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Nitrogen management strategies for boosting growth and yield in Indian mustard (*Brassica juncea*)

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ABSTRACT

Indian mustard (*Brassica juncea* L.) plays a crucial role in Indian agriculture, industry, and trade, yet the country's dependence on edible oil imports necessitates enhanced domestic production. Beyond economic significance, mustard cultivation contributes to environmental sustainability by improving soil structure, preventing erosion, and enhancing nutrient uptake through its deep root system. The field experiment was conducted during winter (*rabi*) seasons of 2022–23 and 2023–24 at ICAR-Indian Agricultural Research Institute, New Delhi to assess the impact of nitrogen management techniques on mustard growth and yield. The experiment was laid out in a randomized complete block design (RCBD) with three replications. The study included eight treatments i.e. T_1, Control; T_2, 100% N (Farmer's practice); T_3, 40% N (basal) + 2 sprays of nano urea at 45 days after sowing (DAS) and 60 DAS through knapsack sprayer (2SNU-KS); T_4, 50% N (basal) + 2 sprays of nano urea at 45 DAS and 60 DAS through knapsack sprayer; T_5, 60% N (basal) + 2 sprays of nano urea at 45 DAS and 60 DAS through knapsack sprayer; T_6, 40% N (basal) + 2 sprays of nano urea at 45 DAS and 60 DAS through drone (2SNU-D); T_7, 50% N (basal) + 2 sprays of nano urea at 45 DAS and 60 DAS through drone and T_8, 60% N (basal) + 2 sprays of nano urea at 45 DAS and 60 DAS through drone. Among the treatments, T_8 exhibited superior performance, enhancing the growth parameters, including plant height, leaf area index, dry matter accumulation compared to knapsack sprayer, conventional methods, and control. This treatment also recorded the highest yield attributes, including the number of siliquae/plant (541.3), seeds/siliqua (13.9), and seed yield (2742 kg/ha), underscoring the efficiency of drone-mediated nitrogen application. These findings highlight the potential of optimized nitrogen management and drone technology in enhancing oilseed production while promoting environmentally sustainable agriculture.

Keywords: Drone, Indian mustard, Nano urea, Nitrogen, Production efficiency

Oilseed crops play an indispensable role in Indian agriculture, industry and trade. India accounts for 15–20% of oilseeds area and 6–7% oilseed production. Despite significant output, over half of India's edible oil needs (16.5 million tonnes) are met by imports, costing ₹138,424 crore in 2022–23. This contrasts sharply with the preceding decade, where imports surged from 5–11.6 million tonnes between 2004–05 and 2013–14 (Anonymous 2023). It is due to higher population growth rate and improvement in the living standard of the Indian (Kumar *et al.* 2024). India, the world's largest vegetable oil importer, must enhance oilseed productivity. Rapeseed-mustard, particularly Indian mustard (*Brassica juncea* L.), ranks second after groundnut in oilseed crops, cultivated on 8.06 Mha area with production and productivity of 11.75 Mt and 1458 kg/ha, respectively (Anonymous 2022). It is predominantly cultivated in Rajasthan, Uttar Pradesh, Haryana, Madhya Pradesh, and Gujarat, though industrialization and urbanization reducing cultivable land. Mustard oil, rich in omega-3 and omega-6 fatty acids, alpha-tocopherol and antioxidants offering various benefits for cardiovascular issue (Manchanda and Passi 2016). Its seed meal, a by-product, is a protein-rich livestock feed, especially for poultry. Also, the vegetative parts of mustard are enjoyed as 'Sarson Ka Saag' in northern India (Ananthanarayan *et al.* 2019).

Agriculture faces the challenge of increasing food production while minimizing environmental damage and conserving resources (Beddington *et al.* 2012). The rising demand for oilseeds underscores the need for innovative techniques that boost productivity and sustainability. Traditional urea, though widely used as a source of nitrogen (N) (Swify *et al.* 2023), often leads to nutrient loss through leaching and volatilization, and enhance soil pollution (Kumar *et al.* 2024) results in reduced use efficiency. Nano

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urea, with its small particle size and controlled release, offers a more efficient alternative (Sharma *et al.* 2022). Likewise, drones equipped with sensors and GPS (Global Positioning System) improve nutrient spraying efficiency, addressing issues with inconsistent knapsack sprayers (Maddikunta *et al.* 2021, Makkar and Gangwar 2022). Therefore, this study aims to evaluate nano urea application with drone and knapsack sprayer, combined with basal urea doses, to assess their effects on yield and yield parameter of Indian mustard, offering insights for modern agriculture.

