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RESEARCH ARTICLE

Impact of integrated nutrient management on productivity and profitability of wheat under long-term (40 years) rice-wheat cropping system

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Abstract

A long-term field experiment was carried out to evaluate the impact of long-term (40 years) different integrated nutrient management strategies on crop growth attributes, productivity and economic profitability of wheat within a rice-wheat cropping system. The study comprised 11 treatment combinations and replicated three times. Organic nutrient sources, including farmyard manure, wheat straw and green manure using *Sesbania aculeata*, were incorporated. The findings demonstrated that applying 50 % of the Recommended Dose of Fertilizers (RDF) combined with 50 % nitrogen (N) from FYM during rice cultivation, followed by 100 % RDF in wheat (T_6), significantly improved wheat grain yield (4435 kg/ha) and yield-related parameters compared to other treatments. Growth attributes, such as plant height, leaf area index, number of tillers per square meter, number of earheads per square meter, grains per earhead, earhead length and 1000-grain weight, showed substantial variation under different nutrient management practices. The treatment T_6 exhibited the superior performance in terms of plant height and yield attributes at various growth stages. Furthermore, T_6 had recorded the highest net returns and benefit-cost (B:C) ratio, indicating a greater economic efficiency. Thus, the present study concludes that replacing 50 % of inorganic nitrogen with organic sources such as FYM, wheat straw/green manure in rice, coupled with 100 % RDF in wheat, enhances crop productivity and profitability and quality of wheat in long-term rice-wheat cropping system of Indo-Gangetic Plains and similar agro-ecological regions worldwide.

Keywords: farm yard manure; green manuring; integrated nutrient management; wheat straw; yield; yield attributes

Introduction

Wheat (*Triticum aestivum*) is a major cereal crop and ranks as the second most important staple food after rice in India. Globally, it occupies an area of 341.57 lakh hectares, with a production of 1120.19 lakh metric tonnes in 2023-24, marking a 14.65 lakh metric tonne increase over the previous year's output of 1105.54 lakh metric tonnes (Ministry of Agriculture & Farmers Welfare, 2023-24). Current fertilizer recommendations primarily focus on NPK leading to nutrient imbalances, soil quality deterioration and reduced crop productivity. Therefore, balanced fertilization strategies must expand beyond NPK to include all essential plant nutrients necessary for sustainable agricultural growth. Modern intensive farming cannot solely rely on chemical fertilizers, organic manures, crop residues, or biofertilizers to meet the complete nutritional requirements of crops (1). Instead, these resources must be applied in combination, following an integrated nutrient management (INM) approach that is practical, economically feasible, socially acceptable and environmentally sustainable (2). Research has demonstrated integrating organic and chemical fertilizers enhances crop yields more effectively than applying recommended dose of chemical fertilizers alone (3). Organic manures also supply micronutrients often depleted by the continuous use of synthetic fertilizers (4). Use of INM practices has thus become crucial for maintaining soil fertility and long-term agricultural productivity. Thus, considering the need for the sustainable nutrient management, the present study was undertaken to evaluate the effects of different integrated nutrient management combinations on growth attributes, yield and economic profitability of wheat within a rice-wheat cropping system. This research aims to provide insights into optimizing nutrient use for enhanced productivity while preserving soil health.

