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EFFECT OF SULPHUR, ZINC AND BORON APPLICATION ON GROWTH, YIELD AND QUALITY OF SESAME (*sesamum indicum* L.)

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ABSTRACT

A field experiment was conducted at Crop Research Centre, ITM University, Gwalior, Madhya Pradesh in *kharif* 2025 to evaluate the effect of various levels of sulphur, zinc and boron on growth, yield and quality parameters of sesame (*Sesamum indicum* L.). The experiment was designed as Randomized Block Design with ten treatments and three replications. The treatments comprised recommended dose of fertilizers was 40:30:20 kg N:P_2O_5:K_2O ha^{-1} alone and in combination with sulphur (40 kg ha^{-1}), zinc (5 kg ha^{-1}), boron (2 kg ha^{-1}) and their various combinations. The results revealed that nutrient management treatments significantly influenced growth, yield, quality, nutrient content and nutrient uptake of sesame. Application of RDF + 40 kg S ha^{-1} + 5 kg Zn ha^{-1} + 2 kg B ha^{-1} (T_9) recorded the highest plant height (76.10 cm), number of branches plant^{-1} (7.33), leaf area index (3.62), chlorophyll content (50.26 SPAD) and dry matter accumulation (497.87 g m^{-2}). The same treatment also produced the highest seed yield (910 kg ha^{-1}), straw yield (2105 kg ha^{-1}) and biological yield (3015 kg ha^{-1}). Quality parameters such as oil content (60.00%) and protein content (24.80%) were also significantly improved under T_9. Furthermore, T_9 recorded the maximum nutrient content of N, P, K, S, Zn and B in seed and straw, along with the highest uptake of N (46.553 kg ha^{-1}), P (11.450 kg ha^{-1}), K (37.500 kg ha^{-1}), S (10.783 kg ha^{-1}), Zn (0.120 kg ha^{-1}) and B (0.090 kg ha^{-1}).

***Keywords* :** Sesame, sulphur, zinc, boron, nutrient content, nutrient uptake, oil content, protein content, yield.

Introduction

Sesame (*Sesamum indicum* L.) is one of the oldest cultivated oil crops in the world, commonly referred to as the "Queen of Oilseeds" owing to its excellent oil quality and high nutritional value. Belonging to the family Pedaliaceae, sesame is well adapted to tropical and subtropical climates. The seed oil content ranges from 45–60% and protein content from 18–25%. The oil has exceptional oxidative stability due to the presence of natural antioxidants sesamin, sesamolin and sesamol which significantly extend shelf life (Ashri, 1998).

Sesame occupies an area of about 14.1 million hectares globally with a production of approximately 7.5 million tons (FAOSTAT, 2022). India is one of the leading producers of sesame and contributes significantly to world production and export. However, productivity in India remains low due to cultivation on marginal lands, erratic rainfall, and inadequate nutrient management.

Plant nutrition plays a critical role in improving sesame productivity. While primary nutrients (N, P, K) have received extensive attention, secondary and micronutrients such as sulphur (S), zinc (Zn) and boron (B) are increasingly recognized as key determinants of crop performance. Sulphur, the fourth important macronutrient after N, P and K, is integral to the biosynthesis of S-containing amino acids and proteins, and is directly involved in oil biosynthesis, making it especially critical for oilseed crops like sesame (Tandon, 2013; Sharma *et al.*, 2013).

Zinc functions in enzyme structure formation, and assists in the biosynthesis of protein, carbohydrates, auxin and chlorophyll. It promotes vegetative growth, flowering and seed formation. Zinc deficiency is widespread in Indian soils, with approximately 50% of agricultural soils reported to be deficient in available zinc (Alloway, 2008; Rattan *et al.*2009).

Boron is essential for cell division, cell wall development, sugar translocation, pollen germination, pollen tube growth and seed formation. Its deficiency adversely affects capsule formation, seed setting and seed yield in sesame. Application of boron has been shown to enhance capsule development and seed filling (Marschner, 2012; Bellaloui *et al.*, 2013).

