EGYPTIAN
JOURNAL
OF BOTANY
(EJBO)

Print ISSN: 0375-9237
Online ISSN: 2357-0350

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PUBLISHED BY
THE EGYPTIAN
BOTANICAL SOCIETY

A sustainable study of nutrient management using different combinations of organic and inorganic fertilizers for enhancing Wheat productivity

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Wheat is a significant cereal crop which plays a crucial role in the global nutritional and food security. So nutrient management strategy for the crop is of uttermost importance. Hence, the present study was designed to provide the optimized condition for Integrated Nutrient Management (INM) strategies on growth and yield parameters of wheat genotype WH 1124. The field experiment was carried out by using biofertilizer, vermicompost, and FYM (Farmyard Manure) with different doses of RDF (Recommended Dose of Fertiliser for N) for two rabi seasons 2021-2023 with 9 treatments (T1 to T9). The results revealed that the T4 (70% recommended dose of fertilizer + 2.5% *Azospirillum* + 2.5% phosphate-solubilizing bacteria + 20% farmyard manure + 5% vermicompost) has a significant effect on all growth and yield attributes, compared to the other integrated nutrient management (INM) treatments. The plant height under T4 varied significantly (29.9%) than T7 (70% RDF + 30% Vermicompost) and 6.13% greater than RDF. The maximum number of tillers recorded in T4 were 16.73% more than RDF. The spike length and LAI were 37.03 and 53.4%, higher than RDF, respectively. The maximum grain yield in T4 (47.4 q/ha) was 38.39% higher than RDF. Also, the maximum straw yield in T4 (62.7 q/ha) was 39.95% greater than the minimum straw yield recorded in T7. The study concluded that T4 treatment provided the optimized condition for sustainable integrated nutrient management of Wheat.

Keywords: Biofertilizer, Farmyard Manure, Leaf Area Index, Nutrient Management, Wheat

ARTICLE HISTORY
Submitted: June 11, 2024
Accepted: October 07, 2024

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DOI: 10.21608/ejbo.2024.296979.2885

EDITED BY: S. Abd Ellatif

INTRODUCTION

Cereals are fundamental for providing energy and nutrition to people worldwide, particularly those in rural areas (Sharma *et al*., 2024a,b). Among cereals, wheat holds the top spot in both production and cultivation areas, followed by corn, rice, and barley (Sharma *et al*., 2023; Liang *et al*., 2024). Approximately one-third of the world's population relies on wheat for nutrition (Nkebiwe *et al*., 2024). It has been pivotal in transitioning agriculture and driving significant advancements in civilization (Zulfiqar *et al*., 2023; Nkebiwe *et al*., 2024). It is rich in carbohydrates, particularly starch, and provides substantial energy (Fazily *et al*., 2021). Moreover, wheat provides proteins, dietary fiber, and essential vitamins and minerals such as B-complex vitamins, iron, magnesium, phosphorus, and zinc (Kurylenko *et al*., 2021; Jangir *et al*., 2022).

Since the onset of the green revolution, Indian agriculture has made impressive advancements (Caldara *et al*., 2021). The higher production of cereals in the country is attributed to the use of high-yielding varieties, synthetic fertilizers, pesticides, and the expansion of irrigation facilities (Singh *et al*., 2024). The excessive use of synthetic fertilizers leads to an imbalance of three essential nutrients, nitrogen, potassium, and phosphate (Nayak *et al*., 2022; Broberg *et al*., 2023; Saleem *et al*., 2023 and Singh *et al*., 2024). Therefore, a major challenge for agricultural scientists is to maximize soil fertility, production, and yield for sustainable agriculture (Sharma *et al*., 2021; Nath *et al*., 2023; Singh *et al*., 2024). These effects might be enhanced with bio-fertilizers such as *Azotobacter*, PSB (phosphate-solubilizing bacteria), and *Azospirillum,* along with inorganic fertilizers, farmyard manure and vermicompost (Caldara *et al*., 2021; Shahid *et al*., 2023). Integrated nutrient management (INM) is a superior endeavor that can benefit the efficacy of fertilizers (Nayak *et al*., 2022; Broberg *et al*., 2023; Saleem *et al*., 2023).