Materials and Methods

The initial soil physicochemical properties of the experimental site (recorded in 1984) included a pH of 7.40, electrical conductivity of 0.29 dS/m, organic carbon content of 0.46 %, available nitrogen (N) of 194 kg/ha, available phosphorus (P) of 23 kg/ha and available potassium (K) of 155 kg/ha. The region has a humid subtropical climate, with monsoon season commencing in early June and continuing until October. The area receives an average annual rainfall of 1280 mm, with approximately 75 % to 80 % of the precipitation occurring between mid-June and mid-October. The mean monthly temperature ranges from 35-39 °C in May and from 5 -10 °C in January. Field experiment was started in 1984 at the Research Farm of Bihar Agricultural University (BAU), Sabour, Bhagalpur, Bihar, India (latitude 25°15′4″ N, longitude 78°2′ 45″ E and an elevation of 86.6 m above sea level). The research was conducted under the network project of the Project Directorate on Farming System Research, Modipuram. During the study period on wheat winter seasons of 2022-23 and 2023-24. The total rainfall recorded at Sabour was 69.4 mm in 2022-23 and 11.3 mm in 2023-24. Weather conditions during the crop growing period featured bright sunshine and typical dry-season cold temperatures, with maximum temperatures ranging from 15.8-34.7 °C in 2022–23 and 16.8-36.7 °C in 2023-24, while the minimum temperatures varied from 5-17.7 °C and 5.8-19.6 °C, respectively. The wheat variety 'HD-2967' was sown at a seed rate of 100 kg/ha on 15 November 2020 and harvested on 5 April 2021. Pre-sowing irrigation of 5 cm was applied, followed by two additional irrigations based on prevailing weather conditions. Standard agronomic practices were consistently implemented to ensure the proper crop maturity. The field experiment comprised 11 treatments and, replicated three times, with plot dimensions of 8.10 × 4.20 m^2. A Randomized Block Design (RBD) was used and treatments were structured to include the different combinations of organic and inorganic nutrient sources. The treatments were as *viz.* T_1: control (no fertilizer, no organic manure) in both rice and wheat, T_2: 50 % RDF in both rice and wheat, T_3: 50 % RDF in rice and 100 % RDF in wheat, T_4:75 % RDF through fertilizers in both rice and wheat,T_5:100 % RDF in both rice and wheat, T_6:50 % RDF and 50 % N through FYM in rice and 100 % RDF in wheat, T_7: 75 % RDF and 25 % N through FYM in rice and 75 % RDF in wheat, T_8:50 % RDF and 50 % N through wheat straw in rice and 100 % RDF in wheat, T_9:75 % RDF and 25 % N through wheat straw in rice and 75 % RDF in wheat, T_{10}: 50 % RDF and 50 % N through green manure (GM) in rice and 100 % RDF in wheat and T_{11}:75 % RDF and 25 % N through GM in rice and 75 % RDF in wheat. The control treatment (T_1) received no fertilizer or organic manure. Recommended fertilizer dose of 150-60-40 kg/ha for N: P_2O_5: K_2O was supplied using urea, single super phosphate and muriate of potash. During wheat cultivation, half of the nitrogen, along with full doses of phosphorus and potassium, was applied at sowing through urea, DAP and MOP, while the remaining nitrogen was top-dressed in two equal splits at 25 and 50 days after sowing (DAS) according to the treatment specifications.The data on plant height, Leaf Area Index (LAI), number of tillers/$meter^2$, number of earheads/$meter^2$, grains/earhead, earhead length and 1000-grain weight were collected by randomly selecting five representative plants from each plot in each replication. Additionally, 1000-grains weight (g) and total yield were measured. Grain and straw yields were recorded from the net plot area of each treatment. The data were statistically analysed by using "ANOVA" (Analysis of Variance) technique on RBD. For each character, the standard error of mean (SEm) and least significant difference (LSD) at the 5 % level of significance were calculated.

Results and Discussion

Effect on growth, yield and yield attributes

The growth attributes *viz.* plant height, LAI and number of tillers/m-2 at different days after sowing differed significantly due to different integrated nutrient management practices (Table 1). Application of 50 % RDF and 50 % N through FYM in rice and 100 % RDF in wheat (T6) showed the best performance in terms of plant height (29.7 cm) at maturity, LAI (2.5) at 100 DAS and number of tillers/m^{-2}(201.1, 412.3, 429.3. 418.7 and 370.2 at 25, 50, 75, 100 DAS and at crop maturity) (Fig. 1) respectively. This indicated the residual impact of substituting 50 % of inorganic nitrogen with FYM in rice on subsequent wheat crop. It also noteworthy that similar effects were observed with other organic nutrient sources, i.e. wheat straw and green manure substituting for 50 % RDF in rice and application of 100 % RDF in wheat were

Table 1. Effect of diverse integrated nutrient management practices on growth attributes of wheat at different crop stages (Pooled data of 2-years)

Rice	Wheat	Plant height at maturity	LAI	Number of tillers m^{-2}				
				25 DAS	50 DAS	75 DAS	100 DAS	Maturity
T1: Control	Control	63.7	0.6	101.0	151.7	194.8	186.6	188.2
T2: 50 % RDF	50 % RDF	93.5	1.9	137.1	281.4	296.4	287.1	273.3
T3: 50 % RDF	100 % RDF	98.6	2.3	172.0	368.0	378.0	365.8	335.1
T4: 75 % RDF	75 % RDF	97.7	2.0	149.9	328.5	338.5	329.3	313.4
T5: 100 % RDF	100 % RDF	98.5	2.3	162.1	344.9	354.9	342.6	331.8
T6: 50 % RDF + 50 % N through FYM	100 % RDF	100.7	2.5	201.1	412.3	429.3	418.7	370.2
T7: 75 % RDF + 25 % N through FYM	75 % RDF	99.5	2.4	179.8	389.0	406.0	390.9	348.2
T8: 50 % RDF + 50 % N through wheat straw	100 % RDF	100.5	2.4	188.0	403.8	416.8	405.0	352.4
T9: 75 % RDF + 25 % N through wheat straw	75 % RDF	98.0	2.2	156.2	342.7	354.7	339.5	318.7
T10:50 % RDF + 50 % N through GM	100 % RDF	100.6	2.4	194.3	403.5	426.5	414.4	361.9
T11: 75 % RDF + 25 % N through GM	75 % RDF	99.1	2.4	165.4	362.4	377.4	364.2	332.4
CD (P=0.05)		6.20	6.2	0.1	10.9	22.8	23.7	23.0

