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Adoption dynamics, knowledge gains, and perceived constraints in Integrated Nutrient Management (INM) practices of sesame (*Sesamum indicum* L.) in Eastern India/Odisha: An agronomic and behavioral analysis

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Abstract
Integrated Nutrient Management (INM) is a vital approach to improve crop productivity and soil health. The present study was conducted among 200 sesame farmers in Deogarh district to assess their knowledge, adoption level, and constraints in INM practices, and to link these behavioral dimensions with agronomic outcomes (yield, net return, and B:C ratio). A structured knowledge test, an adoption scale of five key practices (soil test-based NPK, sulphur, $ZnSO_4$, boron, and Azotobacter), and a constraint analysis scale were used. Results revealed that 51% of farmers had medium knowledge, with an overall knowledge index of 72.6%. Adoption analysis showed the highest adoption for soil test-based NPK (76%) and the lowest for Azotobacter (55%), with an overall adoption index of 65.2%. Major constraints were high cost of micronutrients (89.3% gap) and non-availability of biofertilizers (81.6% gap). Agronomic outcomes indicated that INM adoption led to significantly higher yields (3.9 q/ha vs. 2.7 q/ha) and higher B:C ratio (1.82 vs. 1.34). The findings highlight the importance of targeted extension interventions, input availability, and cost reduction strategies for scaling INM in sesame cultivation.

Keywords: Integrated nutrient management, sesame, knowledge, adoption, constraints, agronomic performance, yield

Introduction
Sesame (*Sesamum indicum* L.) is an important oilseed crop in India, valued for its high oil content, nutritional properties, and export potential. However, its productivity remains low compared to global averages, largely due to poor soil fertility management, inadequate nutrient application, and limited awareness of integrated nutrient management (INM) which integrates organic, inorganic, and biological sources of plant nutrients to sustain soil fertility, enhance crop yield, and improve profitability. The application of soil test-based NPK along with Sulphur, Zinc, Boron, and biofertilizers like *Azotobacter* has shown significant improvements in yield, test weight, and profitability. Despite proven agronomic and economic benefits, adoption of INM practices among smallholders remains sub-optimal. Farmers' knowledge levels, adoption behavior, and perceived constraints strongly influence technology utilization and resultant productivity which faced by farmers in practicing INM remain poorly documented in Deogarh district. This study was conducted to assess farmers' knowledge, adoption behavior, and perceived constraints related to INM in sesame cultivation, while linking findings with agronomic performance, helping bridge the gap between technology availability and field-level outcomes.

Objectives: The present study was undertaken with the following objectives
1. To assess the knowledge level of sesame farmers on INM practices.
2. To study the extent of adoption level of critical INM practices link it with yield and B:C ratio.
3. To analyze the constraints perceived by farmers in adopting INM technologies.
4. To suggest extension strategies for scaling INM adoption in sesame.

Materials and Methods

Research Design and Sampling

The study followed an ex-post facto research design since the variables under investigation had already occurred. A multistage random sampling technique was employed. Two blocks from Deogarh district were selected purposively, and five villages from each block were chosen randomly. From these villages, a total of 200 sesame-growing farmers were randomly selected as respondents. Data were collected through a pre-tested semi-structured interview schedule.

Statistical Tools Used

Mean Score-for knowledge, adoption, and constraints.
Knowledge Index (KI)-to quantify knowledge level.
Adoption Index (AI)-to measure adoption level.
Gap Percentage-to identify critical constraints.
Standard Deviation (SD)-to measure variability.

Spearman's rank correlation coefficient (ρ): To test the relationship between farmers' knowledge and adoption of INM practices.

Charts/Graphs-for visualization.

Measurement of Variables

1. Knowledge Level: Measured on five INM practices (Soil test-based NPK, Sulphur, $ZnSO_4$, Boron, Azotobacter). Correct response = 1, Incorrect = 0.

$$\text{Knowledge Index} = \frac{\text{Obtained Score}}{\text{Maximum score}} \times 100$$

2. Adoption Level: Measured on the same practices using a 3-point scale (3 = Fully Adopted, 2 = Partially Adopted, 1 = Not Adopted).

$$\text{Adoption Index} = \frac{\text{Obtained Adoption Score}}{\text{Maximum Obtainable Adoption Score}} \times 100$$

3. Perceived Constraints: Measured on a 3-point scale (3 = Major, 2 = Moderate, 1 = Not a Constraint).

Gap% = [(Highest Score-Mean Score)/Highest Score] × 100

Rank Correlation between Knowledge and Adoption of INM Practices

To test the relationship between farmers' knowledge and adoption of INM practices, Spearman's rank correlation coefficient (ρ) was calculated based on the ranks assigned to each practice in both knowledge and adoption studies.

