International Journal of Plant & Soil Science

Volume 37, Issue 5, Page 469-477, 2025; Article no.IJPSS.136294
ISSN: 2320-7035

Influence of Integrated Weed Management and Nitrogen Levels on Nutrient Dynamics, Yield, and Quality of Sesame (*Sesamum indicum* L.) under Semi-arid Conditions

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

Article Information

DOI: https://doi.org/10.9734/ijpss/2025/v37i55469

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://pr.sdiarticle5.com/review-history/136294

Original Research Article

Received: 12/03/2025
Accepted: 14/05/2025
Published: 17/05/2025

ABSTRACT

A field experiment was conducted during the *kharif* season, to evaluate the effect of integrated weed-management practices and nitrogen levels on nutrient content, uptake, nitrogen-use efficiency, and seed quality of sesame. The trial followed a factorial randomized block design comprising seven weed-management strategies and three nitrogen rates (0, 20, and 40 kg N ha^{-1}).

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Cite as: *Dadarwal, Pinki, and G.L. Yadav. 2025. "Influence of Integrated Weed Management and Nitrogen Levels on Nutrient Dynamics, Yield, and Quality of Sesame (Sesamum Indicum L.) under Semi-Arid Conditions". International Journal of Plant & Soil Science 37 (5):469-77. https://doi.org/10.9734/ijpss/2025/v37i55469.*

Results revealed that the application of imazethapyr at 0.15 kg ha^{-1} *fb* one hand-weeding at 30 DAS significantly improved crop growth parameters, nutrient content (N, P, K), and seed yield (855 kg ha^{-1}), while also minimizing nutrient depletion by weeds. This treatment was statistically on par with two hand-weedings at 20 and 40 DAS. Nitrogen application up to 40 kg ha^{-1} significantly increased total nutrient uptake (N: 50.44 kg ha^{-1}, P: 9.76 kg ha^{-1}, K: 83.74 kg ha^{-1}), seed protein (17.31%), and oil content (43.39%). However, it also led to higher nutrient removal by weeds under sub-optimal weed control. The findings show that combining effective weed suppression strategies with moderate nitrogen application improves yield, quality, and nutrient-use efficiency of sesame in semi-arid, loamy-sandy soils.

Keywords: Integrated weed-management; nitrogen levels; sesame.

1. INTRODUCTION

Sesame (*Sesamum indicum* L.) is one of the most ancient and drought-tolerant oilseed crops grown in India, valued for its high-quality oil and adaptability to low-input conditions. Despite its resilience, sesame yields remain considerably below potential, largely due to imbalanced nutrient supply and unchecked weed competition (Duary and Hazra, 2013; Meena et al., 2017). Among the essential nutrients, nitrogen (N) plays a pivotal role in enhancing vegetative growth, leaf development, and seed yield. However, nutrient-use efficiency (NUE) in sesame is often poor under traditional systems, where neither fertiliser management nor weed control is optimised (Bijarnia *et al., 2019*). Sesame is a valuable oilseed crop commonly grown under rainfed conditions, which makes it highly susceptible to drought stress (Pandey *et al.,* 2022). Its performance is greatly influenced by various environmental factors and nutrient management strategies. While nitrogen is not specifically addressed in some studies, research has highlighted the importance of other nutrients, such as potassium, in helping sesame withstand drought stress (Pandey *et al.,* 2022).

Studies have shown that sesame benefits from improved nutrient management. For example, the application of boron (B) at different growth stages has been found to significantly enhance seed yield, nutrient uptake, antioxidant activity, and potential oil content (Dhaliwal *et al.,* 2021). This indicates that proper nutrient management, including nitrogen, could potentially boost sesame productivity and quality, especially in semi-arid conditions.