Biofertilizers enhance soil fertility by fixing nitrogen, solubilizing phosphorus, and mobilizing potassium (Bekmurodovich *et al*., 2024). They improve soil structure, aiding in water retention and root penetration (Padhy *et al*., 2024). Additionally, they promote nutrient uptake by plants and suppress soil-borne diseases (Dal *et al*., 2024). Nutrient availability remains lower when INM is administered, but it increases production (Mahmud *et al*., 2023; Farid *et al*., 2023). Overall, INM fosters sustainable agriculture by reducing chemical fertilizer dependency and supporting ecosystem health (Taranova *et al*., 2023). Therefore, the current study was designed to determine the best combination for restoring soil nutrients by INM and its impacts on wheat growth and yield characteristics.

MATERIALS AND METHODS

Study site and experimental design

A two-year field experiment was conducted at a farm located at 28.688027 N latitude and 76.636683 E longitude in Dujana village, Jhajjar, Haryana (India) on the wheat genotype WH 1124 (certified seeds were purchased from ICAR in Karnal) during the Rabi seasons of 2021-2022 and 2022-2023. The experiment was performed in a triplicate randomized block design (RBD) with 9 treatments. The size of the block was 3.0 × 2.0 m (net), and sowing was performed via the seed drilling method with 20 cm lines apart at a rate of 100 kg/ha.

Meteorology

The weekly average atmospheric temperature, relative humidity, rainfall, and wind speed data for the study period were sourced from the Indian Meteorological Department (IMD 2022 & 2023). Throughout the cropping season, spanning from the 1st week of December to the second week of April (2021-2023), the average relative humidity was 75.53%, peaking at 96.7% in the 2nd week of February and decreasing to a low of 34.76% in the 4th week of March across both seasons. The total rainfall recorded during the cropping period was 33.86 mm, with the highest rainfall occurring in the 3rd week of March (7.5 mm). The average temperature during the study was 17.80°C; the warmest week, at 30.52°C, occurred in the 4th week of March, while the coldest, at 9.1°C, occurred in the 2nd week of January. However, the average wind speed was 11.39 km/hr, with the maximum wind speed recorded during the study period of 26.33 km/hr in the 2nd week of March, which contrasts with the minimum of 5.3 km/hr in the 1st week of December.

Soil

A composite sample of soil before sowing was collected carefully and its physicochemical analysis was done in laboratory. Result revealed that, soil was sandy loam (sand 65%, silt 29% and clay 11%) having a pH and EC values of 8.2 and 0.52 dSm^{-1}, respectively. The physicochemical properties of the soil shown in Table 1.

Table 1. Physicochemical properties of soil

Sr. No.	Parameters	Values
1	pH	8.2±0.06
2	EC (dS/m)	0.52±0.005
3	OC (%)	0.21±0.012
4	N (kg/ha)	160.4±0.305
5	P (kg/ha)	12.3±0.173
6	K (kg/ha)	137.5±0.550

Treatments

A total of 9 different treatments with 3 replications were formulated using combinations of inorganic fertilizers, farmyard manure, vermicompost, and biofertilizers. Farmyard manure (FYM) was prepared from animal waste (cow dung and urine), and rice crop residue with a ratio of 7:3. Vermicompost, phosphate-solubilizing bacteria (PSB), and *Azotobacter* were purchased from IFFCO Bazaar. Vermicompost and FYM were applied during tillage. NPK fertilizers, PSB, and *Azotobacter* were applied 40 days after sowing (DAS) and 80 DAS. The treatments were formulated based on the recommended doses of 80, 40, and 20 kg/ha for nitrogen (N), phosphorus (P), and potassium (K) fertilizers, respectively (https://agritech.tnau.ac.in/agriculture/agri_nutrient mgt_wheat.html). The treatments for the experiment were as follows: T1, 100% RDF (Recommended Dose of NPK Fertilizers); T2, 90% RDF + 5% *Azospirillum* + 5% PSB; T3, 80% RDF + 5% *Azospirillum* + 5% PSB + 10% FYM (Farmyard manure); T4, 70% RDF + 2.5% *Azospirillum* + 2.5% PSB + 20% FYM + 5% Vermicompost; T5, 60% RDF + 5% *Azospirillum* + 5% PSB + 30% FYM; T6, 80% RDF + 5% *Azospirillum* + 5% PSB + 10% Vermicompost; T7, 70% RDF + 30% Vermicompost; T8, 60% RDF + 40% Vermicompost; and T9, 50% RDF + 25% FYM + 25% Vermicompost.

