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S Aruna
Ph.D. Scholar, Department of Agronomy, Faculty of Agriculture, Annamalai University, Chidambaram, Tamil Nadu, India

S Kandasamy
Professor, Department of Agronomy, Faculty of Agriculture, Annamalai University, Chidambaram, Tamil Nadu, India

R Raman
Professor, Department of Agronomy, Faculty of Agriculture, Annamalai University, Chidambaram, Tamil Nadu, India

M Meyyappan
Associate Professor, Department of Agronomy, Faculty of Agriculture, Annamalai University, Chidambaram, Tamil Nadu, India

K Dhanasekaran
Professor, Department of Soil Science and Agricultural Chemistry, Faculty of Agriculture, Annamalai University, Chidambaram, Tamil Nadu, India

Corresponding Author:
S Aruna
Ph.D. Scholar, Department of Agronomy, Faculty of Agriculture, Annamalai University, Chidambaram, Tamil Nadu, India

Enhancing growth and yield potential of sesame through interactive effects of nutrient management and growth regulation strategies

S Aruna, S Kandasamy, R Raman, M Meyyappan and K Dhanasekaran

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Abstract
To understand how the integrated use of nutrient management and growth regulation strategies can synergistically enhance growth and yield dynamics of sesame, this field experiment was conducted in the experimental farm, Faculty of Agriculture, Annamalai University, to evaluate the interactive effects of nutrient management and growth enhancement practices by involving foliar spray of plant growth regulators, micronutrients, NPK combinations and manual clipping practices. The experiment was laid out in a randomized block design with ten treatments replicated thrice comprising same levels (100 per cent) of recommended dose of fertilizers (RDF) in combination with different plant growth modulating treatments applied at critical crop growth stages *viz.*, flowering and capsule formation stages in sesame. Growth parameters such as plant height, leaf area index and dry matter production, along with yield attributes including number of capsules per plant, seeds per capsule, and test weight were recorded. The results revealed that integrated application of 100% RDF + Paclobutrazol @100 ppm at flowering and capsule formation stages (T_7), significantly enhanced vegetative growth and reproductive efficiency of sesame by producing increased growth and yield attributes, seed and stover yields (1668 and 2991 kg ha^{-1}, respectively) when compared to 100% RDF + Water spray (control - T_1). Improved source sink relationship and efficient utilization of nutrients under integrated treatments contributed to higher productivity. The study concludes that strategic integration of nutrient management with appropriate plant growth regulator application (100% RDF + Paclobutrazol @100 ppm at flowering and capsule formation stages) is an effective approach for enhancing growth and yield potential of sesame.

Keywords: Sesame, nutrient management, plant growth regulators, yield attributes, seed yield

Introduction
Sesame (*Sesamum indicum* L.) is one of the oldest oilseed crops cultivated worldwide and holds considerable importance in tropical and subtropical regions due to its wide adaptability and nutritional value. Sesame seeds contain high quality edible oil rich in unsaturated fatty acids, along with natural antioxidants such as sesamin and sesamol, which contribute to its oxidative stability and health benefits (Meena *et al.*, 2023) [8]. In India, sesame occupies a prominent position among oilseed crops because of its suitability to rainfed and low-input farming systems and its ability to perform reasonably well under diverse agro-climatic conditions (Bhardwaj *et al.*, 2025) [2]. Despite its nutritional and economic importance, sesame productivity in India remains relatively low, mainly due to poor crop establishment, imbalanced nutrient management, and inefficient partitioning of assimilates between vegetative and reproductive phases. Sesame is grown across the world on an area of 12.84 million hectares, with a production of 6.74 million tonnes and a productivity of 525 kg ha^{-1}. In India, sesame is grown on an area of 16.27 lakh hectares with a production of 7.89 lakh tonnes and a productivity of 485 kg ha^{-1}. (FAOSTAT, 2025) [3].
Efficient nutrient management plays a pivotal role in enhancing growth, yield attributes, and seed yield of sesame. Adequate and timely supply of essential nutrients, particularly nitrogen, phosphorus, and potassium, is crucial for promoting vegetative growth, flowering, capsule development, and seed filling (Sarkar *et al.*, 2025) [14]. However, sole dependence on conventional fertilizer practices often leads to suboptimal nutrient use efficiency, especially

