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Effect of integrated nutrient management on growth and yield of wheat (*Triticum aestivum* L.) under system of wheat intensification

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Abstract

A field experiment was conducted to investigate the effect of different NPK levels, sowing systems, and vermicompost application on the growth, physiological efficiency, yield attributes, and yield of wheat (*Triticum aestivum* L.). The treatments comprised three levels of NPK (50% RDF, 75% RDF, and 100% RDF), three sowing systems [normal planting (NP) at 22.5 cm row spacing and the System of Wheat Intensification (SWI) at 20 × 20 cm and 25 × 25 cm], and vermicompost at 0 and 30 kg N ha⁻¹. Results revealed that increasing NPK levels significantly improved plant height (up to 103.69 cm), shoot dry weight (206.7 g/m), SPAD chlorophyll content (41.76), and LAI (3.67). SWI at 20 × 20 cm recorded greater plant height, SPAD values, and yield attributes than conventional spacing. Vermicompost application enhanced physiological traits, notably increasing LAI to 3.92 and grain yield to 4158 kg/ha. Effective tillers, spike length, grains per spike, 1000-grain weight, and harvest index improved with integrated nutrient management and wider spacing. The results confirm that the synergistic effect of balanced fertilization, improved spatial arrangement, and organic amendments optimizes both vegetative and reproductive performance in wheat.

Keywords: Integrated nutrient management, vermicompost and System of wheat intensification (SWI)

Introduction

Wheat (*Triticum aestivum* L.) is a major global cereal crop, contributing around 20% of global caloric intake and serving as the leading plant protein source. In 2023, global production was ~799 million tonnes over 221 million hectares, with an average yield of 3.6 t/ha (FAO, 2023) [1]. India recorded a record output of 113.29 million tonnes in 2023-24, with major contributions from Uttar Pradesh, Punjab, Rajasthan, Haryana, and Madhya Pradesh (MoAFW, 2024) [10]. Wheat's domestication began ~10,000 years ago in the Fertile Crescent, leading to the evolution of hexaploid bread wheat (Heun *et al.*, 1997) [2]. Despite limited genetic diversity due to polyploidization, wheat thrives across diverse agro-ecologies (Li, 2023) [7]. Nutritionally, wheat provides 70-75% carbohydrates, ~13% protein, dietary fiber, B vitamins, vitamin E, and essential minerals (Healthline, 2025) [3].

Wheat faces mounting challenges from climate change, particularly rising temperatures during the pre-harvest phase, causing yield losses of 4-5 Mt per 1 °C increase in India's Indo-Gangetic Plains (Ulukan, 2024) [16]. Water scarcity and soil degradation further threaten sustainability, necessitating improved management practices. Overuse of chemical fertilizers (NPK) has led to soil nutrient imbalances. Integrated Nutrient Management (INM)-combining inorganic and organic inputs like vermicompost-is being adopted to improve soil health and nutrient efficiency (Singh *et al.*, 2024) [13, 14]. Vermicompost enhances soil microbial activity and nutrient uptake while improving chemical input efficiency (Hrēka *et al.*, 2025) [4]. The System of Wheat Intensification (SWI) improves yield and resource use efficiency through wider spacing, reduced seed rates, early weeding, and alternate irrigation. This study investigates the combined impact of NPK and vermicompost on wheat yield and nutrient uptake, comparing SWI with conventional practices to optimize productivity and sustainability in modern wheat farming.

Materials and Methods

The field experiment was conducted during the rabi season 2024-25 using variety Raj 3077 on sandy loam soils with pH 7.3 and moderate fertility (N: 198 kg/ha, P: 21.3 kg/ha, K: 187.4 kg/ha). The experimental design was a Split-plot with three replications. Main plot factors were three NPK levels: 50%, 75%, and 100% of the recommended dose (120:60:60 kg N:P₂O₅:K₂O ha⁻¹). Subplots included three sowing systems: conventional 22.5 cm row spacing (NP), SWI at 20×20 cm, and SWI at 25×25 cm. Sub-subplots included two vermicompost levels: no vermicompost and vermicompost equivalent to 30 kg N ha⁻¹. Data on plant height, shoot dry weight, chlorophyll content (SPAD), LAI, no of tillers, grains per spike, 1000-grain weight, grain yield, straw yield, and harvest index were recorded. Economic analysis was based on prevailing market prices. The data were statistically analyzed using split-plot ANOVA, and treatment means were compared using LSD at 5% significance.