Growth and yield

The average height of each selected plant was measured at 30, 60, and 90 days after sowing (DAS) and at maturity by randomly choosing five distinct plants from each block. The height was measured from the base of the plant to its longest leaf tip and averaged (Zadoks *et al*., 1974). The spike length, number of spikes, and grains per spike were measured in a representative sample of five plants from each block, and average values were recorded (Zadoks *et al*., 1974). The LAI and HI were determined as suggested by Pierce & Running (1988).

Weight of grains

A seed counter was used to collect a random sample of one thousand seeds, which were subsequently weighed using METTLER-AE240 digital balance with a maximum capacity of 200g and an accuracy of 0.001g.

Protein in grains

Total nitrogen was assessed using the micro-Kjeldhal methodology as proposed by Sweeney et al., (1987), and crude protein was determined using the following formula:

$$Crude\ protein\ content\ (\%) = micro\ Kjeldhal\ N\ (\%) \times 6.25 \quad (1)$$

Further, the percentage was converted into grams by using the following equation:

$$Protein\ in\ grams = Weight\ of\ wheat\ grain\ sample\ \times \frac{Protein\ \%}{100} \quad (2)$$

Statistical analysis

Data was statistically analyzed using one-way and two-way analysis of variance (ANOVA) and reported as the means of three replicates (means ± SD). Tukey's HSD post hoc test was used at a 5% significance level ($p < 0.05$) to compare treatment means. Origin Pro 2024 software was used for graphs and statistical analysis.

RESULTS

Plant height was significantly affected under the different treatments, as indicated in Figure 1. The maximum height was recorded at T4 (95.1 cm), and the minimum height was observed in T7 (73.2 cm) at the harvesting stage which were 6.13% higher and 29.9% lower than the RDF value. The dry matter accumulation was significantly higher in T4 (1049.8 g/m^2), followed by T2 (975.9 g/m^2), T5 (950.1 g/m^2), and T1 (887.1 g/m^2), as shown in Figure 2. The highest value of T4 was 18.34% greater than T1 and 32.21% greater than the lowest value of DMA in T7.

The number of tillers was significantly affected by different treatments as shown in Figure 3. The maximum number of tillers was recorded in T4 (82.65 per meter row) while, the minimum number of tillers was recorded in T7 (64.2 per meter row). The statistical analysis showed that T4 exhibited a 16.73% and 28.93% greater number of tillers compared to RDF (T1) and T7, respectively. Spike length is a crucial yield attribute that was notably affected by different treatments as shown in Figure 4. The maximum spike length was recorded in T4 (14.8 cm), which was 16.73% greater than that in T1 (RDF) and 37.03% greater than the minimum spike length in T6. LAI was significantly different among various treatments at all stages of growth as shown in Figure 5. The highest LAI at 90 DAS was recorded in T4 (4.45), which was 53.4% and 78% higher compared to T1 and T9, respectively.

Analysis of the grain data showed that T4 had the highest average number of grains per spike (33), which was 44.54% greater than that of T1 (RDF), as shown in Figure 6. The grain and straw yield were notably affected by different treatments as shown Figure 7. Considerably higher grain yield was observed in T4 (47.4 q/ha), which was 38.39% greater than that in T1 (RDF) and 65.44% greater than that in T7, as shown in Figure 7 (c). The maximum straw yield occurred in T4 (62.7 q/ha), which was 39.95% greater than the lowest yield reported in T7, as shown in Figure 7 (b). Biological yield analysis revealed that the maximum biological yield occurred in T4 (105.75 q/ha), which was 47.18% greater than the minimum biological yield observed in T8 and 25.14% greater than that in T1, as shown in Figure 7(a). The highest HI was observed in T4 (53.27%) while the minimum was observed in T1 (38.8%) (Figure 7d).

