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PERFORMANCE EVALUATION OF WHEAT (*TRITICUM AESTIVUM* L.) VARIETIES UNDER INTEGRATED NUTRIENT MANAGEMENT STRATEGIES IN THE MANIPUR VALLEY ECOSYSTEM

Leitam Chanu Olivia[1], M. Sumarjit Singh[1] , Diana Shamurailatpam[1], N. Surbala Devi [2], N. Gopimohan Singh[3]

[1]Department of Agronomy, College of Agriculture, Central Agricultural University Imphal, Manipur 795004, India
[2]Department of Soil Science and Agricultural Chemistry, College of Agriculture, Central Agricultural University Imphal, Manipur 795004, India
[3]Department of Basic Science, College of Agriculture, Central Agricultural University Imphal, Manipur 795004, India
Corresponding author: Leitam Chanu Olivia, *oli.leitam@gmail.com*

ABSTRACT

Background: Wheat productivity in the Manipur Valley is constrained by acidic soils, declining nutrient-use efficiency, and the excessive reliance on chemical fertilizers. Integrated nutrient management (INM), combining organic and inorganic nutrient sources, has the potential to enhance crop productivity while sustaining soil health. This study evaluated the performance of wheat varieties under different nutrient management practices to identify the most productive and economically viable combination for the region. Methods: A field experiment was conducted during the rabi seasons of 2022–23 and 2023–24 at the Experimental Farm of the College of Agriculture, Central Agricultural University, Iroishemba, Manipur. The experiment was laid out in a Factorial Randomized Block Design with three replications. Five nutrient management practices were evaluated: recommended dose of fertilizers (M_1), 50% RDF with nano urea sprays (M_2), farmyard manure at 16 t ha^{-1} (M_3), 50% RDF + FYM at 8 t ha^{-1} (M_4), and natural farming using Jeevamrutham and Beejamrutham (M_5). Three wheat varieties, HS-542 (V_1), HS-562 (V_2), and HD-3226 (V_3), were tested. Growth, yield attributes, yield, and economic parameters were recorded and analyzed statistically. Results: Among the varieties, HS-542 (V_1) recorded the highest grain yield (2163.21 kg ha^{-1}), stover yield (4153.80 kg ha^{-1}), spike length (9.36 cm), spikelets per ear (18.91), and filled grains per ear (46.55). Nutrient management significantly influenced crop performance, with M_1 producing the highest grain yield (2639.93 kg ha^{-1}), stover yield (4835.24 kg ha^{-1}), harvest index (35.14%), and test weight (42.58 g), while M_4 performed comparably. The interaction V_1M_1 recorded the maximum grain yield (2969.55 kg ha^{-1}), net return (₹70,296.54 ha^{-1}), and benefit–cost ratio (2.43). Conclusion: HS-542 combined with the recommended fertilizer dose (V_1M_1) was the most productive and profitable treatment. However, integrated nutrient management (M_4) provided comparable productivity and represents a sustainable option for enhancing wheat production and maintaining soil fertility in the Manipur Valley.

KEYWORDS: Wheat, Integrated Nutrient Management, HS-542, Grain Yield, Profitability, Nutrient Use Efficiency, Sustainable Agriculture, Manipur Valley.

INTRODUCTION

Wheat (Triticum aestivum L.) is a vital cereal crop worldwide and serves as a primary source of food and nutritional security. Wheat is vital to agricultural production and rural economies in India. Enhancing wheat productivity has increasingly become challenging due to declining soil fertility, imbalanced fertiliser application, and reduced nutrient-use efficiency, particularly in susceptible agroecosystems. The challenges are especially pronounced in the Manipur Valley of Northeast India, where acidic clay soils, inadequate base saturation, and unique agro-climatic conditions often hinder crop productivity and nutrient availability. Integrated nutrition management (INM), which combines inorganic fertilisers with organic nutrient sources and biological inputs, has emerged as a sustainable method for improving soil fertility and crop yield. The incorporation of organic amendments, such as farmyard manure (FYM), vermicompost, and other organic residues with mineral fertilisers ensures a balanced supply of macro- and micronutrients, enhances soil physical properties, increases microbial activity, and improves nutrient-use efficiency. Integrated approaches have demonstrated the capacity to improve crop growth, biomass accumulation, grain yield, and soil health, while reducing dependence on chemical fertilisers. The acidic soils of Manipur frequently exhibit nutritional deficits and reduced phosphorus availability, resulting in insufficient crop growth and lower fertiliser effectiveness. Extended reliance on chemical fertilisers, without enough organic supplements, has intensified soil degradation and negative nutrient imbalances in various agricultural sectors [4]. Integrated nutrient management can rejuvenate soil biological activity, enhance nutrient cycling, and facilitate the availability of essential nutrients in these contexts [5]. Moreover, a balanced nutrient supply is essential for maximising photosynthetic efficiency, biomass production, assimilate dispersion, and grain development in wheat. Although multiple studies demonstrate the benefits of integrated nutrient management, information regarding the response of different wheat cultivars to various nutrient management systems in the agro-climatic context of the Manipur Valley remains limited.

Genotypic variability in nutrient absorption and utilisation may influence growth, production, and economic returns, underscoring the necessity to identify suitable variety–nutrient management combinations for the region [6]. This study aimed to evaluate the effects of different nutrient management systems on the growth, yield attributes, productivity, and economic feasibility of several wheat cultivars in the Manipur Valley region. The research aimed to determine an efficient and sustainable nitrogen management method that optimises wheat yield while maintaining soil fertility and enhancing resource-use efficiency.

MATERIALS AND METHODS

A field experiment was conducted over two consecutive rabi seasons, 2022–23 and 2023–24, at the Experimental Farm of the College of Agriculture, Central Agricultural University, Iroishemba, Imphal, Manipur, India. The experimental site is situated at 24.8094° N latitude and 93.8932° E longitude, with a height of approximately 790 meters above mean sea level. The region possesses a subtropical climate characterised by cold, arid winters favourable for wheat cultivation. Meteorological data, including temperature, precipitation, and relative humidity during the crop growth period, were obtained from the ICAR, Manipur Centre, Meteorological Observatory.

The experiment employed a Factorial Randomised Block Design (FRBD) with three replications. The interventions comprised two elements: nutritional management measures and wheat varieties. Five nutrient management strategies were evaluated: M_1, the recommended fertiliser dose (RDF) of 80:40:30 kg $N_2O_{52}O$ ha^{-1}; M_2, a basal application of 40:40:30 kg $N_2O_{52}O$ ha^{-1} supplemented with nano urea foliar sprays at the Crown Root Initiation (CRI), jointing, and flowering initiation stages; M_3, farmyard manure (FYM) applied at 16 t ha^{-1}; M_4, integrated nutrient management consisting of 40:40:30 kg $N_2O_{52}O$ ha^{-1} combined with FYM at 8 t ha^{-1}; and M_5, natural farming employing Jeevamrutham and Beejamrutham applications. The research encompassed three wheat cultivars: HS-542 (V_1), HS-562 (V_2), and HD-3226 (V_3). The amalgamation of five nutritional management techniques with three wheat cultivars resulted in fifteen treatment combinations. The experimental field was cultivated by means of successive ploughing and harrowing to attain an optimal tilth. Farmyard manure was incorporated into the soil before sowing in the specified conditions. Seeds intended for the natural farming method were treated with Beejamrutham before sowing. Wheat was sown during the rabi season using the recommended agronomic practices for the region. Fertilisers were applied according to the treatment instructions. In the conventional and integrated nutrient management treatments, phosphorus and potassium were applied as basal doses at planting, whereas nitrogen was supplied according to treatment criteria. Nano urea was applied as a foliar therapy during the CRI, jointing, and flower initiation phases in treatment M_2. Jeevamrutham was administered regularly in the natural farming treatment following prescribed protocols.