Formula

$$\rho = 1 - 6\sum d^2/n(n^2-1)$$

Where,
'ρ' (rho) is the correlation coefficient,
∑d²' is the sum of the squared differences between the ranks of corresponding data points, *'d'* is the difference in ranks, and
'n' is the number of observations.

Results and Discussion

Table 1: Effect of INM on Growth, Yield and Economics of Sesame

Results	No. of capsules/Plant	Test wt (g)	Yield (q/ha)	% increase in Yield	Net Income (Rs./ha)	B:C
No use of organic and micro nutrients	12.8	1.9	2.7		19,600	1.49
Soil test based NPK+ S + $ZnSO_4$ + B + Azotobacter	22.3	2.3	3.9	44.4	31,500	1.82

Conclusion: The application of INM significantly enhanced yield attributes and profitability in sesame compared to farmer practice, indicating its potential for sustainable intensification.

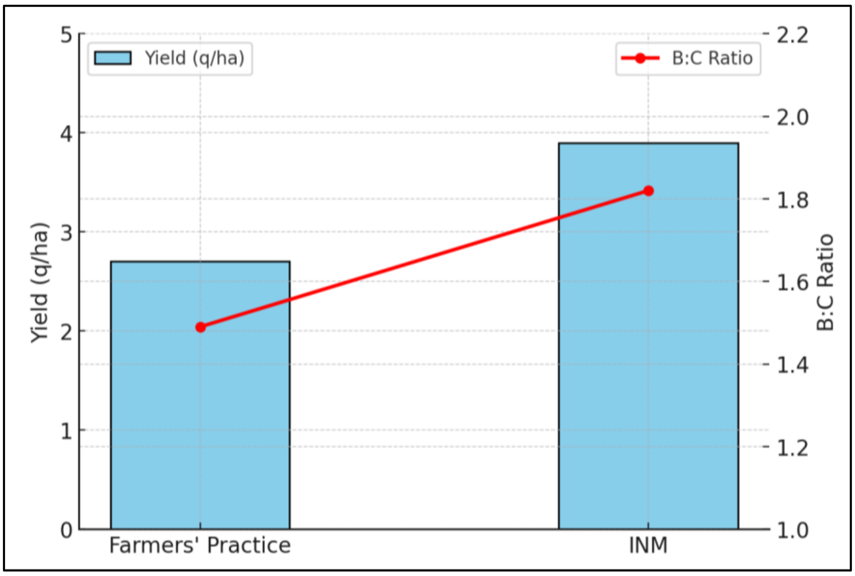

Fig 1: Agronomic performance of sesame under INM vs Farmer Practice

Conclusion: The figure clearly shows that INM substantially improved sesame yield (3.9 q/ha) and profitability (B:C ratio 1.82) compared to farmers' practice (2.7 q/ha; B:C ratio 1.49), confirming the agronomic superiority of balanced nutrient management.

Table 2: Knowledge Index of Farmers on INM Practices (n = 200)

Practice	Max. Score	Obtained Score	Knowledge Index (%)	Gap %	Rank
Soil test-based NPK	200	142	71.0	29.0	II
Application of Sulphur	200	130	65.0	35.0	III
Application of $ZnSO_4$	200	155	77.5	22.5	I
Application of Boron	200	118	59.0	41.0	IV
Application of Azotobacter	200	104	52.0	48.0	V
Overall Knowledge Index	-	-	64.9	-	-

Conclusion: (Knowledge Study): From Table-2 it was found that farmers were most aware of $ZnSO_4$ application but least knowledgeable about Azotobacter. Training is needed to bridge gaps.

