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IMPACT OF NUTRIENT MANAGEMENT ON YIELDS, NUTRIENT UPTAKE AND SOIL PROPERTIES IN CLUSTER BEAN-BARLEY CROPPING SYSTEM

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ABSTRACT

Integrated Nutrient Management enhances crop yield, nutrient uptake, and soil fertility by combining organic, inorganic, and bio-fertilizers for balanced nutrient supply. The present investigation was laid out in randomized block design comprising of ten treatments with three replications. The treatments consisted T_1: control, T_2: 100% recommended dose of fertilizer (RDF), T_3: 75 % RDF, T_4: 50% RDF, T_5: 50% RDF+$ZnSO_4$ @ 20 kg ha^{-1}, T_6: 50% RDF+FYM @ 5 t ha^{-1}, T_7: 50% RDF+$ZnSO_4$ @ 20 kg ha^{-1} + FYM @ 5 t ha^{-1}, T_8: 75% RDF+$ZnSO_4$ @ 20 kg ha^{-1}, T_9: 75% RDF+FYM @ 5 t ha^{-1}, T_{10}: 75% RDF+$ZnSO_4$ @ 20 kg ha^{-1} + FYM @ 5 t ha^{-1}. The results showed that applying 75% RDF along with $ZnSO_4$ at 20 kg ha^{-1} and FYM at 5 t ha^{-1} led to the highest yields in *kharif* cluster bean, including seed, stover, gum, and protein yields. Similarly, in *rabi* barley, this treatment resulted in the highest grain, straw, starch, and protein yields. However, these yields were statistically similar to those obtained with 100% RDF, highlighting that integrated nutrient management can sustain crop productivity while reducing chemical fertilizer use. Significantly highest total N, P, K and Zn uptake by cluster bean crop was recorded with application of 75% RDF + $ZnSO_4$ @ 20 kg ha^{-1} + FYM @ 5 t ha^{-1} to the tune of 47.0 kg ha^{-1}, 8.6 kg ha^{-1} 26.3 kg ha^{-1}, and 55.6 g ha^{-1}, respectively. Similarly, this treatment recorded highest nutrient uptake by barley, with total N, P, K and Zn uptake recorded at 107 kg ha^{-1}, 23.7 kg ha^{-1}, 121 kg ha^{-1}, and 212 g ha^{-1}, respectively. The total N, P and K uptake by both the crop was found to be at par with 100% RDF treatment while the total Zn uptake in the 75% RDF + $ZnSO_4$ @ 20 kg ha^{-1} + FYM @ 5 t ha^{-1} treatment was significantly higher over all the treatment in both crops. The soil available nutrient status did not differ much across the treatments after harvest of both the crops nevertheless, a numerical enhancement was observed in the treatment with 100% recommended dose of fertilizer in both crops, followed by 75% RDF combined with + $ZnSO_4$ @ 20 kg ha^{-1} and 5 t FYM ha^{-1}. The significant difference in available Zn status was observed in treatments consisting Zn fertilizer with or without FYM The soil nutrient status after harvest of cluster bean crop showed slight improvement, revealing the positive effect of legumes on soil fertility.

***Key words*:** Barley, Cluster bean, nutrient uptake, soil properties, yield

Introduction

Sustainable agricultural productivity depends largely on efficient nutrient management practices that enhance crop yields while maintaining soil fertility. The cluster bean (*Cyamopsis tetragonoloba* L.)-barley (*Hordeum vulgare* L.) cropping system is a widely adopted rotational practice in arid and semi-arid regions due to its potential for improving soil health and overall farm productivity. However, imbalanced fertilization and continuous nutrient depletion pose significant challenges to sustaining high yields and soil quality in this system. Integrated Nutrient Management has emerged as a strategic approach to optimize nutrient use efficiency, improve plant growth, and maintain long-term soil health. INM involves the judicious combination of organic, inorganic, and biological nutrient sources to provide a balanced supply of essential nutrients for crops (Singh *et al.*, 2020). Organic amendments, such as farmyard manure, compost, and green manure, contribute to soil organic matter and enhance microbial activity, thereby improving nutrient availability (Kumar *et al.*, 2019). Inorganic fertilizers play a crucial role in meeting immediate nutrient demands, while biofertilizers, including nitrogen-fixing bacteria and mycorrhizal fungi, support nutrient cycling and enhance plant uptake efficiency (Sharma *et al*., 2021). Several studies have demonstrated that INM improves crop yield and nutrient uptake by ensuring a steady and synchronized supply of nutrients throughout the cropping cycle (Verma *et al*., 2022). Additionally, this approach minimizes nutrient losses through leaching, volatilization, and runoff, thereby enhancing soil nutrient retention and reducing environmental impacts (Patel *et al*., 2018). In the cluster bean-barley system, integrating organic and inorganic nutrient sources has been found to improve soil structure, enhance microbial diversity, and increase the availability of macronutrients such as nitrogen (N), phosphorus (P), and potassium (K) (Gupta and Meena, 2020). Thus, a well-planned INM strategy is essential for sustaining the productivity of the cluster bean-barley cropping sequence while ensuring soil fertility conservation. This study aims to evaluate the impact of different nutrient management practices on crop yield, nutrient uptake, and soil properties in this cropping system, providing insights into sustainable agricultural practices that enhance productivity and soil health.