Results and Discussion

The results from the present investigation clearly indicated that integrated nutrient management (INM), comprising varying levels of NPK, different sowing systems, and organic supplementation via vermicompost, significantly influenced growth, physiological efficiency, yield attributes, and yield of wheat (*Triticum aestivum* L.). The overall improvement in crop performance may be attributed to the synergistic interaction of precise nutrient management, spatial arrangement under the System of Wheat Intensification (SWI), and organic amendments, all of which contributed towards enhanced plant growth, better canopy development, and improved reproductive outcomes.

Effect of NPK Levels on Growth and Physiological Parameters

As evident from Table 1, plant height at harvest progressively increased with higher levels of NPK fertilization. The tallest plants (103.69 cm) were recorded under 100% recommended dose of fertilizer (RDF), followed by 99.94 cm under 75% RDF and 93.99 cm under 50% RDF. The differences were statistically significant at the 5% level (LSD = 3.023). This trend supports the notion that balanced and sufficient nutrient supply stimulates vegetative growth, internode elongation, and overall plant stature. These observations corroborate earlier findings by Kumar *et al.* (2018) [6] and Kitila & Workina (2023) [5], who reported that higher NPK doses positively influence cell division and elongation.

Shoot dry weight at harvest followed a similar trend, increasing from 167.3 g/m at 50% RDF to 176.7 g/m at 75% RDF, and reaching a maximum of 206.7 g/m under 100% RDF. This significant increase (LSD = 9.6) indicates enhanced dry matter accumulation when adequate nutrients are available for optimum photosynthetic activity and biomass partitioning. The results are consistent with those reported by Meena *et al.* (2023) [9], who highlighted the role of balanced nutrient application in promoting shoot biomass production.

Physiologically, SPAD values—a proxy for chlorophyll content—also increased with rising nutrient levels. At 60 DAS, the SPAD value was lowest at 39.44 under 50% RDF, moderately higher at 39.74 under 75% RDF, and highest at 41.76 under 100% RDF, with significant differences (LSD = 1.165). This suggests that sufficient nitrogen and balanced macronutrient supply directly enhance chlorophyll synthesis, promoting efficient photosynthesis. These findings align with

Sharma & Verma (2024) [11], who observed improved SPAD values under integrated nutrient practices.

Leaf area index (LAI) at 60 DAS, another important physiological indicator, increased significantly with higher fertilizer levels—from 3.21 under 50% RDF to 3.67 under 100% RDF (LSD = 0.198). A higher LAI indicates greater leaf area per unit ground area, contributing to better light interception and photosynthetic efficiency during key growth stages.

Effect of Sowing System on Growth and Physiological Parameters

The system of sowing also significantly affected growth and physiological traits (Table 1). Plant height was highest (102.98 cm) under SWI at 20 × 20 cm spacing, followed by 98.29 cm under normal planting at 22.5 cm row spacing, and lowest (96.35 cm) under SWI at 25 × 25 cm. The differences were significant (LSD = 3.023). The higher plant height under SWI at 20 × 20 cm may be attributed to improved root growth, aeration, and nutrient uptake facilitated by wider and more uniform spacing, consistent with Singh *et al.* (2022) [12].

Shoot dry weight at harvest was highest (229.9 g/m) under normal planting, whereas SWI at 20 × 20 cm and 25 × 25 cm recorded lower values of 156.4 g/m and 148.9 g/m, respectively. The LSD for shoot dry weight (9.6) confirmed significant differences. This indicates that while SWI may reduce above-ground competition, it also reallocates assimilates to other growth processes.

SPAD values varied slightly across sowing systems. SWI at 25 × 25 cm recorded the highest SPAD value (41.07), followed by SWI at 20 × 20 cm (40.66) and normal planting (39.21). These differences were statistically significant (LSD = 1.165), highlighting SWI's positive impact on maintaining leaf chlorophyll content. The LAI, however, showed no significant differences (NS), though numerically higher values were noted under SWI at 20 × 20 cm (3.56) compared to normal planting (3.43). This indicates that while wider spacing improves individual plant leaf area, the effect may be diluted at the population level.

