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Crop geometry and nitrogen management modulate early vegetative vigour and soil chemical dynamics in Indian mustard (*Brassica juncea* L.)

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ABSTRACT

A field experiment was conducted during rabi 2023-24 and 2025-26 at CCS Haryana Agricultural University, Hisar in a split-plot design comprising three crop geometry (30 × 15 cm, 37.5 × 12 cm and 45 × 10 cm) and nine nitrogen management treatments (N_0 : control (no nitrogen); N_1 : 100% recommended dose of nitrogen (RDN, 80 kg N ha⁻¹); N_2 : 100% RDN + Azotobacter + PSB; N_3 : 87.5% RDN + Azotobacter + PSB; N_4 : 75% RDN + Azotobacter + PSB; N_5 : 87.5% RDN + Azotobacter + PSB + foliar spray of prilled urea @ 2.5%; N_6 : 75% RDN + Azotobacter + PSB + foliar spray of prilled urea @ 2.5%; N_7 : 87.5% RDN + Azotobacter + PSB + foliar spray of nano urea @ 4 mL L⁻¹ and N_8 : 75% RDN + Azotobacter + PSB + foliar spray of nano urea @ 4 mL L⁻¹). Crop geometry did not alter plant height, total dry matter accumulation and dry matter partitioning at 30 DAS. On the contrary, 100% RDN + Azotobacter + PSB produced the highest plant height (24.3 and 22.0 cm) and dry matter accumulation (2.13 and 1.96 g plant⁻¹). It also resulted in greater leaf biomass allocation (74.1 and 72.7%) at 30 DAS during both the years. Post-harvest soil pH, electrical conductivity and organic carbon remained unaffected by either crop geometry or nitrogen management. The study concludes that full N supply combined with Azotobacter and PSB enhanced early vegetative growth and biomass accumulation, while crop geometry had no influence during the initial growth phase.

Keywords: Azotobacter, Crop geometry, Indian mustard, Nitrogen management, PSB

Introduction

Oilseed crops are important sources of edible oils, essential fatty acids and nutrients, with substantial contributions to agricultural production and farm income. Indian mustard (*Brassica juncea* L.) is a major rabi oilseed crop in India, containing 37-49% oil and 35-40% protein. Rapeseed and mustard occupy approximately 8.66 million

ha in India, producing 12.67 million tonnes with an average productivity of 1463 kg ha⁻¹, while Haryana contributes 0.67 million ha and 1.43 million tonnes with a productivity of 2146 kg ha⁻¹ (Directorate of Economics & Statistics, 2026) [1]. Crop geometry and plant density regulate canopy structure, intra-specific competition and resource-use efficiency, thereby influencing radiation interception and crop productivity (Shekhawat *et al.*, 2012) [2]. Optimum plant density promotes efficient utilization of light and nutrients, whereas excessive density may intensify competition and canopy shading (Rathi *et al.*, 2019) [3]. Appropriate spatial arrangement can further enhance photosynthetically active radiation interception and thermal energy utilization during crop growth (Bharat *et al.*, 2022) [4].

Nitrogen is a major determinant of mustard productivity due to its involvement in chlorophyll formation, protein synthesis and metabolic processes. However, losses of applied N through leaching, ammonia volatilization, denitrification and surface runoff reduce crop N recovery and may contribute to environmental pollution (Cameron *et al.*, 2013) [5]. Although prilled urea is widely used, integration biofertilizers may improve nutrient-use efficiency. *Azotobacter* and phosphate-solubilizing bacteria (PSB) contribute to N fixation and P mobilization, respectively (Kumawat *et al.*, 2017) [6]. The effectiveness of nutrient management is closely associated with crop geometry, as plant density and spatial arrangement influence resource competition and nutrient demand. However, the combined effects of crop geometry and integrated nutrient management involving mineral N and biofertilizers in Indian mustard remain inadequately documented. Therefore, the present study was undertaken to evaluate their effects on growth and soil properties of Indian mustard.