Materials and Methods

The experiment was carried out at Department of Agricultural Chemistry and Soil Science, R.B.S. College Research farm Bichpuri, Agra (U.P.) for two consecutive years with cluster bean as *kharif* crop followed by barley during *Rabi* season. Geographically the Agra district is located on South-East of Delhi representing the semi-arid region of South- Western Uttar Pradesh. The experimental site intersects at 27.20 N latitude and 77.90E longitude about 21 km away in the south of Agra city. The experimental soil was sandy loam in texture, alkaline in soil reaction with pH 8.0, EC 0.30 dSm^{-1}, low in organic carbon 3.3 g kg^{-1}, available nitrogen 152 kg ha^{-1}, phosphorus 7.3 kg ha^{-1}, potassium 147 kg ha^{-1} and marginally deficient available zinc content of 0.47 mg kg^{-1}. The experiment was laid out in Randomised block design comprising 10 treatments and replicated thrice. The treatments consisted T_1: control, T_2: 100% recommended dose of fertilizer (RDF), T_3: 75 % RDF, T_4: 50% RDF, T_5: 50% RDF+$ZnSO_4$ @ 20 kg ha^{-1}, T_6: 50% RDF+FYM @ 5 t ha^{-1}, T_7: 50% RDF+$ZnSO_4$ @ 20 kg ha^{-1} + FYM @ 5 t ha^{-1}, T_8: 75% RDF+$ZnSO_4$ @ 20 kg ha^{-1}, T_9: 75% RDF+FYM @ 5 t ha^{-1}, T_{10}: 75% RDF+$ZnSO_4$ @ 20 kg ha^{-1} + FYM @ 5 t ha^{-1} for both the crops. The recommended fertilizer dose was 20:60:40 kg N: P_2O_5: K_2O per hectare for cluster bean and 80:40:40 kg N:P, O : K, O per hectare for barley crop. Urea, single super phosphate, and muriate of potash were used as nutrient sources for nitrogen, phosphorus, and potassium, respectively. While, zinc sulphate was used to supply Zn in both the crops. Well decomposed FYM @ 5 t ha^{-1} was applied before sowing of *kharif* and *Rabi* crop and seed treatment with *Rhizobium* and *Azobacter* was common to all treatments except control. All the other recommended agronomic management practices were followed during the growth period of the crops. Gum content in cluster bean was estimated by adopting the methodology suggested by Association of Official Analytical Chemists (Anonymous, 2005). The starch content in barley was estimated by Anthone method as suggested by David (1990). Total nitrogen content was determined using the Micro-Kjeldahl method as outlined by Bremner and Malvaney (1982). Total phosphorus was analyzed using the Vanadomolybdate Yellow Color method in a nitric acid system, following Jackson (1973). Total potassium was measured with a Flame Photometer, as described by Chapman and Pratt (1961). Zinc content in plant samples was estimated using the method proposed by Zoroski and Bureau (1977). Protein content was calculated by multiplying the total nitrogen content by a factor of 6.25. The total nutrient uptake was computed by multiplying per cent nutrient content with yield of respective crop. The available nitrogen was estimated as per Subbiah and Asija (1956), available phosphorus by Olsen *et al*., (1954) , available potassium by Knudsen *et al*., (1982) , DTPA Zn by Lindsay and Norvell (1978). The observed and laboratory data was analysed statistically, following the methodology recommended by Panse and Sukhatme (1985).

