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Effect of organic agriculture on yield of rice and wheat under rice-wheat cropping system

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Abstract
The rice-wheat cropping system is central to India's food security but faces stagnating yields and soil degradation under conventional farming. This study evaluated the effect of organic agriculture practices farmyard manure (FYM), green manures (Sesbania and Leucaena), blue-green algae (BGA), and Azotobacter applied individually or in combinations, on rice and wheat productivity in an Inceptisol at ICAR-IARI, New Delhi, during 2020-21 and 2021-22. Eight treatments were tested in a randomized block design. Results showed that integrated organic inputs significantly enhanced yields compared to conventional farming. In rice, the highest yields (5.20-5.48 t ha^{-1}) were obtained under combined application of SGM + FYM + BGA, while wheat yields peaked (4.60-4.88 t ha^{-1}) under SGM + FYM + BGA in rice and LGLM + FYM + Azotobacter in wheat. Sole applications of FYM or conventional practices produced the lowest yields. Findings highlight that integrating organic manures and biofertilizers improves productivity, sustains soil health, and offers a viable alternative to input-intensive farming.

Keywords: Azotobacter, blue green algae, FYM, green manuring, rice, wheat

1. Introduction
Rice (*Oryza sativa* L.) remains the cornerstone of food and nutritional security for more than two-thirds of India's population, serving as both a staple diet and a primary livelihood source for millions of rural households (Roy *et al.*, 2023) [33]. The popular expression "Rice is Life" aptly reflects its socio-economic significance in the Indian subcontinent. Nevertheless, mounting pressures from climate change, declining water availability, and the conversion of agricultural land for non-agricultural uses are anticipated to shrink the national rice area by nearly 6-7 million hectares (Mha) by 2050. Despite this projected decline, demand for rice will continue to rise, requiring an estimated 1.1% annual increase in production over the coming four decades to achieve self-sufficiency (CRRI, 2013) [6]. Thus, sustaining and improving rice productivity has become a critical challenge.

Wheat (*Triticum aestivum* L.) is the second most important cereal crop in India after rice and is cultivated widely across temperate and subtropical regions. It occupies a central place in the diets of populations in northwestern and central India, where it is consumed daily as the primary food staple (Reddy Tummala *et al.*, 2018) [32]. India is a global leader in wheat acreage, although yield levels vary considerably across regions. In the highly irrigated states of Punjab, Haryana, and western Uttar Pradesh, yields average 4.5-5.0 t ha^{-1}, whereas in western and central states such as Rajasthan, Madhya Pradesh, and Bihar, productivity lags behind at 1.5-3.0 t ha^{-1} (Grain and Feed Annual, 2019) [14]. During 2017-18, Uttar Pradesh emerged as the top wheat-producing state with 9.75 Mha under cultivation and a production of nearly 31.9 million tonnes (Borse *et al.*, 2019) [3]. Globally, wheat accounts for over 267 Mha of land and contributes approximately 902 million tonnes (MT) of grain annually, underscoring its worldwide significance as a food security crop. However, in India, decades of intensive wheat cultivation supported by high-yielding varieties have led to disproportionate nutrient extraction, increasing fertilizer dependency, and a steady deterioration of soil health, which in turn constrains productivity gains (Reddy Tummala *et al.*, 2018) [32].

The challenge of raising rice and wheat yields is further complicated by persistent yield gaps the difference between potential and actual yields. In the northwestern Indo-Gangetic Plains (IGP), yield gaps for rice are relatively modest (~20% of potential yield), largely due to intensive management and high input use (Nayak *et al.*, 2024) [25]. Data from over 4,000 farmer fields revealed that nitrogen application rates could be reduced substantially without yield penalties in such systems (CIMMYT, 2022; Nayak *et al.*, 2022) [10, 26]. However, in many other regions, particularly in rainfed environments, yield gaps remain wide. For instance, irrigated and rainfed rice systems across Southeast Asia exhibit gaps of 37-66%, averaging nearly 48% of potential yield (Van Ittersum *et al.*, 2013) [50]. For wheat, the global yield gap is estimated at around 51% (Senapati *et al.*, 2022) [38], whereas in India the gap is between 20-40% for rice and about 20-21% for wheat (Jha *et al.*, 2022) [16]. Limited adoption of improved agronomic practices, combined with suboptimal soil and nutrient management, are primary constraints in narrowing these gaps (Singh *et al.*, 2020) [47].