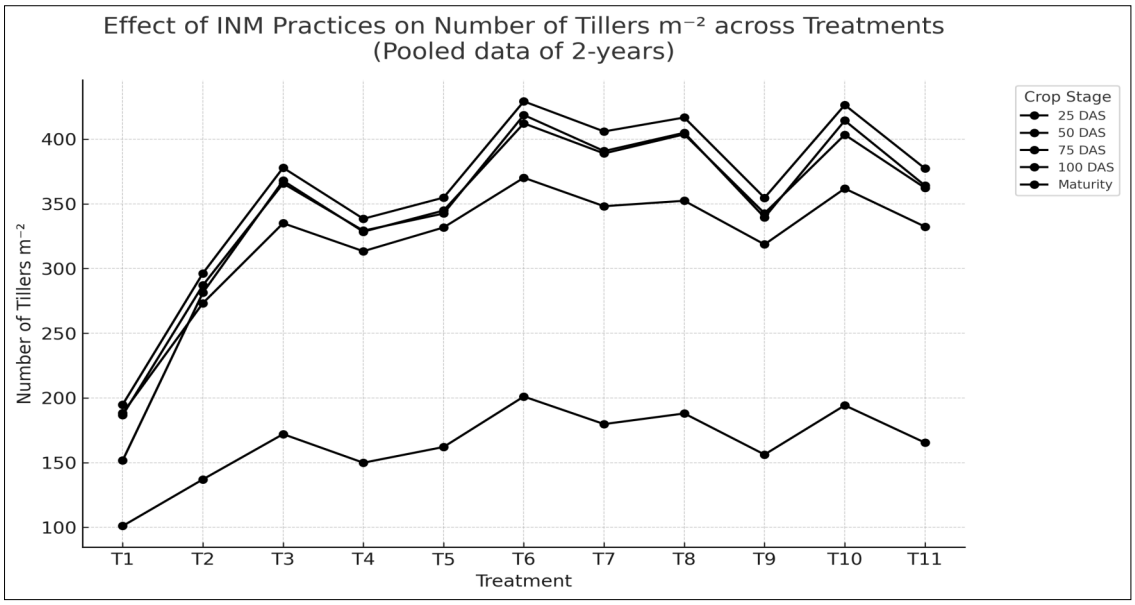

Fig. 1. Effect of diverse integrated nutrient management practices on Number of tillers m^{-2} of wheat at different crop stages (Pooled data of 2-years).

also equally productive but was superior to application of 100 % RDF in inorganic forms to both the crops. This highlights the significance of organic nutrient sources in promoting crop growth and development. FYM proved to be more effective in enhancing nutrient availability, primarily due to its rapid conversion of nutrients from organic to inorganic forms (5-7). Wheat straw decomposes slowly due to its high content of of polysaccharides, waxes and silica. While green manures *Sesbania aculeata* decomposes more readily, Farmyard manures (FYM) proved to be more effective as *Sesbania aculeata* contains a lower total organic matter content per unit of nutrient. Consequently, superior performance of FYM as compared to wheat straw and green manuring with *Sesbania aculeata* can be attributed to its greater nutrient efficiency. Results showed that yield attributes such as number of ear head/m2 (364.55), number of grains/ear head (42.4), length of ear head (12.6) and 1000-grain weight (38.2) differed significantly due to different integrated nutrient management practices (Table 2). The addition of the organic matter enhanced soil properties, leading to improved nutrient availability and uptake. This accelerated nutrient absorption contributed to better crop yield attributes. Application of 50 % RDF and 50 % N through FYM in rice and 100 % RDF in wheat (T6) recorded the highest value of crop yield attributes. This can be attributed to the continuous supply of essential nutrients by FYM throughout the entire crop growth cycle. (8, 9). Application of FYM is more effective than the other organic sources due to its ability to improving the physical and chemical properties of the soil leading to proper crop growth and development (10, 11). Grain and straw yield of wheat was also varied from a minimum of 0.88 kg/ha and 1.24 t/ha under control (T1) to a maximum of 4.44 t/ha and 6.28 t/ha respectively with treatment receiving application of 50 % RDF and 50 % N through FYM in rice and 100 % RDF in wheat (T6) which is significantly superior to rest of treatments followed by application of 50 % RDF and 50 % N through green manures (GM) in rice and 100 % RDF through fertilizers in wheat (T10) (Fig. 2). Thus, integrated use of chemical fertilizers with organic manures viz. FYM, wheat straw or green manure might have added the huge quantity of organic matter in the soil and thereby producing increased grain yield (12-15).