Weeds are a major competitor for nutrients, especially during the early growth phase of sesame. Without effective control, they significantly reduce nutrient uptake by the crop, leading to nutrient losses and poor economic returns. Hand-weeding, although effective, is labour-intensive and less feasible under current labour shortages. Chemical weed control, particularly pre-emergence herbicides like alachlor and imazethapyr, offer timely and cost-effective alternatives, and when combined with a single hand-weeding, may optimise both weed suppression and nutrient availability (Singh *et al*., 2018). Three irrigations at branching, flowering and capsule development stage and 50% N through inorganic + 25% N through FYM + 25% N through vermicompost can be recommended to achieve higher seed yield, higher oil content and oil yield of Summer Sesame (Suresh *et al.,* 2024). The main plot included three levels of mineral nitrogen (urea): F_1 - 0%, F_2 - 50%, and F_3 - 100%, among the mineral nitrogen treatments, the highest growth and yield parameters were observed with F_3, while the lowest were recorded with F_1 (Singh & Bhara*,* 2023). While many studies have reported on weed control efficacy and yield response, few have explored the interactive effect of weed-management strategies and nitrogen levels on nutrient uptake, nutrient content, and nitrogen-use efficiency (NUE) in sesame. Furthermore, understanding how these factors impact economic returns is essential for recommending feasible, resource-efficient production packages, especially in semi-arid regions with light-textured soils.

Results showed that three irrigations at 20, 40, and 60 days after sowing, along with effective weed control through herbicide and manual weeding, significantly improved plant height, branch number, and seed yield, highlighting the importance of efficient water use and integrated weed management for enhancing sesame productivity (Zohirul *et al.,* 2024). The critical period of weed interference prevention (CPWC) plays a key role in ensuring optimal productivity in sesame crops. According to Lins *et al.,* (2019), the CPWC can vary among different sesame cultivars. For instance, BRS Seda requires weed control for 52-67 days, while CNPA G2 needs control for 34-52 days, depending on the acceptable yield loss threshold. This emphasizes the importance of effective weed management during these critical windows to achieve the highest possible sesame yields. Integrated weed management strategies can potentially enhance mustard yield by 20-200%, while also improving quality and environmental sustainability (Shekhawat *et al.,* 2017). In field trials the response of sesame to nitrogen (N). At a T_1, N significantly influenced growth, branching, and seed yield, surpassing two tons per hectare. For high-yielding agro-systems, an optimal N application of 80–120 kg ha^{-1} is recommended for maximum yield, with attention to the negative correlation between seed-Nitrogen and oil content (Golan *et al.,* 2022). Although not directly related to weed control, Nassiri-Mahallati and Jahan (2020) highlight the significance of water management in sesame cultivation, particularly in arid environments. They found that the use of eco-friendly inputs such as superabsorbent polymers and humic acid can improve sesame growth, especially when water is limited.

The present investigation was undertaken to assess the effect of weed-management treatments and their combinations and nitrogen rates on nutrient content, nutrient uptake, nitrogen-use efficiency, and economic profitability of sesame grown under loamy-sandy soils of Rajasthan.

2. MATERIALS AND METHODS

A field study was conducted in the *kharif* season of 2018 at the Agronomy Farm of MJRP College of Agriculture and Research, located in Achrol, Jaipur (Rajasthan). The experimental site is part of agro-climatic zone IIIa and is characterized by loamy-sandy soil texture with moderate fertility. The study utilized a factorial randomized block design (FRBD) comprising seven weed-management strategies and three nitrogen application rates, replicated three times. The weed-management treatments included: (i) untreated control (weedy check), (ii) single hand-weeding at 20 days after sowing (DAS), (iii) two hand-weedings at 20 and 40 DAS, (iv) pre-emergence application of alachlor at 1.5 kg a.i. ha^{-1}, (v) alachlor at 1.5 kg a.i. ha^{-1} followed by (*fb)* one hand-weeding at 30 DAS, (vi) pre-emergence imazethapyr at 0.15 kg a.i. ha^{-1}, and (vii) imazethapyr at 0.15 kg a.i. ha^{-1} *fb* one hand-weeding at 30 DAS. These were evaluated in combination with three nitrogen levels: 0, 20, and 40 kg N ha^{-1}.

Nitrogen was applied in the form of urea, and full doses were incorporated into the soil before sowing. The application rate of urea was as per nitrogen treatment. The sesame variety RT-127 was used for the experiment and applied at 3 kg ha^{-1} in a 4.0 m x 3.0 m plot area. Standard agronomic practices were followed throughout the season, with irrigation, pest management, and thinning performed as needed.

For nutrient analysis, the representative samples of grain and stalk were drawn at the time of threshing. Samples were then sun dried to remove any excess moisture present on the surface then oven dried at 60°C ± 5°C followed by grinding using electrical grinder stainless steel Willey mill and were analyzed for their N, P and K concentrations. Similar procedure was applied for weed samples, and the nutrient loss was calculated using the equation,

$$\text{N/P/K depletion (kg ha}^{-1}\text{)} = \frac{\text{Nutrient concentration in weed (\%)} \times \text{weed dry weight (kg ha}^{-1}\text{)}}{100}$$

Crop and weed data were subjected to analysis of variance (ANOVA) for FRBD as given by Gomez & Gomez (1984).

