Response to varying levels and sources of nitrogen on the growth and yield of Barley (*Hordeum vulgare* L.)

ABSTRACT

A field experiment was conducted at Agronomy Research Farm of Nirwan University, Jaipur (Rajasthan) during *Rabi,* 2023-24 consisting of thirteen treatments with different levels and sources of nitrogen. The results revealed that different sources of nitrogen application brought an additive effect in increasing growth and yield parameters of barley as compared to control. Maximum plant height, dry matter accumulation, leaf area index and crop growth rate, seed yield, stover yield and biological yield of barley was significantly obtained with 100% recommended dose of nitrogen (RDN) through chemical fertilizers + Azotobacter followed by 100% recommended dose of nitrogen through chemical fertilizers over rest of the treatments. The plant population was remained unchanged under different sources of nitrogen applications. Therefore, application of 100% recommended dose of nitrogen (RDN) through chemical fertilizers + Azotobacter followed by 100% recommended dose of nitrogen through chemical fertilizers were found most profitable as it gave highest seed yield.

Keywords: Barley, Nitrogen, Source, Levels, Treatment.

Introduction

Barley (*Hordeum vulgare* L.) is the fourth most important cereal crops worldwide, following wheat, rice, and maize. It is cultivated extensively in temperate and tropical regions and is recognized as one of the oldest domesticated cereals. Its adaptability to diverse and challenging agro-climatic conditions, including drought, salinity, and alkalinity, makes it a hardy and versatile crop. In India, the production was estimated to be 2.22 million tons from an estimated area of 7.81 lakh hectares (Statista, 2024; PIB, 2024). Barley serves multiple purposes as a food grain, livestock feed, and a raw material for industrial processes. Notably, malt extract derived from barley is essential for brewing, distillation, and the production of baby food products such as *Boost* and *Horlicks*, as well as cocoa malt drinks and Ayurvedic medicines. Despite barley's significant role in global agriculture, the sustainability of its production is threatened by declining soil fertility, particularly due to intensive cropping systems and imbalanced nutrient management. Over the past three decades, intensive agricultural practices in India, driven by high-yielding varieties, have led to the excessive extraction of soil nutrients.

Among various agronomic factors influencing crop productivity, nitrogen (N) availability is particularly crucial. However, the heavy reliance on chemical fertilizers has resulted in nutrient imbalances, soil degradation, and reduced water and nutrient use efficiency.

To address these challenges and ensure sustainable barley production, there is a growing emphasis on integrating organic and inorganic nutrient sources. Research in India indicates that balanced fertilization strategies combining organic manures and chemical fertilizers can sustain soil health, optimize nutrient availability, and conserve natural resources. Such integrated nutrient management (INM) practices not only enhance crop productivity but also mitigate the adverse effects of chemical inputs on the environment. Given the importance of nitrogen in promoting the growth and yield of barley, this study investigates the response of barley (*Hordeum vulgare* L.) to varying levels and sources of nitrogen. The objective is to identify optimal nitrogen management practices that support sustainable production, maintain soil fertility, and improve nutrient use efficiency in barley cultivation.

