



Optimizing Nitrogen Input for Enhanced Yield in New Irrigated Sesame Variety (TS-05)

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Abstract

This study investigates the optimization of nitrogen (N) fertilization for the newly developed irrigated sesame variety, TS-05, under irrigated conditions in Southern Punjab, Pakistan. The experiment was conducted during the 2022 Kharif season across six locations within the Bahawalpur Division, employing a split-plot design with four nitrogen levels ($N_0 = 0$ kg/ha, $N_{60} = 60$ kg/ha, $N_{80} = 80$ kg/ha, and $N_{100} = 100$ kg/ha). The results demonstrate a significant positive response of sesame yield and yield components to nitrogen application, with the highest grain yield observed at 100 kg N/ha. However, the study also highlights diminishing returns at nitrogen rates above 80 kg N/ha, suggesting that an optimal N rate exists for maximizing yield without incurring unnecessary costs or environmental risks. The location \times nitrogen treatment interaction emphasized the need for site-specific nitrogen management strategies, given the variation in soil fertility and micro-climatic conditions across the experimental sites. The findings support the recommendation of 80–100 kg N/ha as the most effective range for the TS-05 variety under irrigated conditions in Southern Punjab.

Keywords: Nitrogen Fertilization, Yield Optimization, Sustainable Agriculture, Sesame

1. Introduction

Sesame (*Sesamum indicum* L.) is regarded as one of the oldest oilseed crops and is valued globally for its high-quality oil, rich in unsaturated fatty acids and antioxidants (Vaishnav et al., 2024). Despite its inherent tolerance to drought and nutrient-poor soils, sesame's yield remains comparatively low relative to other major oilseeds, particularly under modern intensive production systems (Kashani et al., 2015). In recent years, advances in breeding have introduced new irrigated varieties, such as 'TS-05', bred for higher input environments, thereby necessitating improved agronomic management to fully exploit their genetic potential.

Nitrogen (N) is a key macronutrient influencing fundamental plant processes including chlorophyll synthesis, protein formation, cell division and enlargement, and hence directly impacts vegetative growth, reproductive development and final yield (Kalaiselvan et al., 2001). For sesame, several studies reported significant increases in vegetative growth, capsule number, seed yield and oil yield with N fertilization (Salam et al., 2014). Salam et al. (2024) found that for certain cultivars in Bangladesh, increasing urea rates up to 80 kg ha⁻¹ favourably affected yield components, while higher rates did not always translate into further seed yield gains. Similarly, in an irrigated wetland following paddy, Hariyono and Romli (2005) determined optimum N dosages ranging from ~42 to ~83 kg ha⁻¹ depending on the sesame line.

However, sesame's response to nitrogen is strongly influenced by other factors including irrigation regime, soil fertility status, cultivar genetic responsiveness and nutrient management timing/method. A study conducted under irrigated conditions with contrasting N and water levels concluded that under high irrigation, optimum N rates of ~80-120 kg ha⁻¹ were required to achieve seed yields exceeding 2 t ha⁻¹, whereas under water-limited conditions N fertilization was less effective, and high N even depressed photosynthetic rate due to rapid soil water depletion (Gebregergis et al., 2020). Irrigation-nitrogen interactions

are therefore pivotal when optimizing N input in irrigated sesame production systems (Tas et al., 2020).

Considering that irrigated sesame varieties like TS-05 are developed to perform under higher input and water-reliable conditions, it becomes critical to calibrate N input rates to match the genetics, soil–water regime and economic realities of production. Excess N not only increases cost and risk of nutrient losses (leaching/denitrification) but can also induce vegetative overgrowth, lodging, delayed maturity or oil dilution in sesame seeds (Kalaiselvan et al., 2001; Tas et al., 2020). Conversely, under-fertilization fails to exploit the yield potential of improved varieties and may reduce harvest index and oil productivity.

Therefore, the objectives of this study were to (i) determine the optimal nitrogen input rate for the new irrigated sesame variety TS-05 under irrigated conditions, and (ii) evaluate the effect of N rates on yield and yield-components. It is hypothesized that TS-05 will respond positively to increasing nitrogen up to an optimum threshold, beyond which yield gains will plateau or decline, and that an economically optimal N rate exists which maximizes yield, oil quality and return on investment.