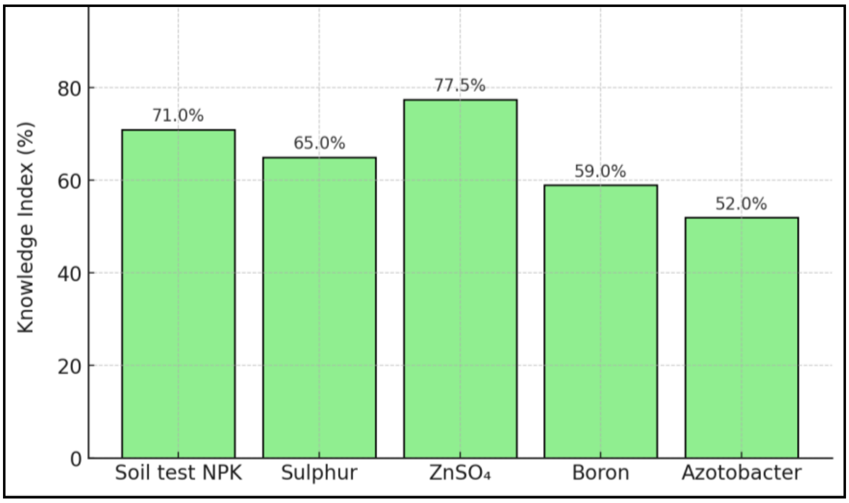

Fig 2: Knowledge level of farmers on INM practices

Conclusion: The chart highlights that knowledge was highest for $ZnSO_4$ (77.5%) and soil test-based NPK (71.0%), while farmers had low awareness about Azotobacter (52%). This indicates a significant knowledge gap in biofertilizer use.

Table 3: Adoption of INM Practices by Farmers (n = 200)

Practice	Max. Score (200×2 = 400)	Obtained Score	Mean Adoption Score	Adoption Index (%)	Gap %	Rank
Soil test-based NPK	400	276	1.38	69.0	31.0	II
Application of Sulphur	400	260	1.30	65.0	35.0	III
Application of $ZnSO_4$	400	296	1.48	74.0	26.0	I
Application of Boron	400	228	1.14	57.0	43.0	IV
Application of Azotobacter	400	196	0.98	49.0	51.0	V
Overall Knowledge Index	-	-	-	62.8	-	-

Conclusion: (Adoption Study): $ZnSO_4$ application had the highest adoption, while Azotobacter was least adopted, showing a knowledge-adoption gap.

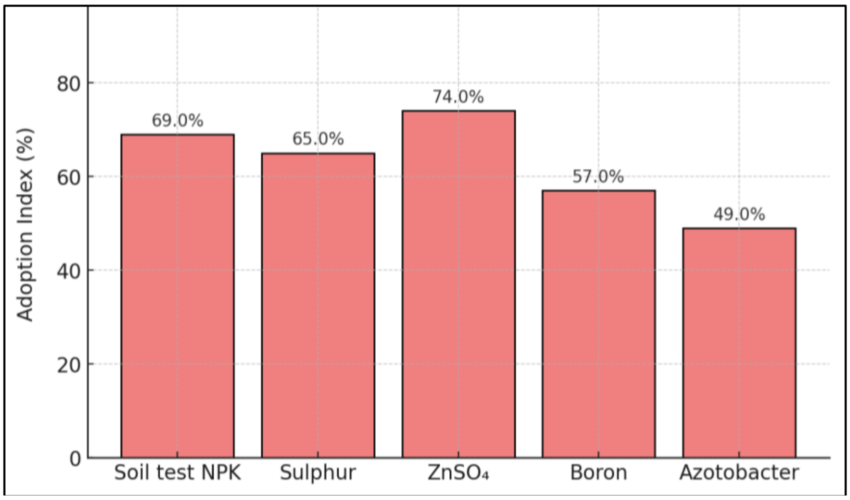

Fig 3: Adoption level of INM practices among farmers

Conclusion: Adoption levels mirrored knowledge patterns, with higher adoption of $ZnSO_4$ (74%) and soil test-based NPK (69%), while Azotobacter remained the least adopted (49%). This reflects the influence of both awareness and input availability on adoption behavior.

Table 4: Constraints in Adoption of INM Practices (n = 200)

Practice	Max. Score (200x3 = 600)	Obtained Score	Mean Score	Gap %	Rank
High cost of inputs	600	542	2.71	9.7	I
Limited availability of micronutrients	600	528	2.64	12.0	II
Lack of knowledge on recommended dose	600	504	2.52	16.0	III
Non-availability of biofertilizers	600	488	2.44	18.7	IV
Lack of soil testing facility	600	466	2.33	22.3	V

Conclusion: High input cost and poor availability of micronutrients were the strongest barriers. Institutional constraints like soil testing facility access further limited adoption.