MATERIALS AND METHODS

The field experiment was conducted during winter (*rabi*) seasons of 2022–23 and 2023–24 at ICAR-Indian Agricultural Research Institute (latitude of 28° 63'N and a longitude of 77° 15'E), New Delhi. The field had an even topography and a well-functioning drainage system. The upper 15 cm depth of soil characterized by a sandy loam texture (sand-58.6%, silt-22.8% and clay-18.6%), water holding capacity (WHC) 43.7%, *p*H 6.7, EC 0.23 dS/m, organic carbon (0.37%), available nitrogen (167 kg/ha), available phosphorus (43.5 kg/ha), and available potassium (212 kg/ha). The experiment was laid out in a randomized complete block design (RCBD) with three replications having eight treatment combinations, viz. T_1, Control; T_2, 100% N (Farmer's practice); T_3, 40% N (basal) + 2 sprays of nano urea at 45 days after sowing (DAS) and 60 DAS through knapsack sprayer; T_4, 50% N (basal) + 2 sprays of nano urea at 45 DAS and 60 DAS through knapsack sprayer; T_5, 60% N (basal) + 2 sprays of nano urea at 45 DAS and 60 DAS through knapsack sprayer; T_6, 40% N (basal) + 2 sprays of nano urea at 45 DAS and 60 DAS through drone; T_7, 50% N (basal) + 2 sprays of nano urea at 45 DAS and 60 DAS through drone and T_8, 60% N (basal) + 2 sprays of nano urea at 45 DAS and 60 DAS through drone. The recommended dose of nitrogen (RDN) was 80 kg/ha (urea) along with 40 kg phosphorus/ha (SSP) and 40 kg potassium/ha (MOP). The doses of phosphorous (20 kg/ha due to high initial available phosphorus) and potassium (40 kg/ha) was applied as basal at the time of sowing and nitrogen application was done based on treatment details, during morning hours and nano urea @1,250 ml/ha was applied at 45 and 60 DAS as per the treatment in each foliar spray. Mustard (cv. Pusa Mustard-28) was sown with seed drill keeping row to row distance of 45 cm and plant to plant distance of 10 cm during both the years using 5.0 kg/ha seed to maintain optimum plant population based on Indian Agricultural Research Institute, New Delhi recommendations. The climatic conditions varied notably across the two years (Fig. 1), with 2022–23 recording lower minimum temperatures (2.90°C), less rainfall (33.6 mm), and lower relative humidity (92.14%) compared to 2023–24 (5.30°C, 52.4 mm, 95.71%). Rainfall was scarce and irregular in 2022–23, while 2023–24 experienced more consistent distribution.

A drone equipped with an advanced spraying technology features a droplet size 100–400 µm, ensuring precise application. With a swath width of 4 m and speed at 3 m/s, it efficiently covers ground while maintaining accuracy. Flying at a height of 3 m, it navigates with agility. Operating optimally in winds below 18 km/h, it maximizes effectiveness. With a generous tank capacity of 16 L and a