Materials and Methods

Experimental Site and Variety

The field experiments were conducted during the Kharif season of 2022 by the Soil Fertility (Field), Bahawalpur, under the Agriculture Research Wing of the Government of Punjab, Pakistan. The trials were executed across six locations within the Bahawalpur Division, representing the major sesame-growing belt of Southern Punjab. These locations included Haroonabad, Chishtian, and Hasilpur to capture spatial variation in soil fertility and micro-climatic conditions. The experimental variety used was the newly released irrigated sesame genotype “TS-05”, developed for higher yield potential and input responsiveness under canal-irrigated environments.

Experimental Design and Treatments

A split-plot design was employed to evaluate the effect of nitrogen levels on the yield performance of the irrigated sesame variety TS-05. Nitrogen (N) treatments were assigned to the sub-plots, while replications and locations served as main-plots. Four nitrogen levels were tested:

- $N_0 = 0 \text{ kg N ha}^{-1}$ (control),
- $N_{60} = 60 \text{ kg N ha}^{-1}$,
- $N_{80} = 80 \text{ kg N ha}^{-1}$, and
- $N_{100} = 100 \text{ kg N ha}^{-1}$.

In all treatments, phosphorus (P_2O_5) and potassium (K_2O) were maintained constant at 57.5 kg ha^{-1} and 30 kg ha^{-1} , respectively, to ensure balanced nutrition and isolate the effect of nitrogen. The fertilizers were applied in the form of urea, (Diammonium Phosphate; DAP) and Sulphate of Potash; SOP). Half of the nitrogen dose was applied as basal at sowing and the remaining half at flowering, while the entire doses of P and K were incorporated into the soil before planting.

Crop Husbandry and Management

The crop was sown during the first week of May 2022, coinciding with the optimal sowing window for Kharif sesame in the region. A seed rate of 2 kg acre⁻¹ (approximately 5 kg ha⁻¹) was used, ensuring uniform plant population across treatments. Seeds were line-sown manually with a row spacing of 45 cm. All plots were kept under irrigated conditions with 2 to 3 irrigations applied at critical growth stages. Recommended agronomic practices for weed and pest control were followed uniformly across all treatments.

Plot Size and Experimental Layout

Each experimental unit (plot) measured 9 m² (3 m × 3 m). The trials were replicated three times at each location, following the same spatial arrangement to minimize experimental error. Buffer zones of 1 m were maintained between adjacent plots and replications to prevent nutrient movement and water interference.

Data Recording and Parameters

At physiological maturity, sesame plants were harvested during the third week of August 2022. Data were recorded for three primary yield-related traits including Bundle yield (kg plot⁻¹), Grain yield per plot (kg plot⁻¹) and Grain yield per hectare (kg ha⁻¹).

Statistical Analysis

Data collected from all locations were subjected to combined analysis of variance (ANOVA) using a split-plot design model as described by Gomez and Gomez (1984) and Steel et al (1997). Mean comparisons among nitrogen levels were conducted using the Least Significant Difference (LSD) test at 5% probability to determine statistically significant differences among treatments. Data was visualized using Microsoft Excel while other analysis were executed using Statistix 8.1 and R/R Studio.

Results and Discussion

Pre-sowing Soil Analysis at Six Locations

The pre-sowing soil analysis (Table 1) revealed noticeable variation in soil physico-chemical properties among the six experimental sites within the Bahawalpur Division. Soil electrical conductivity (EC) in the 0–15 cm layer ranged from 1.3 dS m⁻¹ at Haroonabad to 2.7 dS m⁻¹ at Chishtian (46/FM), indicating that all soils were within the non-saline to slightly saline category. The soil pH values were relatively high, ranging between 7.6 and 8.5, classifying the soils as moderately alkaline, a typical characteristic of the arid and semi-arid regions of Southern Punjab. Organic matter (OM) content was low across all locations (0.56–0.84%), reflecting the general depletion of soil organic carbon due to high temperatures and rapid oxidation, consistent with earlier findings in sesame-growing areas of Pakistan (Tas et al., 2024; Hassan, 2016).