Irrigation, weed control, plant protection strategies, and other intercultural practices were uniformly executed across all treatments [8]. Growth observations were recorded from randomly selected plants in each plot at regular intervals during the crop growth period. The germination percentage was evaluated at 20 days after sowing (DAS) by determining the ratio of germinated seedlings to the total seeds sown. Plant height was measured from the soil surface to the tip of the tallest leaf or spike, excluding awns, at 30-day intervals until harvest. The Crop Growth Rate (CGR) was calculated from periodic dry matter accumulation using the formula $CGR = (W_2 - W_1)/(t_2 - t_1) \times (1/A)$, where W_1 and W_2 represent dry matter weights, t_1 and t_2 denote time intervals, and A indicates ground area. The Net Assimilation Rate (NAR) was determined by dry matter and leaf area assessments, employing the formula $NAR = [(W_2 - W_1)\ (\ln L_2 - \ln L_1)]/[(t_2 - t_1)(L_2 - L_1)]$, and is expressed in grams per square meter per day (g m^{-2} day^{-1}) [9]. At physiological maturity, characteristics contributing to yield, including effective tillers, spike length, number of full grains per spike, test weight, grain yield, straw yield, biological yield, and harvest index, were recorded. Grain and straw yields were evaluated on a plot basis and subsequently expressed in kg ha^{-1}. An economic analysis was performed using contemporary market pricing. The expenses of cultivation, total returns, net returns, benefit-cost ratio, relative economic efficiency, and economic nutrient-use efficiency were calculated. Gross returns were determined from grain and straw yields, while net returns were obtained by deducting total cultivation costs from the gross returns. The benefit-cost ratio was calculated by contrasting gross returns with total cultivation expenses. The experimental data collected over the two years were examined using analysis of variance (ANOVA) appropriate for a Factorial Randomised Block Design. The treatment means were evaluated using the Least Significant Difference (LSD) test at a 5% significance threshold. A pooled analysis was performed across years where treatment × year interactions were considered non-significant. Statistical analyses were performed following the procedures specified by Gomez and Gomez [10].

Table 1: Cropping history of the experimental site (for last 5 years).

Year	Kharif	Rabi
2019-2020	Fallow	Fallow
2020-2021	Fallow	Fallow
2021-2022	Maize	Potato

2022-2023	Fallow	Wheat
2023-2024	Fallow	Wheat

Table 2: Meteorological data during the experimental period

Month	**Temperature (^{o}C)**				**Sunshine (hrs)**	**Rainfall (mm)**		**Relative Humidity (%)**				**Sunshine (hrs)**
	2022-2023		2023-2024		2022-2023	2022-2023	2023-2024	2022-2023		2023-2024		2022-2023
	Max.	Min.	Max.	Min.				700h	1300h	700h	1300h	
Nov	27.2	11.9	26.2	13.2	9.2	5.4	63.9	90.8	44.3	87.4	52.7	7.8
Dec	23.7	8.9	23	11	7.7	18.8	47.3	95.3	47.7	86.2	55.1	6.9
Jan	23.6	5.5	22.2	6.4	8.6	0.0	0.0	92.5	35.3	91.1	41.3	9.0
Feb	26.2	9.7	22.9	9.7	7.4	0.0	61.2	81.7	33.4	91.9	45.5	6.7
Mar	27.3	12.3	26.3	13	5.6	36.6	55.7	76.5	37.4	90.9	40.7	6.6
Apr	29.5	15.8	30.2	18.9	7.8	67.8	82.2	68.8	41.5	93.0	48.3	7.0
Total	157.5	64.1	150.8	72.2	46.3	128.6	310.3	505.6	239.6	540.5	283.6	44
Mean	26.25	10.68	25.13	12.03	7.71	21.43	51.71	84.26	39.93	90.08	47.26	7.33

Table 3: Physico-chemical properties of soil at the experimental site

Particulars	**Value**	**Interpretation**	**Method followed**
(a) Physical properties			
Sand (%)	20.50	Clay	Bouyoucos Hydrometer method (Chopra and Kanwar, 1976)
Silt (%)	19.68		
Clay (%)	59.82		
(b) Chemical properties			
pH	5.36	Acidic	Glass electrode pH meter (Jackson, 1973)
Organic carbon (%)	1.28	High	Walkley and Black rapid titration method (Jackson, 1973)
CEC (meq/100g)	19.06	Medium	Conductivity bridge (Richards, 1954)
EC (dS/m)	0.07	Low	1N NH4OAc at pH 7.0 (Chapman, 1965).
Available nitrogen (kg/ha)	246.21	Medium	Macro- Kjedahl method (Jackson, 1967)
Available phosphorus (kg/ha)	25.81	Medium	Bray's method (Bray and Kurtz, 1945)
Available potassium (kg/ha)	310.91	High	Flame Photometer method (Jackson, 1973)

Figure 1. Experimental Field for study and wheat sample

Figure 2 Growth phase of fully developed wheat plant

Table 4: Effect on field germination due to different varieties of wheat at 20 DAS (%) as influenced by different nutrient management techniques

Treatments	Field germination at 20 days after sowing (%)		
	2022-2023	2023-2024	pooled
V1	91.80	92.13	91.97
V2	92.47	92.07	92.27
V3	92.00	92.20	92.10
S.Em(±)	**0.20**	**0.17**	**0.18**
CD(p=0.05)	**0.59**	**NS**	**NS**
M1	92.22	91.56	91.89
M2	92.22	91.56	91.89
M3	91.67	92.78	92.22
M4	92.11	92.67	92.39
M5	92.22	92.11	92.17
S.Em(±)	**0.26**	**0.21**	**0.24**
CD(p=0.05)	**NS**	**0.66**	**NS**

Table 5: Interaction effect on field germination due to different varieties of wheat at 20 DAS (%) as influenced by different nutrient management techniques

Treatments	**Field germination at 20 days after sowing (%)**		
	2022-2023	**2023-2024**	**pooled**
V1M1	92.00	91.67	91.83
V1M2	92.00	91.33	91.67
V1M3	91.33	93.00	92.17
V1M4	91.33	92.33	91.83
V1M5	92.33	92.33	92.33
V2M1	92.67	91.33	92.00
V2M2	92.33	91.67	92.00
V2M3	92.33	93.00	92.67
V2M4	92.67	93.00	92.83
V2M5	92.33	91.33	91.83
V3M1	92.00	91.67	91.83
V3M2	92.33	91.67	92.00
V3M3	91.33	92.33	91.83
V3M4	92.33	92.67	92.50
V3M5	92.00	92.67	92.33
S.Em(±)	**0.45**	**0.39**	**0.41**
CD(p=0.05)	**NS**	**1.20**	**NS**

Table 6: Effect on Plant height(cm) due to different varieties of wheat at 30 DAS, 60 DAS, 90 DAS and at harvest as influenced by different nutrient management techniques

Treatments	**Plant height(cm) at 30 DAS**			**Plant height(cm) at 60 DAS**			**Plant height(cm) at 90 DAS**			**Plant height(cm) at harvest**		
	2022-2023	**2023-2024**	**Pooled**	**2022-2023**	**2023-2024**	**Pooled**	**2022-2023**	**2023-2024**	**Pooled**	**2022-2023**	**2023-2024**	**Pooled**
V1	14.33	14.03	14.18	37.83	38.10	37.96	76.67	77.13	76.90	77.08	77.48	77.28
V2	13.33	13.18	13.26	35.48	36.22	35.85	75.48	74.53	75.00	76.17	74.94	75.56
V3	13.07	12.54	12.86	32.86	32.92	32.89	73.03	72.86	72.94	74.05	73.30	73.67
S.Em(±)	**0.40**	**0.36**	**0.39**	**0.15**	**0.43**	**0.45**	**0.93**	**0.71**	**0.83**	**0.72**	**0.60**	**0.58**

CD(p=0.05)	**NS**	**NS**	**NS**	**1.53**	**1.30**	**1.37**	**2.80**	**2.17**	**2.44**	**2.15**	**1.83**	**1.65**
M1	16.33	16.50	16.42	39.41	39.68	39.54	79.37	78.73	79.05	81.11	79.13	80.12
M2	14.22	14.09	14.16	37.63	37.38	37.50	76.01	75.97	75.99	76.99	76.30	76.65
M3	12.78	13.53	13.16	31.99	33.21	32.60	72.64	72.34	72.49	72.66	72.90	72.78
M4	15.22	15.40	15.31	38.88	38.93	38.90	78.25	78.60	78.42	78.72	78.93	78.83
M5	12.67	13.40	13.03	29.04	29.53	29.29	69.02	68.54	68.78	69.36	68.93	69.14
S.Em(±)	**0.51**	**0.43**	**0.43**	**0.70**	**0.63**	**0.63**	**1.21**	**1.14**	**1.17**	**0.93**	**0.81**	**0.81**
CD(p=0.05)	**1.55**	**1.29**	**1.29**	**2.07**	**1.90**	**1.90**	**3.65**	**3.43**	**3.52**	**2.80**	**2.45**	**2.45**