Results and Discussion

Yields of cluster bean and barley

The pooled data of two consecutive years indicated that the integrated nutrient management in cluster bean-barley system demonstrated positive effect on yields of both the crop thereby increasing their gum, starch and protein yields (Table 1). The application of 75% RDF combined with $ZnSO_4$ at 20 kg ha^{-1} and FYM at 5 t ha^{-1} resulted in the highest recorded yields, including seed yield (11.9 q ha^{-1}), stover yield (20.3 q ha^{-1}), gum yield (316 kg ha^{-1}), and protein yield (192 kg ha^{-1}), significantly outperforming all other nutrient management treatments. However, these yields were statistically comparable to those obtained with the application of 100% RDF without FYM, which produced seed, stover, gum, and protein yields of 11.4 q ha^{-1}, 20.3 q ha^{-1}, 305 kg ha^{-1}, and 183 kg ha^{-1}, respectively. In barley, the significantly and highest grain yield (43.7 q ha^{-1}), straw yield (66.9 q ha^{-1}), starch yield (2311 kg ha^{-1}) and protein yield (527 kg ha^{-1}) was recorded with the similar treatment *i.e.* application of

Table 1: Influence of nutrient management on yields of cluster bean and barley crop under cluster bean-barley cropping system. (Pooled mean data).

S. No.	Treatments	*Kharif* Cluster bean				*Rabi* Barley			
		Seed	Stover	Gum	Protein	Grain	Straw	Starch	Protein
		---(q ha^{-1})---		---(kg ha^{-1})---		---(q ha^{-1})---		---(kg ha^{-1})---	
T_1	Control	7.3	15.9	163	113	32.9	56.3	1712	378
T_2	100% RDF	11.4	20.3	305	183	42.7	65.5	2250	509
T_3	75% RDF	9.7	18.1	249	150	38.0	61.4	1989	447
T_4	50% RDF	8.2	16.5	208	127	34.9	59.4	1804	407
T_5	50%RDF+$ZnSO_4$ @ 20 kg ha^{-1}	8.7	17.1	222	135	36.1	60.2	1890	424
T_6	50%RDF+FYM @ 5 t ha^{-1}	9.0	17.6	231	141	37.4	60.6	1974	440
T_7	50%RDF+$ZnSO_4$ @ 20 kg ha^{-1}+FYM @ 5 t ha^{-1}	10.5	18.9	274	164	39.0	62.0	2050	467
T_8	75%RDF+$ZnSO_4$ @ 20 kg ha^{-1}	10.7	18.9	276	167	39.5	62.4	2081	471
T_9	75%RDF+FYM @ 5 t ha^{-1}	10.9	19.3	285	173	41.5	64.3	2179	497
T_{10}	75%RDF+$ZnSO_4$ @ 20 kg ha^{-1}+FYM @ 5 t ha^{-1}	11.9	20.6	316	192	43.7	66.9	2311	527
SEm$\pm$		0.17	0.22	4.6	3.1	0.40	0.53	27.3	9.5
CD@0.05		0.52	0.63	13.1	8.8	1.15	1.50	77.8	27.0

75% RDF + $ZnSO_4$ @ 20 kg ha^{-1}+FYM @ 5 t ha^{-1} nevertheless, application of 100% RDF without FYM which showed the comparable grain yield (42.7 q ha^{-1}), straw yield (65.5 q ha^{-1}), starch yield (2250 kg ha^{-1}) and protein yield (509 kg ha^{-1}).

The enhanced growth and productivity of both crops can be attributed to improved soil fertility, increased nutrient availability, and stimulated microbial activity. The application of FYM contributes to the enrichment of soil organic matter, enhances nutrient retention, and improves soil structure, facilitating better root development and efficient nutrient uptake (Mandal *et al.*, 2020; Choudhary *et al.*, 2021). Additionally, the combined application of $ZnSO_4$ and FYM may have increased the bioavailability of zinc by reducing its fixation in the soil, thereby supporting improved crop growth and higher yields. Ajam *et al.*, (2024) also observed a significant increase in cluster bean yield with the integrated use of nutrients, particularly the combined application of NPK and Zn fertilizers. Similarly, Meena and Jat, (2016) reported an increase in gum and protein yield due to zinc application. These findings align with the study conducted by Rawat *et al.*, (2017), which demonstrated an improvement in gum yield with the combined application of 75% of the recommended dose of fertilizers and 5 t ha^{-1} of vermicompost. The results are further supported by the findings of Singh *et al.*, (2016), Sharma *et al.*, (2019), and Lal *et al.*, (2023), who reported similar yield enhancements under integrated nutrient management practices. In the case of barley, Kumar and Jat (2021) documented higher yields in a barley-based cropping system when 75% RDF was supplemented with FYM and microbial consortia. Likewise, Liza Kumari *et al.* (2022) reported significant improvements in yield and yield attributes in barley due to the adoption of INM practices.