The weight per 1000 grains was significantly different in T4 as compared to other treatments as shown in Figure 8a. The maximum weight of 1000 grains were reported in the T4 (38.36 gm) which was followed by T5 (34.23gm), T1 (34.03gm), T6 (33.53gm), and T7 (33.46) while minimum was reported in T2 (33.16gm). Highest protein in wheat grains was reported in T4 (13.9gm), which was statistically higher than other treatments whereas, the minimum protein was reported in T2 (10.6gm) and T9 (10.8gm) as shown in Figure 8b. Observed data showed, T4 exhibited 19.14% higher protein than RDF (T1) and 30.72% higher than T2.

DISCUSSION

The results of field experiments investigating the effects of different integrated nutrient management (INM) treatments on wheat growth and yield characteristics revealed several significant findings. The significant increase in plant height under T4 can be attributed to the biofertilizers (*Azospirillum* and PSB), which stimulated plant growth through better nutrient absorption (Yan *et al.*, 2024). This demonstrates the potential of biofertilizers to enhance plant stature, contributing to better light interception and photosynthetic efficiency. The combination of 70% RDF with biofertilizers and organic amendments (vermicompost and FYM) in T4 appears to have provided an optimal nutrient environment for plant growth, resulting in higher biomass accumulation. The benefits of biofertilizers extend beyond just plant growth and development.

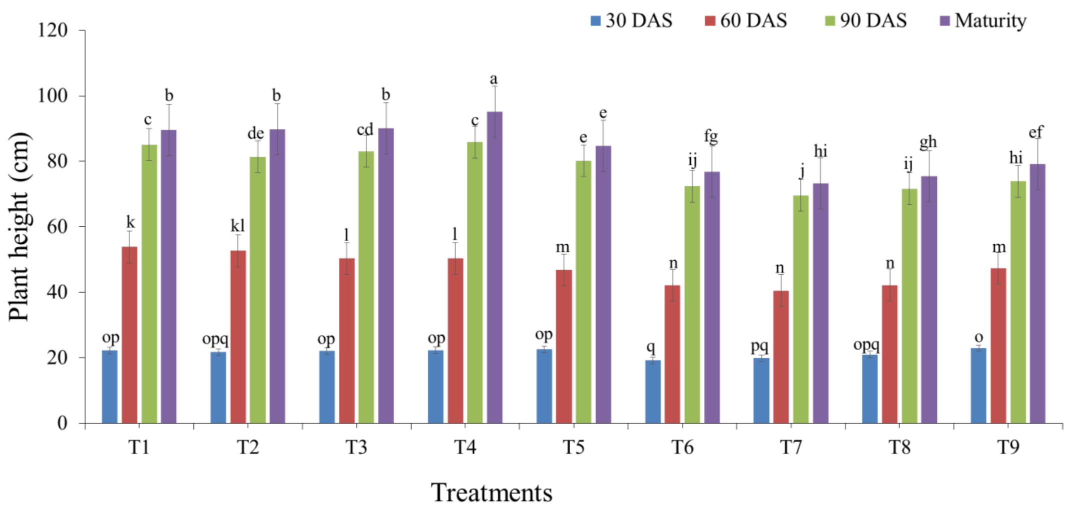

Figure 1. Wheat plant height (cm) at successive growth stages affected by different INM treatments where lowercase letters represent significant differences as evaluated by Tukey's post hoc test ($p < 0.05$)