Soils of Gwalior and Madhya Pradesh are generally low in organic carbon and deficient in sulphur, zinc and boron, resulting in reduced nutrient availability and crop productivity. Combined application of these nutrients along with recommended NPK is, therefore, essential for optimum sesame productivity (Chaudhary *et al.*, 2015; Meena *et al.*, 2016).

Several studies have evaluated the individual effects of S, Zn or B on sesame, but information on their interaction effects on growth, yield, quality and nutrient uptake remains limited. The present study was, therefore, conducted to assess the combined effect of sulphur, zinc and boron with RDF on growth, yield and quality of sesame under the agro-climatic conditions of Gwalior, Madhya Pradesh.

Materials and Methods

A field experiment was carried out at Crop Research Centre, School of Agriculture, ITM University, Gwalior, Madhya Pradesh during *Kharif* 2025 to evaluate the effect of sulphur, zinc and boron on growth, yield and quality of sesame (*Sesamum indicum* L.). The experimental site is located at latitude 26°14′ N and longitude 78°19′ E at an altitude of 197 m above mean sea level. The experiment was laid out in a Randomized Block Design with ten treatments and three replications. The recommended dose of fertilizers was 40:30:20 kg N: P_2O_5: K_2O ha^{-1}. Sulphur was applied at 40 kg ha-1 as gypsum, zinc at 5 kg ha^{-1} as zinc sulphate, and boron at 2 kg ha^{-1} as borax (soil application) or 0.5% $ZnSO_4$ + 0.2% H_3BO_3 (foliar spray T_{10})

The experimental soil was sandy loam in texture with pH 7.35, low in available N (167.2 kg ha^{-1}), available P (14.5 kg ha^{-1}) and available K (238.4 kg ha^{-1}) as determined by standard methods (Subbaiah and Asija, 1956; Olsen *et al.*1954; Jackson, 1973). The sesame variety 'Bombay Super Hybrid Karishma' was sown at 3 kg ha^{-1} with row spacing of 45 cm and plant spacing of 15 cm. All recommended agronomic practices were followed uniformly during the crop season.

Growth parameters, yield attributes, seed yield, straw yield, quality parameters (oil and protein content) and economics were recorded at appropriate growth stages. The following derived parameters were calculated using the formulas given below:

Leaf area index

Leaf area index (LAI) was estimated at various growth stages: 30, 60, 90 DAS and at harvest stage. The LAI was calculated using the measured values of leaf area, considering the area occupied by each plant based on the formula proposed by Watson (1952).

LAI = Leaf area per plant (cm^2) / Ground area occupied by the plant (cm^2)

Oil Content (%)

Oil content of sesame seed was determined by the Soxhlet extraction method using petroleum ether (boiling range 60–80°C) as the extraction solvent. Finely ground seed samples were subjected to continuous extraction for six hours. After solvent evaporation, the extracted oil was weighed and oil content was expressed as percentage of dry seed weight.Oil Content (%) = [(W_2 – W_1) / W_0] × 100,Where,W_0 = Weight of seed sample (g),W_1 = Weight of empty extraction flask (g),W_2 = Weight of flask + extracted oil (g)

Protein Content (%)

Protein content was estimated using the Macro-Kjeldahl method. Seed samples were digested with concentrated sulphuric acid in the presence of a catalyst mixture. The digested material was distilled after addition of sodium hydroxide, and the liberated ammonia was collected in boric acid solution and titrated against standard sulphuric acid.

Nitrogen percentage was calculated and converted to crude protein using the standard conversion factor of 6.25.

Protein Content (%) = Nitrogen (%) × 6.25

Data were analyzed statistically using analysis of variance (ANOVA) for RBD and treatment means were compared using the Least Significant Difference (LSD) test at 5% level of significance (Gomez and Gomez, 1984). The treatment details are presented in Table 1.