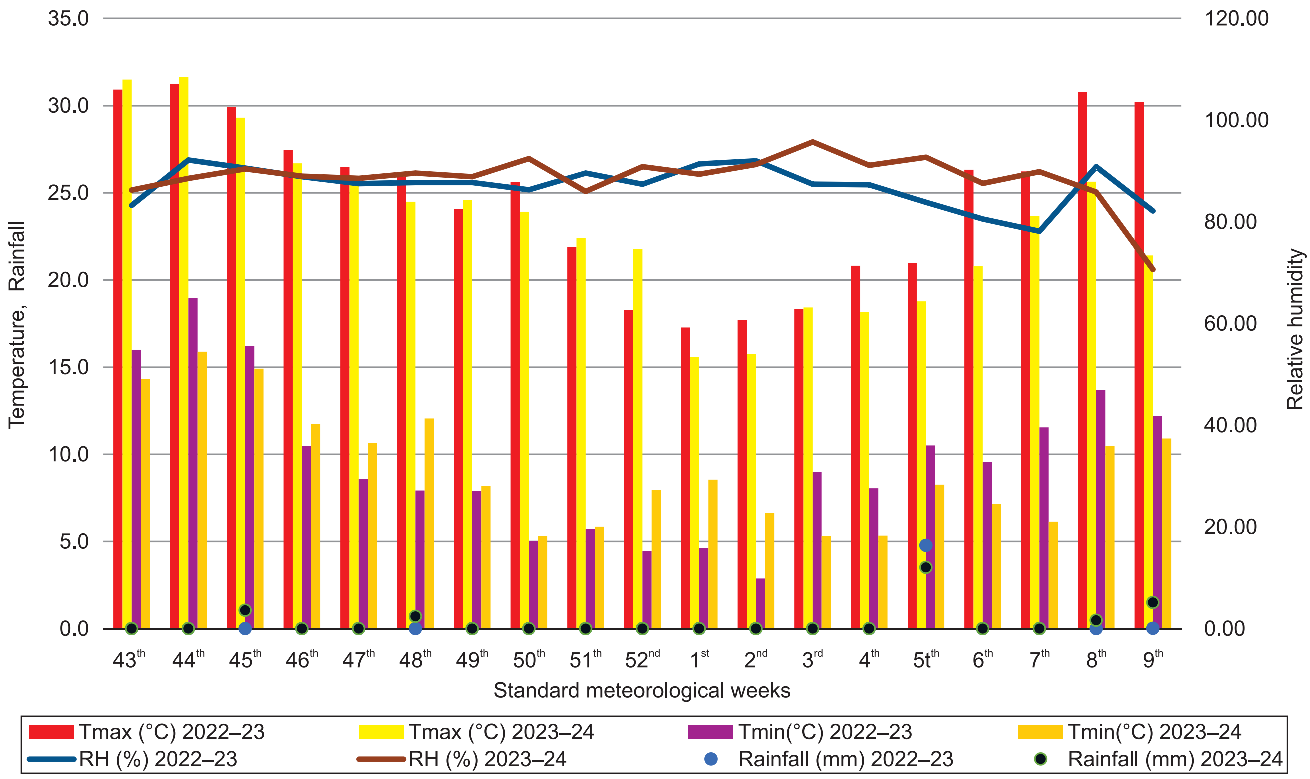

Fig. 1 Standard meteorological weeks during experimentations.

spray rate of 1.2 L/min, it covers an expansive 2 acres/flight, making it an indispensable tool for efficient and thorough agricultural operations.

Data collection involved tagging five plants per plot for growth metrics and yield component estimation. Data on plant height, leaf area index (LAI), dry matter accumulation/plant, number of siliquae/plant, number of seeds/siliquae and seed yield were recorded as per the standard procedures. Plant height was measured at 60 and 80 DAS and at harvest stage of crop. The leaf area was measured by using leaf area meter at 60 and 80 DAS and the LAI was calculated by dividing total leaf area by land area using the formula (Watson 1947):

$$\text{LAI} = \frac{\text{Total leaf area (cm}^2)}{\text{Total ground area (cm}^2)}$$

For dry matter accumulation, 5 plants were selected, combined and sun-dried. Subsequently, these plants were oven-dried at a constant temperature of 65°C until reached the constant weight. Dry matter accumulation per plant was measured at 60 and 80 DAS and at the harvest. The number of siliquae/plant was determined by counting and averaging of tagged plants. Ten siliquae were randomly chosen from each plant, then threshed and cleaned individually to count and average the number of seeds/siliquae. Grain yield/plot was recorded after manual threshing, winnowing, and cleaning, and adjusted to account for 8% moisture content. The obtained plot seed yield was converted to kg/ha. Production efficiency (kg/ha/day) was calculated by dividing the grain yield by the duration of the crop's growth cycle.

$$\text{Production efficiency} = \frac{\text{Grain yield (kg/ha)}}{\text{Crops duration (day)}}$$

The statistical analysis employed analysis of variance (ANOVA), and treatment means were compared at a 5% confidence level using the least significant differences (LSD). Bartlett test of variance was executed to determine the homogeneity of error variances across the years followed by pooled analysis of two years. The correlation panel graph was drawn using Rstudio2024.04.0-735 software.