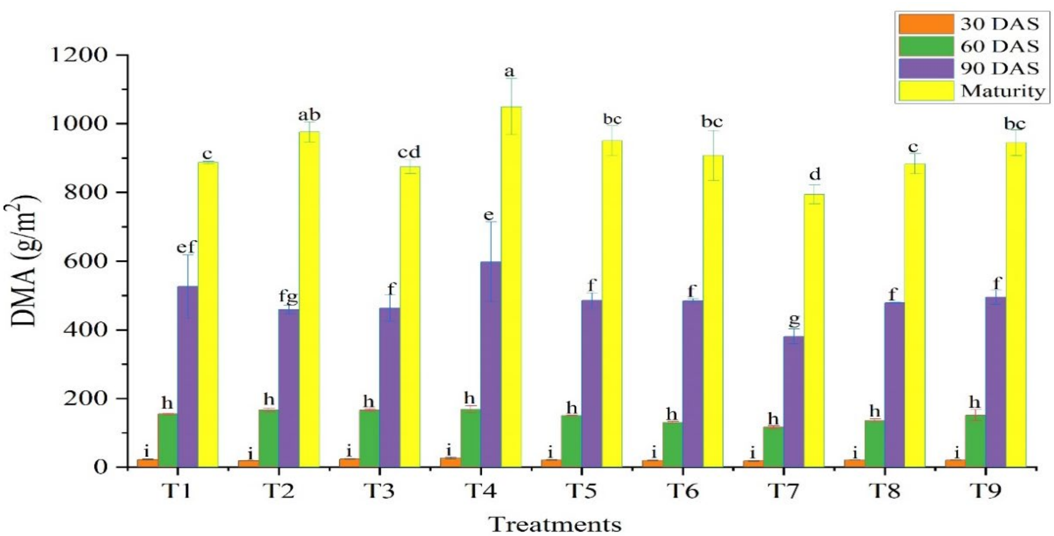

Figure 2. Dry matter accumulation (DMA) of wheat affected by different INM treatments at successive growth stages, where lowercase letters represent significant differences as evaluated by Tukey's post hoc test ($p < 0.05$)

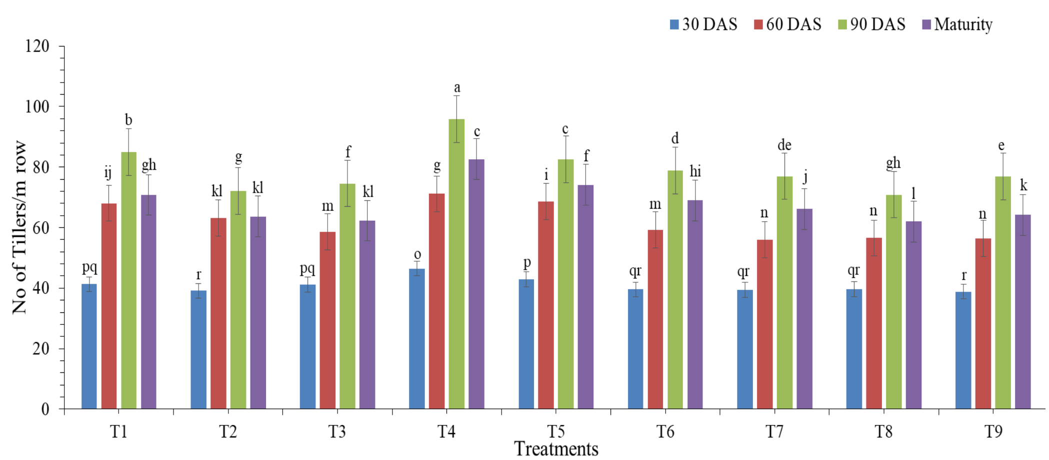

Figure 3. Number of tillers per meter row at successive growth stages under different INM treatments where lowercase letters represent significant differences as evaluated by Tukey's post hoc test ($p < 0.05$)

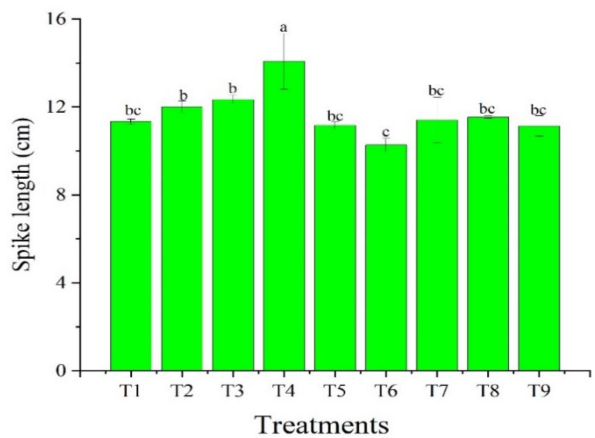

Figure 4. Effects of different INM treatments on spike length of wheat at successive growth stages affected where lowercase letters represent significant differences as evaluated by Tukey's post hoc test ($p < 0.05$).