3. RESULT AND DISCUSSION

3.1 Growth and Yield Parameters

The effect of weed management and nitrogen rate on dry matter accumulation, number of capsules plant^{-1}, grain yield, stalk yield, and harvest index are presented in Table 1. Among the treatments, pre-emergence application of imazethapyr at 0.15 kg ha^{-1} *fb* one hand-weeding at 30 DAS recorded the highest values for all observed parameters. This treatment produced the greatest dry matter at 50 DAS (118.14 g) and harvest (141.51 g), the maximum number of capsules plant^{-1} (60.85), highest grain yield (855 kg ha^{-1}), and stalk yield (2977 kg ha^{-1}), and achieved the highest harvest index (22.42%). It was statistically at par with two hand-weeding at 20 and 40 DAS, which also showed superior performance. All weed-control treatments significantly outperformed the weedy check across parameters. The superior performance of imazethapyr + HW and two hand-weeding can be attributed to their ability to maintain a weed-free environment during the critical early growth stages, which improves light interception, reduces competition for nutrients and water, and enhances photosynthetic efficiency (Singh *et al*., 2018). Similar results were reported by Bhadauria *et al.,* (2012), who observed improved nutrient uptake and yield in sesame under integrated weed management due to prolonged weed-free periods. Efficient weed control also contributes to better nutrient uptake, supporting greater dry matter accumulation and improved capsule development (Al-Khateeb *et al.,* 2021).

Nitrogen application also had a positive and significant effect on sesame performance (Table 1). Application of 40 kg N ha^{-1} resulted in the highest dry matter accumulation, number of capsules $plant^{-1}$ (53.33), grain yield (787 kg ha^{-1}), and stalk yield (2882 kg ha^{-1}), showing clear improvement over 20 kg and 0 kg N levels. However, harvest index was not significantly influenced by nitrogen application. Higher nitrogen application enhanced dry matter production, capsule formation, and yield parameters, likely due to increased chlorophyll content and enzymatic activity that stimulate vegetative growth and reproductive organ development. This is consistent with findings by Singh *et al.,* (2021), who noted that sesame responds positively to nitrogen up to moderate levels, beyond which diminishing returns are observed. The non-significant effect of nitrogen on harvest index suggests that both grain and biomass increased proportionally, a trend noted in similar studies by Hekal *et al.,* 2024; Chandrasekaran *et al.,* 2024; Goswami *et al.,* 2025.

3.1.1 Nutrient content and removal in weeds

The influence of weed-management practices and nitrogen rate on nitrogen (N), phosphorus (P), and potassium (K) content in weed biomass is presented in Fig. 1. All weed-control treatments significantly increased nutrient content in weeds compared to the weedy check. Among the treatments, imazethapyr at 0.15 kg ha^{-1} *fb* HW at 30 DAS and two hand-weeding at 20 and 40 DAS showed the highest N content in weeds (1.887% and 1.853%, respectively), significantly greater than other treatments. Similar trends were observed for P and K content, where these treatments, along with alachlor 1.5 kg ha^{-1} *fb* HW at 30 DAS, consistently recorded higher P and K content in weed biomass. The increased nutrient levels associated with these methods probably indicate a better recovery of weed growth and a slower aging process in partially controlled yet still present weed populations, especially for plants that flourish with minimal to moderate competition. The addition of nitrogen also had a notable impact on the nutrient levels found in weeds. Increasing N from 0 to 20 kg ha^{-1} significantly enhanced N and K content in weeds but further increase to 40 kg N ha^{-1} did not yield a statistically significant rise. In contrast, P content increased consistently and significantly with each nitrogen level, reaching its peak (0.414%) at 40 kg N ha^{-1}, which was 91.7% higher than control. These results are in line with earlier research showing that nitrogen fertilisation not only promotes crop growth but also stimulates nutrient uptake by co-occurring weed flora due to improved root activity and overall nutrient cycling (Patel *et al.,* 2018). Higher nutrient concentrations in weed tissues under N-fertilised and partially weed-suppressed plots underscore the dual role of N in boosting both crop and weed nutrient status. This emphasizes the need for carefully planned nutrient management alongside prompt weed management to prevent weeds from unknowingly absorbing nutrients, which can lead to decreased nutrient capture by weeds, which can reduce nutrient-use efficiency. Additionally, weed species like *Echinochloa* and *Amaranthus*, often dominant in sesame fields, are known to be highly responsive to applied nitrogen and phosphorus, especially under sub-optimal control conditions.