under marginal soil fertility and moisture-limited conditions, resulting in limited yield response (Kankal *et al.*, 2024) [4]. Plant growth regulators (PGRs) have emerged as effective tools for modifying plant physiological processes such as cell division, elongation, assimilate translocation, and reproductive development. In sesame, judicious application of PGRs has been shown to regulate excessive vegetative growth, improve source-sink balance, reduce flower and capsule drop, and enhance seed setting efficiency (Meena *et al.*, 2023) [8]. Paclobutrazol and mepiquat chloride, when applied at critical stages like flowering and capsule formation, have been reported to improve yield attributes by redirecting assimilates towards reproductive sinks and improving canopy architecture (Qureshi *et al.*, 2024) [11].

The interaction between nutrient management and plant growth regulators offers a promising strategy for improving growth and yield attributes of sesame. Synchronization of nutrient supply with physiological regulation of plant growth can optimize biomass production, enhance reproductive efficiency, and ultimately improve seed yield and economic returns (Bhardwaj *et al.*, 2025) [2]. Micronutrient elements such as zinc (Zn) and manganese (Mn) are critical for numerous physiological and biochemical processes in plants, including activation of enzymes, chlorophyll synthesis, efficient photosynthesis, and nutrient metabolism. In sesame, foliar application of micronutrients like $ZnSO_4$ and $MnSO_4$ has been reported to significantly improve growth, yield components, and nutrient uptake by alleviating limitations associated with soil fixation and low availability during critical phenological stages (Maheshwari *et al.*, 2023) [7]. Foliar nutrition involving NPK combinations, $ZnSO_4$, and $MnSO_4$ markedly enhance growth traits such as leaf area index and seed yield in irrigated sesame compared to unfed controls, indicating the positive effect of supplemental foliar nutrition beyond soil applied basal doses (Ramesh *et al.*, 2025) [13] and also foliar application of balanced NPK solutions directly supplies readily absorbed macronutrients during key reproductive phases, improving nutrient synchronization with plant demand and thereby enhancing photosynthetic efficiency, assimilate partitioning, and yield attributes in crops. In this context, the present study was undertaken to evaluate the combined influence of nutrient management practices and plant growth enhancement practices on growth, yield parameters and yield of sesame with the objective of identifying effective and economically viable management strategies for enhancing sesame productivity under field conditions.

Materials and Methods

The field experiment was conducted in the experimental farm, Department of Agronomy, Annamalai University, Annamalai Nagar during June to Sepetember 2024 and 2025. The geographical location of the experimental farm is located at 11° 24' N latitude, 79° 44' E longitude, at an altitude of + 5.79 m above mean sea level. The region enjoys a moderately warm climate, featuring hot summers and is located within the North East Monsoon zone.

During June to September of 2024 and 2025, the weekly mean maximum temperature 35.9°C and 38.9°C respectively. The weekly mean minimum temperature was around 21.6 °C and 21.7°C, respectively. The mean relative humidity level was 69 and 73.5 per cent during June to September of 2024 and 2025 respectively. The average annual rainfall recorded in this region is 1500 mm. The soil had a pH of 7.4 and found to be low in available nitrogen, medium in available phosphorous and high in available potassium, respectively. The experiment was laid out in randomized block design with ten treatments *viz.*, T_1 - 100% RDF + Water spray, T_2 - 100% RDF + Foliar application of 0.5% $ZnSo_4$ at flowering and capsule formation stages, T_3 -100% RDF + Foliar application of 0.5% $MnSo_4$ at flowering and capsule formation stages, T_4 - 100% RDF + Manual clipping, T_5 - 100% RDF + NAA @ 100 ppm at flowering and capsule formation stages, T_6 - 100% RDF + Mepiquat chloride @ 100 ppm at flowering and capsule formation stages, T_7 - 100% RDF + Paclobutrazol @100 ppm at flowering and capsule formation stages, T_8 - 100% RDF + Cycocel @100ppm at flowering and capsule formation stages, T_9 - 100% RDF + NPK 19:19:19 combination @1% at flowering and capsule formation stages, T_{10} - 100% RDF + NPK 10:26:26 combination @2% at flowering and capsule formation stages. The sesame crop was fertilized as per the recommended fertilizer schedule of 35:23:23 kg N, P_2O_5 and K_2O ha^{-1} and recommended seed rate of 5 kg ha^{-1} was adopted. Biometric observations of growth and yield parameters were recorded in every plot for the five randomly tagged plants at various growth phases *viz.*, 30, 60 DAS and at harvest.