Table 7: Interaction effect on Plant height(cm) due to different varieties of wheat at 30 DAS, 60 DAS, 90 DAS and at harvest as influenced by different nutrient management techniques

Treatments	**Plant height(cm) at 30 DAS**			**Plant height(cm) at 60 DAS**			**Plant height(cm) at 90 DAS**			**Plant height(cm) at harvest**		
	2022-2023	**2023-2024**	**Pooled**	**2022-2023**	**2023-2024**	**Pooled**	**2022-2023**	**2023-2024**	**Pooled**	**2022-2023**	**2023-2024**	**Pooled**
V1M1	18.00	19.10	18.55	40.55	41.55	41.05	81.00	80.60	80.80	82.14	80.90	81.52
V1M2	17.00	16.77	16.88	42.33	42.03	42.18	77.67	78.20	77.93	78.60	78.40	78.50
V1M3	15.67	16.10	15.88	36.85	35.92	36.38	75.00	74.33	74.67	74.34	74.90	74.62
V1M4	16.33	18.00	17.17	39.00	40.10	39.55	79.33	80.70	80.02	80.00	81.20	80.60
V1M5	14.67	15.20	14.93	30.40	30.90	30.65	70.33	71.80	71.07	70.33	72.00	71.17
V2M1	16.00	16.50	16.25	39.33	39.90	39.62	80.00	79.40	79.70	81.17	79.80	80.48
V2M2	12.33	13.40	12.87	36.67	37.00	36.83	75.67	75.10	75.38	77.17	75.60	76.38
V2M3	11.00	13.00	12.00	31.33	35.30	33.32	73.00	72.60	72.80	73.47	73.00	73.23
V2M4	15.33	15.20	15.27	40.33	38.80	39.57	79.00	78.20	78.60	79.17	78.50	78.83
V2M5	12.00	12.80	12.40	29.72	30.10	29.91	69.73	67.33	68.53	69.90	67.80	68.85
V3M1	15.00	13.90	14.45	38.33	37.60	37.97	77.11	76.20	76.66	80.03	76.70	78.37

V3M2	13.33	12.10	12.72	33.89	33.10	33.49	74.70	74.60	74.65	75.20	74.90	75.05
V3M3	11.67	11.50	11.58	27.78	28.40	28.09	69.91	70.10	70.00	70.17	70.80	70.48
V3M4	14.00	13.00	13.50	37.29	37.90	37.60	76.41	76.90	76.65	77.00	77.10	77.05
V3M5	11.33	12.20	11.77	27.00	27.60	27.30	67.00	66.50	66.75	67.83	67.00	67.42
S.Em(±)	**0.89**	**0.88**	**0.89**	**1.22**	**1.15**	**1.19**	**2.09**	**1.88**	**2.05**	**1.62**	**1.59**	**1.60**
CD(p=0.05)	**2.67**	**2.65**	**2.67**	**3.67**	**3.46**	**3.58**	**6.27**	**5.65**	**6.16**	**4.87**	**4.78**	**4.81**

Table 8: Effect on CGR (g/m2/day) due to different varieties of wheat at 30-60 DAS and 60-90 DAS as influenced by different nutrient management techniques

Treatments	**CGR (g/m2/day) at 30-60 DAS**			**CGR (g/m2/day) 60-90 DAS**		
	2022-2023	2023-2024	pooled	2022-2023	2023-2024	pooled
V1	11.40	11.91	11.66	21.04	20.90	20.97
V2	11.27	11.28	11.27	20.90	20.73	20.82
V3	10.66	10.25	10.46	20.32	20.08	20.20
S.Em(±)	**0.15**	**0.18**	**0.17**	**0.17**	**0.23**	**0.22**
CD(p=0.05)	**0.48**	**0.55**	**0.52**	**0.52**	**0.70**	**0.62**
M1	12.38	12.38	12.38	23.59	21.26	22.43
M2	11.67	11.47	11.57	20.87	20.61	20.74
M3	10.57	10.71	10.64	18.60	20.48	19.54
M4	11.91	12.02	11.97	22.84	21.69	22.26
M5	9.02	9.15	9.09	19.54	20.17	19.85
S.Em(±)	**0.19**	**0.23**	**0.22**	**0.22**	**0.24**	**0.21**
CD(p=0.05)	**0.60**	**0.71**	**0.68**	**0.68**	**0.73**	**0.63**

Table 9: Interaction effect on CGR (g/m2/day) due to different varieties of wheat at 30-60 DAS and 60-90 DAS as influenced by different nutrient management techniques

Treatments	**CGR (g/m2/day) at 30-60 DAS**	**CGR (g/m2/day) at 60-90 DAS**

	2022-2023	**2023-2024**	**pooled**	**2022-2023**	**2023-2024**	**pooled**
V1M1	12.97	12.82	12.89	23.25	21.81	22.53
V1M2	11.81	12.83	12.32	21.05	19.74	20.39
V1M3	10.82	12.19	11.50	18.66	19.76	19.21
V1M4	12.10	12.16	12.13	22.71	22.48	22.60
V1M5	9.30	9.57	9.44	19.52	20.72	20.12
V2M1	12.64	12.34	12.49	23.11	21.70	22.41
V2M2	11.82	11.41	11.61	20.71	20.51	20.61
V2M3	10.61	11.09	10.85	18.54	20.22	19.38
V2M4	12.01	12.22	12.12	22.74	21.59	22.17
V2M5	9.25	9.34	9.30	19.40	19.65	19.53
V3M1	11.54	11.98	11.76	24.41	20.28	22.34
V3M2	11.39	10.17	10.78	20.85	21.57	21.21
V3M3	10.27	8.85	9.56	18.60	21.44	20.02
V3M4	11.61	11.69	11.65	23.06	21.00	22.03
V3M5	8.49	8.56	8.52	19.70	20.13	19.91
S.Em(±)	**0.34**	**0.41**	**0.37**	**0.38**	**0.48**	**0.49**
CD(p=0.05)	**1.08**	**1.24**	**1.05**	**1.17**	**1.46**	**1.49**

Table 10: Effect on NAR (g/m2/day) due to different varieties of wheat at 30-60 DAS and 60-90 DAS as influenced by different nutrient management techniques

Treatments	**NAR (g/m2/day) 30-60 DAS**			**NAR (g/m2/day) 60-90 DAS**		
	2022-2023	2023-2024	pooled	2022-2023	2023-2024	pooled
V1	0.14	0.15	0.14	0.08	0.08	0.08
V2	0.14	0.14	0.14	0.08	0.08	0.08
V3	0.14	0.13	0.14	0.08	0.08	0.08
S.Em(±)	**0.01**	**0.01**	**0.01**	**0.01**	**0.01**	**0.01**
CD(p=0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
M1	0.14	0.14	0.14	0.08	0.07	0.07
M2	0.13	0.14	0.14	0.07	0.07	0.07
M3	0.14	0.14	0.14	0.08	0.08	0.08

M4	0.15	0.16	0.15	0.09	0.08	0.08
M5	0.13	0.13	0.13	0.09	0.08	0.08
S.Em(±)	**0.02**	**0.02**	**0.02**	**0.02**	**0.02**	**0.02**
CD(p=0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**

Table 11: Interaction effect on NAR (g/m2/day) of different varieties of wheat at 30-60 DAS and 60-90 DAS as influenced by different nutrient management techniques

Treatments	**NAR (g/m2/day) 30-60 DAS**			**NAR (g/m2/day) 60-90 DAS**		
	2022-2023	**2023-2024**	**pooled**	**2022-2023**	**2023-2024**	**pooled**
V1M1	0.14	0.14	0.14	0.08	0.07	0.07
V1M2	0.13	0.15	0.14	0.07	0.07	0.07
V1M3	0.14	0.16	0.15	0.08	0.08	0.08
V1M4	0.15	0.16	0.15	0.08	0.09	0.09
V1M5	0.13	0.13	0.13	0.08	0.08	0.08
V2M1	0.14	0.14	0.14	0.08	0.07	0.08
V2M2	0.13	0.14	0.14	0.07	0.07	0.07
V2M3	0.14	0.14	0.14	0.08	0.08	0.08
V2M4	0.15	0.16	0.15	0.09	0.08	0.08
V2M5	0.13	0.13	0.13	0.09	0.08	0.08
V3M1	0.14	0.14	0.14	0.08	0.07	0.08
V3M2	0.13	0.13	0.13	0.07	0.08	0.07
V3M3	0.14	0.12	0.13	0.08	0.09	0.08
V3M4	0.15	0.15	0.15	0.09	0.08	0.09
V3M5	0.13	0.12	0.13	0.09	0.08	0.09
S.Em(±)	**0.04**	**0.04**	**0.04**	**0.04**	**0.04**	**0.04**
CD(p=0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**