In terms of nutrient removal which is presented in Fig. 2, the lowest depletion of all three nutrients was recorded under imazethapyr at 1.5 kg ha^{-1} *fb* HW at 30 DAS, which removed only 9.16, 1.80 and 8.00 kg NPK ha^{-1} respectively, representing a 71–76% reduction over the unweeded control. This treatment remained at par with two HW at 20 and 40 DAS and alachlor at 1.5 kg ha^{-1} *fb* HW at 30 DAS. These reductions are attributed to early and sustained weed suppression, which minimizes nutrient uptake by competing species and improves nutrient retention for the crop (Venu *et al., 2022*). Increasing nitrogen rates, however, significantly enhanced nutrient depletion by weeds. At 40 kg N ha^{-1}, weeds extracted the highest nutrient amounts (18.82 kg N, 4.04 kg P, and 16.06 kg K ha^{-1}), showing increases of up to 50% over the unfertilised plots. The higher N availability benefits both crop and weed growth, especially under less effective weed-control conditions. These findings reinforce the need to balance fertiliser input with weed management to avoid unintended nutrient losses and reduced nutrient-use efficiency (Aadi & Almarie, 2024).

3.1.2 Nutrient content and uptake in sesame

The nutrient content and uptake of N, P, K in sesame were significantly influenced by both weed management and nitrogen rates (Table 2 and 3). Among all treatments, imazethapyr at 0.15 kg ha^{-1} *fb* HW at 30 DAS recorded the highest concentrations of nitrogen (2.92% in seed, 1.14 % in stover), phosphorus (0.73 % in seed, 0.16 % in stover), and potassium (1.65 % in seed, 2.52 % in stover). These values were statistically superior to most other treatments and were closely followed by two hand-weeding at 20 and 40 DAS and alachlor at 1.5 kg ha^{-1} *fb* HW at 30 DAS. The enhanced nutrient levels in both the reproductive and vegetative parts resulting from these treatments can be linked to effective weed control, which reduced competition for nutrients, leading to better uptake and movement of nutrients to the crops (Bhadauria *et al*., 2012). These improvements translated into significantly higher total nutrient uptake under effective weed control. W_7 recorded the maximum uptake of N (57.54 kg ha^{-1}), P (11.38 kg ha^{-1}), and K (89.82 kg ha^{-1}), followed by W_3 and W_5. This trend indicates that timely weed management not only boosts crop yield but also improves nutrient acquisition efficiency, a key factor in nutrient budgeting and soil fertility management. Similar results were observed by Vaishnav *et al.,* 2024, Khuong *et al.,* 2023.

Nutrient content and uptake increased significantly with rising nitrogen application (Table 2 and 3). The 40 kg N ha^{-1} rate (N_3) recorded the highest nutrient concentration in both seed (2.77% N, 0.690% P, 1.579% K) and stover (1.05% N, 0.150% P, 2.451% K), as well as the highest total uptake values for nitrogen (50.44 kg ha^{-1}), phosphorus (9.76 kg ha^{-1}), and potassium (83.74 kg ha^{-1}). The incremental gains in nutrient uptake with increasing N rate reflect nitrogen's role in promoting vegetative growth, enzymatic activity, and efficient translocation of absorbed nutrients. These results align with the findings of Golan *et al.* (2020) who reported enhanced nutrient uptake and distribution in sesame and other dryland crops with moderate nitrogen application.

Table 1. Effect of weed management and nitrogen rates on crop growth and yield attributes of sesame

