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Effect of Integrated Nitrogen Management on Plant Growth and Yield Performances of Barley (*Hordeum vulgare* L.)

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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Abstract

Integrated nitrogen management may improve barley productivity by combining mineral nitrogen with organic nutrient sources. A field experiment was conducted during the 2025–26 rabi season at the Agronomy Experimental Farm, Tantia University, Sri Ganganagar, Rajasthan, to assess the effects of nitrogen-management treatments on growth, yield attributes, grain and straw yields, and economic returns. Nine treatments comprising different rates and combinations of the recommended dose of nitrogen (RDN), farmyard manure (FYM) and vermicompost were evaluated in a randomised block design with three replications. Plant height at successive growth stages, spike length, effective tillers, spikes per plant, grains per spike, test weight and crop yield were recorded, and economic returns were calculated. Treatment T_5 (100% RDN + 1.0 t ha^{-1} vermicompost) recorded the highest plant height at

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harvest (107.09 cm), spike length (9.39 cm), effective tillers (370 m^{-2}), spikes per plant (11.95), grains per spike (46.33) and test weight (41.52 g). It also produced the highest grain yield (53.15 q ha^{-1}), straw yield (66.18 q ha^{-1}) and biological yield (119.33 q ha^{-1}). For several parameters, its performance was comparable to T_4 (100% RDN + 2.5 t ha^{-1} FYM). T_5 had the highest reported net return (₹82,540 ha^{-1}) and benefit ratio (2.71). Under the conditions evaluated, applying the full recommended nitrogen dose together with vermicompost was associated with favourable agronomic and economic performance.

Keywords: Barley; integrated nitrogen management; vermicompost; FYM; grain yield; economic returns; net return; B:C ratio.

1. Introduction

Barley (*Hordeum vulgare* L.) is one of the earliest domesticated cereal crops and remains an important component of global food, feed, fodder and malting systems. Its broad adaptation to diverse agro-ecological conditions, including drought, salinity and relatively low-fertility soils, makes it particularly valuable in marginal and water-limited production environments (Baik & Ullrich, 2008). In India, barley is predominantly cultivated during the rabi season and contributes to food and nutritional security, livestock feeding and the malting and brewing industries, particularly in semi-arid regions where environmental and resource constraints limit the productivity of other cereals (Singh, 1993).

Nitrogen (N) is a key determinant of cereal productivity because it is integral to chlorophyll, amino acids, proteins, nucleic acids and numerous metabolic enzymes. Adequate N availability promotes leaf development, chlorophyll synthesis, photosynthetic activity, tillering, biomass accumulation and grain formation in barley, whereas N deficiency markedly restricts growth and yield (Fageria, 2014; Marschner, 2012). Conversely, excessive or poorly synchronised N application can reduce nitrogen-use efficiency (NUE), increase lodging and nutrient losses, and contribute to nitrate leaching, ammonia volatilization and nitrous oxide emissions (Ladha *et al.*, 2005; Raun & Johnson, 1999). Thus, improving the synchronisation between crop N demand and N supply is central to achieving productive and environmentally sustainable barley production. Conventional cereal production has largely depended on mineral N fertilisers because of their rapid nutrient availability and predictable agronomic response. However, long-term and imbalanced fertiliser use without adequate organic inputs may contribute to declining soil organic matter, deterioration of soil quality, nutrient imbalance and environmental pollution (Weil & Brady, 2017). These concerns, together with increasing fertiliser costs and the need to improve NUE, have stimulated interest in integrated nitrogen management (INM). INM involves the complementary use of mineral fertilisers with organic manures, crop residues and biological nutrient sources to improve nutrient availability, soil fertility and nutrient-use efficiency while sustaining crop productivity (Dwivedi *et al.*, 2017; Yadav *et al.*, 2025).

In barley field experiments, variation in nitrogen and water availability has been associated with differences in grain yield and quality, emphasising the context-dependent response to nutrient inputs (Cammarano *et al.*, 2024). A multi-year winter-barley study also found that nitrogen application timing and genotype affected yield formation and nitrogen balance (Bukowiecki *et al.*, 2025).

