%, respectively, under T₁. The dilution of the

mineral soil matrix by low-density biochar particles, together with improved aggregation driven by higher organic matter and microbial activity, is the most plausible explanation for the lighter, more porous and more water-retentive soil condition observed under the higher biochar doses (Mukherjee and Lal, 2013; Blanco-Canqui, 2017; Atkinson *et al.*, 2010; Abel *et al.*, 2013) [27, 7, 3, 1].

Table 3: Effect of inorganic fertilizer, biochar and biofertilizer on post-harvest soil physical properties

Treatment	Bulk density (Mg m ⁻³)	Particle density (Mg m ⁻³)	Pore space (%)	Water-holding capacity (%)
T ₁	1.48	2.64	43.9	40.2
T ₂	1.46	2.63	44.5	41.3
T ₃	1.44	2.63	45.2	42.8
T ₄	1.41	2.62	46.2	44.1
T ₅	1.37	2.61	47.5	46.7
T ₆	1.35	2.61	48	47.3
T ₇	1.4	2.61	46.4	44.8
T ₈	1.35	2.6	48.1	47.5
T ₉	1.32	2.59	49	49.2
F-test	S	S	S	S
SEm±	0.02	0.01	0.35	0.42
CD (5%)	0.06	0.03	1.04	1.24

Growth parameters

Plant height, number of leaves per plant and dry-matter accumulation all increased significantly and progressively with crop age and with increasing levels of RDF, biochar and biofertilizer (Table 4). At 90 DAS, plant height ranged from 165.2 cm under T₁ to 217.9 cm under T₉, the number of leaves per plant from 11.2 to 15.8, and dry-matter accumulation from 158.6 to 241.6 g plant⁻¹. A similar, dose-dependent increase was evident at the earlier 30 and 60 DAS stages. The larger, more vigorous

canopy produced under the integrated treatments is attributable to the combined availability of balanced mineral nutrients, biochar-mediated improvement in the soil physical environment, and biofertilizer-assisted nitrogen fixation and phosphorus mobilisation, all of which favour greater nutrient uptake and photosynthetic assimilation, as also reported by Hammad *et al.* (2011) [17], Fageria *et al.* (2011) [13] and Amanullah *et al.* (2016) [2].

Table 4: Effect of inorganic fertilizer, biochar and biofertilizer on growth parameters of maize at 30, 60 and 90 DAS

Treatment	Plant height (cm) 30 / 60 / 90 DAS	Leaves plant ⁻¹ 30 / 60 / 90 DAS	Dry matter accumulation (g plant ⁻¹ , 90 DAS)
T ₁	38.4 / 128.4 / 165.2	6.4 / 9.8 / 11.2	158.6
T ₂	41.2 / 134.6 / 172.6	6.9 / 10.4 / 11.8	168.9
T ₃	43.6 / 140.8 / 179.4	7.3 / 11.0 / 12.4	179.8
T ₄	42.1 / 145.2 / 183.8	7.6 / 11.4 / 12.8	186.4
T ₅	45.4 / 151.7 / 190.9	8.1 / 12.0 / 13.4	197.6
T ₆	47.8 / 158.9 / 198.6	8.6 / 12.6 / 14.0	209.8
T ₇	46.3 / 160.5 / 200.4	8.9 / 12.9 / 14.3	215.3
T ₈	49.6 / 167.8 / 208.7	9.4 / 13.6 / 15.0	227.9
T ₉	52.4 / 175.6 / 217.9	9.9 / 14.3 / 15.8	241.6
F-test	S / S / S	S / S / S	S
SEm±	1.2 / 2.4 / 2.9	0.28 / 0.34 / 0.37	4.2
CD (5%)	3.6 / 7.1 / 8.6	0.82 / 1.01 / 1.10	12.4

Yield attributes and yield

Cob length, number of grains per cob and test weight, along with grain, stover and biological yield, were significantly higher under the integrated treatments than under sole or lower levels of fertilizer (Table 5). Treatment T₉ recorded the longest cobs (19.8 cm), the most grains per cob (482), the highest test weight (282 g) and the highest grain, stover and biological yield (58.9, 98.5 and 157.4 q ha⁻¹, respectively)—an increase of about 69% in grain yield over T₁ (34.8 q ha⁻¹). This superiority follows logically from the greater plant height, leaf area and dry-matter accumulation recorded under the same treatment (Table 4), since better

vegetative growth generally translates into more effective cob elongation, grain set and grain filling under adequate, balanced nutrition, as noted by Faloye *et al.* (2019) ^[14] and Amanullah *et al.* (2016) ^[2]. The corresponding gains in nitrogen, phosphorus and potassium uptake—from 82.6, 17.4 and 64.8 kg ha⁻¹ under T₁ to 143.9, 30.8 and 113.6 kg ha⁻¹ under T₉ (Table 5)—confirm that the yield advantage of the integrated treatments reflects genuinely higher nutrient acquisition rather than simple biomass dilution, in line with Ciampitti and Vyn (2012) ^[11], Kizito *et al.* (2019) ^[21] and Joseph *et al.* (2021) ^[20].