Treatment	Dry matter accumulation (g)		Capsule plant^{-1}	Seed yield (kg ha^{-1})	Stover yield (kg ha^{-1})	Harvest index (%)
	50 DAS	Harvest				
Weed management						
W_1	71.70	94.03	31.56	514	2098	19.61
W_2	94.78	107.24	48.63	706	2576	21.60
W_3	113.89	134.02	57.22	818	2933	21.81
W_4	86.02	105.94	40.20	636	2366	21.19
W_5	106.42	125.86	53.19	770	2808	21.52
W_6	92.20	117.43	44.70	670	2501	21.21
W_7	118.14	141.51	60.85	855	2977	22.42
SEm±	**3.33**	**3.69**	**1.79**	**22**	**96**	**0.54**
Cd (P = 0.05)	**9.50**	**10.53**	**5.12**	**64**	**275**	**1.54**
Nitrogen rate						
N_1	89.63	108.57	39.03	613	2275	21.14
N_2	98.17	118.90	49.80	729	2668	21.43
N_3	104.98	126.55	55.33	787	2882	21.14
SEm±	**2.35**	**2.61**	**1.27**	**16**	**68**	**0.38**
Cd (P = 0.05)	**6.72**	**7.45**	**3.62**	**45**	**194**	**NS**

Table 2. Effect of weed management and nitrogen rates on nutrient content (NPK) of sesame

Treatment	Nitrogen (%)		Phosphorus (%)		Potassium (%)	
	Seed	Stover	Seed	Stover	Seed	Stover
Weed management						
W_1	2.384	0.821	0.561	0.119	1.228	2.113
W_2	2.636	0.938	0.653	0.137	1.461	2.389
W_3	2.823	1.154	0.749	0.160	1.686	2.485
W_4	2.416	0.895	0.588	0.125	1.332	2.227
W_5	2.702	1.030	0.657	0.145	1.500	2.439
W_6	2.524	0.911	0.615	0.129	1.409	2.273
W_7	2.924	1.141	0.739	0.168	1.657	2.529
SEm±	**0.073**	**0.029**	**0.021**	**0.004**	**0.043**	**0.070**
Cd (P = 0.05)	**0.208**	**0.082**	**0.061**	**0.011**	**0.124**	**0.201**
Nitrogen rate						
N_1	2.461	0.899	0.597	0.126	1.375	2.247
N_2	2.659	1.005	0.669	0.144	1.449	2.355
N_3	2.769	1.049	0.690	0.150	1.579	2.451
SEm±	**0.051**	**0.020**	**0.015**	**0.003**	**0.032**	**0.050**
Cd (P = 0.05)	**0.147**	**0.058**	**0.043**	**0.007**	**0.090**	**0.142**

Table 3. Effect of weed management and nitrogen rates on total nutrient uptake (NPK), protein and oil content of sesame

Treatment	Total N uptake (kg ha^{-1})	Total P uptake (kg ha^{-1})	Total N uptake (kg ha^{-1})	Protein content (%)	Oil content (%)
Weed management					
W_1	28.80	5.22	50.70	14.90	38.22
W_2	41.58	8.05	72.31	16.48	40.70
W_3	53.17	10.36	87.00	17.64	44.30
W_4	35.29	6.41	62.14	15.10	38.85
W_5	47.06	9.16	80.32	16.89	43.14
W_6	38.31	7.17	66.57	15.78	40.37
W_7	57.54	11.38	89.82	18.28	45.50
SEm±	**2.43**	**0.47**	**4.07**	**0.45**	**1.25**
Cd (P = 0.05)	**6.95**	**1.33**	**11.62**	**1.30**	**3.58**
Nitrogen rate					
N_1	34.11	6.45	59.48	15.38	39.49
N_2	44.78	8.55	74.86	16.62	41.90
N_3	50.44	9.76	83.74	17.31	43.39
SEm±	**1.72**	**0.33**	**2.88**	**0.32**	**0.88**
Cd (P = 0.05)	**4.92**	**0.94**	**8.22**	**0.92**	**2.53**

3.2 Protein and Oil Content

Seed quality in regarding of protein and oil content was significantly influenced by both weed-management and nitrogen rates (Table 3). The maximum protein level (18.28%) and oil content (45.50%) were recorded under imazethapyr at 0.15 kg ha^{-1} *fb* hand-weeding at 30 DAS (W_7), with similar benefits observed from by two hand-weedings (W_3) and alachlor at 1.5 kg ha^{-1} *fb* HW (W_5). These treatments were significantly superior to the weedy check and other less intensive methods. The enhancement in seed quality under these treatments is attributed to improved nutrient availability and reduced competition from weeds, which supports greater protein synthesis and lipid accumulation in the developing seeds. This finding is in accordance with El-Damarany (2017), who reported that effective weed control improves assimilate partitioning and enhances seed biochemical quality in sesame. Seed protein and oil content increased progressively with higher nitrogen application. The 40 kg N ha^{-1} treatment (N_3) produced the highest protein content (17.31%) and oil content (43.39%), showing significant improvements over 0 and 20 kg N levels. Nitrogen enhances protein biosynthesis