Table 1: Treatment details of the experiment

Treatment	Description
T_1	Control
T_2	RDF (40:30:20 kg N:P_2O_5:K_2O ha^{-1})
T_3	RDF + 5 kg Zn ha^{-1}
T_4	RDF + 40 kg S ha^{-1}
T_5	RDF + 2 kg B ha
T_6	RDF + 40 kg S ha^{-1} + 5 kg Zn ha^{-1}
T_7	RDF + 40 kg S ha^{-1} + 2 kg B ha^{-1}
T_8	RDF + 5 kg Zn ha^{-1} + 2 kg B ha^{-1}
T_9	RDF + 40 kg S ha^{-1} + 5 kg Zn ha^{-1} + 2 kg B ha^{-1}
T_{10}	RDF + 40 kg S ha-1 + 0.5% Zn + 0.2% B (foliar)

Results and Discussion

The application of sulphur, zinc and boron significantly affected the growth, yield, quality and economics of sesame. Treatment T_9 (RDF + 40 kg S ha^{-1} + 5 kg Zn ha^{-1} + 2 kg B ha^{-1}) recorded the highest values for most parameters and was superior to all other treatments. The enhancement observed in T_9 can be attributed to the synergistic effects of sulphur, zinc and boron in promoting photosynthesis, enzyme activation, protein and oil biosynthesis, and reproductive development.

Growth Parameters

Application of sulphur, zinc and boron significantly influenced the growth parameters of sesame Table 2 and Figure 1. Treatment T_9 recorded the highest plant height (76.10 cm), branches plant^{-1} (7.33), leaf area index (3.62) and chlorophyll content (50.26 SPAD). These values were statistically *at par* with T_{10} and T_6 but significantly superior to all other treatments. The improvement in plant height may be attributed to the role of sulphur in protein and chlorophyll synthesis which promotes cell elongation and meristematic activity. Similar results were reported by Sharma *et al.* (2013) who observed maximum plant height in sesame with combined S and Zn application. Zinc promotes auxin biosynthesis and cell division, thereby contributing to increased branching and leaf area (Alloway, 2008). The higher chlorophyll content in T_9 is consistent with findings of Meena *et al.*2016, who reported increased SPAD values with sulphur and micronutrient application in sesame. Boron contributes to carbohydrate metabolism and translocation, enhancing overall dry matter accumulation (Marschner, 2012).

Table 2 : Effect of nutrient management on growth parameters of sesame

Treatment	Plant Height (cm)	Branches Plant^{-1}	LAI	Chlorophyll Content (SPAD)	Dry Matter Accumulation (g m^{-2})
T_1	58.30	5.17	2.46	36.20	382.60
T_2	66.00	6.13	3.05	41.43	433.50
T_3	68.50	6.27	3.24	42.33	445.80
T_4	65.90	6.40	3.28	44.27	452.60
T_5	66.50	6.20	3.18	41.13	440.50
T_6	70.00	6.90	3.40	46.70	475.20
T_7	69.60	6.80	3.35	45.59	472.30
T_8	69.30	6.53	3.30	44.77	463.70
T_9	76.10	7.33	3.62	50.26	497.87
T_{10}	71.20	6.97	3.56	48.50	480.40
SE(m)±	0.76	0.18	0.05	2.12	7.29
LSD *(P=0.05)*	2.29	0.55	0.16	6.37	21.83