The Green Revolution succeeded in raising cereal production by introducing high-yielding varieties coupled with irrigation and synthetic fertilizer use. Indian rice yields rose from approximately 2 t ha^{-1} in the 1960s to nearly 6 t ha^{-1} by the 1990s, while wheat yields also advanced substantially (Evenson & Gollin, 2003) [13]. Yet, this input-intensive model is increasingly showing diminishing returns. Excessive nitrogen application remains a particular concern; crops absorb only 20-50% of applied nitrogen, with the remainder lost to leaching, runoff, and gaseous emissions (Ju *et al.*, 2009) [17]. Such inefficiencies not only increase production costs but also aggravate soil degradation, groundwater pollution, and greenhouse gas emissions (Tilman *et al.*, 2002) [48]. Long-term experiments indicate that rice yields stagnate under fixed nitrogen application rates, highlighting the unsustainability of chemical fertilizer dependence (Cassman, 1999) [5]. Consequently, more ecologically sound and cost-effective nutrient management strategies are urgently needed.

Organic nutrient sources including farmyard manure (FYM), green manures (GM), and biofertilizers offer a promising alternative. Unlike synthetic fertilizers, organic inputs improve soil health holistically by enriching organic matter content, enhancing microbial activity, and fostering stable aggregate formation. FYM supplies essential nutrients while improving soil structure and water-holding capacity (Moharana *et al.*, 2012; Gupta *et al.*, 2006) [15, 24]. Green manures, particularly leguminous species, contribute substantial nitrogen to cropping systems and often outperform FYM alone in raising yield performance (Sharma & Mitra, 1991) [39]. Biofertilizers, based on microbial inoculants such as blue-green algae (BGA), Azotobacter, and Azospirillum, fix atmospheric nitrogen and enhance nutrient bioavailability in an eco-friendly manner (Singh *et al.*, 2011) [44]. Reports suggest that biofertilizers can increase yields by 10-40% while simultaneously reducing the need for synthetic fertilizers by nearly 30% (Vessey, 2003) [51]. For rice, Azotobacter species play a critical role in nitrogen fixation in the rhizosphere and have demonstrated potential to mitigate salinity stress while promoting growth (Razie *et al.*, 2008; Sahoo *et al.*, 2014, 2021) [31, 34].

Several studies have demonstrated the synergistic benefits of combining organic manures with biofertilizers. For instance, Singh and Singh (2005) [45] reported marked yield improvements with FYM and vermicompost applications compared to unfertilized controls. Similarly, incorporation of green gram as a green manure crop enhanced yields of both rice and wheat in sequential systems (Saxena & Yadav, 1998) [36]. Integrated nutrient management trials across diverse agro-ecologies consistently show that blending biofertilizers, green manures, and FYM not only sustains yields but also improves soil biological quality indices (Chanu *et al.*, 2025; Bhatt *et al.*, 2021; Singh *et al.*, 2023) [2, 7, 42]. These findings collectively reinforce the hypothesis that judicious use of organic nutrient sources, either individually or in combination, can significantly improve productivity and soil health in rice-wheat systems.

The present study is designed to evaluate the contribution of biofertilizers, green manures, and farmyard manure applied individually and in various combinations on rice and wheat yields under an Inceptisol soil environment. By testing these practices against conventional methods, the research aims to identify sustainable pathways for bridging yield gaps, improving soil quality, and ensuring long-term resilience of the rice-wheat system.

2. Material and methods

2.1 Experimental Site and Soil Characteristics

The field experiment was conducted at the research farm of the ICAR-Indian Agricultural Research Institute (IARI), New Delhi, India (28°38′14.8″N, 77°08′45.6″E; 228.61 m above mean sea level). The experimental soil is classified as a Typic Ustochrept (Inceptisol) and is sandy clay loam in texture. The site has been under a long-term rice-wheat cropping system since 2003, involving both organic and conventional nutrient management practices. The trials were undertaken across two consecutive cropping years, during the *kharif* (rice) and *rabi* (wheat) seasons of 2020-21 and 2021-22. Pusa Basmati-1 and HD 3086 were grown as test cultivars for rice and wheat, respectively.

2.2 Experimental Design and Layout

The study was arranged in a Randomized Complete Block Design (RCBD) with eight treatments and three replications. Each plot measured 23.04 m² (4.8 m × 4.8 m). Randomization of treatments was done following the procedure of Fisher and Yates (1963). Rice transplanting was carried out in mid-July of both years, while wheat was sown in November after rice harvest. The experimental treatments included a conventional farming practice as control and seven different organic nutrient management combinations.