Results and Discussion

Growth parameters (Table 1)

The progressive increase in growth parameters from 30 DAS to harvest reflects the normal growth trajectory of sesame, wherein vegetative expansion intensifies after establishment and peaks during the reproductive phase. The non-significant differences among treatments at 30 DAS for plant height and dry matter production indicate that early growth was primarily governed by inherent varietal potential and basal nutrient availability, with the influence of growth regulators becoming evident only at later stages, as also reported by Kumar *et al.* (2022) [5] and Nayak *et al.* (2023) [9]. Significantly superior plant height (32.8, 111.5, 115 cm at 30, 60 DAS and at harvest, respectively) leaf area index (3.9), number of branches per plant (6.5), and dry matter production (779.1, 2965.8, 3443.8 kg ha^{-1} at 30, 60 DAS and at harvest, respectively) recorded under 100% RDF + paclobutrazol @ 100 ppm applied at flowering and capsule formation (T_7) at 60 DAS and harvest demonstrate the effectiveness of integrating balanced nutrition with physiological growth regulation. Adequate nutrient supply enhanced cellular division, chlorophyll synthesis, and photosynthetic efficiency, while paclobutrazol optimized assimilate partitioning by modulating gibberellin biosynthesis, reducing excessive stem elongation, and promoting lateral growth, leaf retention, and canopy efficiency. Although paclobutrazol is categorized as a growth retardant, its careful application under adequate nutrient supply enhanced canopy structure, promoted greater branching, and increased biomass production, thereby reinforcing the source sink relationship, as also reported in sesame and other oilseed crops by Patel *et al.* (2022) [10] and Li *et al.* (2025) [6]. Comparable improvements in leaf area index and branching under mepiquat chloride treatments further highlight the role of growth retardants in regulating canopy structure and enhancing light interception (Zhang *et al.*, 2024) [15]. Foliar application of $ZnSO_4$ and balanced NPK fertilizers also contributed to moderate improvements in growth by supporting enzymatic activity, chlorophyll synthesis, and sustained nutrient availability during reproductive stages (Ramesh *et al.*, 2023) [12]. In contrast, consistently lower growth performance under the control treatment underscores the importance of growth regulating and supplemental nutrient interventions beyond basal fertilization. The uniform trends observed during June to September 2024 and

2025 experiments confirm the stability of treatment effects, clearly indicating that synchronizing recommended fertilizer dose with suitable growth regulators is a reliable strategy for enhancing overall vegetative growth and biomass production in sesame.

Yield Parameters and Yield (Table 2)

The significant variation in the number of capsules per plant and seeds per capsule across treatments underscores the strong impact of integrated nutrient management and growth regulators on the reproductive performance of sesame. Similar to the growth parameters higher data was recorded in the yield parameters *viz.*, number of capsules per plant (88) and number of seeds per capsule (68.5) were obtained under 100% RDF combined with paclobutrazol @ 100 ppm at flowering and capsule formation (T_7). It suggests improved source sink balance and more effective assimilate partitioning toward reproductive organs. This is supported by recent findings where paclobutrazol applications significantly influenced yield components, including capsule number, by modulating hormonal balance and plant architecture in sesame (Qureshi *et al.*, 2024) [11]. Integrated nutrient management studies have also demonstrated that balanced nutrient supply enhances capsule number and seeds per capsule by improving nutrient uptake and reproductive efficiency under optimum fertility conditions. Similar findings were highlighted by Kankal *et al.*, 2024 [4] and Bhardwaj *et al.*, 2025 [2]. In addition, nitrogen and growth regulator interactions in sesame have been shown to significantly increase the number of capsules per plant and seeds per capsule, indicating the importance of synchronized nutrient and hormonal regulation for reproductive growth as reported by Sarkar *et al.*, 2025 [14]. In contrast, untreated control generally exhibited lower capsule and seed numbers (39, 50.9 respectively), likely due to limited assimilate allocation to reproductive sinks and higher vegetative competition, a trend similarly reported in studies on sesame yield components under standard fertilizer regimes. Collectively, these recent findings from multiple authors Bhardwaj *et al.*, 2025 [2], Kankal *et al.*, 2024 [4], Sarkar *et al.*, 2025 [14] affirm that the combination of balanced nutrient management and appropriately timed growth regulator application markedly enhances key reproductive traits in sesame, thereby improving yield potential.