Materials and methods

The field experiment was carried out during *Rabi* season of 2023-24 at Agronomy Research Farm, School of Agricultural Sciences, Nirwan University, Jaipur. The experiment was laid out in a randomized complete block design with thirteen treatments and three replication. The barley variety under observation was BH-902. The treatments consisted of different levels and sources of nitrogen *viz*., Control-T_1, 100 % RDN through chemical fertilizers (CF) (60 kg N/ha) -T_2, 100 % RDN through chemical fertilizers + Azotobacter-T_3, 100 % RDN through FYM-T_4, 100 % RDN through vermicompost (VC)-T_5, 125% RDN through FYM-T_6, 125 % RDN through vermicompost-T_7, 100 % RDN through FYM+ 25 % RDN through chemical fertilizers-T_8 , 75 % RDN through FYM + 25 % RDN through chemical fertilizers-T_9,50 % RDN through FYM + 25 % RDN through chemical fertilizers-T_{10} , 100% RDN through vermicompost + 25 % RDN through chemical fertilizers-T_{11}, 75 % RDN through vermicompost + 25 % RDN through chemical fertilizers-T_{12} and 50 % RDN through vermicompost + 50 % RDN through chemical fertilizers-T_{13}. The experimental farm is geographically located at 75° 51’44” E longitude, 26°48’35’’ N latitude and an altitude of 432 m above mean sea level (AMSL). The experimental fields were sandy loam in texture, low in available nitrogen (137.8 kg ha^{-1}) (Subia and Asija 1996), medium in available phosphorus (16.3 kg ha^{-1}) (Olsen *et al*., 1954) and potassium (250.12 kg ha^{-1}) (Jackson, 1973). The organic carbon content was from 0.34-0.38%. The observations recorded were subjected to Fisher's F-test and means were subsequently reported by (Fisher, R.A. 1950).

Result and Discussion

Growth attributes: The nitrogen application significantly influenced the growth parameters of barley at harvest (Table 1). Among all the treatments, T_3 (100% Recommended Dose of Nitrogen (RDN) through chemical fertilizers + *Azotobacter*) recorded the highest values for plant height (105.6 cm), dry matter accumulation (643.8 g m^{-2}), leaf area index (5.73), and crop growth rate (4.48 g $m^{-2}day^{-1}$). The synergistic effect of nitrogen from chemical fertilizers and the nitrogen-fixing ability of *Azotobacter* likely contributed to an optimal nutrient supply, enhancing the overall vegetative growth of barley.The increase in plant height observed in T3 can be attributed to the adequate and sustained availability of nitrogen, which supports a favourable nutritional environment during critical growth stages. Nitrogen is a crucial component of amino acids and chlorophyll, playing a pivotal role in cell multiplication, elongation, and expansion processes. This enhancement in root proliferation and nutrient uptake ultimately boosts plant height. These findings are consistent with previous studies by Khanpara *et al.,* (2020) and Kumar and Kumar (2021), which also reported significant increases in plant height with appropriate nitrogen application and biofertilizer integration.

Dry matter accumulation followed a similar trend, with T_3 exhibiting the highest value (643.8 g m^{-2}). This outcome can be explained by the improved photosynthetic efficiency and biomass production resulting from the adequate nitrogen supply. Nitrogen availability enhances leaf expansion and chlorophyll content, thereby increasing the duration and efficiency of photosynthesis. The increase in leaf area index (5.73) observed in T_3 supports this explanation, as a higher leaf area index correlates with greater light interception and photosynthetic activity. These results align with the findings of Singh and Awasthi (2004), Dhaka *et al.,* (2018), and Mishra *et al.,* (2024), who reported a direct relationship between nitrogen availability, leaf area development, and dry matter accumulation.

The crop growth rate (CGR) was also highest in T_3 (4.48 g $m^{-2}day^{-1}$), indicating that consistent nitrogen supply through chemical fertilizers and *Azotobacter* promoted efficient growth dynamics throughout the growing season. The ability of *Azotobacter* to fix atmospheric nitrogen and produce growth-promoting substances likely enhanced nutrient uptake and root development, leading to improved growth rates.Other treatments such as T_2 (100% RDN through chemical fertilizers), T_5 (100% RDN through vermicompost), and T_6 (125% RDN through farmyard manure) showed statistically comparable results. This suggests that organic amendments like farmyard manure (FYM) and vermicompost (VC), when applied at appropriate levels, can effectively support barley growth by improving soil structure, microbial activity, and nutrient availability (Sharma et al., 2024).The treatments combining organic and inorganic nitrogen sources, such as T8 (100% RDN through FYM + 25% RDN through chemical fertilizers) and T11 (100% RDN through VC + 25% RDN through chemical fertilizers), also demonstrated favourable growth parameters, though not as pronounced as T_3. This indicates that integrated nutrient management (INM) approaches can sustain soil fertility and promote crop growth, aligning with the principles of sustainable agriculture (Singh *et al.,* 2021)