They also offer a sustainable and environmentally friendly alternative to traditional chemical fertilizers. Biofertilizers are biodegradable, non-toxic, and free from harmful chemicals, making them an attractive option for farmers and gardeners looking to reduce their environmental footprint. Sharma *et al*. (2021), also emphasized the importance of integrated nutrient management for enhancing growth of rice and wheat by using treatments comprised combination of chemical fertilizers (100% NPK and 150% NPK) and organic manures (100% NPK+FYM, 100% NPK+GM and 100% NPK+SI) along with unfertilized control. The increase in tiller number is crucial for wheat as it directly correlates with potential grain yield. Kumar et al. (2020) studied the effect of three organic sources *i.e.*, sewage sludge (SS), vermicompost (VC) and *Sesbania* green manure in combination with 75% of recommended fertilizers (RDF) on growth, yield and micronutrient uptake by rice-wheat cropping system and found that number of tillers was highest in case of 75% RDF + 25% N through organic amendments. In the current study, the combined use of RDF and biofertilizers positively influences reproductive growth, which was seen in spike length, grains, grain weight and the protein in the grains. Maximum grain weight and protein was also reported in T4 by the integrated supply of nutrients. Ramadhan (2022) used five combinations of organic and inorganic nutrient and revealed that organic and inorganic amendments affected plant growth, yield components, grain yield significantly.

Along with biofertilizers (Azotobacter and PSB), FYM significant improvement in LAI was also noticed in current study. After sowing (DAS), the Dry Matter Accumulation (DMA) increased, but the differences between treatments were not distinct. This could be attributed to the variations in microbial activities, which can affect the rate of nutrient uptake and utilization by plants. However, as the plants continued to grow, the differences between treatments became more pronounced.

By 120 DAS, a significant difference in LAI was observed, with the treatment combining biofertilizers and FYM showing a substantial increase in LAI compared to other treatments. This suggests that the synergistic effect of biofertilizers and FYM on plant growth and development becomes more apparent as the plants mature. However, on 120 DAS, a significant difference was observed. The increase in production was due to rapid availability of N using synthetic fertilizer (Sharma et al., 2021). When plants can allocate a greater proportion of their biomass towards grain production, it can lead to increased yields and improved crop performance.

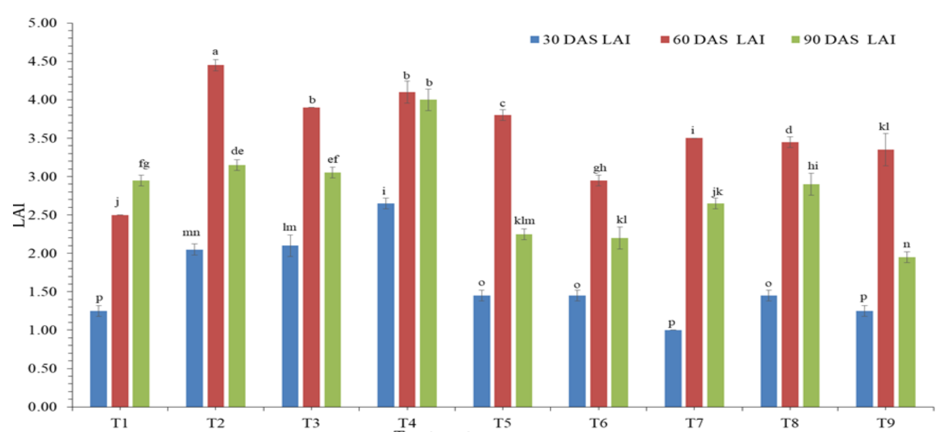

Figure 5. Effects of various INM treatments on Leaf area index of wheat at successive growth stages; lowercase letters indicate significant differences according to Tukey's post hoc test ($p < 0.05$).