The significant differences in seed yield and stalk yield among treatments highlight the substantial benefits of integrating balanced nutrient management with targeted growth regulator application in sesame. During both the years 2024 and 2025, the highest seed yield (1668 kg ha^{-1}) under 100% RDF combined with paclobutrazol @ 100 ppm applied at flowering and capsule formation (T_7) clearly demonstrates that optimized nutrient supply coupled with physiological regulation can enhance reproductive success and assimilate partitioning toward economic yield. Enhanced seed yield under paclobutrazol application has been reported in recent studies, where paclobutrazol improved reproductive efficiency and reduced shattering losses, thereby increasing seed yield in sesame genotypes under rainfed conditions (Ahmed *et al.*, 2023) [1]. Similarly, Qureshi *et al.* (2024) [11] showed that growth regulator treatments significantly boosted seed yield compared to control by regulating plant growth and improving assimilate distribution. The uniformly lower seed yield in the control treatment (T_1) suggests limited nutrient use efficiency and an absence of growth modulation, a trend also observed in research where untreated sesame plants produced lower yields due to inadequate assimilate partitioning toward seed production (Sarkar *et al.*, 2025) [14]. Consistency in yield responses of treatment pairs such as T_4 and T_8, and T_9 and T_{10} indicates that similar levels of growth control or foliar nutrition can produce equivalent yields, as found in integrated nutrient studies (Bhardwaj *et al.*, 2025) [2]. A similar pattern was noted for stover yield, where 100% RDF combined with paclobutrazol @ 100 ppm applied at flowering and capsule formation (T_7) also recorded the highest stover yield (2991 kg ha^{-1}), reflecting enhanced vegetative growth and resource capture. Recent work has demonstrated that integrating recommended fertilizer doses with growth regulators improves overall plant productivity and biomass partitioning in sesame and other oilseed crops (Qureshi *et al.*, 2024) [11]. The lowest seed and stover yields (1018.5 and 2244.2 kg ha^{-1}, respectively) in the control (T_1) further support the role of combined nutrient and growth regulation in sustaining vigorous vegetative development. Overall, the results corroborate recent findings that synchronized nutrient management and application of paclobutrazol at critical growth stages significantly improve both seed yield and vegetative biomass in sesame, reinforcing the importance of integrated crop management for yield maximization.

Table 1: Effect of nutrient management and growth regulating treatments on growth parameters of sesame (Pooled data of June to September 2024 and 2025)

Treatments		Plant height (cm)			LAI	Number of branches $plant^{-1}$	Dry matter production ($kgha^{-1}$)		
		30 DAS	60 DAS	At harvest	60 DAS	60 DAS	30 DAS	60 DAS	At harvest
T_1 -	100% RDF + Water spray	34.3	90.1	93.6	1.1	3.92	700.5	1007.5	1485.5
T_2 -	100% RDF + Foliar application of 0.5% $ZnSo_4$ at flowering and capsule formation stages	33.5	105.2	108.7	3.1	5.90	757.8	2494.5	2872.5
T_3 -	100% RDF + Foliar application of 0.5% $MnSo_4$ at flowering and capsule formation stages	33.1	96.5	100.0	1.5	4.88	722.4	1956.2	2134.2
T_4 -	100% RDF + Manual clipping at 35 DAS	31.6	93.2	96.7	1.3	4.23	717.1	1746.3	1944.3
T_5 -	100% RDF + NAA @ 100 ppm at flowering and capsule formation stages	32.4	102.4	105.9	2.9	5.60	752.7	2289.5	2667.4
T_6 -	100% RDF + Mepiquat chloride @ 100 ppm at flowering and capsule formation stages	35.0	108.3	111.8	3.6	6.22	728.7	2619.1	3097.1
T_7 -	100% RDF + Paclobutrazol @100 ppm at flowering and capsule formation stages	32.8	111.5	115.0	3.9	6.54	779.1	2965.8	3443.8
T_8 -	100% RDF + Cycocel @100ppm at flowering and capsule formation stages	32.2	92.6	96.1	1.2	4.20	711.8	1666.4	1844.4
T_9 -	100% RDF + NPK 19:19:19 combination @ 1% at flowering and capsule formation stages	34.3	99.3	102.8	2.3	5.20	716.7	2111.6	2489.6
T_{10} -	100% RDF + NPK 10:26:26 combination @ 2% at flowering and capsule formation stages	32.0	98.5	102.0	2.3	5.18	728.7	2078.7	2456.7
Total		328.2	997.6	1032.6	23.3	51.87	7315.4	20935.6	24435.6
S.Ed		1.18	2.11	2.21	0.06	0.12	23.04	50.30	58.20
CD 5%		NS	4.3	4.64	0.12	0.26	NS	105.7	122.28