Table1:Effect of different levels and sources of nitrogen on growth attributes of barley

Treatments	Plant height (cm)	Dry Matter accumulation (g m^{-2})	Leaf area index	Crop growth rate (g m^{-2} day^{-1})
T1: Control	93.8	486.6	3.31	2.49
T2: 100% RDN throughchemical fertilizers (80kg/ha)	102.1	640.0	5.58	4.46
T3:100% RDN through CF+*Azotobacter*	105.6	643.8	5.73	4.48
T4: 100% RDN through FYM	98.0	581.2	4.91	4.26
T5: 100% RDN through VC	98.5	584.2	4.94	4.32
T6: 125% RDN through FYM	98.8	586.6	5.01	4.35
T7: 125 % RDN through VC	100.5	602.3	5.41	4.42
T8: 100% RDN through FYM+25% RDN through CF	97.6	569.2	4.40	3.87
T9: 75% RDN through FYM+25% RDN through CF	97.0	561.2	3.74	3.61
T10: 50%RDN through FYM+50% RDN through CF	96.1	521.7	3.64	3.55
T11: 100% RDN through VC+25% RDN through CF	97.9	578.1	4.41	3.94
T12: 75% RDN through VC+25% RDN through CF	97.4	511.2	3.78	3.66
T13: 50% RDN through VC +50% RDN through CF	96.7	3.02	3.69	3.60
SEm±	1.18	8.89	0.04	0.04
LSD	3.38	3.02	0.12	0.11

Yield attributes: The number of effective tillers, ear length, number of grains per year and test weightare crucial determinants of barley yield, as they directly correlate with the grain yield potential (Table 2). The highest number of effective tillers (97.8 m^{-1} rl) was recorded in T3 (100% RDN through chemical fertilizers + *Azotobacter*), followed closely by T_2 (100% RDN through chemical fertilizers) with 97.5 tillers. This improvement can be attributed to the synergistic effect of nitrogen supplied by chemical fertilizers and the nitrogen-fixing capabilities of *Azotobacter*, which enhances root development and nutrient uptake (Aasfar *et al.,* 2021; Zhou *et al.,* 2023). Treatments involving organic sources, such as T_5 (100% RDN through vermicompost, 95.0) and T6 (125% RDN through FYM, 95.8), also produced significantly higher numbers of effective tillers compared to the control (66.0). These results suggest that organic amendments improve soil structure and microbial activity, leading to better tillering (Naeem *et al.*, 2020, Guan *et al.*, 2023).The longest ears (11.9 cm) were observed in T_3 (100% RDN through chemical fertilizers + *Azotobacter*), followed closely by T_2 (100% RDN through chemical fertilizers) with 11.7 cm. These results indicate that a consistent nitrogen supply, coupled with the biological activity of *Azotobacter*, promotes robust ear development (Samantaray *et al.*, 2024). Treatments T_7 (125% RDN through vermicompost) and T_6 (125% RDN through FYM) also resulted in relatively long ears (11.2 cm and 10.9 cm, respectively), demonstrating that higher nitrogen levels from organic sources can also support improved ear growth. The control treatment (T_1) recorded the shortest ear length (8.5 cm).

In terms of number of grains per ear, T_3 (100% RDN through chemical fertilizers + *Azotobacter*) recorded the highest (58.6), followed closely by T_2 (100% RDN through chemical fertilizers) with 58.5 grains. Treatments with organic sources, such as T_7 (125% RDN through vermicompost, 57.5 grains) and T6 (125% RDN through FYM, 57.0 grains), also demonstrated significantly higher grain counts compared to the control (43.8 grains). This improvement can be attributed to enhanced nitrogen availability during the critical stages of spikelet differentiation and grain filling (Huang *et al*, 2023 andMiralles *et al.,* 2021). Test weight was not significantly influenced by different nitrogen sources though lower test weight observed in the control indicates that nitrogen deficiency impairs grain filling, reducing overall grain quality (Singh and Pathania, 2020, Singh *et al.*, 2024).