RESULTS AND DISCUSSION

Growth parameters of mustard: The influence of variable nitrogen levels and its application techniques on growth parameters of Indian mustard such as plant height, leaf area index, and dry matter accumulation/plant were found to be significant. The mean data of plant height recorded at 60, 80 DAS and at harvest, showed significant difference among the different treatment under study (Table 1). At 60 and 80 DAS, T_8 [60% N (basal) + 2 sprays of nano urea at 45 DAS and 60 DAS through drone] showed significantly higher plant height as compared to control and other drone sprayed treatments [T_6, 40% N (basal) + 2 sprays of nano urea at 45 DAS and 60 DAS through drone and T_7, 50% N (basal) + 2 sprays of nano urea at 45 DAS and 60 DAS through drone]. The T_8 reported 4.67, 5.64 and 13.67% higher plant height compared to others drone treatments (i.e. T_7, and T_6) and control, respectively at 60 DAS, and 6.20, 9.02 and 15.76% higher plant height compared to T_7, T_6 and control, respectively at 80 DAS. The same treatment also exhibited significantly higher plant height (4.85, 7.39 and 15.16%) than T_7, T_6 and control at harvest. While comparing the plant height as affected with Knapsack sprayer, treatment T_5 [60% N (basal) + 2 sprays of nano urea at 45 DAS and 60 DAS] resulted in significantly higher plant height compared to rest of the treatments but was statistically comparable to treatment T_4 [50% N (basal) + 2 sprays of nano urea at 45 DAS and 60 DAS] at all the observational stages. At 60 and at harvest, plant height of treatment T_8 was statistically at par with T_2 and T_5 and significantly higher as compared to control and other treatments. The combined application of different rates of urea fertilizer as basal and nano urea as foliar spray (45 and 60 DAS) boosted the availability of nitrogen to plant, enhanced cell protoplasm, its elongation and multiplication and early root growth. That led to higher absorption of nutrients from deeper layers of soil and ultimately resulting in an increased plant growth. The ability of plants to grow taller could be due to readily available nitrogen as a foliar spray through drone and knapsack, which is a key component of protoplasm and aids in photosynthesis as well as speeds up metabolism, cell division, and cell elongation (Kaur *et al.* 2020, Kumar *et al.* 2024). The treatment which uses drone for nano urea spray recorded more plant height compared to knapsack sprayer. This could be attributed to the spray's finer droplet size and uniform canopy coverage, which are more efficiently absorbed by stomata (Jain *et al.* 2023).

At 60 DAS, T_8 exhibited a significantly higher LAI than other drone treatments (T_7, and T_6) and the control, with increases of 18.91%, 25.83%, and 103.15%, respectively. At 80 DAS, T_8 maintained a significant advantage over T_6 and the control (40.02% and 89.81%) but remained statistically at par with T_7 (7.9%). Among knapsack treatments, T_5 consistently recorded the highest LAI at both 60 and 80 DAS, significantly outperforming the control, T_3, and T_4. At 60 DAS, T_5 showed a 20.94%, 33.05%, and 97.37% higher LAI than T_4, T_3, and the control, respectively, while at 80 DAS, it exceeded them by 14.53%, 44.72%, and 81.74%. The nitrogen applied as basal resulted in initial fulfilment of nitrogen availability for better emergence, stronger root system and faster plant growth and during peak grand growth period, the application of nano urea through drone and knapsack sprayer could be factors in increased LAI. In general, nano urea provides a slow, steady, and time-dependent release of nitrogen from vacuole of cell to ensure their delivery to the plant in a balanced and need-based manner. Similarly, T_8 also resulted in a significant increase in dry matter accumulation at 60, 80 DAS and at harvest compared to rest of the treatments. When evaluating treatments involving drone spraying, T_8 exhibited notably greater dry matter accumulation (10.09%, 22.64%, and 90.63%) at 60 DAS and (8.99%, 24.84%, and 84.29%) at 80 DAS compared to T_7, T_6, and control respectively. Among the knapsack treatments, T_5 exhibited significantly greater dry matter accumulation at 60, 80 DAS, and at harvest compared to the control, T_3, and T_4. Specifically, at 60 DAS, T_5 showed increase of 11.84%, 32.43%, and 81.48% in dry matter accumulation compared to T_4, T_3, and the control, respectively. At 80 DAS, these increases were 12.40%, 32.09%, and 73.64% higher for T_5 compared to T_4, T_3, and the control, respectively. At harvest, T_5 showed increase of 14.72%, 33.44% and 73.51% in dry matter accumulation compared to T_4, T_3, and the control, respectively. According to Sharifi and Raei (2011) and Tohidi *et al.* (2012), Leaf Area Index (LAI) is a key indicator of crop growth that plays a crucial role in assessing the effectiveness of agricultural practices, as it helps in optimizing crop production. A higher LAI facilitates greater solar energy absorption, which in turn boosts biomass production. This relationship between LAI and solar energy absorption directly influences crop yield, as enhanced energy capture leads to more significant biomass accumulation. Furthermore, the increase in total dry matter as crops mature can be attributed to factors such as the crop's growth pattern, a higher rate of CO_2 fixation, and the increased activity of RuBP carboxylase during crop growth (Zhang *et al.* 2024). This emphasizes the importance of LAI not only as a growth indicator but also as a crucial factor for improving agricultural productivity.