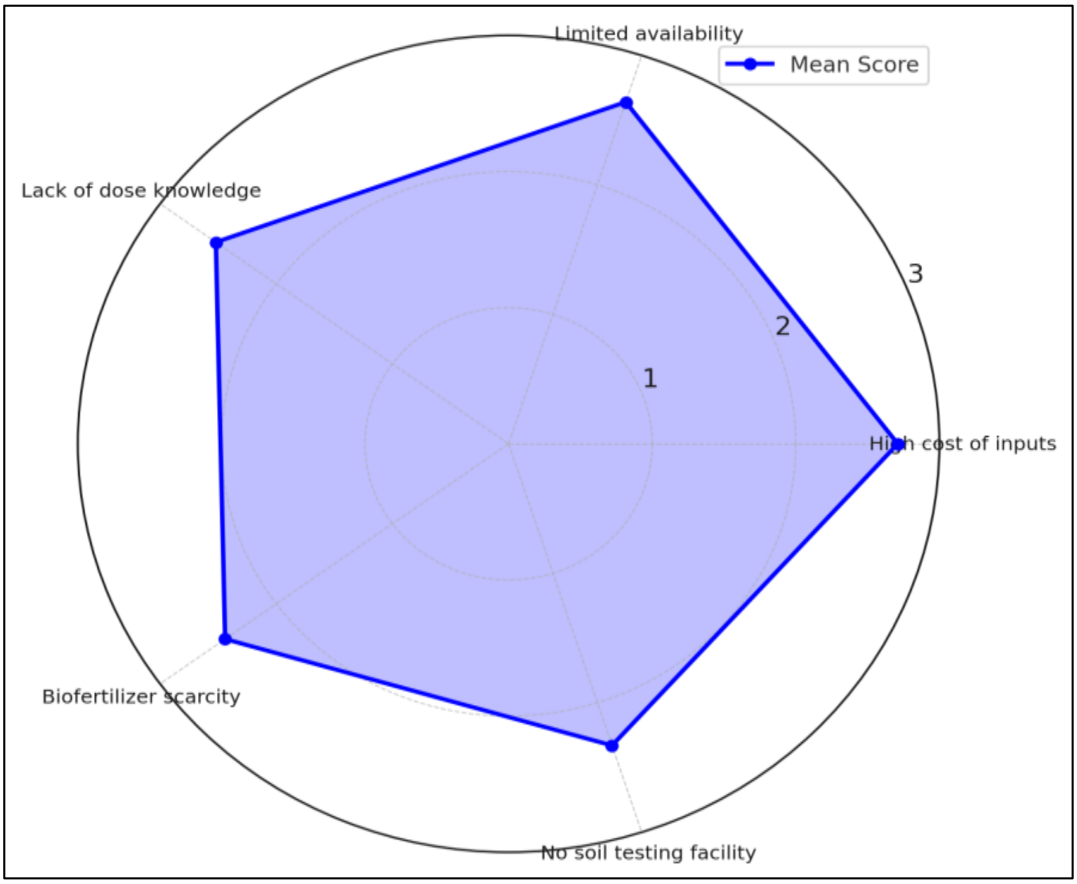

Fig 4: Constraints in adoption of INM practices

Conclusion: The radar chart shows that the most severe constraints were high cost of inputs (Mean Score 2.71) and limited availability (2.64), while institutional issues like lack of soil testing facilities (2.33) also hindered adoption. Addressing these constraints is essential to scale up INM.

Table 5: Rank correlation between knowledge and adoption of INM practices:

INM Practice	Knowledge Rank	Adoption Rank	$d = (R_1 - R_2)$	d^2
Soil test-based NPK	II	II	0	0
Application of Sulphur	III	III	0	0
Application of $ZnSO_4$	I	I	0	0
Application of Boron	IV	IV	0	0
Application of Azotobacter	V	V	0	0
Σd^2	-	-	-	0

Where
n = 5 practices
$\rho = 1-6(0)/5\ (25 - 1) = 1.0$

Conclusion (Rank Correlation): The Spearman's rank correlation ($\rho = 1.0$) indicates a perfect positive relationship between knowledge and adoption of INM practices. This demonstrates that higher knowledge directly translated into higher adoption, reinforcing the critical role of farmer education and awareness in technology diffusion.