2.3 Organic Inputs and Treatment Details

Eight treatments were evaluated (Table 1). Farmyard manure (FYM) was applied at 10 Mg ha^{-1} either singly to rice, to wheat, or to both crops depending on treatment. For green manuring, Sesbania was sown at a seed rate of 50 kg ha^{-1}; the biomass (2.5-3.0 Mg ha^{-1} dry matter) was incorporated into the soil at 45 days after sowing. In wheat, *Leucaena leucocephala* leaves and twigs were applied at 1.6 Mg ha^{-1} (dry weight). Blue-green algae (BGA) inoculum was applied at 1.5 kg ha^{-1} three to four days after rice transplanting. For wheat, *Azotobacter* was introduced through seed treatment at a rate of 500 g ha^{-1}. The quality of organic amendments was characterized by their C:N ratios: Sesbania green manure (21.8:1; Cd 0.056 mg kg^{-1}), *Leucaena leucocephala* green leaves (25.0:1), BGA (20:1), and FYM (47.3:1).

Table 1: Experimental treatments applied in rice-wheat system

Treatment No.	Treatment label	Description
T_1	Conventional farming	Standard inorganic fertilization
T_2	FYM-Rice	FYM @ 10 t ha⁻¹ applied only to rice
T_3	FYM-Wheat	FYM @ 10 t ha⁻¹ applied only to wheat
T_4	FYM-Both crops	FYM @ 10 t ha⁻¹ applied to rice and wheat
T_5	SGM + LGLM	Sesbania green manure to rice; *Leucaena* leaves to wheat
T_6	SGM + BGA + LGLM + Azotobacter	Sesbania + BGA to rice; *Leucaena* + *Azotobacter* to wheat
T_7	SGM + FYM	Sesbania + FYM to rice; *Leucaena* + FYM to wheat
T_8	Integrated treatment	Sesbania + FYM + BGA to rice; *Leucaena* + FYM + *Azotobacter* to wheat

2.4 Statistical analysis

Data from both years were analyzed using analysis of variance (ANOVA) appropriate for RCBD. Treatment means were compared using the least significant difference (LSD) test at the 5% probability level to determine significant differences among treatments (Gomez & Gomez, 1984) [53].

3. Results and discussion

3.1 Effect of Organic Agriculture on Rice Yield

Rice grain yields recorded during 2020-21 and 2021-22 under different nutrient management practices are summarized in Table 2. Yields varied significantly across treatments, reflecting the influence of organic and integrated nutrient strategies. In 2020-21, the lowest yield (4.0 t ha⁻¹) was observed in plots receiving FYM only to wheat (T_3), closely followed by conventional farming (T_1: 4.2 t ha⁻¹). Application of FYM to both rice and wheat (T_4: 4.9 t ha⁻¹) and Sesbania green manure (SGM) integrated with BGA (T_6: 4.65 t ha⁻¹) substantially enhanced yield relative to conventional practice. The highest yields were achieved under SGM + FYM + BGA (T_8: 5.2 t ha⁻¹), followed by SGM + FYM (T_7: 5.1 t ha⁻¹). A similar trend was observed during 2021-22, with T_1 (4.6 t ha⁻¹) and T_3 (4.4 t ha⁻¹) consistently producing the lowest yields. In contrast, T4 improved yield to 5.3 t ha⁻¹, while T_6 resulted in 4.97 t ha⁻¹. Once again, T_8 recorded the maximum yield (5.48 t ha⁻¹), followed closely by T_7 (5.42 t ha⁻¹). The consistency of T_7 and T_8 across both years highlights the superior performance of integrated nutrient management involving FYM, green manures, and biofertilizers.