Total nutrient uptake by cluster bean crop

The pooled mean data presented in Table 2 pertaining to total nutrient uptake by cluster bean crop indicated significant variations. The application of 75% RDF along with $ZnSO_4$ at 20 kg ha^{-1} and FYM at 5 t ha^{-1} (T_{10}) resulted in the highest total nutrient uptake by cluster bean, with total N, P, K, and Zn uptake recorded at 47.0 kg ha^{-1}, 8.6 kg ha^{-1} 26.3 kg ha^{-1}, and 55.6 g ha^{-1}, respectively. However, the total nutrient uptake under this treatment was statistically comparable to the total

Table 2: Nutrient uptake by cluster bean crop as influenced by different nutrient management treatments (Pooled mean data).

S.No.	Nutrient uptake			
	N	P	K	Zn
	(kg ha^{-1})			(g ha^{-1})
T_1	28.7	5.0	16.7	33.4
T_2	45.4	8.0	25.3	51.4
T_3	36.8	6.5	21.3	44.6
T_4	31.0	5.6	18.9	37.3
T_5	33.2	5.6	19.9	42.2
T_6	34.8	5.8	20.4	41.8
T_7	40.1	7.0	22.7	48.6
T_8	40.7	7.0	23.1	49.4
T_9	42.2	7.6	24.0	49.1
T_{10}	47.0	8.6	26.3	55.6
SEm$\pm$	0.79	0.34	0.54	0.82
CD@0.05	2.25	0.84	1.54	2.33

T_1: Control, **T_2:** 100% RDF, **T_3:** 75 % RDF, **T_4:** 50% RDF, **T_5:** 50% RDF+$ZnSO_4$ @ 20 kg ha^{-1}, **T_6:** 50% RDF+FYM @ 5 t ha^{-1}, **T_7:** 50% RDF+$ZnSO_4$ @ 20 kg ha^{-1} + FYM @ 5 t ha^{-1}, **T_8:** 75% RDF+$ZnSO_4$ @ 20 kg ha^{-1}, **T_9:** 75% RDF+FYM @ 5 t ha^{-1}, **T_{10}:** 75% RDF+$ZnSO_4$ @ 20 kg ha^{-1} + FYM @ 5 t ha^{-1}

Table 3: Nutrient uptake by barley crop as influenced by different nutrient management treatments (Pooled mean data).

S.No.	Nutrient uptake			
	N	P	K	Zn
	(kg ha^{-1})			(g ha^{-1})
T_1	78	17.0	99	103
T_2	104	22.6	119	179
T_3	93	19.8	110	162
T_4	86	17.8	102	124
T_5	88	18.0	105	164
T_6	91	18.5	107	139
T_7	95	19.8	110	171
T_8	97	20.1	111	178
T_9	101	21.4	116	171
T_{10}	107	23.7	121	212
SEm$\pm$	3.37	0.50	1.65	3.43
CD@0.05	9.60	1.43	4.69	6.90

T_1: Control, **T_2:** 100% RDF, **T_3:** 75 % RDF, **T_4:** 50% RDF, **T_5:** 50% RDF+$ZnSO_4$ @ 20 kg ha^{-1}, **T_6:** 50% RDF+FYM @ 5 t ha^{-1}, **T_7:** 50% RDF+$ZnSO_4$ @ 20 kg ha^{-1} + FYM @ 5 t ha^{-1}, **T_8:** 75% RDF+$ZnSO_4$ @ 20 kg ha^{-1}, **T_9:** 75% RDF+FYM @ 5 t ha^{-1}, **T_{10}:** 75% RDF+$ZnSO_4$ @ 20 kg ha^{-1} + FYM @ 5 t ha^{-1}

nitrogen (45.4 kg ha^{-1}), total phosphorus (8.0 kg ha^{-1}) and total potassium (25.3 kg ha^{-1}) observed with 100% RDF application without FYM. Notably, the total zinc uptake in this treatment was significantly higher (55.6 g ha^{-1}) than in all other nutrient management treatments.