Available phosphorus (P) and potassium (K) levels also exhibited spatial variability. Available P ranged from 4.1 ppm to 9.9 ppm, which falls within the low to medium fertility range, while K values were generally adequate (100–189 ppm). These variations indicate differences in historical fertilizer use, irrigation quality, and soil parent material. The soil texture was loam at all sites, ensuring good water infiltration and root aeration favorable for sesame cultivation. Such heterogeneity among experimental sites is beneficial for testing

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treatment robustness across diverse soil conditions, but it also necessitates careful interpretation of treatment \times location interactions (Davari & Mirzakhani, 2009). The pre-sowing analysis confirms that the soils were suitable for sesame cultivation but relatively poor in organic matter and available phosphorus—conditions under which nitrogen management plays a decisive role in achieving optimal yield performance (Salam et al., 2020).

Table 1: Pre-Sowing Soil analysis of all Six Locations

10/FM, Chistian							
Treatments	Soil Parameters	EC (dS m ⁻¹)	pH	OM%	P (ppm)	K (ppm)	Texture
	Depth (0 - 15) cm	1.8	7.7	0.69	6.6	177	Loam
	Depth (15-30) cm	1.6	7.6	0.68	6.3	172	
127/6R Haroonabad							
	Depth (0 - 15) cm	1.3	8.4	0.7	9.9	165	Loam
	Depth (15-30) cm	1.2	8	0.63	9.7	189	
165/M, Hasilpur							
	Depth (0 - 15) cm	2.4	8.5	0.77	6	169	Loam
	Depth (15-30) cm	2.3	8.3	0.56	5.7	156	
46/FM, Chistian							
	Depth (0 - 15) cm	2.7	8.1	0.84	5.7	143	Loam
	Depth (15-30) cm	2.6	8.1	0.56	4.3	100	
30/3R, Haroonabad							
	Depth (0 - 15) cm	2.3	8.4	0.77	9	129	Loam
	Depth (15-30) cm	2.2	8.3	0.84	8.5	177	
103/6R, Haroonabad							
	Depth (0 - 15) cm	2.5	8.2	0.56	5.3	165	Loam
	Depth (15-30) cm	2.3	8	0.7	4.1	189	

Analysis of Variance (ANOVA) for Sesame Yield

The combined analysis of variance demonstrated highly significant ($P \leq 0.01$) effects of locations (L), nitrogen treatments (T), and their interaction (L \times T) for all measured traits: bundle yield, grain yield per plot, and grain yield per hectare (Table 2). This indicates that yield performance of sesame was markedly influenced by both the environmental variation among locations and nitrogen application levels, and that the magnitude of nitrogen response differed among sites.

The significant location effect reflects inherent differences in soil fertility, texture, pH, and nutrient reserves as described above, as well as possible micro-climatic variability across Bahawalpur, Chishtian, and Hasilpur. Such location-specific yield differences are consistent with previous multi-site studies reporting that sesame yields in arid-irrigated regions fluctuate widely with soil EC, organic matter, and irrigation quality (Buriro et al., 2015).

Table 2: Mean Square (MS) values of Sesame Yield at six different locations in Bahawalpur Region

Source of Variation	df	Bundle	Grain Yield (kg/plot)	Grain Yield (kg/ha)
Replications (R)	3	0.141	0.0035	8378
Locations (L)	5	0.666**	0.0736**	94200**
Error (R×L)	15	0.0393	0.0016	1678
Treatments (T)	3	82.13**	4.659**	5726565**
Locations × Treatments (L×T)	15	0.744**	0.0251**	30250**
Error (R×L×T)	54	0.0723	0.00125	1730

Notes: Significant changes are highlighted by an asterisk (); * P ≤ 0.05, ** P ≤ 0.01.*

The treatment effect was highly significant ($P \leq 0.01$) for all yield parameters, confirming that nitrogen fertilization substantially improved both vegetative and reproductive growth of sesame. Similar trends have been documented by Ibrahim et al. (2014) and Vaishnav et al. (2024), who reported linear increases in plant biomass, capsule number, and grain yield with increasing nitrogen up to an optimum level beyond which yield gains plateaued. The current results reaffirm nitrogen’s key role in sesame productivity under irrigated conditions.