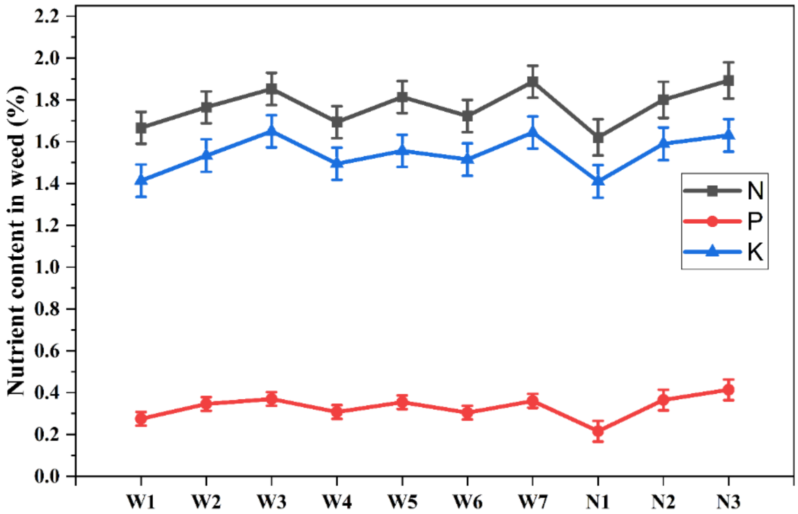

Fig. 1. Effect of weed management and nitrogen rate on nutrient (NPK) content in weed

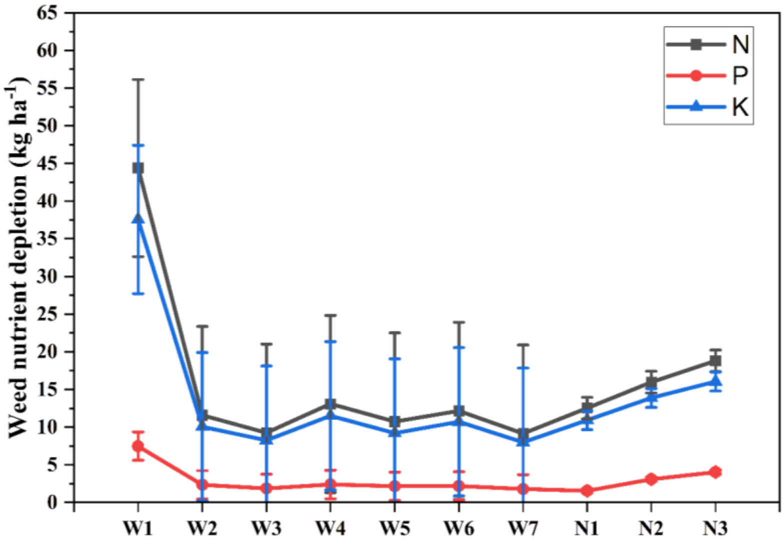

Fig. 2. Effect of weed management and nitrogen rate on nutrient depletion (NPK) by weed

through its role in amino acid formation and enzyme activation and indirectly influences oil content by improving source-sink balance and assimilate transport. These results align with the findings of Bellaloui *et al.,* 2018, Abdiani *et al.,* 2024, who observed that moderate nitrogen rates improve both seed protein and oil ratios in sesame.

4. CONCLUSION

The study shows that minimizing weed competition and nutrient depletion while increasing nutrient uptake, seed output, and quality in sesame can be achieved with integrated weed management, particularly imazethapyr followed by hand-weeding. Without having an adverse effect on the harvest index, the application of 40 kg N ha-1 greatly increased nutrient accumulation and utilization efficiency. Enhancing sesame yield and resource-use efficiency in semi-arid agro-ecosystems can be achieved by combining herbicidal control with hand weeding and optimum nitrogen nutrition.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models

(ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

ACKNOWLEDGEMENTS

The author extends his gratitude to the MJRP College of Agriculture and Research, Jaipur for providing the essential resources and support for this research. Additionally, the collaborative efforts of all contributing authors are acknowledged for their valuable contributions to this study, enhancing the quality of the forthcoming journal publication.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Peer-review history:
The peer review history for this paper can be accessed here:
https://pr.sdiarticle5.com/review-history/136294