Net return and benefit: cost ratio

Economic analysis revealed that net returns (₹93171/ha) and B:C ratio (2.01) of wheat crop differed noticeably in different nutrient management options (Table 2) and that was directly related to price of crop produced and cost incurred on nutrient inputs under different treatments (Fig. 2). Variable cost was involved with source of nutrient input in different treatments. The data showed that net return and B:C ratio in terms of wheat were higher with application of 50 % RDF and 50 % N through FYM in rice and 100 % RDF in wheat (T_6) which was significantly superior over rest of treatments. The treatments involving the substitution of 50 % inorganic N by FYM and application of 50 % RDF in rice followed by 100 % RDF in wheat increased net return by 30 % over application of 100 % RDF in both the crops. The treatment showing a higher yield eventually resulted in increased profitability. The result confirmed that higher yield under organic nutrient source treatments have been the reason behind its cost effectiveness (16, 17).

Future scope

The findings of this study highlight several directions for future research. Long-term assessments of Integrated Nutrient Management (INM) strategies should focus on their effects on soil health, particularly in relation to microbial dynamics, enzymatic activities and nutrient cycling processes that are fundamental to sustained soil fertility. Evaluating the impact of various INM treatments on Nutrient Use Efficiency (NUE) in rice-wheat systems is essential for optimizing input utilization and minimizing nutrient losses. In the context of increasing climate variability, it is imperative to investigate the potential of INM practices to enhance crop resilience under abiotic stresses such as drought, heat and irregular rainfall. Furthermore, quantification of carbon sequestration potential and greenhouse gas emission reductions under long-term INM is necessary to support the development of climate-resilient and environmentally sustainable agricultural systems.