Effect of Vermicompost on Growth and Physiological Parameters

The application of vermicompost significantly influenced plant growth and physiological traits. As shown in Table 1, plant height increased from 98.26 cm under no vermicompost to 100.16 cm under 30 kg N ha⁻¹ through vermicompost. The LSD (1.765) confirmed statistical significance. This enhancement aligns with Kumar *et al.* (2018) [6] and Kitila & Workina (2023) [5], who observed that vermicompost improves soil structure, microbial activity, and nutrient availability, resulting in better plant stature.

Shoot dry weight increased from 182.6 g/m to 199.3 g/m with vermicompost addition, with a significant LSD (8.1). This suggests improved biomass accumulation due to increased nutrient mineralization and uptake. SPAD values increased slightly from 40.18 to 40.44 with vermicompost, but the difference was non-significant, indicating that while vermicompost enhances nitrogen availability, its incremental effect on chlorophyll content might be limited when baseline soil fertility is adequate.

A notable improvement was observed in LAI, which rose significantly from 2.98 under no vermicompost to 3.92 with 30 kg N ha⁻¹ through vermicompost (LSD = 0.12). This demonstrates vermicompost's effectiveness in enhancing canopy development, consistent with Sharma & Verma (2024) [11].

Effect of NPK Levels on Yield Attributes and Yield

Yield attributes improved significantly with increasing NPK levels (Table 2). Effective tillers per m² increased from 330 under 50% RDF to 363 under 75% RDF and 382 under 100% RDF (LSD = 14.29). This confirms that sufficient nutrient supply supports tiller emergence and survival. Spike length improved from 10.43 cm to 12.36 cm across the same gradient (LSD = 0.83), indicating improved panicle development under balanced fertilization. Grains per spike increased significantly from 29.32 to 35.66 (LSD = 1.37), and 1000-grain weight rose from 33.54 g to 36.82 g (LSD = 1.03).

The grain yield increased substantially from 3307 kg/ha under 50% RDF to 3702 kg/ha under 75% RDF, reaching 4066 kg/ha under 100% RDF (LSD = 101.64). Straw yield followed a similar trend, increasing from 5823 kg/ha to 6577 kg/ha (LSD = 231.80). The harvest index improved slightly from 36.2% to 38.2% (LSD = 0.58), indicating efficient partitioning of assimilates towards economic yield. These results align with Meena *et al.* (2023)^[9] and Tiwari *et al.* (2023)^[15], who highlighted the yield-enhancing potential of balanced NPK management.

Effect of Sowing System on Yield Attributes and Yield

The sowing system had a notable impact on yield components. Effective tillers were highest (367 m⁻²) under SWI at 20 × 20 cm, followed by normal planting (354 m⁻²) and SWI at 25 × 25 cm (354 m⁻²). Spike length was longest (11.87 cm) under SWI at 20 × 20 cm, with significant differences (LSD = 0.83). Grains per spike and 1000-grain weight also improved under SWI at 20 × 20 cm (33.50 grains/spike and 37.08 g, respectively). These findings indicate that the SWI method optimizes tiller survival, root proliferation, and spike development due to improved spacing and resource use efficiency (Singh *et al.*, 2022; Malik &

Mehta, 2023)^[12, 8].

Grain yield was highest (3863 kg/ha) under SWI at 20 × 20 cm, followed by normal planting (3688 kg/ha). The lowest yield (3524 kg/ha) was under SWI at 25 × 25 cm. Straw yield was also highest under SWI at 20 × 20 cm (6586 kg/ha), confirming superior biomass production. The harvest index varied slightly, with SWI at 20 × 20 cm recording 37.3% compared to 35.6% under SWI at 25 × 25 cm. These results validate SWI's effectiveness in boosting both yield and biomass (Sharma & Verma, 2024)^[11].

Effect of Vermicompost on Yield Attributes and Yield

Vermicompost significantly enhanced yield parameters (Table 2). Effective tillers increased from 339 to 379 m⁻² (LSD = 10.11), grains per spike from 30.24 to 35.39 (LSD = 0.97), and 1000-grain weight from 34.55 g to 36.88 g (LSD = 1.06). The grain yield improved markedly from 3226 kg/ha without vermicompost to 4158 kg/ha with 30 kg N ha⁻¹ through vermicompost (LSD = 54.35). Straw yield also rose from 5739 kg/ha to 7066 kg/ha (LSD = 106.31). The harvest index increased slightly from 36.4% to 37.2% (LSD = 0.30). These improvements substantiate the role of vermicompost in enhancing nitrogen use efficiency and biomass production (Tiwari *et al.*, 2023)^[15].