Organic amendments such as farmyard manure (FYM), composts and other locally available organic resources provide nutrients through gradual mineralisation and simultaneously contribute organic carbon to the soil. Their incorporation can improve soil aggregation, water-holding capacity, microbial activity and nutrient-retention capacity, thereby creating a more favourable rhizosphere environment for root development and nutrient acquisition (Weil & Brady, 2017; Gaur, 1990; Liu *et al.*, 2024). Biological nutrient inputs, including *Azotobacter*, *Azospirillum* and phosphate-solubilising microorganisms, can further complement nutrient management through biological N fixation and enhanced nutrient mobilisation (Bhattacharyya & Jha, 2012). Consequently, combining organic, biological and mineral nutrient sources may provide a more sustained and balanced nutrient supply than reliance on a single source. Barley has a substantial N requirement, and N availability strongly influences productive tillering, spike development, grain number, grain protein concentration and final yield (Baethgen *et al.*, 1995). Previous studies have demonstrated that integrated application of organic manures and mineral N can improve barley growth, nutrient uptake, yield attributes and grain yield compared with individual nutrient sources (Kumawat *& Jat, 2005; Kumawat et al.*, 2006). Moreover, integrated nutrient management can enhance soil organic carbon and biological activity, potentially improving the long-term nutrient-supplying capacity of agricultural soils (Paramesh *et al.*, 2023; Tefera *et al.*, 2022). However, the magnitude of crop response depends on soil fertility, climatic conditions, nutrient source, application rate, synchronisation of nutrient release and genotype. Therefore, location-specific evaluation remains essential for identifying effective and economically viable INM strategies.

In Himachal Pradesh, combinations of chemical fertiliser and organic manure produced different growth and yield responses in barley (Kumari *et al.*, 2024). Similarly, a field study in Dehradun reported differences in barley growth and yield among treatments combining inorganic fertiliser and FYM (Shivani *et al.*, 2024). A two-season experiment in Ethiopia further found that compost combined with mineral nitrogen improved malt barley yield and selected soil properties relative to an unfertilised control, with treatment responses also varying by season (Wole *et al.*, 2026).

The semi-arid production environments of north-western Rajasthan are characterised by high evaporative demand and soils in which nutrient availability can constrain cereal productivity. Under such conditions, efficient N management is particularly important for achieving higher productivity while minimising nutrient losses and maintaining soil quality. However, information on suitable combinations of organic and inorganic N sources for barley under the agro-climatic conditions of Sri Ganganagar remains comparatively limited. Therefore, the present investigation was undertaken to evaluate the effect of integrated nitrogen management on the growth, yield and economic performance of barley at Tantia University, Sri Ganganagar, Rajasthan, with the specific objectives of assessing its effects on (i) crop growth, (ii) yield and yield attributes, and (iii) economic returns.

2. Materials and Methods

Experimental site and soil: A field experiment was conducted during the rabi season of 2025–26 at the Agronomy Experimental Farm, Faculty of Agriculture, Tantia University, Sri Ganganagar, Rajasthan, India, located in the Irrigated North Western Plain

Zone-Ib at an elevation of 175.6 m above mean sea level. The experimental soil was sandy loam and alkaline (pH 8.65), with low organic carbon (0.17%) and available N (125.44 kg ha^{-1}), and medium levels of available P (16.90 kg ha^{-1}) and K (147.84 kg ha^{-1}).

Experimental design and treatments: The experiment was conducted in a randomised block design (RBD) with nine nitrogen-management treatments and three replications. Barley variety DWRUB 52 was sown on 15 October 2025 at 100 kg seed ha^{-1} with 20-cm row spacing in plots measuring 3 × 3 m. The nine treatments comprised T1:100% RDN (recommended dose of nitrogen), T2: 80% RDN, T3: 60% RDN, T4: 100% RDN + 2.5 t/ha FYM, T5: 100% RDN + 1.0 t/ha vermicompost, T6: 80% RDN + 20% RDN through FYM, T7: 80% RDN + 20% RDN through vermicompost, T8: 60% RDN + 40% RDN through FYM, T9: 60% RDN + 40% RDN through vermicompost. Standard agronomic practices were followed, with three irrigations in addition to the pre-sowing irrigation.

Crop management and observations: The field was prepared by ploughing, harrowing and planking following pre-sowing irrigation. Barley was manually sown at 100 kg ha^{-1} with 20-cm row spacing. Three irrigations were applied during the crop period in addition to the pre-sowing irrigation. Weed and pest management were undertaken as required using the recommended field practices. At maturity, the crop was harvested separately from each net plot, dried, threshed and weighed to determine grain and straw yields. Growth observations included plant height at 30, 60 and 90 DAS and at harvest, as well as spike length, while yield attributes comprised effective tillers m^{-2}, spikes plant^{-1}, grains spike^{-1} and test weight. Grain, straw and biological yields were recorded from the net plot and expressed in q ha^{-1}, and harvest index was calculated as the ratio of grain yield to biological yield × 100. Five randomly selected plants were used for biometric observations.