Material and Methods

A field experiment was conducted on Indian mustard during rabi 2023-24 and 2025-26 at the Agronomy Research Farm, CCS HAU, Hisar, Haryana (29°08'56" N, 75°42'50" E; 215 m above mean sea level). The sandy loam soil had pH 7.6, EC 0.26 dS m⁻¹, organic carbon 0.39% and available N, P₂O₅ and K₂O of 120,

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21.4 and 320 kg ha⁻¹, respectively. The experiment followed a split-plot design with three replications, crop geometry 30 × 15 cm, 37.5 × 12 cm and 45 × 10 cm in main plots. The nine nitrogen management treatments in the sub-plots were: N₀: control (no nitrogen); N₁: 100% recommended dose of nitrogen (RDN, 80 kg N ha⁻¹); N₂: 100% RDN + *Azotobacter* + PSB; N₃: 87.5% RDN + *Azotobacter* + PSB; N₄: 75% RDN + *Azotobacter* + PSB; N₅: 87.5% RDN + *Azotobacter* + PSB + foliar spray of prilled urea @ 2.5% ; N₆: 75% RDN + *Azotobacter* + PSB + foliar spray of prilled urea @ 2.5% ; N₇: 87.5% RDN + *Azotobacter* + PSB + foliar spray of nano urea @ 4 mL L⁻¹ and N₈: 75% RDN + *Azotobacter* + PSB + foliar spray of nano urea @ 4 mL L⁻¹. P (30 kg P₂O₅ ha⁻¹) and K (20 kg K₂O ha⁻¹) were applied uniformly. The crop was sown at a seed rate of 5 kg ha⁻¹ on 26 October 2023 and 4 November 2025. Fertilizer application, irrigation

and other agronomic operations were carried out according to crop requirements and the recommended package of practices of CCS HAU. The crop was manually harvested at maturity before threshing and recording of yield parameters. Five randomly selected plants were tagged in each plot and plant height was recorded at 30 DAS. Height was measured from the base of the main shoot to the base of the fully expanded. For dry matter accumulation and partitioning, three plants were sampled randomly from the border rows at 30 DAS. The above-ground biomass was separated into stem & leaves and subsequently oven-dried at 65 ± 5 °C till constant weight. The dried components were weighed separately using an electronic balance and total dry matter accumulation was expressed as g plant⁻¹. The proportion of dry matter contributed by each plant component was calculated as:

$$\% \text{ contribution in dry matter accumulation} = \frac{\text{Dry matter of individual plant component}}{\text{Total plant dry matter of a plant}} \times 100$$

After crop harvest, soil samples were collected randomly from each plot, pooled to form a composite sample (500 g) and shade-dried until a constant weight was reached. Soil pH, electrical conductivity (EC) and organic carbon (OC) were determined using the glass-electrode method (Jackson, 1973) [7], conductivity bridge method (Richards, 1954) [8] and Walkley *et al.* (1934) [9] wet digestion method, respectively. The experimental data were subjected to analysis of variance (ANOVA). Treatment effects were tested using the *F*-test at 5% levels of significance and the critical difference (C.D.) was calculated at the corresponding significance level for comparison of treatment means.

Results

Plant height

Plant height (Table 1) at 30 DAS was not significantly affected by crop geometry in either year; numerically higher values were recorded under 45 cm × 10 cm (G₃) followed by 37.5 cm × 12 cm (G₂) and 30 cm × 15 cm (G₁). On the contrary, nitrogen management significantly influenced plant height during both years. When 100% RDN + *Azotobacter* + PSB (N₂) was applied, the maximum plant height at 30 DAS (24.3, 22.0 cm) representing increases of 14.62 and 16.40% over control during 2023-24 and 2025-26, respectively.

Dry matter accumulation

Crop geometry had no discernible effect on total dry matter accumulation at 30 DAS (Table 1) whereas nitrogen management caused a significant difference. Among the treatments, 100% RDN + *Azotobacter* + PSB (N₂) produced the greatest dry matter accumulation at 30 DAS and it was statistically similar rest of the treatments except control (N₀). The increase in dry matter was to the tune of 10.94 and 12.64% as compared to control during 2023-24 and 2025-26, respectively.

Dry matter partitioning

The crop geometry failed to reach the level of significance at all crop growth stages during both years of experimentation. The nitrogen management treatments significantly affected dry matter partitioning of the Indian mustard at all crop growth stages. The data showed that at 30 DAS, dry matter partitioned to the stem was non-significant in between all the treatments, while in leaves, the proportion of dry matter partitioned with the application of 100% RDN + *Azotobacter* + PSB (74.1 and 72.7%) was significantly higher, which remained statistically at par with the rest of the treatments except control (72.5 and 71.9%) during both seasons (Table 1).