The variation in nutrient uptake by cluster bean with the combined application of 75% RDF, FYM, and $ZnSO_4$ may be attributed to improved nutrient availability from FYM. Additionally, Zn application promotes root growth, enhancing water and nutrient uptake. This synergistic effect of FYM and Zn further boosts nutrient absorption in cluster bean. These findings align with those of Singh *et al.*, (2016), who reported increased nutrient uptake in cluster bean with the combined application of FYM and Zn fertilizers. Similarly, Mastiholi *et al.*, (2022) observed enhanced nutrient uptake with organic supplements, while Ajam *et al.*, (2024) noted a significant improvement with the integrated use of NPK and Zn nutrients.

Total nutrient uptake by barley crop

The pooled data in Table 3 indicate that the application of 75% RDF combined with FYM at 5 t ha^{-1} and $ZnSO_4$ at 20 kg ha^{-1} (T_{10}) resulted in the highest nutrient uptake by barley, with total nitrogen, phosphorus, potassium, and zinc uptake recorded at 107 kg ha^{-1}, 23.7 kg ha^{-1}, 121 kg ha^{-1}, and 212 g ha^{-1}, respectively. However, these values were statistically comparable to those observed in the 100% RDF treatment (T_2), which recorded total nitrogen, phosphorus, and potassium uptake of 104 kg ha^{-1}, 22.6 kg ha^{-1}, and 119 kg ha^{-1}, respectively. Notably, zinc uptake (212 g ha^{-1}) in the 75% RDF + FYM + $ZnSO_4$ treatment was significantly higher than in all other treatments.

These findings align with the results of Goswami and Pandey (2018), who reported a significant increase in nutrient uptake by barley due to the synergistic effect of inorganic fertilizers combined with FYM and Zn. Similarly, Kumar and Jat (2021) observed enhanced nutrient uptake with the application of 75% RDF, 5 t ha^{-1} FYM, and biomix. Moreover, Singh *et al.*, (2023) documented higher nutrient uptake in barley following Zn fertilizer application.

Available nutrient status

The pooled mean data on the available nutrient status after harvesting *kharif* cluster bean and *rabi* barley is presented in Table 4. The results indicate that available nitrogen, phosphorus, and potassium levels after harvest were not significantly affected by different nutrient

Table 4: Available nutrient status after harvest cluster bean and barley crop (Pooled mean data).

S. No.	Treatments	Available nutrient status							
		Kharif Cluster bean				*Rabi* Barley			
		N	P	K	Zn	N	P	K	Zn
		---(kg ha^{-1})---		---(mg kg^{-1})---		---(kg ha^{-1})---		---(mg kg^{-1})---	
T_1	Control	151	7.4	148	0.46	146	7.1	144	0.44
T_2	100% RDF	162	7.6	154	0.48	166	7.7	154	0.48
T_3	75% RDF	159	7.5	153	0.48	163	7.6	153	0.46
T_4	50% RDF	155	7.4	151	0.47	159	7.4	151	0.46
T_5	50%RDF+$ZnSO_4$ @ 20 kg ha^{-1}	157	7.5	152	0.49	161	7.5	153	0.50
T_6	50%RDF+FYM @ 5 t ha^{-1}	157	7.5	151	0.48	161	7.5	151	0.47
T_7	50%RDF+$ZnSO_4$ @ 20 kg ha^{-1}+FYM @ 5 t ha^{-1}	157	7.5	153	0.50	159	7.5	154	0.50
T_8	75%RDF+$ZnSO_4$ @ 20 kg ha^{-1}	159	7.6	153	0.50	163	7.6	153	0.50
T_9	75%RDF+FYM @ 5 t ha^{-1}	161	7.6	154	0.49	163	7.6	153	0.49
T_{10}	75%RDF+$ZnSO_4$@ 20 kg ha^{-1}+FYM @ 5 t ha^{-1}	161	7.6	155	0.51	165	7.7	155	0.53
SEm$\pm$		5.7	0.41	2.2	0.010	5.8	0.41	2.7	0.013
CD@0.05		NS	NS	NS	0.030	17.5	NS	8.2	0.040

management treatments. However, numerically higher available nitrogen was observed in the treatment with 100% RDF compared to other treatments.