Economic analysis: The cost of cultivation, gross return, net return and benefit:cost ratio (B:C) were calculated for each treatment using the prevailing input and output prices. Gross returns were calculated using the prevailing selling prices of ₹2,150 q^{-1} for grain and ₹300 q^{-1} for straw. Net return was calculated as gross return minus cost of cultivation. The benefit:cost ratio was calculated as gross return divided by total cost of cultivation. Accordingly, the B:C ratio expresses gross return per rupee of cultivation expenditure, whereas net return expresses the amount remaining after cultivation costs are deducted.

$$\text{B: C Ratio} = \frac{\text{Gross Return (Rs/ha)}}{\text{Total cost of Cultivation (Rs/ha)}}$$

Statistical analysis: The experimental data were subjected to analysis of variance (ANOVA) appropriate for the RBD using R statistical software. Treatment means were compared using the critical difference (CD) at the 5% probability level, and standard error of the mean (SEm) and the coefficient of variation (CV) were calculated. Statistical significance was tested at $P \leq 0.05$ following Gomez and Gomez (1984).

3. Results and Discussion

Growth parameters: The treatment effects were significant at the 5% level for all growth parameters (Table 1). The maximum plant height was recorded with T_5 (100% RDN + 1.0 t ha^{-1} vermicompost), registering 28.36, 68.60, 100.53 and 107.09 cm at 30, 60 and 90 DAS and at harvest, respectively, and was statistically at par with T_4 (100% RDN + 2.5 t ha^{-1} FYM). The minimum plant height was observed under T_3 (60% RDN), with 20.31, 53.80, 93.95 and 97.15 cm, respectively. Spike length was significantly influenced by integrated nitrogen management, with the maximum spike length (9.39 cm) recorded under T_5 (100% RDN + 1.0 t ha^{-1} vermicompost), followed by T_4 (8.90 cm), whereas the minimum (5.68 cm) occurred under T_3 (60% RDN).

Table 1. Effect of integrated nitrogen management on growth parameters of barley

Treatments	Ht. 30 DAS	Ht. 60 DAS	Ht. 90 DAS	Ht. Harvest	Length ofspike (cm)
T_1	26.31	65.04	98.31	104.08	8.74
T_2	23.35	58.90	96.18	100.23	7.07
T_3	20.31	53.80	93.95	97.15	5.68
T_4	26.69	66.04	99.36	106.13	8.90
T_5	28.36	68.60	100.53	107.09	9.39
T_6	24.33	60.83	96.30	101.19	7.78
T_7	25.29	63.11	97.66	102.23	8.28
T_8	21.28	55.67	93.85	98.26	6.01
T_9	22.38	57.27	95.62	99.16	6.53
SE(m)±	0.46	0.74	0.22	0.38	0.34
C.D.$_{@5\%}$	1.21	2.15	0.64	1.11	1.04

The superior growth under T_5 may be attributed to the combined and sustained availability of nutrients from mineral nitrogen and vermicompost, which favoured cell division, chlorophyll formation, photosynthesis and biomass accumulation. The beneficial effect of organic amendments may also be associated with improved nutrient availability and rhizospheric conditions, resulting in enhanced vegetative growth. The maximum plant height and spike length under T_5, followed by T_4 (100% RDN + 2.5 t ha^{-1} FYM), indicate that integrated nutrient supply was more effective than reduced nitrogen alone. Similar improvements in plant height and tillering with combined organic manure and nitrogen fertilisation has been reported in barley by Kumawat *et al.* (2006), while Kumar *et al.* (2020) also reported improved yield attributes with integrated nitrogen, vermicompost and bio-input management. These findings are further supported by Jat *et al.* (2021), who observed significant improvements in barley productivity under integrated fertiliser and FYM application.

Yield attributes: Nitrogen-management treatments influenced the yield attributes of barley (Table 2). Effective tiller density ranged from 330.33 m^{-2} under T_3 to 370.00 m^{-2} under T_5, while T_4 recorded 362.00 m^{-2}. The mean number of spikes per plant was highest under T_5 (11.95), followed by T_4 (11.10), and lowest under T_3 (8.18). A similar pattern was observed for the number of grains per spike, with 46.33 under T_5, 44.80 under T_4 and 38.64 under T_3. The T_5–T_4 differences were 0.85 spikes per plant and 1.53 grains per spike, both below the corresponding critical differences at the 5% level (1.19 and 3.51, respectively). Thus, T_5 and T_4 were statistically comparable for these two attributes, although T_5 recorded the higher means. Test weight was also highest under T_5 (41.52 g), followed by T_4 (41.08 g).