Table 12: Effect on effective tillers/plant and spike length (cm) due to different varieties of wheat as influenced by different nutrient management techniques

Treatments	**Effective tillers/plant**			**Spike length (cm)**		
	2022-2023	2023-2024	pooled	2022-2023	2023-2024	pooled
V1	2.15	2.44	2.29	9.27	9.46	9.36

V2	2.23	2.35	2.29	8.79	9.10	8.94
V3	2.02	2.28	2.15	8.63	8.95	8.79
S.Em(±)	**0.10**	**0.07**	**0.09**	**0.09**	**0.08**	**0.07**
CD(p=0.05)	**NS**	**NS**	**NS**	**0.28**	**0.26**	**0.23**
M1	2.61	2.66	2.63	9.7	9.91	9.81
M2	2.28	2.35	2.32	8.93	8.89	8.91
M3	2.13	2.23	2.18	8.58	8.9	8.74
M4	2.41	2.82	2.62	9.31	9.67	9.49
M5	1.24	1.7	1.47	7.94	8.48	8.21
S.Em(±)	**0.08**	**0.09**	**0.10**	**0.25**	**0.20**	**0.19**
CD(p=0.05)	**0.25**	**0.28**	**0.31**	**0.76**	**0.62**	**0.60**

Table 13: Interaction effect on effective tillers/plant and spike length (cm) due to different varieties of wheat as influenced by different nutrient management techniques

Treatments	**Effective tillers/plant**			**Spike length (cm)**		
	2022-2023	2023-2024	pooled	2022-2023	2023-2024	pooled
V1M1	2.79	2.90	2.84	10.10	10.23	10.17
V1M2	2.19	2.28	2.24	9.13	9.23	9.18
V1M3	2.00	2.24	2.12	9.03	9.17	9.10
V1M4	2.45	2.96	2.71	9.73	9.97	9.85
V1M5	1.33	1.80	1.57	8.33	8.70	8.52
V2M1	2.82	2.70	2.76	9.60	9.83	9.72
V2M2	2.44	2.37	2.41	8.67	8.67	8.67
V2M3	2.22	2.19	2.21	8.53	8.87	8.70
V2M4	2.52	2.88	2.70	8.97	9.60	9.28
V2M5	1.17	1.61	1.39	8.17	8.53	8.35
V3M1	2.22	2.38	2.30	9.40	9.67	9.53
V3M2	2.22	2.40	2.31	9.00	8.77	8.88
V3M3	2.17	2.27	2.22	8.17	8.67	8.42
V3M4	2.27	2.63	2.45	9.23	9.43	9.33

V3M5	1.23	1.70	1.47	7.33	8.20	7.77
S.Em(±)	**0.22**	**0.16**	**0.19**	**0.43**	**0.41**	**0.43**
CD(p=0.05)	**0.67**	**0.49**	**0.58**	**1.32**	**1.27**	**1.32**

Table 14: Effect on number of spikelets/ear and Number of filled grains/ear due to different varieties of wheat as influenced by different nutrient management techniques

Treatments	**Number of spikelets/ear**			**Number of filled grains/ear**		
	2022-2023	2023-2024	pooled	2022-2023	2023-2024	pooled
V1	18.83	18.99	18.91	44.94	48.15	46.55
V2	17.99	18.42	18.20	42.68	46.37	44.53
V3	17.13	17.88	17.51	41.19	44.85	43.02
S.Em(±)	**0.25**	**0.19**	**0.21**	**0.38**	**0.39**	**0.39**
CD(p=0.05)	**0.75**	**0.59**	**0.65**	**1.15**	**1.18**	**1.17**
M1	19.68	19.70	19.69	48.97	49.24	49.11
M2	18.07	17.77	17.92	43.38	44.74	44.06
M3	17.07	17.88	17.47	40.25	45.55	42.9
M4	18.70	19.47	19.08	45.80	48.68	47.24
M5	16.40	17.33	16.86	36.28	44.09	40.19
S.Em(±)	**0.32**	**0.25**	**0.28**	**0.49**	**0.50**	**0.50**
CD(p=0.05)	**0.97**	**0.76**	**0.84**	**1.49**	**1.52**	**1.50**

Table 15: Interaction effect on number of spikelets/ear and Number of filled grains/ear due to different varieties of wheat as influenced by different nutrient management techniques

Treatments	**Number of spikelets/ears**			**Number of filled grains/ear**		
	2022-2023	**2023-2024**	**pooled**	**2022-2023**	**2023-2024**	**pooled**
V1M1	20.55	20.40	20.48	51.37	51.00	51.19
V1M2	18.55	18.10	18.32	44.51	47.00	45.76
V1M3	17.69	18.33	18.01	41.53	45.73	43.63

V1M4	19.80	20.50	20.15	48.49	51.27	49.88
V1M5	17.56	17.60	17.58	38.78	45.76	42.27
V2M1	19.38	19.50	19.44	48.44	48.71	48.57
V2M2	17.56	17.80	17.68	42.13	43.82	42.98
V2M3	17.31	18.10	17.70	40.66	47.81	44.24
V2M4	18.20	19.10	18.65	44.59	47.53	46.06
V2M5	17.48	17.60	17.54	37.55	44.00	40.77
V3M1	19.10	19.20	19.15	47.09	48.02	47.56
V3M2	18.10	17.40	17.75	43.49	43.40	43.45
V3M3	16.22	17.20	16.71	38.55	43.10	40.83
V3M4	18.09	18.80	18.45	44.31	47.23	45.77
V3M5	14.14	16.80	15.47	32.52	42.50	37.51
S.Em(±)	**0.56**	**0.44**	**0.48**	**0.86**	**0.87**	**0.87**
CD(p=0.05)	**1.68**	**1.32**	**1.45**	**2.58**	**2.63**	**2.61**

Table 16: Effect on Test weight (g) and Grain yield (kg/ha) due to different varieties of wheat as influenced by different nutrient management techniques.

Treatments	**Test weight (g)**			**Grain yield (kg/ha)**		
	2022-2023	2023-2024	pooled	2022-2023	2023-2024	pooled
V1	41.92	42.13	42.03	1959.02	2367.39	2163.21
V2	41.87	42.05	41.96	1921.88	2178.80	2050.34
V3	41.86	41.95	41.90	1670.76	2029.24	1850.00
S.Em(±)	**0.10**	**0.12**	**0.11**	**45.74**	**61.87**	**54.41**
CD(p=0.05)	**NS**	**NS**	**NS**	**137.24**	**185.91**	**164.21**
M1	42.63	42.52	42.58	2618.11	2661.76	2639.93
M2	41.89	42.13	42.01	1947	2087.90	2017.45

M3	41.51	41.61	41.56	1658.61	1977.77	1818.19
M4	42.44	42.49	42.47	2227.26	2803.40	2515.33
M5	40.94	41.46	41.20	801.80	1428.21	1115.00
S.Em(±)	**0.13**	**0.15**	**0.14**	**59.05**	**79.88**	**70.24**
CD(p=0.05)	**0.41**	**0.46**	**0.43**	**178.05**	**240.14**	**211.12**

Table 17: Interaction effect on Test weight (g) and Grain yield (kg/ha) due to different varieties of wheat as influenced by different nutrient management techniques