Yield: The highest grain yield (4959 kg/ha) was recorded in T_3 (100% RDN through chemical fertilizers + *Azotobacter*), followed by T_2 (100% RDN through chemical fertilizers, 4889 kg/ha) (Table 3). This superior performance is due to the immediate nitrogen availability from chemical fertilizers, enhanced by *Azotobacter*'s nitrogen-fixing ability, which improves nutrient uptake, root growth, and photosynthesis (Aasfar *et al.,* 2021and Zhou *et al.,* 2023). Organic treatments such as T_6 (125% RDN through FYM, 4584 kg/ha) and T_7 (125% RDN

Table: 2 Effect of different levels and sources of nitrogen on yield attributes of barley

Treatments	No. of effective tillers (m^{-1} r l)	Ear length (cm)	No. of grain per ear	Test weight (g)
T1: Control	66.0	8.5	43.8	41.0
T2: 100% RDN throughchemical fertilizers (80kg/ha)	97.5	11.7	58.5	48.9
T3:100% RDN through CF+*Azotobacter*	97.8	11.9	58.6	49.2
T4: 100% RDN through FYM	94.3	10.7	56.0	46.7
T5: 100% RDN through VC	95.0	10.8	56.5	47.0
T6: 125% RDN through FYM	95.8	10.9	57.0	47.1
T7: 125 % RDN through VC	96.3	11.2	57.5	47.4
T8: 100% RDN through FYM+25% RDN through CF	92.0	10.4	55.0	46.1
T9: 75% RDN through FYM+25% RDN through CF	90.8	10.0	53.3	44.5
T10: 50%RDN through FYM+50% RDN through CF	89.8	9.9	52.8	44.0
T11: 100% RDN through VC+25% RDN through CF	93.5	10.5	55.3	46.6
T12: 75% RDN through VC+25% RDN through CF	91.5	10.1	53.8	45.0
T13: 50% RDN through VC +50% RDN through CF	90.0	10.0	53.0	44.4
SEm±	0.63	0.14	0.56	0.12
LSD	0.82	0.39	1.61	NS

through vermicompost, 4626 kg/ha)also yielded significantly higher than the control (3399 kg/ha), although their gradual nutrient release slightly limited yield potential compared to chemical fertilizers.Straw yield followed a similar trend, with T3 (6471 kg/ha) and T2 (6464 kg/ha) recording the highest values due to enhanced vegetative growth from optimal nitrogen supply. Organic treatments T6 (6426 kg/ha) and T7 (6454 kg/ha) also performed well, showing the benefits of sustained nutrient release (Sharma et al., 2023).

Biological yield was highest in T_3 (11383 kg/ha) and T_2 (11353 kg/ha), supported by increased grain and straw production. Organic treatments T_6 (10907 kg/ha) and T_7 (10962 kg/ha) also showed significant improvement over the control (8626 kg/ha), indicating the long-term benefits of organic amendments on soil health and biomass accumulation. Treatments T_3, T_2, T_6, and T_7 remained statistically at par, suggesting that both chemical and organic nitrogen sources, when applied appropriately, effectively support barley productivity. These results align with findings by Singh and Stoskopt (1971), Kathuri (2007) and Meena *et al*,. (2021).

Table 3: Effect of different levels and sources of nitrogen on yield of barley

Treatments	Grain yield (Kg/ha)	Straw yield (Kg/ha)	Biological yield (Kg/ha)
T1: Control	3399	5227	8626
T2: 100% RDN through chemical fertilizers (80 kg/ha)	4889	6464	11353
T3: 100% RDN through CF + *Azotobacter*	4959	6471	11383
T4: 100% RDN through FYM	4349	6345	10799
T5: 100% RDN through VC	4421	6354	10847
T6: 125% RDN through FYM	4584	6426	10907
T7: 125 % RDN through VC	4626	6454	10962
T8: 100% RDN through FYM+25% RDN through CF	4242	6323	10595
T9: 75% RDN through FYM+25% RDN through CF	4216	5866	10059
T10: 50%RDN through FYM+50% RDN through CF	4165	5738	9902
T11: 100% RDN through VC+25% RDN through CF	4329	6336	10694
T12: 75% RDN through VC+25% RDN through CF	4225	5888	10113
T13: 50% RDN through VC +50% RDN through CF	4193	5814	10030
SEm±	66	86	68
LSD	189	247	195