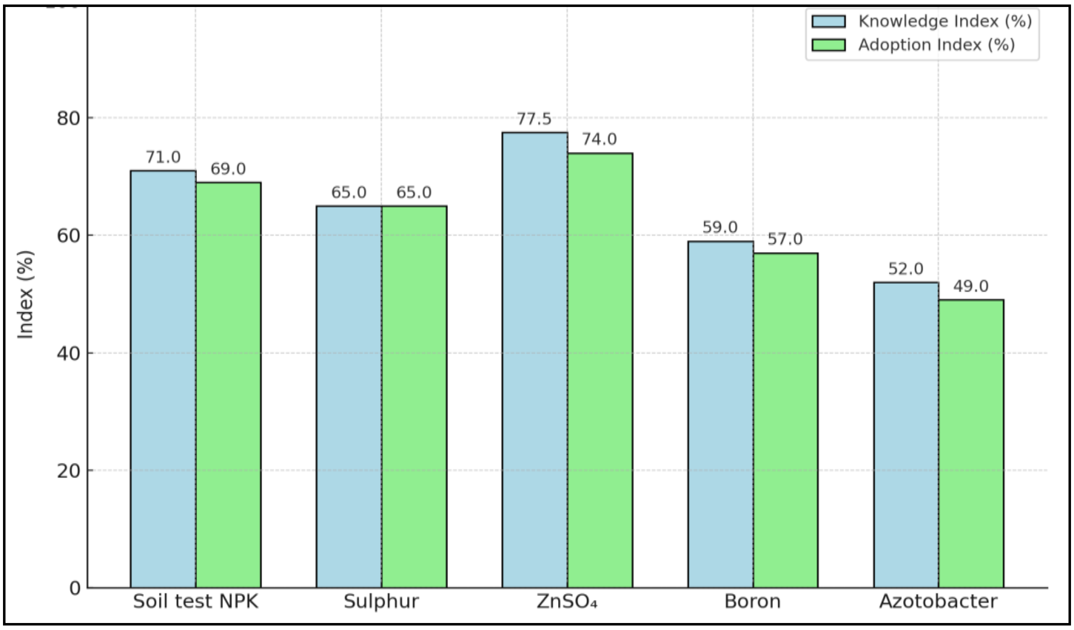

Fig 5: Side-by-side bar chart comparing Knowledge Index (%) and Adoption Index (%) of INM practices.

Conclusion: The bars show a parallel ranking of knowledge and adoption across all five INM practices. Practices with higher knowledge (e.g., $ZnSO_4$: 77.5%) also had higher adoption (74%), while those with lower knowledge (e.g., Azotobacter: 52%) recorded the lowest adoption (49%). This figure supports the Spearman's rank correlation result (ρ = 1.0), establishing that knowledge and adoption are strongly and positively related.

Summary and Conclusion

The study conducted in Deogarh district, Odisha, integrated both agronomic trials and extension research to evaluate the effect and adoption of Integrated Nutrient Management (INM) practices in sesame. Agronomic results showed that INM (Soil test-based NPK + S + $ZnSO_4$ + B + Azotobacter) significantly outperformed farmers' practice in yield (3.9 vs. 2.7 q/ha), net income (₹31,500 vs. ₹19,600/ha), and B:C ratio (1.82 vs. 1.49). Extension studies with 200 respondents revealed that farmers had moderate knowledge (64.9%) and moderate adoption (62.8%) of INM practices. Knowledge and adoption were highest for $ZnSO_4$ and soil test-based NPK, while Azotobacter lagged behind. The major constraints were high cost and limited availability of micronutrients, lack of soil testing facilities, and inadequate awareness of biofertilizers. Rank correlation analysis confirmed a perfect positive relationship (ρ = 1.0) between knowledge and adoption, underscoring the importance of knowledge in driving adoption.

Recommendations

The findings of this study highlight the need for a two-pronged strategy—strengthening the technical adoption of INM practices while addressing the socio-economic and institutional constraints faced by farmers and clearly established that Integrated Nutrient Management (INM) practices are agronomically superior and economically viable for sesame cultivation in Deogarh district, To enhance adoption, it is recommended that extension agencies intensify capacity-building programs through demonstrations,farmer-to-farmer learning models and need-based training, particularly focusing on bridging the knowledge gap micronutrient (Zn, B, S) and biofertilizer use. Establishing mobile and village-level soil testing facilities would enable farmers to adopt site-specific nutrient management more effectively. Policy interventions, including subsidies and credit support for INM inputs, can further reduce financial barriers to adoption. Moreover, public-private partnerships should be encouraged to ensure timely availability of quality inputs. Finally, farmer-to-farmer extension through lead farmers may be leveraged for rapid diffusion of INM practices. Collectively, these measures will accelerate the diffusion of INM practices, enhance sesame productivity, improve farmer income, and contribute to sustainable oilseed production systems in Deoghar, Odisha.

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