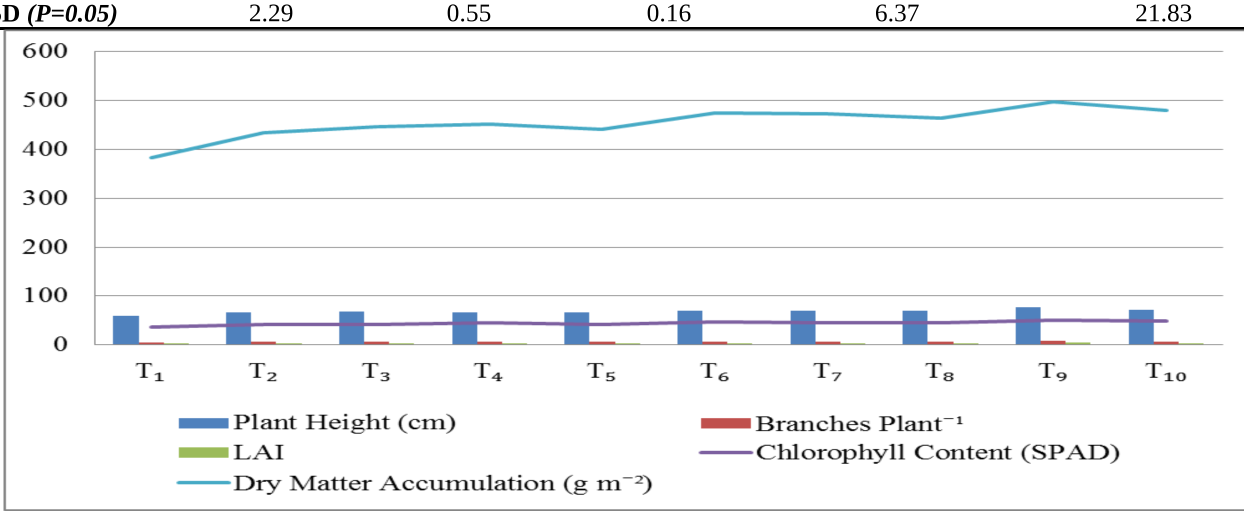

Fig. 1: Effect of nutrient management on growth parameters of sesame

Yield Attributes and Yield

Yield attributes were significantly enhanced with integrated nutrient application Table 3 and Figure 2. The highest capsules plant^{-1} (41.50), seeds capsule-1 (89.50) and test weight (4.08 g) were recorded under T_9. These values were statistically comparable with T_{10} and

T_6 but superior to all other treatments. Sulphur promotes nutrient translocation and protein synthesis, which supports capsule development, while zinc enhances pollen viability and fertilization efficiency. Boron plays a pivotal role in pollen germination and pollen tube growth, directly influencing seed setting. The improved capsule number and seeds capsule^{-1} is in agreement with Rathore *et al.* (2015), who reported a significant increase in yield attributes of sesame with zinc application, and Singh *et al.* (2020), who recorded higher capsule number with boron fertilization under rainfed conditions.

Table 3 : Effect of nutrient management on yield attributes of sesame

Treatment	Capsule Length (cm)	Capsules Plant^{-1}	Seeds Capsule^{-1}	Test Weight (g)
T_1	1.52	18.50	50.00	2.34
T_2	1.98	26.00	64.00	2.95
T_3	2.18	30.00	70.00	3.20
T_4	2.22	31.50	72.50	3.32
T_5	2.20	30.50	71.00	3.25
T_6	2.48	37.00	82.50	3.84
T_7	2.46	36.50	81.00	3.78
T_8	2.30	33.50	76.00	3.48
T_9	2.68	41.50	89.50	4.08
T_{10}	2.52	38.00	84.00	3.92
SE(m)±	0.027	0.55	0.94	0.042
LSD *(P=0.05)*	0.08	1.67	2.84	0.126

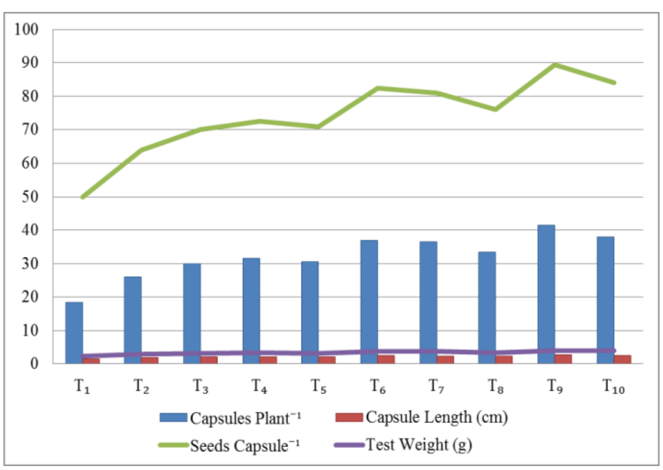

Fig. 2: Effect of nutrient management on yield attributes of sesame

Seed yield, straw yield, biological yield and harvest index were significantly affected by nutrient management Table 4 and Figure 3. Treatment T_9 recorded the highest seed yield (910 kg ha^{-1}), straw yield (2105 kg ha^{-1}), biological yield (3015 kg ha^{-1}) and harvest index (30.18%). This was statistically *at par* with T_{10} and T_6. The balanced supply of S, Zn and B along with RDF ensures adequate availability of essential nutrients throughout the crop growth cycle, resulting in superior yield. These findings are in conformity with Yadav *et al.* (2011), who reported maximum seed yield of sesame with sulphur application, and Yadav *et al.* (2022), who recorded significant improvement in productivity under integrated nutrient management in sesame.