Soil chemical properties

The perusal of data (Table 2) indicated that crop geometry and nitrogen management treatments failed to cause any significant variation in soil properties after crop harvest viz., soil pH, electrical conductivity (EC) and organic carbon (OC).

Discussion

Effect on growth parameters

At 30 DAS, crop geometry did not significantly influence plant height, total dry matter accumulation or dry matter partitioning in either year, which may be attributed to limited canopy development and inter-plant competition during the early vegetative phase. Whereas, nitrogen management significantly affected these attributes, with enhanced growth under adequate N supply likely associated with greater N availability and the complementary effects of biofertilizers on chlorophyll synthesis, protein formation and vegetative growth (Khuntay *et al.*, 2026) [10]. The higher proportion of biomass allocated to leaves under N₂ further indicates enhanced leaf development and assimilatory capacity during early crop growth, consistent with the characteristic pattern of biomass partitioning in mustard at the initial growth stage (Patel *et al.*, 2022; Tyagi and Upadhyay, 2026) [11].

Effect on soil properties

Crop geometry and nitrogen management did not significantly alter soil pH, electrical conductivity (EC) or organic carbon (OC) after harvest in either year. The absence of significant changes may be attributed to the short experimental duration and the comparatively slow response of these soil properties to changes in crop and nutrient management. In particular, soil OC reflects the balance between organic C inputs and decomposition and therefore may require a longer period to exhibit measurable changes. Similar findings have been reported in Indian mustard by Gupta *et al.* (2026) [12], Singh *et al.* (2018) [13], Bhanuwanti *et al.* (2022) [14] and Kumar *et al.* (2021) [15].

Conclusion

Crop geometry did not significantly influence early growth, dry matter accumulation or dry matter partitioning of Indian mustard, whereas nitrogen management significantly affected these parameters. Application of 100% RDN + *Azotobacter* + PSB consistently enhanced early plant growth and biomass accumulation compared with the control. Neither crop geometry nor nitrogen management significantly altered soil pH, EC or organic carbon during the study period. Thus, integrated application of 100% RDN with *Azotobacter* and PSB improved early crop growth.

Future prospects

The impacts of crop geometry and integrated nitrogen management over a longer time span and under various soil and agroclimatic conditions should be assessed in future studies. A more thorough knowledge of the sustainability of these techniques would come from studies that evaluate soil nutrient dynamics, nitrogen-use efficiency, over a period of several years. The potential of biofertilizers as sustainable alternatives to chemical fertilizers and in improving nitrogen consumption while preserving production and enhancing soil health may also be investigated in future studies.

Table 1. Growth parameters of Indian mustard as influenced by different crop geometry and nitrogen management at 30 DAS

Treatments	Plant height (cm)		Total dry matter accumulation (g plant ⁻¹)		Dry matter partitioning (g plant ⁻¹)			
					Stem		Leaves	
	2023-24	2025-26	2023-24	2025-26	2023-24	2025-26	2023-24	2025-26
Crop geometry								
G ₁ = 30 cm × 15 cm	23.1	21.1	2.08	1.90	0.54 (26.0)	0.51 (26.6)	1.54 (73.3)	1.40 (73.5)
G ₂ = 37.5 cm × 12 cm	23.8	21.4	2.07	1.89	0.56 (26.9)	0.52 (27.5)	1.52 (72.1)	1.37 (72.3)
G ₃ = 45 cm × 10 cm	24.3	21.8	2.04	1.86	0.57 (27.9)	0.53 (28.5)	1.47 (70.5)	1.33 (71.0)
SEm±	0.56	0.46	0.04	0.03	0.01	0.01	0.03	0.03
CD (P = 0.05)	NS	NS	NS	NS	NS	NS	NS	NS
Nitrogen management								
N ₀ = Control	21.2	18.9	1.92	1.74	0.53 (27.5)	0.49 (28.1)	1.39 (72.5)	1.25 (71.9)
N ₁ = 100% RDN (80 kg ha ⁻¹)	24.2	21.9	2.11	1.95	0.56 (26.3)	0.51 (26.3)	1.56 (73.7)	1.43 (73.7)
N ₂ = 100% RDN + Azo + PSB	24.3	22.0	2.13	1.96	0.55 (25.9)	0.54 (27.3)	1.58 (74.1)	1.42 (72.7)
N ₃ = 87.5% RDN + Azo + PSB	24.1	21.8	2.10	1.89	0.56 (26.4)	0.51 (27.2)	1.55 (73.6)	1.38 (72.8)
N ₄ = 75% RDN + Azo + PSB	23.9	21.6	2.03	1.88	0.55 (27.2)	0.53 (28.1)	1.48 (72.8)	1.35 (71.9)
N ₅ = 87.5% RDN + Azo + PSB + FS of prilled urea @ 2.5%	24.2	21.8	2.05	1.89	0.56 (27.1)	0.53 (27.8)	1.50 (72.9)	1.37 (72.2)
N ₆ = 75% RDN + Azo + PSB + FS of prilled urea @ 2.5%	23.7	21.5	2.05	1.86	0.56 (27.5)	0.52 (27.7)	1.49 (72.5)	1.35 (72.3)
N ₇ = 87.5% RDN + Azo + PSB + FS of nano urea @ 4 ml L ⁻¹	24.1	21.9	2.11	1.93	0.57 (26.9)	0.53 (27.6)	1.54 (73.1)	1.40 (72.4)
N ₈ = 75% RDN + Azo + PSB + FS of nano urea @ 4 ml L ⁻¹	23.8	21.5	2.07	1.87	0.57 (27.4)	0.51 (27.5)	1.51 (72.6)	1.36 (72.5)
SEm(±)	0.5	0.5	0.04	0.04	0.01	0.01	0.03	0.03
C.D. (P = 0.05)	1.6	1.4	0.12	0.11	NS	NS	0.09	0.08