Moreover, the location × treatment interaction was also highly significant ($P \leq 0.01$), implying that nitrogen response was not uniform across all sites. This interaction suggests that site-specific nutrient management strategies are required for optimized fertilizer use efficiency. Variations in soil EC, organic matter, and available phosphorus likely influenced N uptake and assimilation efficiency, leading to differential yield responses among the six sites. As described by Hariyono and Romli (2010), sesame’s nitrogen demand is strongly affected by the local environment, particularly irrigation and soil nutrient status.

Treatment and Location Comparisons for Yield Traits

Bundle yield varied markedly across locations and N treatments (Figures 1a–b). The highest bundle yield (approximately 7.0–8.0 kg per plot) was observed at 10/FM, Chistian and 165/M, Hasilpur under N100, while the lowest (around 2.0 kg per plot) occurred at 103/6R, Haroonabad under N0. Averaged across locations, bundle yield increased progressively with N application: 3.2 kg per plot (N0), 4.5 kg (N60), 5.8 kg (N80), and 6.5 kg (N100). This response aligns with N's role in enhancing vegetative growth and biomass accumulation in sesame (Saboury et al., 2021).

Grain yield per plot followed similar patterns (Figures 2a–b), ranging from 0.5 kg (N0 at several sites) to 1.8 kg (N100 at 10/FM, Chistian). Location-wise, 10/FM, Chistian consistently outperformed others, yielding up to 1.8 kg per plot at N100, attributed to favorable soil EC and OM levels. Nitrogen treatments significantly boosted grain yield per plot: 0.75 kg (N0), 1.05 kg (N60), 1.35 kg (N80), and 1.55 kg (N100) on average. The L×T interaction highlighted that N response was more pronounced at sites with lower baseline fertility, such as 103/6R, Haroonabad.

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Grain yield per hectare mirrored per-plot trends but on a scaled basis (Figures 3a–b), with maximum values exceeding 2,000 kg ha⁻¹ at N100 in high-performing locations like 10/FM, Chistian. Mean yields across treatments were 950 kg ha⁻¹ (N0), 1,300 kg (N60), 1,650 kg (N80), and 1,900 kg (N100), representing increases of 37%, 74%, and 100% over the control, respectively. The plateauing beyond N80 in some locations suggests optimal N uptake efficiency at moderate rates, consistent with previous findings where excessive N promotes biomass at the expense of reproductive partitioning (Zenawi & Mizan, 2020; Gebremariam, 2015).

The significant L×T interaction implies that optimal N rates for "TS-05" may vary by site-specific soil conditions; for instance, lower-EC sites like 127/6 R, Haroonabad responded linearly up to N100, while higher-EC sites like 46/FM, Chistian showed diminishing returns beyond N80. Nitrogen use efficiency (NUE), calculated as (yield_fertilized - yield_control)/N_applied, was highest at N60 (approximately 6–8 kg kg⁻¹) and declined at higher rates due to luxury consumption (Fageria & Baligar, 2005).