After the harvest of *kharif* cluster bean, the 100% RDF treatment recorded the highest available nitrogen (162 kg ha^{-1}), followed closely by 75% RDF + $ZnSO_4$ at 20 kg ha^{-1} + FYM at 5 t ha^{-1} (161 kg ha^{-1}). Available phosphorus and potassium remained unchanged across treatments. However, available Zn (DTPA-Zn) was significantly higher in T_{10} (75% RDF + ZnSO„ @ 20 kg ha^{-1} + FYM @ 5 t ha^{-1}) at 0.51 mg kg^{-1}, which was statistically at par with 50% RDF + $ZnSO_4$ @ 20 kg ha^{-1} (0.49 mg kg^{-1}), 50% RDF + $ZnSO_4$ @ 20 kg ha^{-1} + FYM @ 5 t ha^{-1} (0.50 mg kg^{-1}), and 75% RDF + $ZnSO_4$ @ 20 kg ha^{-1} (0.50 mg kg^{-1}).

Similarly, after the harvest of *rabi* barley, the treatment with 75% RDF + $ZnSO_4$ @ 20 kg ha^{-1} + FYM @ 5 t ha^{-1} recorded the highest available nitrogen (165 kg ha^{-1}) and available potassium (155 kg ha^{-1}), significantly surpassing the control (146 kg ha^{-1}) and (144 kg ha^{-1}) respectively, though it was statistically at par with other treatments. Available phosphorus levels remained similar across treatments. However, available Zn content was significantly higher (0.53 mg kg^{-1}) in the 75% RDF + $ZnSO_4$ @ 20 kg ha^{-1} + FYM @ 5 t ha^{-1} treatment compared to the control (0.44 mg kg^{-1}), 100% RDF (0.48 mg kg^{-1}), 75% RDF (0.46 mg kg^{-1}), 50% RDF (0.46 mg kg^{-1}), and 50% RDF + FYM @ 5 t ha^{-1} (0.47 mg kg^{-1}), though it remained statistically similar to the other treatments. The variation in available Zn content highlights the importance of Zn fertilizer and organic manure application in soils with marginal deficiency. Overall, a slight improvement in soil nutrient status was observed after the harvest of the cluster bean crop, reflecting the beneficial impact of legumes on soil fertility.

Although the increase in available nutrient status was not statistically significant, a numerical enhancement was observed in the treatment with 100% recommended dose of fertilizer in both crops, followed by 75% RDF combined with + $ZnSO_4$ @ 20 kg ha^{-1} and 5 t FYM ha^{-1}. This improvement can be attributed to a balanced nutrient supply and additional nutrient supplementation provided by organic manures.

The findings align with those of Goswami and Pandey (2018) and Mastiholi *et al*., (2022), who reported an improvement in available nutrient status following the application of organic amendments. The combined application of zinc fertilizer and FYM has been shown to enhance soil available zinc levels. This synergistic effect can be attributed to the organic matter in FYM, which enhances soil structure and microbial activity, thereby improving zinc solubility and availability to plants. Similar observations were also reported by Goswami and Pandey (2018). Furthermore, the results are consistent with the findings of Meena *et al*., (2018), Singh *et al*., (2016), and Dogra *et al*., (2017), who documented a significant increase in soil zinc levels with the combined application of Zn fertilizer and organic manure.

Conclusion

The study assessed the influence of nutrient management on yield, nutrient uptake, and soil properties in a cluster bean-barley cropping system. The combined application of 75% of the recommended chemical fertilizers along with zinc and farmyard manure (FYM) enhanced nutrient availability, leading to improved crop yields and nutrient uptake in both cluster bean and barley. The preceding leguminous crop contributed to improved soil fertility, benefiting the subsequent rabi barley. However, the observed benefits could have been more pronounced with a long-term evaluation under consistent nutrient management practices. To gain deeper insights into the sustainability of these strategies, a long-term study is recommended to assess the impact of nutrient management in legume-based cropping systems, particularly in the marginal soils of Agra district.

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