Yield attributes and yield of mustard: T_8 exhibited a significant improvement in key yield attributes, including the number of siliquae/plant (541.33), seeds/siliqua (13.85), seed yield (2742 kg/ha), and harvest index (27.52%), outperforming the control (312.11, 11.80, 1934 kg/ha, and 23.71%, respectively) and other treatments (Table 2). However, the number of seeds/siliqua in T_8 remained statistically at par with T_2, T_7, T_5, and T_4, while seed yield was comparable to T_2 and T_5. Similarly, the harvest index in T_8 showed no significant difference from T_6, T_4, T_7, T_2, and T_5. Additionally, T_8 recorded the highest biological yield (10,272 kg/ha), which was statistically similar to T_2, T_5, and T_7, demonstrating its overall effectiveness in enhancing crop productivity. Among the various treatments, the seed yield attained in T_8 was comparable to that of T_2 and T_5. This suggests that utilizing 40% less urea as compare to T_2 could yield similar results as foliar spraying of nano urea via drone and knapsack methods, with the drone method indicating superior crop performance. N application through drone revealed higher values of yield attributing characteristics, viz. number of siliquae per plant, number of seeds per siliqua over N application through knapsack sprayer in all N levels, indicating more uniform distribution of spray droplets and efficient canopy interception of N through drone compared to knapsack sprayer. This might consequently improve the seed yield of mustard under drone mediated N application than N application through knapsack sprayer. However, the highest yield was noted under T_8 (2742 kg/ha) might be due to improved growth and development of photosynthetic parts under uniform supply of N throughout the growth period. The observations recorded on various growth parameters like plant height, leaf area and dry matter accumulation (Table1) showed that drone application exhibited superior crop performance which resulted in better crop yield and yield attributing characters. However, lower N levels in T_3 and T_6 may not be sufficient to meet the crop N demand, henceforth, resulted in poor crop yield. Combination of different rates of urea fertilizer as basal and foliar application of nano urea provide nutrient to plant for a longer period of time. This increased the availability of essential nutrients to plant, improve the photosynthesis and plant growth attributes, crop growth rate and ultimately increased yield attributes through improved supply of the NPK in general and nitrogen availability specifically. Better and more availability of nutrients for a longer period leads to better crop vigour, higher photosynthesis, more biological yield and finally increased partitioning to grain (Kaur *et al.* 2023 and 2024).

Table 1 Effect of nitrogen and its application techniques on growth parameters of Indian mustard

Treatment	Plant height (cm)			Leaf area index		Dry matter accumulation (g/plant)		
	60 DAS	80 DAS	At harvest	60 DAS	80 DAS	60 DAS	80 DAS	At harvest
T_1	139.2±3.5^{d}	159.4±1.2^{e}	160.7±2.5^{d}	1.93±0^{d}	2.46±0.09^{d}	13.82±0.2^{f}	23.17±0.34^{e}	29.06±0.74^{f}
T_2	155.7±3.0^{ab}	177.1±1.4^{b}	180±2.8^{ab}	3.86±0.16^{a}	4.53±0.12^{a}	25.84±0.49^{ab}	41.58±0.49^{a}	52.27±0.49^{ab}
T_3	148.2±0.2^{c}	166.5±0.8^{d}	168.6±2.6^{cd}	2.86±0.10^{c}	3.09±0.08^{c}	18.94±0.49^{e}	30.46±0.79^{d}	37.78±1.27^{e}
T_4	150.1±1.3^{bc}	173.7±3.0^{bc}	175.4±2.7^{bc}	3.15±0.08^{bc}	3.90±0.14^{b}	22.43±0.33^{cd}	35.79±0.98^{bc}	43.95±0.64^{cd}
T_5	152.7±3.6^{abc}	175.2±0.2^{bc}	179.0±3.7^{ab}	3.81±0.10^{a}	4.47±0.12^{a}	25.09±0.56^{ab}	40.23±0.56^{a}	50.42±0.56^{ab}
T_6	149.8±0.9^{bc}	169.3±1.1^{cd}	172.3±0.8^{bc}	3.12±0.11^{bc}	3.34±0.07^{c}	21.49±0.19^{d}	34.2±0.3^{cd}	42.03±0.87^{de}
T_7	151.2±3.8^{bc}	173.8±3.5^{b}	176.5±2.2^{bc}	3.30±0.09^{b}	4.33±0.11^{a}	23.94±0.62^{bc}	39.18±1.02^{ab}	48.77±1.56^{bc}
T_8	158.3±2.0^{a}	184.5±0.7^{a}	185.1±2.8^{a}	3.92±0.08^{a}	4.67±0.14^{a}	26.35±0.63^{a}	42.7±0.83^{a}	53.77±1.29^{a}