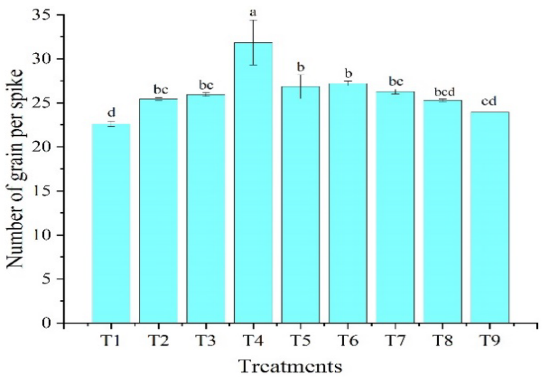

Figure 6. Effects of different INM treatments on uumber of grains per spike of wheat where lowercase letters represent significant differences as evaluated by Tukey's post hoc test ($p < 0.05$)

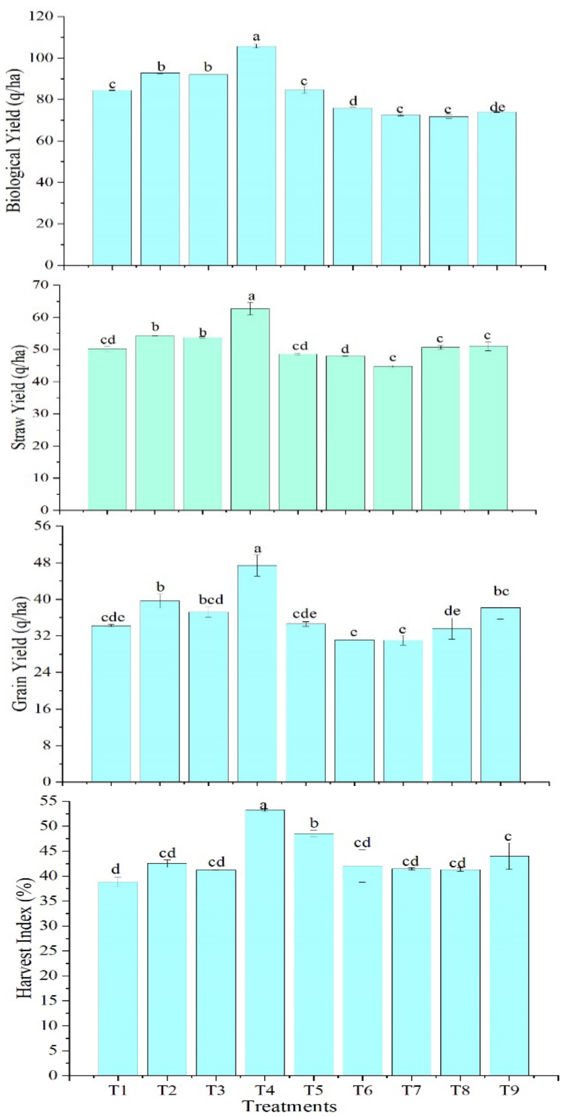

Figure 7. Effects of different INM treatments on the yield attributes of wheat where lowercase letters indicate significant differences according to Tukey's post hoc test ($p < 0.05$).