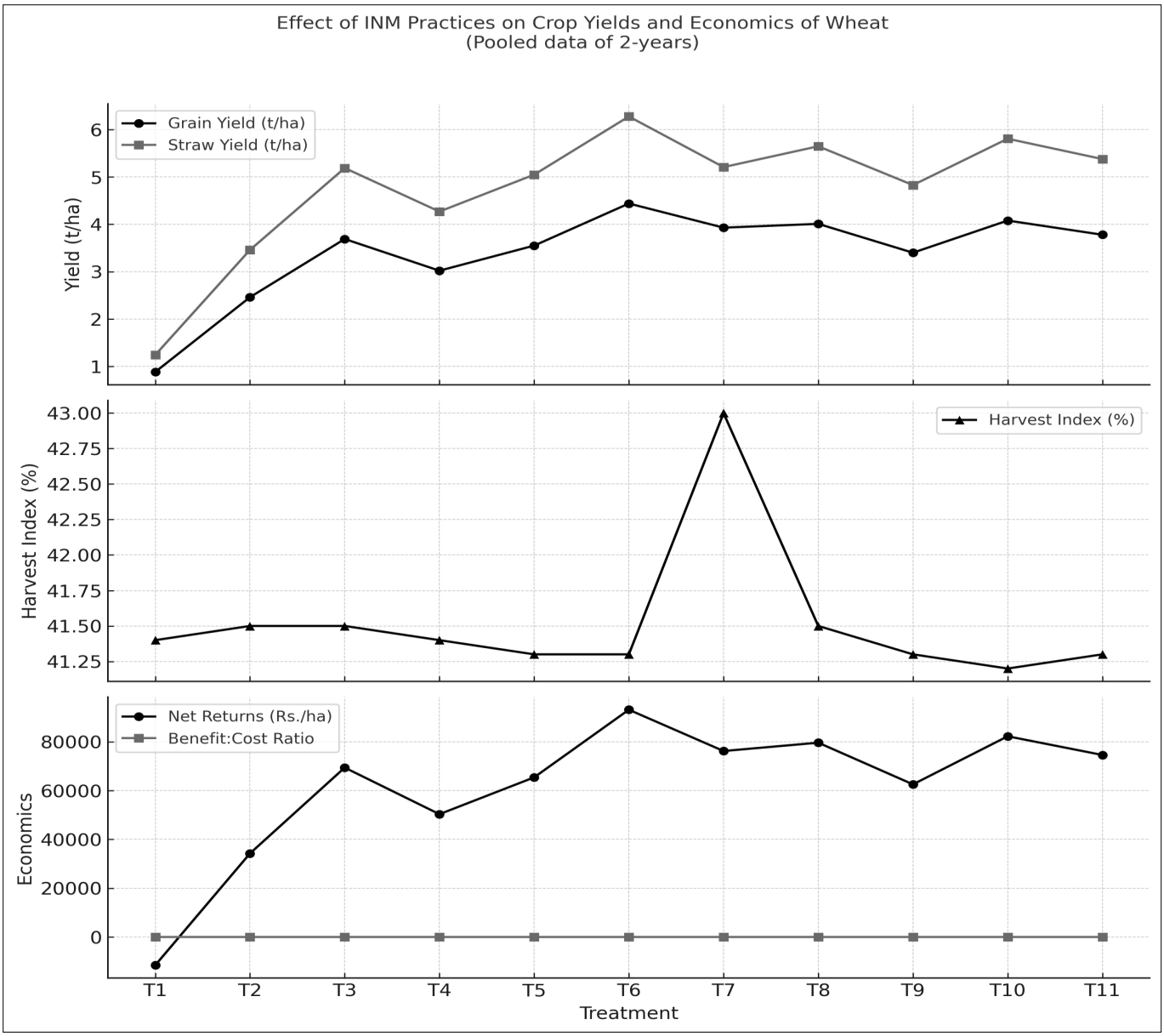

Fig. 2. Effect of diverse integrated nutrient management practices on crop yields and economics of wheat at different crop stages (Pooled data of 2-years).

Table 2. Effect of diverse integrated nutrient management practices on yield attributes, crop yields and economics of wheat ((Pooled data of 2-years

Rice	Wheat	Earhead/m² (no.)	Grains/ earhead (no.)	Earhead (cm)	1000 grain weight (g)	Grain yield (t/ha)	Straw yield (t/ha)	Harvest index (%)	Net returns (Rs. /ha)	Benefit: Cost ratio
T1: Control	Control	182.9	21.0	7.9	29.4	0.9	1.2	41.4	-11540.0	-0.3
T2: 50 % RDF	50 % RDF	269.8	29.9	8.9	35.0	2.5	3.5	41.5	34270.0	0.8
T3: 50 % RDF	100 % RDF	329.6	36.7	10.4	36.6	3.7	5.2	41.5	69440.0	1.5
T4: 75 % RDF	75 % RDF	308.0	33.1	9.6	36.1	3.0	4.3	41.4	50346.0	1.1
T5: 100 % RDF	100 % RDF	328.8	35.3	10.3	36.5	3.6	5.1	41.3	65440.0	1.4
T6: 50 % RDF + 50 % N through FYM	100 % RDF	364.6	42.4	12.6	38.2	4.4	6.3	41.3	93171.0	2.0
T7: 75 % RDF + 25 % N through FYM	75 % RDF	346.0	38.0	10.6	37.1	3.9	5.2	43.0	76240.0	1.7
T8: 50 % RDF + 50 % N through wheat straw	100 % RDF	346.2	40.7	11.1	37.8	4.0	5.7	41.5	79659.0	1.7
T9: 75 % RDF + 25 % N through wheat straw	75 % RDF	315.6	34.1	10.0	36.4	3.4	4.8	41.3	62571.0	1.4
T10:50 % RDF + 50 % N through GM	100 % RDF	357.2	41.2	12.1	37.9	4.1	5.8	41.2	82282.0	1.8
T11: 75 % RDF + 25 % N through GM	75 % RDF	328.4	36.9	10.6	36.8	3.8	5.4	41.3	74625.0	1.7
CD (P=0.05)		20.6	2.4	0.7	2.3	0.2	0.3	NS	7304	7304.0

Conclusion

Thus, the results of 40 years long-term field experimentation concluded that the farmers may adopt the substitution of 50 % inorganic N either through FYM or wheat straw or green manuring with *Sesbania aculeata* and 50 % RDF in rice followed by 100 % RDF in wheat for improving growth as well as productivity of wheat crop under the rice-wheat cropping system.

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Authors' contributions

BM carried out the material preparation, data collection. SK carried out the analysis and interpretation of result. RK carried out analysis of data. MG participated in the design of the study and performed the statistical analysis. SS conceived of the study and contributed data and coordination. JNS carried out interpretation of data. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests.

Ethical issues: None

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