T_1, Control; T_2, 100% N (Farmer's practice); T_3, 40% N (basal) + 2 sprays of nano urea at 45 days after sowing (DAS) and 60 DAS through knapsack sprayer; T_4, 50% N (basal) + 2 sprays of nano urea at 45 DAS and 60 DAS through knapsack sprayer; T_5, 60% N (basal) + 2 sprays of nano urea at 45 DAS and 60 DAS through knapsack sprayer; T_6, 40% N (basal) + 2 sprays of nano urea at 45 DAS and 60 DAS through drone; T_7, 50% N (basal) + 2 sprays of nano urea at 45 DAS and 60 DAS through drone and T_8, 60% N (basal) + 2 sprays of nano urea at 45 DAS and 60 DAS through drone.

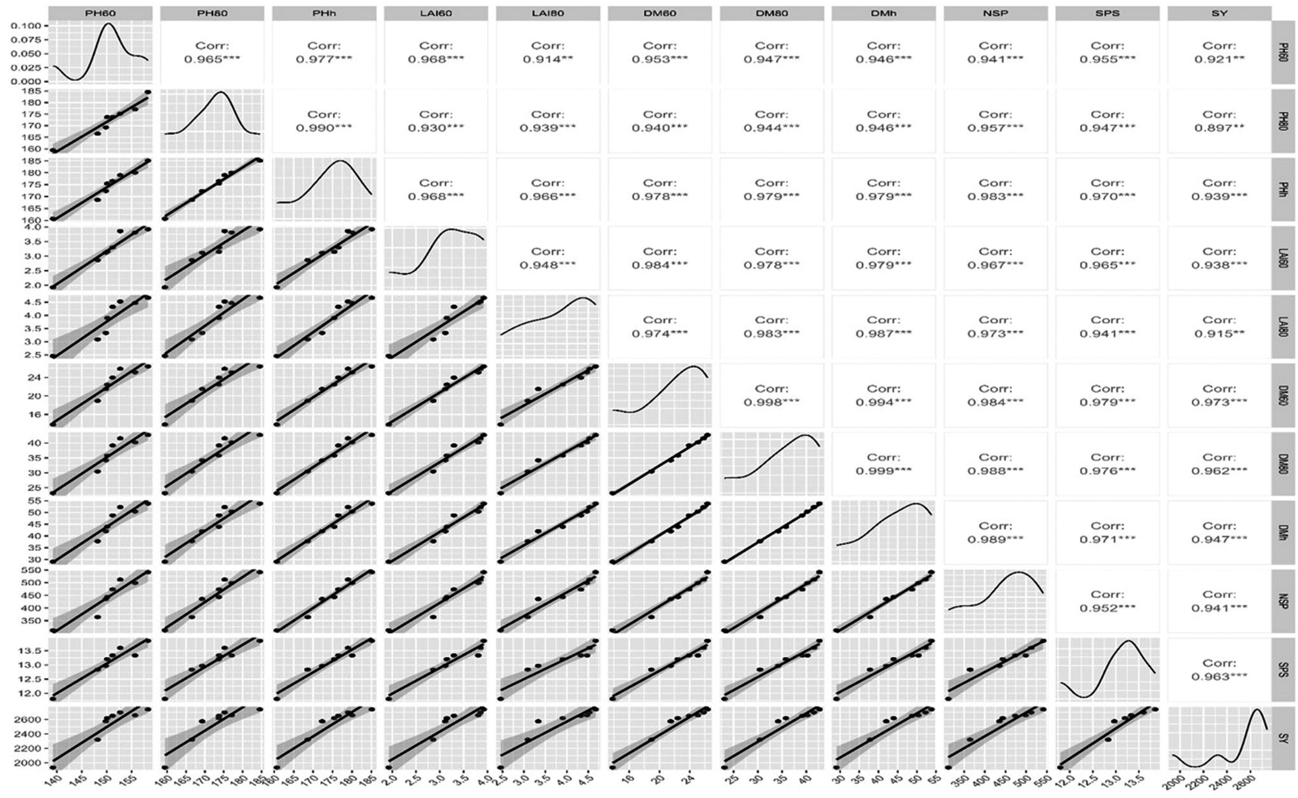

Fig. 2 Correlation panel graph between different growth and yield parameters of Indian mustard (N=110).
PH60, Plant height at 60 days after sowing (DAS); PH80, Plant height at 80 DAS; PHh, Plant height at harvest; LAI60, Leaf area index at 60; LAI80, Leaf area index at 80 DAS; DM60, Dry matter at 60; DM80, Dry matter at 80; DMh, Dry matter at harvest; NSP, Number of siliquae/plant; SPS, Seed/siliquae; SY, Seed yield; Significance level, *0.05, **0.01, ***0.001.

Table 2 Influence of variable nitrogen and its application methods on seed yield and yield parameters of Indian mustard

Treatment	No. of siliquae/ plant	No. of seed/ siliquae	Seed yield (kg/ha)	Biological yield (kg/ha)	Harvest index (%)	Production efficiency (kg/ha/day)
T_1	312.1±4.8^{f}	11.8±0.3^{d}	1934±34^{e}	8167±249^{d}	23.7±0.49^{c}	14.9 ± 0.26^{e}
T_2	512.3±10.7^{b}	13.6±0.3^{ab}	2699±21^{ab}	10021±204^{ab}	26.9±0.47^{ab}	20.8 ± 0.16^{ab}
T_3	364.3±5.6^{e}	12.8±0^{c}	2321±42^{d}	8904±216^{c}	26.1±0.16^{b}	17.9 ± 0.32^{d}
T_4	443.6±6.8^{d}	13.2±0.1^{abc}	2619±32^{bc}	9458±279^{bc}	27.7±0.49^{a}	20.1 ± 0.25^{bc}