Treatments	**Test weight (g)**			**Grain yield (kg/ha)**		
	2022-2023	**2023-2024**	**pooled**	**2022-2023**	**2023-2024**	**pooled**
V1M1	42.66	42.57	42.61	2934.15	3004.95	2969.55
V1M2	41.91	42.10	42.01	1918.38	2139.34	2028.86
V1M3	41.56	41.70	41.63	1608.67	1989.46	1799.06
V1M4	42.45	42.60	42.53	2398.69	3109.04	2753.87
V1M5	41.02	41.70	41.36	935.23	1594.15	1264.69
V2M1	42.62	42.40	42.51	2784.66	2667.92	2726.29
V2M2	41.82	42.00	41.91	2028.98	2046.52	2037.75
V2M3	41.54	41.83	41.69	1756.57	2045.97	1901.27
V2M4	42.45	42.43	42.44	2263.54	2781.18	2522.36
V2M5	40.93	41.57	41.25	775.65	1352.39	1064.02
V3M1	42.61	42.60	42.60	2135.52	2312.40	2223.96
V3M2	41.94	42.30	42.12	1893.64	2077.86	1985.75
V3M3	41.43	41.30	41.37	1610.61	1897.88	1754.25
V3M4	42.43	42.43	42.43	2019.55	2519.99	2269.77
V3M5	40.87	41.10	40.99	694.51	1338.07	1016.29
S.Em(±)	**0.22**	**0.26**	**0.24**	**102.28**	**138.36**	**121.66**
CD(p=0.05)	**0.67**	**0.79**	**0.73**	**306.42**	**416.08**	**365.18**

Table 18: Effect on Stover yield (kg/ha) and Harvest index (%) due to different varieties of wheat as influenced by different nutrient management techniques

Treatments	**Stover yield (kg/ha)**	**Harvest index (%)**

	2022-2023	2023-2024	pooled	2022-2023	2023-2024	pooled
V1	4105.53	4202.06	4153.80	31.35	35.88	33.61
V2	4002.00	4006.98	4004.49	31.67	35.01	33.34
V3	3632.00	3982.70	3807.35	30.60	33.58	32.09
S.Em(±)	**93.18**	**52.01**	**77.02**	**0.53**	**0.54**	**0.55**
CD(p=0.05)	**281.44**	**156.99**	**231.88**	**1.62**	**1.64**	**1.65**
M1	4755.56	4914.93	4835.24	35.38	34.90	35.14
M2	4060.00	4070.00	4065.00	32.39	33.90	33.15
M3	3426.67	3488.83	3457.75	32.59	36.16	34.38
M4	4615.56	4895.20	4755.38	32.91	36.35	34.63
M5	2708.11	2950.60	2829.36	22.76	32.82	27.79
S.Em(±)	**120.71**	**67.52**	**99.67**	**0.69**	**0.70**	**0.70**
CD(p=0.05)	**363.33**	**202.67**	**299.36**	**2.10**	**2.11**	**2.12**

Table 19: Interaction effect on Stover yield (kg/ha) and Harvest index (%) due to different varieties of wheat as influenced by different nutrient management techniques.

Treatments	**Stover yield (kg/ha)**			**Harvest index (%)**		
	2022-2023	**2023-2024**	**pooled**	**2022-2023**	**2023-2024**	**pooled**
V1M1	5066.67	5142.20	5104.43	36.66	36.88	36.77
V1M2	4073.33	4210.40	4141.87	32.01	33.69	32.85
V1M3	3470.00	3554.10	3512.05	31.65	35.86	33.76
V1M4	4846.67	4958.40	4902.53	33.10	38.53	35.82
V1M5	3071.00	3145.20	3108.10	23.32	34.42	28.87
V2M1	5023.33	4951.30	4987.32	35.64	35.01	35.33
V2M2	4173.33	4005.40	4089.37	32.69	33.79	33.24
V2M3	3350.00	3410.00	3380.00	34.37	37.49	35.93
V2M4	4750.00	4823.00	4786.50	33.47	36.57	35.02
V2M5	2713.33	2845.20	2779.27	22.17	32.21	27.19

V3M1	4176.67	4651.30	4413.98	33.83	32.80	33.31
V3M2	3933.33	3994.20	3963.77	32.48	34.21	33.34
V3M3	3460.00	3502.40	3481.20	31.75	35.14	33.44
V3M4	4250.00	4904.20	4577.10	32.17	33.94	33.06
V3M5	2340.00	2861.40	2600.70	22.78	31.82	27.30
S.Em(±)	**209.10**	**117.12**	**172.51**	**1.21**	**1.21**	**1.22**
CD(p=0.05)	**629.31**	**351.04**	**518.50**	**3.63**	**3.66**	**3.68**

Table 20: Economic analysis of different varieties of wheat as influenced by different nutrient management techniques

Treatments	Cost of cultivation (Rs/ha)	Gross return (Rs/ha)	Net return (Rs/ha)	Benefit cost ratio	Relative economic efficiency (%)	Economic nutrient use efficiency (%)
V1M1	10256	119247.54	70296.54	2.43	243.60	685.41
V1M2	9498	83435.71	35242.71	1.73	173.12	371.05
V1M3	17824	73503.25	16984.25	1.30	130.05	95.28
V1M4	16024	111093.04	56374.04	2.03	203.02	351.81
V1M5	1795	53588.45	13098.45	1.32	132.34	729.71
V2M1	10256	110382.11	61431.11	2.25	225.49	598.97
V2M2	9498	83589.36	35396.36	1.73	173.44	372.67
V2M3	17824	76684.45	20165.45	1.35	135.67	113.13
V2M4	16024	102642.1	47923.1	1.87	187.58	299.07
V2M5	1795	45578.51	5088.51	1.12	112.56	283.48
V3M1	10256	91080.54	42129.54	1.86	186.06	410.77
V3M2	9498	81392.56	33199.56	1.68	168.88	349.54
V3M3	17824	71842.35	15323.35	1.27	127.11	85.97

V3M4	16024	93173.25	38454.25	1.70	170.27	239.97
V3M5	1795	43372.25	2882.25	1.07	107.11	160.57

RESULTS

Field germination at 20 days post-sowing was not significantly influenced by wheat varieties or nutrient management strategies in the aggregated analysis (Tables 4 and 5), indicating uniform crop establishment across treatments. Among the varieties, V_2 (HS-562) exhibited the highest pooled germination rate at 92.27%, succeeded by V_3 (HD-3226) at 92.10% and V_1 (HS-542) at 91.97%. Notwithstanding significant varietal differences documented in 2022–23, these inconsistencies were not maintained in the consolidated data.

Nutrient management measures did not dramatically affect pooled germination. The highest germination rate was seen in M_4 (Integrated Nutrient Management) at 92.39%, followed by M_3 at 92.22%, M_5 at 92.17%, and both M_1 and M_2 at 91.89%. The interaction effect between varieties and nutrient management strategies was negligible. Among the treatment combinations, V_2M_4 displayed the greatest aggregated germination rate at 92.83%, whereas V_1M_2 exhibited the lowest at 91.67%.

The minimal impact of nutrition management on germination can be attributed to the dominance of seed quality and environmental variables over nutrient availability during the initial growth phase. Plant height demonstrated a continuous increase from 30 days post-sowing until harvest in both years of the study (Tables 6 and 7). The aggregated investigation demonstrated significant varietal discrepancies in plant height at 60 days after sowing (DAS), 90 DAS, and at harvest. Variety V_1 (HS-542) demonstrated the highest plant heights, measuring 37.96 cm, 76.90 cm, and 77.28 cm at 60 DAS, 90 DAS, and harvest, respectively, whereas V_3 (HD-3226) exhibited the lowest values.

Nutrient management strategies significantly influenced plant height at all growth stages. The highest pooled plant height was seen in M_1 (RDF at 80:40:30 kg $N_2O_{52}O$ ha^{-1}), which was statistically similar to M_4 (Integrated Nutrient Management). The lowest plant height was observed under M_5 (Natural Farming). The enhanced growth noted under M_1 and M_4 can be attributed to the adequate and balanced supply of nutrients, particularly nitrogen, which facilitated vegetative growth and biomass accumulation.

The interaction between wheat varieties and nutrition management systems significantly influenced plant height at all growth stages. Thirty days post-sowing, the highest pooled plant height of 18.55 cm was recorded for V_1M_1 (HS-542 with RDF at 80:40:30 kg $N_2O_{52}O$ ha^{-1}), while the lowest height of 11.58 cm was seen for V_3M_3. Sixty days post-sowing, V_1M_2 displayed the maximum plant height (42.18 cm), whilst V_3M_5 exhibited the minimum height (27.30 cm). A similar trend was observed at 90 DAS and harvest, with V_1M_1 demonstrating the tallest plants (80.80 cm and 81.52 cm, respectively), whilst V_3M_5 exhibited the shortest plants (66.75 cm and 67.42 cm, respectively). The increased growth seen under V_1M_1 and V_1M_4 indicates HS-542's enhanced responsiveness to optimal nutrient availability under sanctioned fertiliser and integrated nutrient management systems, resulting in superior vegetative growth and biomass accumulation (Table 6).