Table 2. Effect of integrated nitrogen management on yield attributes of barley

Treatments	Number of effective tillers per meter^{-2}	Number of spikes per plant	Number of grains per spike	Test weight (g)
T_1	359.67	11.05	44.36	40.96
T_2	342.00	9.57	41.39	39.80
T_3	330.33	8.18	38.64	38.66
T_4	362.00	11.10	44.80	41.08
T_5	370.00	11.95	46.33	41.52
T_6	346.67	10.28	42.38	40.16
T_7	351.67	10.79	43.39	40.53
T_8	334.33	8.51	39.40	39.04
T_9	338.67	9.03	40.45	39.41
SE(m)±	1.22	0.39	1.16	0.18
C.D.$_{@5\%}$	3.78	1.19	3.51	0.55

The higher number of effective tillers, spikes plant^{-1} and grains spike^{-1} under T_5 demonstrate the positive response of barley reproductive development to adequate and balanced nutrient availability. Nitrogen promotes vegetative growth and tiller formation, while organic amendments provide a sustained nutrient supply that may improve nutrient-use efficiency during reproductive development. The present results agree with Kumar *et al.* (2020), who reported higher spike length and grains spike^{-1} under integrated nitrogen and vermicompost-based nutrient management. Woldesenbet *et al.* (2014) similarly reported improved productive tillers and grains spike^{-1} when inorganic fertilisers were integrated with organic nutrient sources. The significant response of test weight suggests that nutrient management exerted a stronger influence on spike number and grain number than on individual grain mass.

Yield and harvest index: The treatment effects were significant at the 5% level for yield and harvest index of barley (Table 3). Grain yield was significantly influenced by integrated nitrogen management, with the highest yield recorded under T_5 (100% RDN + 1.0 t ha^{-1} vermicompost), followed by T_4 (100% RDN + 2.5 t ha^{-1} FYM), whereas the lowest yield occurred under reduced nitrogen treatment T_3 (60% RDN). Straw yield was highest under T_5 (66.18 q ha^{-1}), followed by T_4 (63.56 q ha^{-1}), while the minimum (50.09 q ha^{-1}) was recorded under T_3. Similarly, biological yield was highest under T_5 (119.33 q ha^{-1}) and T_4 (113.31 q ha^{-1}) and lowest under T_3 (90.63 q ha^{-1}). The greater biomass production under T_5 reflects its superior plant height, tillering and overall vegetative growth resulting from adequate mineral nitrogen supplemented with vermicompost. The enhanced nutrient availability and improved crop growth consequently increased both above-ground biomass and total biological productivity. Harvest index varied significantly among treatments, with the highest value (46.13%) recorded under T_8 (60% RDN + 40% RDN through FYM), followed by T_9 (45.75%), whereas the lowest value (44.26%) occurred under T_4; T_5 recorded 44.55%.

Table 3. Effect of integrated nitrogen management on yield and harvest index of barley

Treatments	Grain yield (q/ha)	Straw yield (q/ha)	Biological yield (q/ha)	Harvest Index (%)
T_1	49.71	62.15	111.86	44.44
T_2	46.60	56.17	102.78	45.35
T_3	40.55	50.09	90.63	44.73
T_4	51.35	63.56	113.31	44.26
T_5	53.15	66.18	119.33	44.55
T_6	47.63	58.09	105.72	45.06
T_7	48.66	60.11	108.77	44.74
T_8	44.68	52.18	96.86	46.13
T_9	45.70	54.21	99.90	45.75
SE(m)±	0.63	0.95	1.46	0.27
C.D.$_{@5\%}$	1.92	2.86	4.42	0.83

Biological yield represents the combined grain and straw yield, reflecting the total above-ground harvested biomass. For T_5, grain yield (53.15 q ha^{-1}) and straw yield (66.18 q ha^{-1}) together amounted to 119.33 q ha^{-1}, the biological yield reported in Table 3. T_3 recorded the lowest reported biological yield (90.63 q ha^{-1}), alongside the lowest grain and straw yields. The difference in reported biological yield between T_5 and T_3 (28.70 q ha^{-1}) exceeded the critical difference at the 5% level (4.42 q ha^{-1}). Biological yield therefore describes the total harvested biomass, while harvest index describes the proportion of that biomass represented by grain.