Table 4 : Effect of nutrient management on yield of sesame

Treatment	Seed Yield (kg ha^{-1})	Straw Yield (kg ha^{-1})	Biological Yield (kg ha^{-1})	Harvest Index (%)
T_1	435	1415	1850	23.51
T_2	610	1725	2335	26.12
T_3	705	1865	2570	27.43
T_4	735	1900	2635	27.89
T_5	720	1885	2605	27.64
T_6	835	2035	2870	29.09
T_7	820	2015	2835	28.92
T_8	780	1975	2755	28.31
T_9	910	2105	3015	30.18
T_{10}	865	2055	2920	29.62
SE(m)±	12.66	31.66	26.29	0.34
LSD *(P=0.05)*	37.91	94.80	78.71	1.04

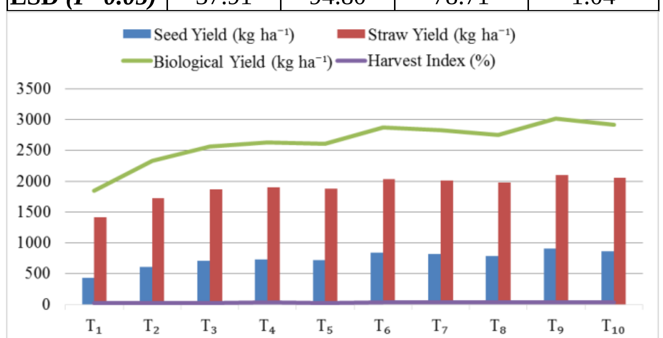

Fig. 3: Effect of nutrient management on yield of sesame

Quality Parameters

Nutrient management significantly influenced quality parameters of sesame Table 5 and Figure 4. Treatment T_9 recorded the highest oil content (60.00%) and protein content (24.80%), which was statistically *at par* with T_{10} and T_6 but superior to all other treatments. Sulphur is a structural component of amino acids (cysteine and methionine) and directly participates in fatty acid synthesis in oilseeds. The enhanced oil content under T_9 may be attributed to sulphur's role in activating enzymes involved in lipid biosynthesis, which is consistent with findings of

Aulakh *et al.* (2009), who reported significant improvement in oil content of oilseed crops with sulphur fertilization. Zinc plays an important role in enzyme activation and assimilate partitioning, contributing to increased protein content. Similar results were reported by Mishra *et al.* (2021), who observed higher oil and protein content in sesame with sulphur and zinc application under semi-arid conditions. Boron enhances sugar translocation to seeds, thereby improving seed quality and composition (Bellaloui *et al.*, 2013).

Table 5 : Effect of nutrient management on quality parameters of sesame

Treatment	Oil Content (%)	Protein Content (%)
T_1	46.20	18.60
T_2	51.00	21.20
T_3	53.50	22.20
T_4	54.50	22.60
T_5	52.50	21.80
T_6	57.50	23.80
T_7	56.50	23.40
T_8	55.50	23.00
T_9	60.00	24.80
T_{10}	58.50	24.20
SE(m)±	0.77	0.60
LSD *(P=0.05)*	2.33	1.80