RDN - Recommended dose of Nitrogen; Azo- *Azotobacter*; PSB - Phosphorus solubilizing bacteria; FS - foliar spray at flower initiation and siliqua formation.

*Values in parenthesis indicate per cent contribution of different plant parts to total weight.

Table 2. Soil chemical properties of Indian mustard as influenced by different crop geometry and nitrogen management

Treatments	Soil chemical properties					
	pH		EC (dS m ⁻¹)		Organic carbon (%)	
	2023-24	2025-26	2023-24	2025-26	2023-24	2025-26
Crop geometry						
G ₁ = 30 cm × 15 cm	7.61	7.67	0.27	0.29	0.38	0.39
G ₂ = 37.5 cm × 12 cm	7.66	7.67	0.27	0.29	0.38	0.39
G ₃ = 45 cm × 10 cm	7.68	7.68	0.28	0.29	0.37	0.38
SEm±	0.10	0.08	0.004	0.004	0.01	0.01
CD (P = 0.05)	NS	NS	NS	NS	NS	NS
Nitrogen management						
N ₀ = Control	7.71	7.80	0.28	0.30	0.35	0.37
N ₁ = 100% RDN (80 kg ha ⁻¹)	7.65	7.70	0.28	0.29	0.38	0.38
N ₂ = 100% RDN + Azo + PSB	7.64	7.63	0.27	0.29	0.39	0.39
N ₃ = 87.5% RDN + Azo + PSB	7.66	7.70	0.28	0.29	0.38	0.39
N ₄ = 75% RDN + Azo + PSB	7.66	7.67	0.28	0.29	0.37	0.38
N ₅ = 87.5% RDN + Azo + PSB + FS of prilled urea @ 2.5%	7.68	7.63	0.28	0.29	0.38	0.39

(continued on next page)

Treatments	Soil chemical properties					
	pH		EC (dS m ⁻¹)		Organic carbon (%)	
	2023-24	2025-26	2023-24	2025-26	2023-24	2025-26
N ₆ = 75% RDN + Azo + PSB + FS of prilled urea @ 2.5%	7.62	7.60	0.27	0.29	0.38	0.39
N ₇ = 87.5% RDN + Azo + PSB + FS of nano urea @ 4 ml L ⁻¹	7.69	7.63	0.28	0.29	0.38	0.39
N ₈ = 75% RDN + Azo + PSB + FS of nano urea @ 4 ml L ⁻¹	7.54	7.67	0.27	0.29	0.37	0.39
SEm(±)	0.08	0.11	0.003	0.003	0.004	0.004
C.D. (P = 0.05)	NS	NS	NS	NS	NS	NS

RDN - Recommended dose of Nitrogen; Azo- *Azotobacter*; PSB - Phosphorus solubilizing bacteria; FS - foliar spray at flower initiation and siliqua formation.

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