These findings corroborate earlier reports suggesting that integrated nutrient supply systems provide the most effective strategy for maintaining long-term productivity (Ramesh *et al.*, 2009) [29]. Green manures not only improve soil fertility but also contribute to carbon sequestration and biological activity, while FYM provides a slow and sustained nutrient release (Sharma, 2002) [41]. Similar outcomes were reported by Maskina *et al.* (1988), who observed a 32% increase in rice yield under FYM application alone, and by Chinnusamy *et al.* (2006) [9], who found that combining biofertilizers such as BGA, PSB, and *Azospirillum* enhanced rice growth and yield traits. More recent studies confirm that integrated use of organics with biofertilizers and partial inorganic inputs significantly improves rice productivity and soil quality indices (Meena *et al.*, 2020; Singh *et al.*, 2023; Baghel & Singh, 2025) [1, 22]. Overall, the results clearly establish that the conjunctive use of FYM, SGM, and biofertilizers (T_7 and T_8) not only improved rice yield but also ensured yield stability across seasons. This highlights the crucial role of integrated organic strategies in enhancing nutrient use efficiency and sustaining productivity in rice-based systems.

Table 2: Effect of Organic Agriculture on Rice Grain Yield

Treatment	Rice Grain Yield (t ha⁻¹)	
	2020-21	2021-22
T_1	4.20	4.60
T_2	4.15	4.57
T_3	4.00	4.40
T_4	4.90	5.30
T_5	4.55	4.85
T_6	4.65	4.97
T_7	5.10	5.42
T_8	5.20	5.48
LSD ($P \leq 0.05$)	0.12	0.10

3.2 Effect of Organic Agriculture on Wheat Yield

Wheat yields during 2020-21 and 2021-22 are presented in Table 3. A similar pattern to rice was observed; with conventional farming (T_1) and sole FYM application to rice (T_2) producing the lowest yields (3.8 and 3.65 t ha⁻¹ in 2020-21; 4.06 and 3.91 t ha⁻¹ in 2021-22, respectively). Moderate improvements were achieved with FYM application to both crops (T_4: 4.15 and 4.39 t ha⁻¹) and with SGM + BGA in rice combined with *Leucaena* leaves and *Azotobacter* in wheat (T_6: 4.0 and 4.26 t ha⁻¹). The highest yields were consistently obtained under T_8 (SGM + FYM + BGA in rice and *Leucaena* + FYM + *Azotobacter* in wheat), which produced 4.6 and 4.88 t ha⁻¹ in the two years, respectively. T_7 (SGM + FYM in rice and *Leucaena* + FYM in wheat) also performed well, with yields of 4.35 and 4.63 t ha⁻¹. The yield improvements under integrated practices align with previous research. Yadav *et al.* (2018) and Suryawanshi *et al.* (2019) [46, 52] reported that combining inorganic fertilizers with FYM significantly improved wheat yields. Similarly, Chaudhry *et al.* (2017) [8] demonstrated that RDF supplemented with vermicompost and biofertilizers increased grain yield by over 20% compared with RDF alone. More recent findings by Ramanandan *et al.* (2020) [28] further support that integrated nutrient supply, including FYM, biofertilizers, and micronutrient supplementation, enhances grain, straw, and biological yields while improving harvest index.

In agreement with our findings, several long-term studies confirm that wheat productivity benefits substantially from integrated nutrient management (Singh *et al.*, 2018; Sharma *et al.*, 2016) [40, 43]. Such practices not only raise yields but also improve soil physical and chemical properties, thereby ensuring sustained productivity in the rice-wheat cropping system. The results across both crops and years provide strong evidence that sole reliance on conventional practices or single organic inputs is insufficient to maintain high productivity. Instead, integrated application of FYM, SGM, BGA, and biofertilizers consistently delivered superior performance in terms of both rice and wheat yields. These outcomes reinforce the importance of adopting integrated nutrient management strategies for enhancing soil fertility, increasing nutrient use efficiency, and achieving yield stability in intensive rice-wheat systems.

Table 3: Effect of Organic Agriculture on Wheat Grain Yield

Treatment	Wheat Grain Yield (t ha^{-1})	
	Wheat (Nov 2020-21)	Wheat (Nov 2021-22)
T_1	3.8	4.06
T_2	3.65	3.91
T_3	3.95	4.23
T_4	4.15	4.39
T_5	3.95	4.17
T_6	4	4.26
T_7	4.35	4.63
T_8	4.6	4.88

4. Conclusion

The findings of this study clearly indicate that organic nutrient management practices substantially improved the productivity of the rice-wheat system on Inceptisol soils compared with conventional farming. The consistent yield advantages observed under treatments combining farmyard manure, green manures, and biofertilizers highlight the value of integrated organic strategies in enhancing crop performance. By supplying nutrients in a balanced and sustained manner, these practices not only closed existing yield gaps but also improved soil health and resource use efficiency.

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