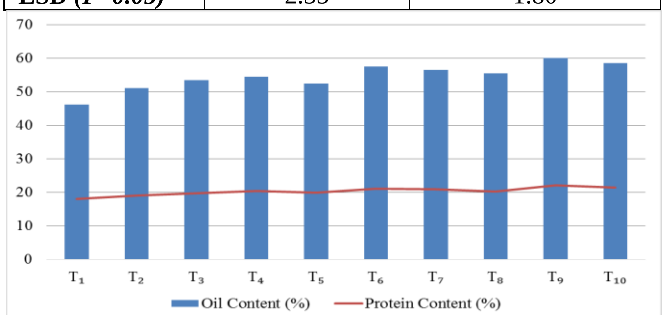

Fig. 4: Effect of nutrient management on quality parameters of sesame

Nutrient Content in Seed and Straw

Nutrient management treatments significantly influenced the nutrient concentration in both seed and straw of sesame Table 6 and Figure 5. The combined application of RDF along with 40 kg S ha^{-1}, 5 kg Zn ha^{-1} and 2 kg B ha^{-1} (T_9) recorded the highest nitrogen (3.55 and 0.62%), phosphorus (0.68 and 0.25%), potassium (0.69 and 1.48%), sulphur (0.44 and 0.32%), zinc (53 and 33 ppm) and boron (38 and 26 ppm) content in seed and straw, respectively. The increase in nutrient concentration under T_9 may be attributed to improved nutrient availability in the rhizosphere, enhanced root development and synergistic interaction among sulphur, zinc and boron. In contrast, the control treatment (T_1) recorded the lowest nutrient content due to inadequate nutrient availability and restricted nutrient uptake.

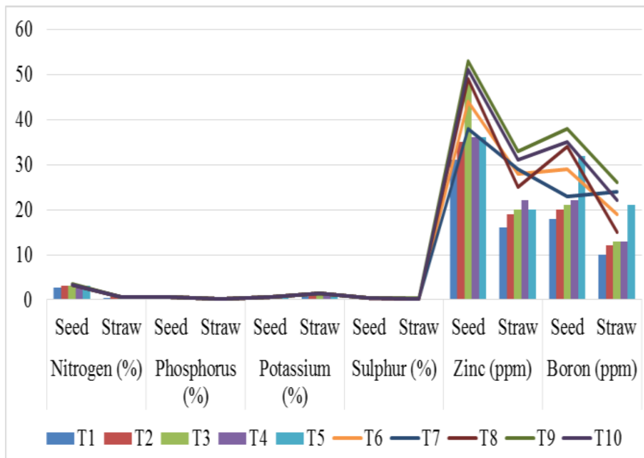

Fig. 5: Effect of nutrient management on nutrient content in seed and straw of sesame

Table 6 : Effect of nutrient management on nutrient content in seed and straw of sesame

Treatment	Nitrogen (%)		Phosphorus (%)		Potassium (%)		Sulphur (%)		Zinc (ppm)		Boron (ppm)	
	Seed	**Straw**	**Seed**	**Straw**	**Seed**	**Straw**	**Seed**	**Straw**	**Seed**	**Straw**	**Seed**	**Straw**
T_1	2.610	0.440	0.480	0.120	0.520	1.100	0.220	0.140	31	16	18	10
T_2	3.050	0.520	0.580	0.180	0.610	1.350	0.280	0.180	35	19	20	12
T_3	3.160	0.540	0.590	0.190	0.620	1.360	0.290	0.190	48	20	21	13
T_4	3.280	0.550	0.610	0.210	0.630	1.390	0.380	0.260	36	22	22	13
T_5	3.180	0.540	0.600	0.190	0.620	1.380	0.290	0.180	36	20	32	21
T_6	3.380	0.580	0.630	0.220	0.658	1.420	0.400	0.280	44	28	29	19
T_7	3.350	0.570	0.620	0.210	0.650	1.410	0.390	0.270	38	29	23	24
T_8	3.250	0.570	0.640	0.210	0.640	1.400	0.310	0.200	49	25	34	15
T_9	3.550	0.620	0.680	0.250	0.690	1.480	0.440	0.320	53	33	38	26
T_{10}	3.430	0.590	0.640	0.230	0.660	1.440	0.410	0.290	51	31	35	22
SE(m)±	0.15	0.03	0.03	0.01	0.04	0.09	0.02	0.02	2.60	0.95	1.10	0.78
LSD *(P=0.05)*	0.45	0.09	0.09	0.03	0.12	0.26	0.06	0.05	7.80	2.85	3.30	2.34