Table 5: Effect of inorganic fertilizer, biochar and biofertilizer on yield attributes, yield and nutrient uptake of maize

Treatment	Cob length (cm)	Grains cob ⁻¹	Test weight (g)	Grain yield (q ha ⁻¹)	Stover yield (q ha ⁻¹)	Biological yield (q ha ⁻¹)	N uptake (kg ha ⁻¹)	P uptake (kg ha ⁻¹)	K uptake (kg ha ⁻¹)
T ₁	13.8	328	228	34.8	62.4	97.2	82.6	17.4	64.8
T ₂	14.6	346	235	37.6	66.8	104.4	88.9	18.9	69.6
T ₃	15.4	365	242	40.5	71.2	111.7	95.8	20.5	74.9
T ₄	15.9	378	248	42.8	74.6	117.4	101.6	21.8	79.3
T ₅	16.7	398	255	45.9	79.3	125.2	109.4	23.6	85.7
T ₆	17.6	420	262	49.2	84.1	133.3	118.3	25.4	92.8
T ₇	18.1	435	268	51	87.6	138.6	123.6	26.7	97.4
T ₈	19	458	275	54.6	92.8	147.4	132.8	28.6	104.9
T ₉	19.8	482	282	58.9	98.5	157.4	143.9	30.8	113.6
F-test	S	S	S	S	S	S	S	S	S
SEm±	0.42	9.6	4.1	1.32	2.14	2.86	3.4	0.9	2.8
CD (5%)	1.24	28.3	12.1	3.89	6.32	8.45	10.1	2.7	8.3

Economics of maize cultivation

The cost of cultivation rose from ₹48,200 ha⁻¹ under T₁ to ₹60,099 ha⁻¹ under T₉ on account of the added expenditure on fertilizer, biochar and biofertilizer, but this extra cost was more than offset by the accompanying gain in yield (Table 6). Gross return increased from ₹69,600 to ₹1,17,800 ha⁻¹ and net return from ₹21,400 to ₹57,701 ha⁻¹ between T₁ and T₉, while the benefit:cost ratio improved from 1:1.44 to 1:1.96 over the same range. The superior economics of T₉ stem directly from the substantially higher grain and stover yield realised under this treatment, which comfortably compensated for the additional input cost, corroborating the findings of Gezahegn (2021) ^[15] and Bhandari *et al.* (2021) ^[5] that integrated nutrient management is economically advantageous for maize cultivation.

performance across all the parameters studied and may be recommended as an effective and sustainable nutrient-management practice for white maize cultivation under agro-climatic conditions similar to those of Prayagraj. Long-term, multi-location trials are suggested to confirm the residual and cumulative benefits of this integrated nutrient-management strategy.

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Table 6: Economics of maize cultivation under different treatments

Treatment	Cost of cultivation (₹ ha ⁻¹)	Gross return (₹ ha ⁻¹)	Net return (₹ ha ⁻¹)	B:C ratio
T ₁	48,200	69,600	21,400	1:1.44
T ₂	50,800	75,200	24,400	1:1.48
T ₃	53,150	81,000	27,850	1:1.52
T ₄	51,675	85,600	33,925	1:1.66
T ₅	54,275	91,800	37,525	1:1.69
T ₆	56,625	98,400	41,775	1:1.74
T ₇	55,149	1,02,000	46,851	1:1.85
T ₈	57,749	1,09,200	51,451	1:1.89
T ₉	60,099	1,17,800	57,701	1:1.96

Conclusion

Integrated application of inorganic fertilizer with wheat-straw biochar and biofertilizer improved post-harvest soil fertility and physical condition, enhanced growth, yield attributes, yield and nutrient uptake, and increased profitability of white maize, without any adverse effect on soil pH or salinity. Among the nine combinations tested, 100% RDF applied together with 5.0 t ha⁻¹ wheat-straw biochar and seed inoculation with *Azospirillum* and phosphate-solubilizing bacteria (T₉) consistently gave the best

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