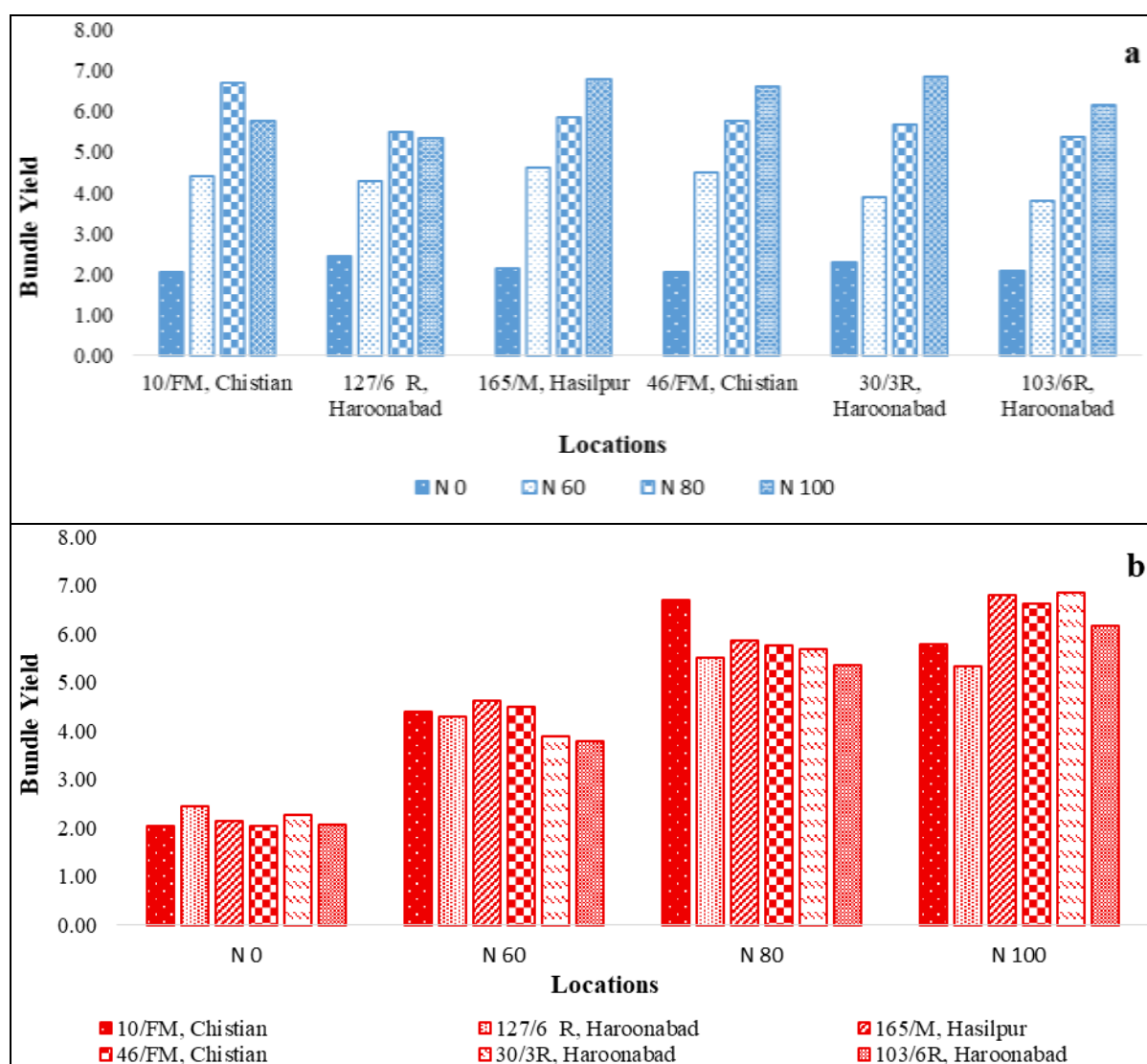


Figure 1a-b: Comparison of Bundle Yield per plot (kg) at six different locations in Punjab on the basis of (a) Locations (b) Nitrogen Treatments

These results recommend 80–100 kg N ha⁻¹ for "TS-05" under irrigated loam soils in Bahawalpur Division, balancing yield gains (up to 100% over unfertilized) with sustainability, while avoiding risks of lodging or environmental N losses associated with over-application (Kalaiselvan et al., 2001).