Nutrient Uptake

Nutrient uptake by sesame increased progressively with the application of RDF and micronutrients over the control Table 7 and Figure 6. Among the treatments, T_9 (RDF + 40 kg S ha^{-1} + 5 kg Zn ha^{-1} + 2 kg B ha^{-1}) recorded the highest uptake of N (46.553 kg ha^{-1}), P (11.450 kg ha^{-1}), K (37.500 kg ha^{-1}), S (10.783 kg ha^{-1}), Zn (0.120 kg ha^{-1}) and B (0.090 kg ha^{-1}), followed by T_{10} and T_6. The control treatment (T_1) recorded the lowest uptake of all nutrients. Application of RDF alone (T_2) significantly improved nutrient uptake over control, while individual application of Zn (T_3), S (T_4) and B (T_5) further enhanced nutrient absorption. Combined application treatments T_6, T_7 and T_8 recorded higher uptake than individual nutrient applications, indicating the beneficial interaction among sulphur, zinc and boron. The increased uptake under integrated nutrient management may be attributed to improved nutrient availability, greater root growth and higher biomass production.

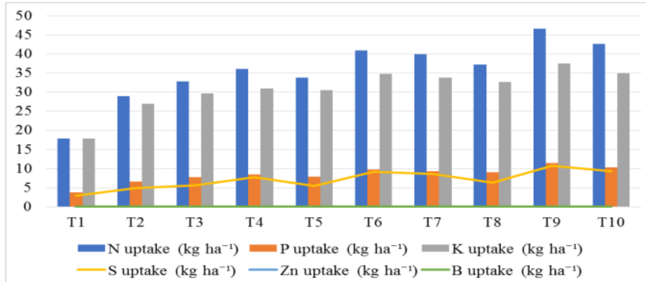

Fig. 6: Effect of nutrient management on nutrient uptake by sesame

Table 7 : Effect of nutrient management on nutrient uptake by sesame

Treatment	N uptake (kg ha^{-1})	P uptake (kg ha^{-1})	K uptake (kg ha^{-1})	S uptake (kg ha^{-1})	Zn uptake (kg ha^{-1})	B uptake (kg ha^{-1})
T_1	17.879	3.787	17.827	2.940	0.037	0.021
T_2	28.913	6.643	27.010	4.840	0.053	0.031
T_3	32.800	7.703	29.737	5.620	0.087	0.040
T_4	36.050	8.470	31.007	7.733	0.063	0.041
T_5	33.810	7.903	30.480	5.480	0.063	0.061
T_6	40.987	9.737	34.807	9.213	0.087	0.062
T_7	39.997	9.313	33.743	8.640	0.077	0.051
T_8	37.207	8.983	32.640	6.370	0.097	0.070
T_9	46.553	11.450	37.500	10.783	0.120	0.090
T_{10}	42.690	10.267	34.883	9.327	0.107	0.080
SE(m)±	1.82	0.01	1.95	0.41	0.004	0.003
LSD *(P=0.05)*	5.42	0.03	5.81	1.23	0.012	0.009

Conclusion

The present investigation demonstrated that nutrient management practices significantly influenced the growth, yield, quality, nutrient content, nutrient uptake and economics of sesame. Application of RDF in combination with sulphur, zinc and boron proved superior to RDF alone and individual nutrient applications. Among the treatments, T_9 RDF + 40 kg S ha^{-1} + 5 kg Zn ha^{-1} + 2 kg B ha^{-1} recorded the highest plant height (76.10 cm), number of branches $plant^{-1}$ (7.33), leaf area index (3.62), chlorophyll content (50.26 SPAD), dry matter accumulation (497.87 g m^{-2}), yield attributes, seed yield (910 kg ha^{-1}), straw yield (2105 kg ha^{-1}) and biological yield (3015 kg ha^{-1}). The same treatment also resulted in maximum oil content (60.00%) and protein content (24.80%), indicating a positive effect of balanced nutrient supply on sesame quality. Treatment T_9 further recorded the highest nutrient concentration of nitrogen, phosphorus, potassium, sulphur, zinc and boron in both seed and straw. Similarly, maximum uptake of N (46.553 kg ha^{-1}), P (11.450 kg ha^{-1}), K (37.500 kg ha^{-1}), S (10.783 kg ha^{-1}), Zn (0.120 kg ha^{-1}) and B (0.090 kg ha^{-1}) was observed under this treatment, reflecting enhanced nutrient availability, absorption and utilization by the crop.

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