The Crop Growth Rate (CGR) was significantly influenced by both wheat varieties and nutrient management practices during the periods of 30–60 days after sowing (DAS) and 60–90 DAS. Among the varieties, V_1 demonstrated the highest pooled CGR of 11.66 g m^{-2} day^{-1} from 30 to 60 DAS and 20.97 g m^{-2} day^{-1} from 60 to 90 DAS, remaining statistically comparable to V_2 but significantly exceeding V_3, which presented the lowest CGR values of 10.46 and 20.20 g m^{-2} day^{-1}, respectively.

The heightened CGR seen in V_1 can be attributed to its enhanced growth vigour, augmented photosynthetic efficiency, and greater dry matter accumulation.

Nutrient management tactics markedly affected the crop growth rate in both growth phases.

Between 30- and 60-days post-sowing, the highest pooled crop growth rate (CGR) was seen in M_1 (12.38 g m^{-2} day^{-1}), succeeded by M_4 (11.97 g m^{-2} day^{-1}), whereas the lowest was recorded in M_5 (9.09 g m^{-2} day^{-1}). In the interval of 60–90 DAS, M_1 demonstrated the highest aggregated CGR at 22.43 g m^{-2} day^{-1}, followed closely by M_4 at 22.26 g m^{-2} day^{-1}, whilst M_5 recorded the lowest at 19.85 g m^{-2} day^{-1}. The heightened CGR in M_1 and M_4 can be attributed to the steady and balanced nutrient provision, which promoted vigorous crop growth, enhanced assimilate generation, and augmented dry matter accumulation throughout the growth phase.

Optimal Tillers per Plant and Spike Length

Tables 8 and 9 demonstrate that the quantity of effective tillers per plant and spike length were influenced by wheat varieties and nutrition management approaches.

The number of effective tillers per plant shown no significant variation across the wheat varieties in either year or in the combined analysis. However, V_1 and V_2 had higher numerical values (2.29), followed by V_3 (2.15). The enhanced tiller production in V_1 and V_2 can be attributed to their superior genetic capacity for tiller development and survival under the prevailing agro-climatic circumstances (Table 7). Nutrient management strategies significantly influenced the number of effective tillers per plant. The highest total count of effective tillers was observed in M_1 (2.63), which was statistically similar to M_4 (2.62) but significantly above M_2 (2.32), M_3 (2.18), and M_5 (1.47). The minimal value was documented under M_5. The superior performance of M_1 and M_4 can be attributed to adequate and balanced nutrient availability, which promoted vigorous vegetative growth, enhanced tiller start, and improved tiller survival. Spike length was significantly affected by both wheat varieties and nutrient management practices. Among the variations, V_1 exhibited the longest pooled spike length (9.36 cm) and significantly surpassed V_2 (8.94 cm) and V_3 (8.79 cm), while V_2 and V_3 were statistically similar. The extended spikes observed in V_1 may be attributed to its superior genetic capacity and augmented assimilate production and translocation to developing spikes.

Of the nutrient management techniques, M_1 demonstrated the greatest pooled spike length (9.81 cm), followed by M_4 (9.49 cm), whilst M_5 presented the lowest measurement (8.21 cm). M_1 was statistically comparable to M_4, and both treatments shown significant superiority over the alternative nutrient management strategies. The increased spike length under M_1 and M_4 can be attributed to enhanced nutrient availability during the crop growth period, promoting better spike development and resource allocation to reproductive structures. Overall, wheat varieties did not significantly influence the number of effective tillers per plant, while V_1 and V_2 exhibited numerically higher tiller counts compared to V_3. In contrast, spike length was significantly affected by varietal differences, with V_1 producing the longest spikes. Nutrient management strategies significantly influenced the number of effective tillers per plant and spike length, with M_1 and M_4 consistently outperforming other treatments, hence illustrating their effectiveness in improving wheat productivity in the agro-climatic conditions of the Manipur Valley.

Interaction Effect on Effective Tillers per Plant and Spike Length

The interplay between wheat cultivars and nutrition management strategies markedly affected both the number of effective tillers per plant and spike length. The highest pooled value for effective tillers per plant was seen in V_2M_1 (2.76), followed by V_1M_4 (2.71) and V_2M_4 (2.70), which were statistically comparable. The minimum quantity of effective tillers was recorded for V_2M_5 (1.39), succeeded by V_3M_5 (1.47) and V_1M_5 (1.57). The enhanced efficacy of combinations featuring M_1 and M_4 can be ascribed to superior nutrient availability, augmented vegetative growth, and increased tiller viability, while the diminished values associated with M_5 suggest insufficient nutrient provision for optimal tiller development (tables 9, 10, 11).

A comparable trend was noted for spike length. The highest pooled spike length was seen in V_1M_1 (10.17 cm), succeeded by V_1M_4 (9.85 cm), V_2M_1 (9.72 cm), and V_3M_1 (9.53 cm), which exhibited statistical equivalence. The shortest spike length was recorded for V_3M_5 (7.77 cm), succeeded by V_2M_5 (8.35 cm) and V_3M_3 (8.42 cm). The extended spikes under V_1M_1 and V_1M_4 may result from the greater genetic potential of V_1 and the sufficient nutrition supply from traditional and integrated nutrient management approaches, which enhanced spike growth and assimilate translocation.

The interaction results demonstrated that nutrient management strategies M_1 and M_4 were more efficacious across varieties, especially when paired with V_1 and V_2, leading to enhanced tiller production and spike growth. Conversely, combinations including M_5 consistently exhibited the lowest values for both metrics, underscoring the significance of sufficient nutrient availability in promoting wheat development and production characteristics within the agro-climatic context of the Manipur Valley.

Number of Spikelets per Ear and Number of Filled Grains per Ear as Influenced by Wheat Varieties and Nutrient Management Practices

The data in Tables 12 and 13 demonstrated that both wheat types and nutrition management strategies significantly affected the number of spikelets per ear and the number of filled grains per ear over both years of testing and in the pooled analysis. The yield-attributing characteristics are crucial in ascertaining eventual grain production, since they indicate the crop's efficiency in utilising available resources during the reproductive phase.

Among the wheat types, V_1 had the highest average number of spikelets per ear (18.91), succeeded by V_2 (18.20) and V_3 (17.51). According to the aggregated critical difference (CD) value of 0.65, V_1 had a significant superiority over both V_2 and V_3, while V_2 also showed a notable advantage over V_3. The exceptional performance of V_1 can be ascribed to its intrinsic genetic potential for spike development, increased nutritional absorption capability, and effective transport of assimilates to reproductive organs, leading to improved spikelet creation. The relatively fewer spikelets noted in V_3 indicates diminished reproductive efficacy and spike development.

Nutrient management strategies also substantially influenced the quantity of spikelets per ear. The maximum pooled value was observed in M_1 (19.69), which was statistically comparable to M_4 (19.08), since the difference between them was below the pooled critical difference of 0.84. Both treatments demonstrated significant superiority above M_2 (17.92), M_3 (17.47), and M_5 (16.86). The minimum value documented under M_5 signifies insufficient nutrition availability throughout the crucial phases of spike initiation and development. The enhanced performance of M_1 and M_4 can be ascribed to a consistent and equitable nutrient provision that promoted improved spike differentiation, meristematic activity, and spikelet development.

Impact on the Quantity of Filled Grains per Ear

A notable disparity in the quantity of full grains per ear was detected among the wheat cultivars. The maximum aggregated count of filled grains per ear was seen in V_1 (46.55), succeeded by V_2 (44.53) and V_3 (43.02). As the disparities among the variations surpassed the pooled critical difference value of 1.17, all three kinds exhibited substantial differences from each other. The increased grain filling capacity of V_1 may correlate with enhanced photosynthetic efficiency, improved assimilate translocation, and augmented sink strength during grain growth. In contrast, the diminished quantity of full grains in V_3 indicates suboptimal grain placement and decreased efficacy in assimilate distribution.