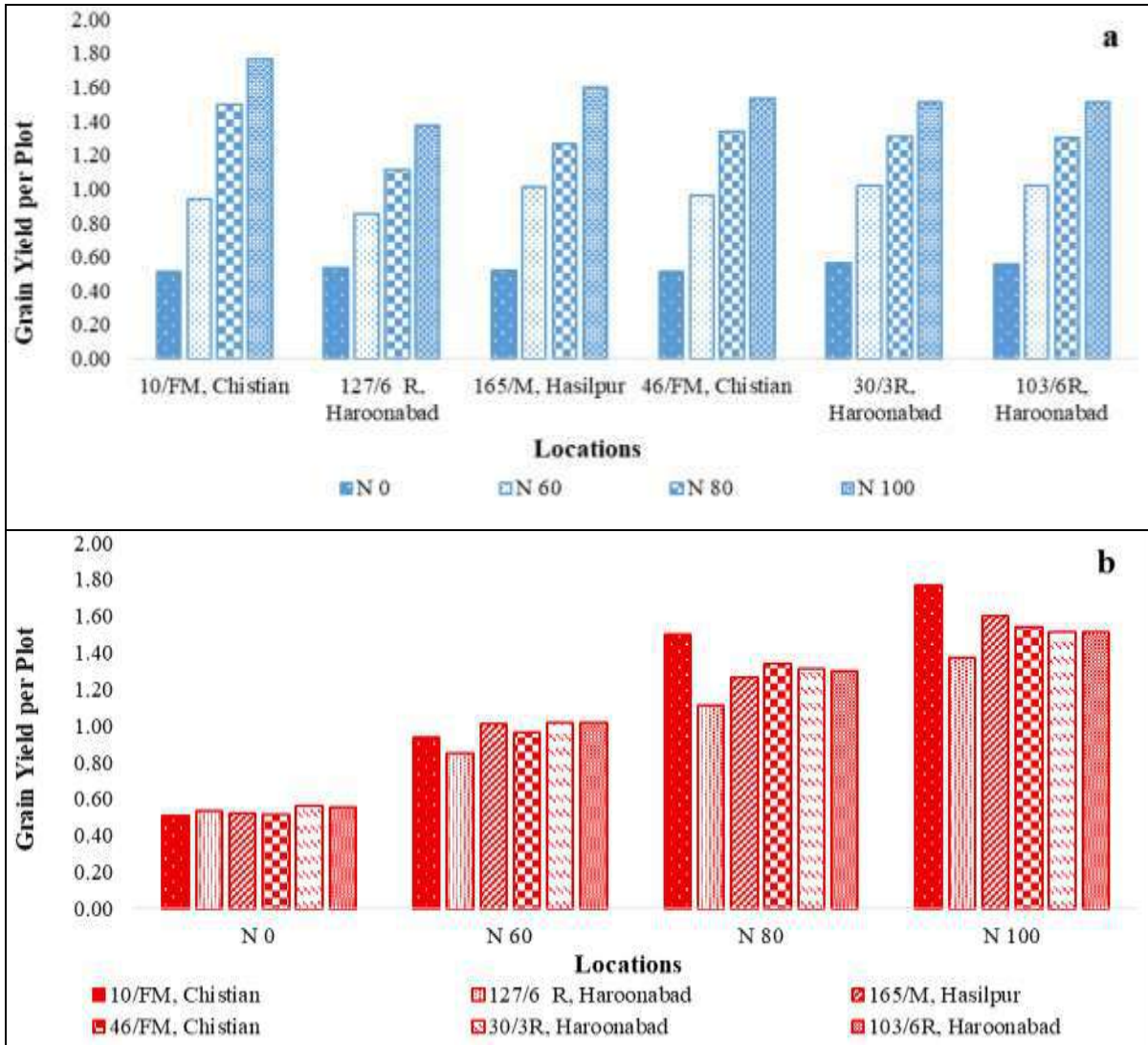


Figure 2a-b: Comparision of Grain Yield per plot (kg) at six different locations in Punjab on the basis of (a) Locations (b) Nitrogen Treatments