Table 2: Effect of nutrient management and growth regulating treatments on yield parameters and yield of sesame (Pooled data of June to September 2024 and 2025)

Treatments		Yield parameters		Yield	
		Number of capsules plant^{-1}	Number of seeds capsule^{-1}	Seed yield (kg ha^{-1})	Stover yield (kg ha^{-1})
T_1 -	100% RDF + Water spray	39	50.9	1018.5	2244.2
T_2 -	100% RDF + Foliar application of 0.5% $ZnSo_4$ at flowering and capsule formation stages	76	62.6	1495.5	2721.2
T_3 -	100% RDF + Foliar application of 0.5% $MnSo_4$ at flowering and capsule formation stages	56	54.0	1124.5	2350.0
T_4 -	100% RDF + Manual clipping at 35 DAS	50	51.5	1096.4	2296.8
T_5 -	100% RDF + NAA @ 100 ppm at flowering and capsule formation stages	68	60.1	1328.6	2609.0
T_6 -	100% RDF + Mepiquat chloride @ 100 ppm at flowering and capsule formation stages	81	65.5	1556.9	2835.4
T_7 -	100% RDF + Paclobutrazol @100 ppm at flowering and capsule formation stages	88	68.5	1668.0	2991.0
T_8 -	100% RDF + Cycocel @100ppm at flowering and capsule formation stages	49	52.0	1089.7	2273.3
T_9 -	100% RDF + NPK 19:19:19 combination @ 1% at flowering and capsule formation stages	63	57.0	1295.9	2571.8
T_{10} -	100% RDF + NPK 10:26:26 combination @ 2% at flowering and capsule formation stages	61	56.8	1263.6	2485.7
Total		631	574.8	12937.6	25378.4
S.Ed		1.51	1.35	30.73	59.87
CD 5%		3.18	2.85	64.56	125.79

Conclusion

The results of the present investigation clearly demonstrate that sesame productivity is strongly influenced by the integration of nutrient management and growth regulating treatments. Across both the years, the application of 100% recommended dose of fertilizers (RDF) in combination with paclobutrazol @ 100 ppm at flowering and capsule formation stages consistently produced superior growth, yield attributes, seed yield and stalk yield compared to all other treatments. This integrated approach effectively improved source sink balance, enhanced assimilate partitioning and optimized canopy architecture, resulting in higher reproductive efficiency and biomass accumulation.

Treatments involving other growth regulators and foliar nutrient applications showed moderate improvements, indicating that physiological regulation and supplemental nutrition play supportive roles in yield enhancement. However, the consistently lower performance of the control treatment highlights the limitations of relying on basal nutrient application alone without growth regulation. The stability of treatment effects across two experimental seasons further confirms the reliability and reproducibility of the integrated nutrient growth regulator strategy.

Overall, the study concludes that synchronizing balanced nutrient supply with judicious application of paclobutrazol at critical reproductive stages is an effective and practical agronomic strategy for maximizing seed and stalk yield of sesame. Adoption of this integrated management practice can contribute to improved productivity and profitability of sesame cultivation under similar agro climatic conditions.

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