Among the nutrient management approaches, M_1 exhibited the highest average number of filled grains per ear (49.11), succeeded by M_4 (47.24), M_2 (44.06), M_3 (42.90), and M_5 (40.19). Statistical analysis indicated that M_1 was markedly superior to all other treatments, although M_4 demonstrated considerable superiority over M_2, M_3, and M_5. The augmented grain filling noted in M_1 and M_4 can be ascribed to greater nutrient availability during the crop growth period, resulting in elevated photosynthetic activity, improved pollen viability, increased grain set, and effective transport of assimilates to the developing grains.

Nutrient deficit under M_5 negatively impacted grain production and filling, leading to a reduced number of filled grains per ear. The results unequivocally indicate that both varietal traits and nutrient management strategies significantly affected spikelet development and grain filling in wheat. Variety V_1 consistently yielded the greatest quantity of spikelets and full grains per ear, indicating its greater reproductive capacity and resource utilisation efficiency. Among the nutrient management strategies, M_1 proved to be the most successful treatment, closely followed by M_4, suggesting that these activities created a conducive nutrient environment for reproductive growth and grain development. Consequently, the cultivation of V_1 alongside effective nutrient management strategies, such as M_1 or M_4, is advisable for augmenting yield-contributing characteristics and promoting wheat productivity in the agro-climatic context of the Manipur Valley.

Interaction Effect of Wheat Varieties and Nutrient Management Strategies on Test Weight and GrainYield

The interplay between wheat varieties and nutrient management approaches markedly affected both test weight and grain yield throughout the trial duration, suggesting that the efficacy of specific wheat varieties fluctuated in accordance with diverse nutrient management tactics. The notable interaction effect indicates that the manifestation of yield and yield-contributing characteristics was contingent upon the synergistic impact of genotype and nutrient availability.

Interaction Effect on Test Weight

The aggregated results demonstrated considerable variance in test weight across the various variety × nutrient management combinations. The maximum pooled test weight (42.61 g) was observed in the combination V_1M_1, which was statistically comparable to V_3M_1 (42.60 g), V_1M_4 (42.53 g), V_2M_1 (42.51 g), V_2M_4 (42.44 g), and V_3M_4 (42.43 g), as the disparities among these treatments were below the pooled critical difference (CD) value of 0.73 g. The results demonstrate that nutrient management strategies M_1 and M_4 were equally efficacious in enhancing grain weight across all kinds (Table 16). The minimum pooled test weight was observed in V_3M_5 (40.99 g), succeeded by V_2M_5 (41.25 g) and V_1M_5 (41.36 g). These therapy combinations were markedly less effective than those using M_1 and M_4. The enhanced test weight noted in combinations M_1 and M_4 can be ascribed to the consistent and balanced nutrient supply during the crop growth period, facilitating effective photosynthate generation and translocation to the developing grains. This led to improved grain filling and the accumulation of reserve food ingredients, resulting in larger and heavier grains. Nutrient limits under M_5 negatively impacted grain development, resulting in reduced grain weight.

Interaction Effect on Crop Yield

The interaction effect on grain production was markedly significant, indicating that the responsiveness of wheat cultivars to nutrient management strategies varied substantially. Of all treatment combinations, V_1M_1 achieved the greatest pooled grain yield (2969.55 kg ha^{-1}), succeeded by V_1M_4 (2753.87 kg ha^{-1}), V_2M_1 (2726.29 kg ha^{-1}), V_2M_4 (2522.36 kg ha^{-1}), and V_3M_4 (2269.77 kg ha^{-1}). The aggregated CD value of 365.18 kg ha^{-1} indicates that V_1M_1 was statistically comparable to V_1M_4 and V_2M_1, signifying similar efficacy across these optimal treatment combinations. Nonetheless, these combinations markedly surpassed the majority of the other variety x nutrient management regimens.

The minimum grain yield was seen in V_3M_5 (1016.29 kg ha^{-1}), succeeded by V_2M_5 (1064.02 kg ha^{-1}) and V_1M_5 (1264.69 kg ha^{-1}). The subpar performance of these combinations underscores the adverse impact of insufficient nitrogen availability on crop yield. The exceptional performance of V_1M_1 is due to the synergistic effect of the high-yield potential of variety V_1 and the effective nutrition delivery from M_1. This combination improved the pace of crop growth, tiller production, spike development, spikelet formation, grain filling, and assimilate translocation, ultimately leading to greater grain yield. Nutrient deficit under M_5, in contrast, inhibited vegetative growth and reproductive development, resulting in inadequate spike production, a diminished number of full grains, and a decreased yield (table 17).

The interaction study unequivocally revealed that the efficacy of nutrient management strategies was significantly affected by varietal performance. Combinations of treatments M_1 and M_4 consistently yielded superior test weight and grain yield across all wheat varieties, while combinations incorporating M_5 exhibited the lowest values. Among all treatment combinations, V_1M_1 proved to be the most productive, achieving the greatest test weight (42.61 g) and grain yield (2969.55 kg ha^{-1}), closely followed by V_1M_4 and V_2M_1. The efficacy of these combinations can be ascribed to augmented nutrient absorption, enhanced photosynthetic performance, increased biomass production, superior yield-related characteristics, and effective translocation of assimilates to developing grains. Consequently, within the agro-climatic parameters of the Manipur Valley, the amalgamation of variety V_1 with nutrient management practice M_1 is deemed the most advantageous approach for optimising grain output and enhancing grain quality characteristics in wheat farming.

Impact of Wheat Varieties and Nutrient Management Strategies on Stover Yield and Harvest Index

The findings in Tables 18 and 19 indicated that both wheat varieties and nutrient management strategies significantly affected stover yield and harvest index across both years and in the combined study. Among the wheat types, V_1 exhibited the largest cumulative stover yield (4153.80 kg ha^{-1}), succeeded by V_2 (4004.49 kg ha^{-1}) and V_3 (3807.35 kg ha^{-1}). According to the aggregated CD value (231.88 kg ha^{-1}), V_1 was statistically comparable to V_2 but greatly outperformed V_3. The increased stover yield in V_1 may be ascribed to its superior vegetative growth and biomass accumulation ability. Nutrient management strategies substantially influenced stover yield. The maximum pooled stover output was observed in M_1 (4835.24 kg ha^{-1}), which was statistically comparable to M_4 (4755.38 kg ha^{-1}). Both treatments demonstrated significant superiority above M_2 (4065.00 kg ha^{-1}), M_3 (3457.75 kg ha^{-1}), and M_5 (2829.36 kg ha^{-1}). Increased nutrient availability in M_1 and M_4 facilitated higher biomass production, while nutritional deficit in M_5 led to the lowest stover output.

Impact on Harvest Index

The harvest index was strongly affected by the wheat varieties. The highest pooled harvest index was observed in V_1 (33.61%), succeeded by V_2 (33.34%) and V_3 (32.09%). V_1 and V_2 were statistically comparable but significantly superior to V_3, indicating more efficient allocation of assimilates towards grain production.

Among nutrient management strategies, M_1 achieved the greatest harvest index at 35.14%, succeeded by M_4 at 34.63%, M_3 at 34.38%, M_2 at 33.15%, and M_5 at 27.79%. M_1, M_4, M_3, and M_2 had statistically comparable harvest indices, but M_5 demonstrated a markedly inferior harvest index. The diminished harvest index under M_5 indicates suboptimal assimilate distribution resulting from insufficient nutrition availability.

The findings demonstrate that V_1 yielded the greatest stover output and harvest index, but M_1 emerged as the most efficient nutrient management strategy, closely succeeded by M_4. Consequently, the integration of V_1 with M_1 or M_4 may be deemed effective for augmenting biomass production, harvest efficiency, and overall wheat yield.

Interaction Effect of Wheat Varieties and Nutrient Management Practices on Stover Yield and Harvest Index

The interplay between wheat cultivars and nutrient management strategies markedly affected stover production and harvest index. The maximum pooled stover yield was seen in V_1M_1 (5104.43 kg ha^{-1}), which was statistically comparable to V_2M_1 (4987.32 kg ha^{-1}) and V_1M_4 (4902.53 kg ha^{-1}). The minimum stover yield was recorded at V_3M_5 (2600.70 kg ha^{-1}). The increased stover yield under V_1M_1 was ascribed to enhanced nutrient availability, robust vegetative development, and elevated dry matter accumulation (Table 19).