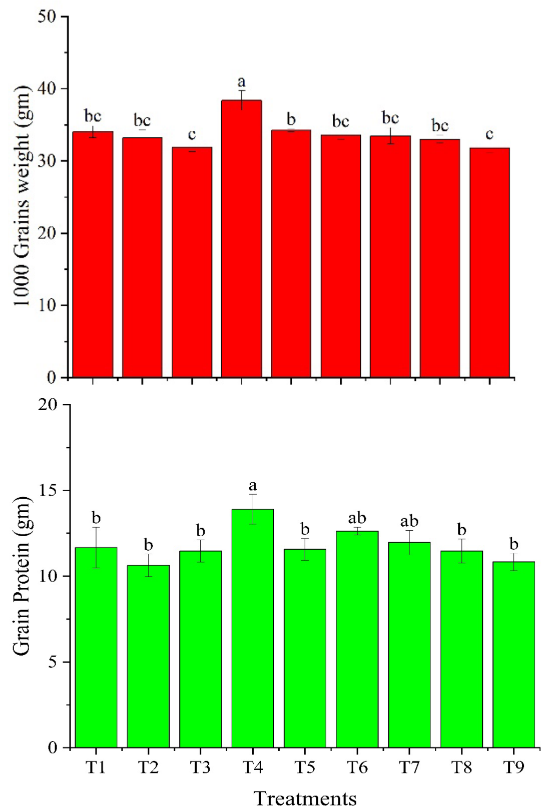

Figure 8. (a) Average weight of 1000 wheat grains and (b) Protein per 100 gm of wheat grain under different INM treatments, where lowercase letters represent the significance difference as evaluated by Tukey's post hoc test ($p < 0.05$)

The incorporation of biofertilizers in chemical fertilizers likely enhanced the overall crop performance, as supported by Caldara *et al*., 2021. Walia et al. (2024) had also focused on importance of integrated nutrient management in rice-wheat system. The analysis of the data revealed significant differences in weight per 1000 grains and protein content among the various treatments. The results showed that T4 exhibited the maximum weight per 1000 grains, which was significantly higher than the other treatments. This suggests that the specific combination of factors used in T4, such as nutrient application and crop management practices, had a positive impact on grain filling and development (Broberg *et al*., 2023). The protein content of wheat grains is a critical factor in determining its nutritional value and quality. Observation in this study showed that uses of NPK fertilizer along with biofertilizers resulted in high protein in grains. This suggests that the specific combination of factors, such as nutrient application and crop management practices, had a positive impact on protein synthesis and accumulation in the grains.

CONCLUSION

In this two-year study, 9 treatments with different combinations of inorganic, organic and bio-fertilisers were used to investigate the effects on the growth and yield of Wheat. Among all the treatments, T4 (T4, 70% RDF + 2.5% Azospirillum + 2.5% PSB + 20% FYM + 5% Vermicompost) showed significantly higher growth and yield. In comparison to RDF, T4 exhibited a significant increase in several key growth parameters such as plant height (6.13%), tiller counts (16.73%), leaf area index (53.4%), and spike length (16.73). Moreover, the grain yield and biological yield have also shown a statistically significant increase in treatment T4, compared to RDF and other treatments. These findings concluded that the application of inorganic fertilizers in conjunction with biofertilizers and organic amendments could be a promising avenue for sustainable agriculture, offering sustainable solutions to boost crop productivity and ensure global food security.

ABBREVIATIONS

Abbreviation	Meaning
°C	Degree celsius
ANOVA	Analysis of variance
cm	Centimetre
DAS	Days after sowing
DMA	Dry matter accumulation
dS/m	Deci siemens per meter
EC	Electrical conductivity
FYM	Farmyard manure
g/m^2	Gram per meter square
gm	Gram
HI	Harvest index
ICAR	Indian council of agriculture
INM	Integrated nutrient management
Kg/ha	Kilogram per hectare
LAI	Leaf area index
NPK	Nitrogen, phosphorus and potassium
PSB	Phosphate solubilizing bacteria
q/ha	Quintal per hectare
RDF	Recommended Dose of Fertiliser
SD	Standard deviation
t/ha	Ton per hectare
T1-T9	Treatment first to nine

DATA AVAILABILITY STATEMENT

All data generated or analyzed in the present study have been included and are available within this article.

AUTHORS' CONTRIBUTION

Wazir Singh: Execution of the sampling/analysis work, writing original draft; Vikram Mor: Conception and design of the work, Data correction, Proof reading; Mohinder Singh: designing of the treatment and critical revision; Pradeep Khyalia: Data and statistical analysis, interpretation writing, Proofreading.

CONFLICT OF INTEREST STATEMENT

The authors certify that they are not affiliated with or involved with any organization or entity with any financial interest or nonfinancial interest in the subject matter or materials discussed in this paper.

ETHICAL APPROVAL

Not Applicable

FUNDING

No funding was received for the research.

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