Interaction Effects

Most interactions between factors were non-significant, except for grains per spike and 1000-grain weight, where interactions between sowing system and fertilizer levels were significant (LSD = 2.12 and 3.34, respectively). This highlights the complementary effects of SWI and balanced fertilization on reproductive traits.

Table 1: Effect of NPK Levels, Sowing System, and Vermicompost on Growth and Physiological Parameters of Wheat

Treatment	Plant Height at Harvest (cm)	Shoot Dry Weight at Harvest (g/m)	SPAD (60 DAS)	LAI (60 DAS)
NPK Levels				
50%RDF	93.99	167.3	39.44	3.21
75%RDF	99.94	176.7	39.74	3.47
100%RDF*	103.69	206.7	41.76	3.67
S.Em±	1.426	4.2	0.550	0.059
LSD(P=0.05)	3.023	9.6	1.165	0.198
System of sowing				
NP at 22.5cm row	98.29	229.9	39.21	3.43
SWI at 20cm x 20cm	102.98	156.4	40.66	3.56
SWI at 25 cm x 25 cm	96.35	148.9	41.07	3.36
S.Em±	1.426	4.2	0.550	0.059
LSD(P=0.05)	3.023	9.6	1.165	NS
Interaction(S×F)	NS	NS	NS	NS
Vermicompost				
NoVC**	98.26	182.6	40.18	2.98
30kgNha ⁻¹ through VC	100.16	199.3	40.44	3.92
S.Em±	0.840	3.8	0.36	0.18
LSD(P=0.05)	1.765	8.1	NS	0.12
Interaction	5.296	NS	NS	NS

Table 2: Effect of NPK Levels, Sowing System, and Vermicompost on Yield Attributes and Yield of Wheat

Treatment	Effective Tillers (m ⁻²)	Spike Length (cm)	Grains Spike ⁻¹	1000-Grain Weight (g)	Grain Yield (kg/ha)	Straw Yield (kg/ha)	Harvest Index (%)
NPK Levels							
50%RDF	330	10.43	29.32	33.54	3307	5823	36.2
75%RDF	363	11.46	33.47	35.29	3702	6308	37.0
100%RDF*	382	12.36	35.66	36.82	4066	6577	38.2
S.Em±	6.74	0.39	0.65	0.41	47.95	109.35	0.27
LSD(P=0.05)	14.29	0.83	1.37	1.03	101.64	231.80	0.58
System of sowing							
NP at 22.5cm row	354	10.69	31.73	33.97	3688	6494	36.5
SWI at 20cm x 20cm	367	11.87	33.50	37.08	3863	6586	37.3
SWI at 25 cm x 25 cm	354	11.69	33.22	36.60	3524	6128b	35.6
S.Em±	6.74	0.39	0.65	0.41	47.95	109.35	0.27
LSD(P=0.05)	NS	0.83	1.37	1.03	101.64	231.80	0.58
Interaction(S×F)	NS	NS	2.12	3.34	NS	NS	NS
Vermicompost							
NoVC**	339	11.30	30.24	34.55	3226	5739	36.4
30kgNha ⁻¹ throughVC	379	11.54	35.39	36.88	4158	7066	37.2
S.Em±	4.81	0.20	0.46	0.50	25.87	50.60	0.15
LSD(P=0.05)	10.11	NS	0.97	1.06	54.35	106.31	0.30
Interaction	NS	NS	2.91	3.17	163.05	318.94	0.91

Conclusion

Integrated nutrient management, combining optimal NPK levels, the System of Wheat Intensification, and vermicompost, significantly improved wheat growth, physiological efficiency, and yield performance. The synergistic effects enhanced plant stature, chlorophyll content, tiller density, spike development, and grain yield, validating INM as a robust strategy for sustainable wheat production. These findings reinforce the importance of harmonizing inorganic and organic nutrient sources alongside improved agronomic practices for higher productivity and soil health.

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