The harvest index exhibited considerable variation among the treatment combinations. The greatest pooled harvest index was observed in V_1M_1 (36.77%), followed by V_2M_3 (35.93%) and V_1M_4 (35.82%), which were statistically comparable. The minimum harvest index was recorded for V_2M_5 at 27.19%. Augmented nutrient availability in M_1 and M_4 facilitated improved assimilate allocation to grain production, yielding elevated harvest index values.

The interaction study revealed that pairings of M_1 and M_4 consistently yielded higher stover and harvest index across types. Among all combinations, V_1M_1 proved to be the most effective treatment, achieving the maximum biomass production and harvest efficiency, and is thus suggested for optimising wheat productivity.

Economic Assessment of Wheat Varieties and Nutrient Management Strategies

The economic analysis demonstrated significant heterogeneity across the combinations of variety and nutrient management for profitability, benefit ratio (B ratio), relative economic efficiency (REE), and economic nutrient use efficiency (ENUE). Among all treatments, V_1M_1 achieved the highest gross return (₹119,247.54 ha^{-1}) and net return (₹70,296.54 ha^{-1}), succeeded by V_2M_1 and V_1M_4. The lowest gross return (₹43,372.25 ha^{-1}) and net return (₹2,882.25 ha^{-1}) were recorded for V_3M_5. The enhanced returns under V_1M_1 were primarily attributable to increased grain yield and improved utilisation of administered fertilisers.

The maximum benefit ratio (2.43) was seen in V_1M_1, succeeded by V_2M_1 (2.25) and V_1M_4 (2.03), while the minimum value was noted in V_3M_5 (1.07). In a similar vein, V_1M_1 exhibited the highest relative economic efficiency (243.60%), succeeded by V_2M_1 (225.49%) and V_1M_4 (203.02%), but the lowest relative economic efficiency was noted for V_3M_5 (107.11%).

The efficiency of economic nutrient utilisation shown considerable variation across treatments. The peak ENUE was documented for V_1M_5 at 729.71%, succeeded by V_1M_1 at 685.41% and V_2M_1 at 598.97%. The elevated ENUE under V_1M_5 was chiefly attributable to its reduced nutrient input cost, yielding superior returns per unit of nutritional investment despite diminished total production.

V_1M_1 proved to be the most lucrative and economically viable treatment combination, achieving the best gross return, net return, benefit ratio, and relative economic efficiency, in addition to a substantial ENUE. Consequently, the integration of variety V_1 with nutrient management strategy M_1 is advisable as the most economically feasible alternative for wheat production in the agro-climatic context of the Manipur Valley, succeeded by V_2M_1 and V_1M_4.

Discussion

This study unequivocally established that wheat growth, yield characteristics, productivity, biomass accumulation, and economic returns were markedly affected by varietal variations and nutrient management strategies within the agro-climatic context of the Manipur Valley. HS-542 (V_1) demonstrates higher performance in most growth and yield metrics, indicating its enhanced adaptation to prevailing environmental circumstances and superior capacity to efficiently utilise available resources. Genotypic variations in nutrient absorption, assimilate distribution, and biomass allocation have been documented to markedly affect crop growth and production in wheat [11,12].

Field germination was not significantly influenced by wheat varieties or nutrient management strategies, suggesting that seed emergence was predominantly determined by seed quality and environmental circumstances rather than nutrition availability in the early phases of crop growth. Comparable findings have been documented in wheat, indicating that nutrition management strategies had minimal impact on germination % [13].

The height of the plants and the pace of crop development grew steadily over the growth period and were markedly improved under M_1 and M_4 conditions. Sufficient nutritional availability, especially nitrogen, facilitates chlorophyll formation, cellular division, leaf area expansion, and photosynthetic efficiency, thereby improving dry matter accumulation and vegetative growth [14,15]. The enhanced efficacy of integrated nutrient management (M_4) indicates that the amalgamation of inorganic fertilisers and organic sources has optimised nutrient synchronisation, nutrient-use efficiency, and soil biological activity. Numerous researches have observed analogous advantages of integrated nutrition management on wheat growth and biomass production [16,17].

Yield-contributing traits, including spike length, spikelet count per ear, and full grain count per ear, were strongly affected by both varietal attributes and nutrient management strategies. Variety V_1 yielded longer spikes and a higher quantity of spikelets and full grains per ear compared to the other types. These characteristics directly influence sink capacity and the possibility for grain production. The enhanced reproductive success of V_1 may be ascribed to its elevated genetic potential and effective allocation of assimilates towards the development of spikes and grains [18,19].

M_1 and M_4 consistently yielded superior values for yield-attributing attributes among nutrient management techniques. The consistent availability of nutrients over the crop growth period likely improved spike initiation, pollen viability, grain setting, and the transport of assimilates to developing grains. Nitrogen, phosphorus, and potassium are essential for reproductive development and grain production, resulting in enhanced yield components and grain yield [20]. The reduced values recorded under M_5 suggest that the nitrogen provision from natural farming alone was inadequate to satisfy crop requirements under the experimental conditions.

Grain yield was markedly affected by both cultivars and nutrient management strategies. Variety V_1 had the best grain yield owing to its exceptional growth traits, elevated crop growth rate, extended spikes, increased spikelet production, and improved grain filling. Comparable varietal responses have been recorded in wheat across several agro-climatic situations [21]. Among the nutrient management treatments, M_1 achieved the maximum grain yield, closely followed by M_4. The increased productivity resulting from these treatments can be ascribed to a balanced nutrient supply, greater nutrient absorption, enhanced photosynthetic efficiency, and effective translocation of assimilates to growing grains [22]. The notable interaction effects between wheat types and nutrient management approaches underscore the necessity of choosing suitable genotype-management pairings. The combination V_1M_1 consistently yielded the best grain output, test weight, stover yield, harvest index, and economic returns, demonstrating a robust positive interaction between a high-yielding genotype and sufficient nutrient availability. Comparable genotype × nutrient management interactions have been documented in wheat, where varietal yield potential was optimised under balanced nutrient provision [23]. The yield of stover and the harvest index were strongly affected by varietal and nutrient management variables. The elevated stover yield observed in V_1, M_1, and M_4 indicates increased biomass buildup due to improved vegetative growth and nutrient accessibility. The elevated harvest index noted under V_1M_1 signifies a more effective allocation of assimilates towards grain production, resulting in enhanced economic yield. Previous reports have indicated analogous enhancements in biomass production and harvest efficiency by balanced nutrient management [24,25].

The economic study corroborated the agronomic findings. The treatment combination V_1M_1 had the highest gross return, net return, benefit ratio, and relative economic efficiency owing to its exceptional grain and straw yields. Despite V_1M_5 exhibiting the maximum economic nutrient-use efficiency due to reduced nutrient input costs, its overall productivity and profitability were significantly inferior to those realised under V_1M_1. The data suggest that balanced nutrient application, which sustains better production, is crucial for maximising profitability and guaranteeing the long-term sustainability of wheat farming [26,27].

The findings unequivocally indicate that balanced nutrient management, especially via recommended fertiliser application and integrated nutrient management strategies, is essential for enhancing wheat development, yield formation, productivity, and profitability. The findings underscore the significance of using nutrient-responsive cultivars like HS-542 to optimise the advantages of nutrient management strategies in the acidic soil conditions of the Manipur Valley.

CONCLUSION

The research shown that the wheat variety HS-542 (V_1) surpassed HS-562 (V_2) and HD-3226 (V_3) in terms of growth, yield characteristics, grain yield, stover yield, harvest index, and economic returns. Among nutrient management strategies, the optimal fertiliser dosage (M_1) demonstrated the greatest efficacy, closely followed by integrated nutrient management (M_4). The interaction between variety and nutrient management was significant, with the combination V_1M_1 producing the highest grain yield (2969.55 kg ha^{-1}), stover yield (5104.43 kg ha^{-1}), harvest index (36.77%), and economic returns. Thus, cultivating HS-542 with the recommended fertiliser dosage is the most productive and economically viable method for wheat production in the agro-climatic conditions of the Manipur Valley, while integrated nutrient management may serve as a sustainable alternative for maintaining productivity and soil health.

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