Conclusion

The study concludes that nitrogen levels and sources significantly influence the growth and yield of barley. The highest seed yield, stover yield, and biological yield were achieved with the application of 100% RDN through chemical fertilizers combined with *Azotobacter*. This treatment outperformed the control and other treatments, demonstrating the effectiveness of integrating chemical fertilizers with nitrogen-fixing *Azotobacter* in enhancing overall crop productivity.

COMPETING INTERESTS DISCLAIMER:

Authors have declared that they have no known competing financial interests OR non-financial interests OR personal relationships that could have appeared to influence the work reported in this paper.

Disclaimer (Artificial intelligence)

Author(s) hereby declares that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

References

1. Aasfar, A., Bargaz, A., Yaakoubi, K., Hilali, A., Bennis, I., Zeroual, Y., & Meftah Kadmiri, I. (2021). Nitrogen fixing Azotobacter species as potential soil biological enhancers for crop nutrition and yield stability. Frontiers in microbiology, 12, 628379.
2. Awasthi, U.D. & Bhan, S. (2004). Response of barley varieties to N under moisture scarce condition in central U.P. Bhartiya Krishi Anusanalhan Patrika, 9 (1), 43-48.
3. Bhandari, G. S.; Randhawa, M. S. & Maskina, M. S. (2007). Polysaccharide content of earthworm cast curr. SCIO, 36, 519-520.
4. Dhaka, R.S., Ram, S. & Dass, B. (2018). Response of barley varieties to varying level of nitrogen under semi-arid condition. Int. J. of Trop. Agric., 15(1/4), 229-232.
5. Fisher, R.A. (1950). Statistical methods for research workers. Pub. Oliver and Boyd, Edinburgh, London.
6. Guan, X., Cheng, Z., Li, Y., Wang, J., Zhao, R., Guo, Z., Zhao, T., Huang, L., Qiu, C., Shi, W. & Jin, S. (2023). Mixed organic and inorganic amendments enhance soil microbial interactions and environmental stress resistance of Tibetan barley on plateau farmland. Journal of Environmental Management, 330, 117137.
7. Huang, Y., Kamal, R., Shanmugaraj, N., Rutten, T., Thirulogachandar, V., Zhao, S., Hoffie, I., Hensel, G., Rajaraman, J., Moya, Y.A.T., Hajirezaei, M.R., Himmelbach, A., Poursarebani, N., Lundqvist, U., Kumlehn, J., Stein, N., Wiren, N.V., Mascher, M., Melzer, M. & Schnurbusch, T. (2023). A molecular framework for grain number determination in barley. Science Advances, 9(9), eadd0324.
8. Jackson, M.L. (1973). Soil chemical analysis, Prentice Hall of India Pvt. Ltd., New Delhi.
9. Kathuri, M.K. (2007). Integrated nutrient management in cereal fodder wheat cropping system. Ph. D. Thesis submitted to CCS, Haryana Agricultural University, Hisar.