The highest grain, straw and biological yields under T_5 were a consequence of the cumulative improvement in plant growth and yield attributes. The relatively higher harvest index under the treatments receiving a greater proportion of nitrogen through FYM

indicates improved partitioning of accumulated biomass towards grain production. Integration of mineral nitrogen with vermicompost probably ensured better nutrient availability throughout crop growth, resulting in greater canopy development, productive tillering and assimilate accumulation. Similar responses have been documented by Jat *et al.* (2021), who found that integrated fertiliser and FYM application significantly increased grain, straw and biological yields of barley, and by Roy and Singh (2006), who reported positive effects of nitrogen and vermicompost on barley grain and straw productivity. Kumawat *et al.* (2016) also reported significant improvements in barley grain yield with vermicompost-based nutrient management.

Economic returns: Economic returns differed among the nitrogen-management treatments (Table 4).

Table 4. Effect of integrated nitrogen management on economics of barley

Treatments	Cost of Cultivation (Rs./ha)	Gross Return (Rs./ha)	Net Return (Rs./ha)	B:C Ratio
T_1	47215.22	125521.50	78306.28	2.66
T_2	45503.48	117049.17	71545.69	2.57
T_3	43215.25	108794.67	65579.42	2.52
T_4	48107.54	126771.50	78663.96	2.64
T_5	48368.67	130908.67	82540.00	2.71
T_6	46488.94	119838.67	73349.73	2.58
T_7	47348.42	122653.00	75304.58	2.59
T_8	44037.52	111716.00	67678.48	2.54
T_9	45463.64	114509.83	69046.19	2.52

The highest net return and benefit:cost ratio under T_5 demonstrate that the additional expenditure on vermicompost was compensated by the increase in grain and straw productivity. Similar economic advantages of integrated nutrient management have been reported in barley by Jat *et al.* (2021), while Terefe *et al.* (2024) demonstrated that combining mineral nitrogen with vermicompost can improve both barley productivity and economic returns. The present findings therefore indicate that integration of 100% RDN with vermicompost was economically viable under the experimental conditions, owing to greater marketable yield and returns despite its comparatively higher cultivation cost. For T_5, dividing the reported gross return (₹1,30,908.67 ha^{-1}) by its cultivation cost (₹48,368.67 ha^{-1}) gives a B:C ratio of 2.71 after rounding. This means that ₹2.71 in gross returns was obtained for every ₹1 spent on cultivation, equivalent to approximately ₹1.71 in net return per rupee spent. The reported B:C ratio under T_5 exceeded those under T_1 (2.66), T_4 (2.64), and T_3 and T_9 (2.52 each).

4. Conclusion

The 2025–26 field trial in Sri Ganganagar indicated that barley growth, yield components and productivity varied with the combination of mineral nitrogen and organic nutrient sources. Among the nine evaluated treatments, T_5, consisting of 100% of the recommended dose of nitrogen supplemented with 1.0 t ha^{-1} vermicompost, gave the highest grain yield (53.15 q ha^{-1}), straw yield (66.18 q ha^{-1}) and biological yield (119.33 q ha^{-1}). This treatment also recorded the greatest spike length (9.39 cm), effective tiller density (370 m^{-2}), grains per spike (46.33) and test weight (41.52 g), alongside the highest plant height at harvest. Treatment T_4, comprising 100% RDN with 2.5 t ha^{-1} farmyard manure, gave comparable results for selected growth and yield attributes, although differences were not uniform across all measurements. The economic analysis ranked T_5 highest for the reported net return and benefit ratio. The findings therefore support the potential of combining the full recommended nitrogen dose with vermicompost for barley production under the specific soil and management conditions studied. Confirmation under additional seasons and locations is needed before wider recommendations are made.

5. Limitations of the Study

These findings relate to one barley variety evaluated at a single site during the 2025–26 rabi season. Consequently, the relative performance of the nitrogen-management treatments may differ under other soil conditions, weather patterns, varieties and production systems. The economic comparisons are also specific to the input and output prices used in the study. Further trials across seasons and representative locations would help establish the consistency of the agronomic and economic responses.

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Declaration of AI Use

This manuscript was prepared through the intellectual contributions of the author(s) to the study design, data analysis, interpretation of results, and scholarly content. ChatGPT, Claude and Perplexity were used solely to assist with grammatical refinement and reference formatting during manuscript revision. The author(s) accept full responsibility for the accuracy, integrity, and final content of the manuscript.

Competing Interests

Authors have declared that no competing interests exist.

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