T_5	498.8±7.6^{b}	13.3±0.3^{abc}	2660±15^{abc}	9940±206^{ab}	26.8±0.43^{ab}	20.5 ± 0.12^{abc}
T_6	435.4±5.0^{d}	13.0±0.2^{bc}	2576±28^{c}	9319±150^{bc}	27.6±0.42^{a}	19.8 ± 0.21^{c}
T_7	473.3±7.2^{c}	13.3±0.1^{abc}	2653±30^{abc}	9685±216^{ab}	27.4±0.31^{ab}	20.4 ± 0.23^{abc}
T_8	541.3±11.3^{a}	13.9±0.2^{a}	2742±19^{a}	10272±224^{a}	26.7±0.67^{ab}	21.1 ± 0.14^{a}

T_1, Control; T_2, 100% N (Farmer's practice); T_3, 40% N (basal) + 2 sprays of nano urea at 45 days after sowing (DAS) and 60 DAS through knapsack sprayer; T_4, 50% N (basal) + 2 sprays of nano urea at 45 DAS and 60 DAS through knapsack sprayer; T_5, 60% N (basal) + 2 sprays of nano urea at 45 DAS and 60 DAS through knapsack sprayer; T_6, 40% N (basal) + 2 sprays of nano urea at 45 DAS and 60 DAS through drone; T_7, 50% N (basal) + 2 sprays of nano urea at 45 DAS and 60 DAS through drone and T_8, 60% N (basal) + 2 sprays of nano urea at 45 DAS and 60 DAS through drone.

The seed yield revealed a strong positive correlation with several key factors throughout the plant growth stages. At 60 and 80 DAS, the LAI showed significant correlation coefficients of R^2=0.938 and 0.915, respectively. Furthermore, dry matter accumulation observed at 60, 80, and at harvest displayed distinguished correlations with R^2 values of 0.973, 0.962, and 0.947, respectively. Additionally, the number of siliquae/plant showed a correlation coefficient of R^2=0.941, while the number of seeds/siliqua showed a coefficient of R^2=0.963 (Fig. 2). These findings provide further support for the assumption that these growth factors play a key role in determining mustard seed yield.

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