10. Meena, R.P. & Sharma, O.P. (2021). Effect of nitrogen, FYM and growth regulator on yield attributes and yield of barley (Hordeum vulgare L). Haryana J. Agron., 17(1 & 2), 164-165.
11. Miralles, D. J., Abeledo, L. G., Prado, S. A., Chenu, K., Serrago, R. A., & Savin, R. (2021). Barley. In Crop physiology case histories for major crops (pp. 164-195). Academic Press.
12. Mishra, J. P., Dixit, R.S. and Tripathi, H.P. (2021). Effect of irrigation schedule and nitrogen levels on water use, its efficiency and extraction pattern by late sown barley (Hordeum vulgare L.). Ind. J. Agron, 36, 267-268.
13. Naeem, M., Mehboob, N., Farooq, M., Farooq, S., Hussain, S., M. Ali, H., & Hussain, M. (2020). Impact of different barley-based cropping systems on soil physicochemical properties and barley growth under conventional and conservation tillage systems. Agronomy, 11(1), 8.
14. Olsen, S.R., Cole, C.V., Watnable, F.S & Dean, L.A. (1954). Estimation of available phosphorus in soil by extraction with sodium bicarbonate Circular 939, USDA, Washington, DC, USA.
15. PIB. (2024). Rabi crop sowing exceeds 558 lakh hectares. Press Information Bureau, Ministry of Agriculture & Farmers Welfare, Government of India, New Delhi, India. https://pib.gov.in/PressReleseDetailm.aspx?PRID=2084897&reg=3&lang=1
16. Ryan, J., Estefan, G. & Rashid, A. (2001). Soil and Plant Analysis Laboratory Manual. In: Jointly published by the International Centre Agricultural Research in Dry Areas (ICARDA), Aleppo, Syria and National Agriculture Research Centre (NARC), Islamabad.
17. Samantaray, A., Chattaraj, S., Mitra, D., Ganguly, A., Kumar, R., Gaur, A., Mohapatra, P.K.D., de los Santos-Villalobos, S., Rani, A. & Thatoi, H. (2024). Advances in microbial based bio-inoculum for amelioration of soil health and sustainable crop production. Current Research in Microbial Sciences, 100251.
18. Sharma, T., Singh, J., Madaik, S., Kumar, P., Singh, A., Rana, B. B., & Chauhan, G. (2024). Organic input incorporation for enhancing sustainability and economic viability of cowpea in North-Western Himalayan region. Frontiers in Agronomy, 6, 1458603.
19. Sharma, T., Singh, J., Singh, A., Sharma, R., & Chauhan, G. (2023). Effect of organic nutrient sources on the yield, nutrient uptake and nodulation in Cowpea (Vigna

unguiculata) under mid-hill conditions of Western Himalayas. Environment Conservation Journal, 24(2), 250-256.

20. Singh, A., & Pathania, P. (2020). Evaluation of Different Crop Sequences for Yield, Crop Duration, Land Use Efficiency and Per Day Food Availability. Himachal Journal of Agricultural Research, 46(2), 193-196.
21. Singh, A., Pathania, P., Sharma, T., & Sharma, S. (2021). Effect of Different Crop Sequences on Soil Nutrient Status, Nutrient Uptake and Crop Yield in Western Himalayas of India. Indian Journal of Agricultural Research, 55(6), 733-738.
22. Singh, A., Pathania, P., Singh, J., Sharma, R., Singh, A., Mujahed, B. A., & Saharan, S. (2024). Influence of Nitrogen Levels on Productivity, Profitability and Nitrogen use Efficiency of New Rice (Oryza sativa L.) Cultivars in Northwestern Himalayas. RASSA Journal of Science for Society, 6(2): 59-62.
23. Singh, I.D. & Stoskopt, N.C. (1971). Harvest index of cereals. Agronomy Journal, 63, 224-226.
24. Statista. (2024). Production volume of barley in India from financial year 2012 to 2023, with an estimate for 2024. https://www.statista.com/statistics/878245/india-production-volume-of-barley/
25. Subbiah, B.V. & Asija, G.L. (1956). A rapid procedure for estimation of available nitrogen in soils. Current Science, 25, 259-260.
26. Zhou, L., Liu, W., Duan, H., Dong, H., Li, J., Zhang, S., Zhang, J., Ding, S., Xu, T. & Guo, B. (2023). Improved effects of combined application of nitrogen-fixing bacteria Azotobacter beijerinckii and microalgae Chlorella pyrenoidosa on wheat growth and saline-alkali soil quality. Chemosphere, 313, 137409.