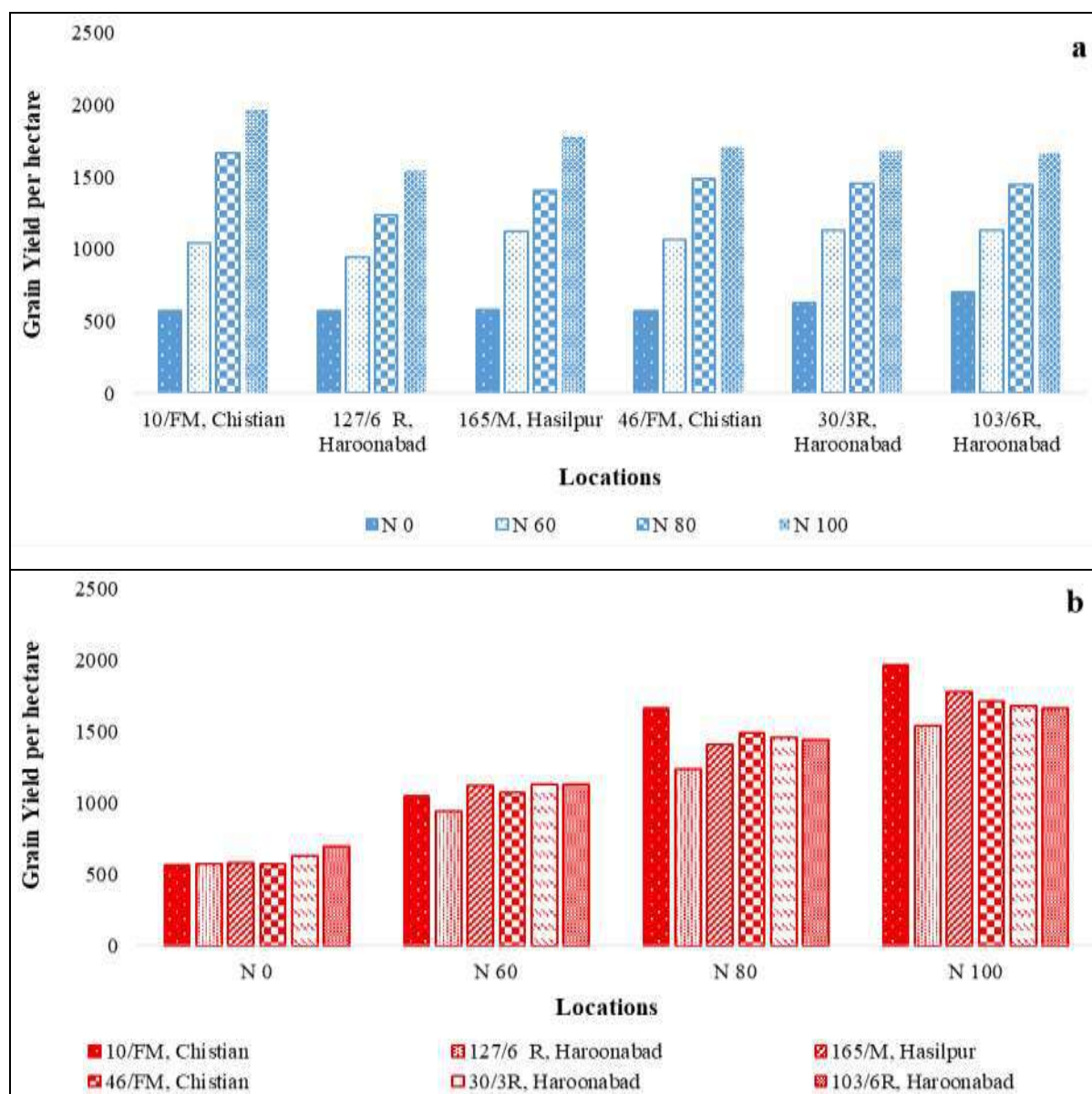


Figure 3a-b: Comparison of Grain Yield per hectare (kg) at six different locations in Punjab on the basis of (a) Locations (b) Nitrogen Treatments

Conclusion:

In conclusion, the study underscores the critical role of nitrogen fertilization in enhancing the yield potential of the TS-05 irrigated sesame variety under optimal agronomic conditions. Nitrogen application significantly improved both vegetative growth and reproductive development, with substantial yield increases observed at 80–100 kg N/ha. However, the diminishing returns at higher nitrogen rates highlight the importance of fine-tuning fertilization practices to maximize economic returns while minimizing environmental impact. The variation in nitrogen response across different locations further reinforces the necessity for tailored nutrient management strategies. Overall, the results provide valuable insights for sesame growers in Southern Punjab, guiding them toward more efficient and sustainable nitrogen use in irrigated sesame production systems.

Author's Contribution

Planning, Execution and Data Recording; MJQ, MRF, ZKN, IM: Supervision and Monitoring; MAQ, ZC, MRF: Writing – original draft; MJQ, AA, MK, MNI, FH, AA: Writing – review & editing; AN, FA, MN, AS, FA, IN: Graphical Representation; IRN, MA, MR

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