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RESOURCE OPTIMIZATION THROUGH CROP GEOMETRY AND FERTILIZER MANAGEMENT FOR SUSTAINABLE PRODUCTIVITY OF GREEN GRAM (*VIGNA RADIATA* L. WILCZEK) VARIETIES UNDER SEMI-ARID CONDITIONS OF RAJASTHAN, INDIA

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ABSTRACT

The present investigation was carried out during 2025-26 at the Agronomy Research Farm of Jaipur National University, Jaipur, Rajasthan to evaluate the influence of fertilizer levels, crop geometry and genotypes on the growth and yield of green gram. The experiment was laid out in a split-plot design with four replications comprising eighteen treatment combinations. Three fertility levels were assigned to the main plots: 75% RDF: 15 kg N and 30 kg P_2O_5 ha^{-1}, 100% RDF: 20 kg N and 40 kg P_2O_5 ha^{-1} and 125% RDF: 25 kg N and 50 kg P_2O_5 ha^{-1}. In subplots, three spacing treatments (30 cm × 10 cm, 40 cm × 10 cm and 50 cm × 10 cm) and two genotypes (PDM-139 and RMG-975) were evaluated. The findings revealed that application of 125% RDF recorded significantly higher plant height (57.21 cm), branches per plant (7.48), dry matter (16.05 g plant^{-1}), pods per plant (25.44), seeds per pod (9.38), 1000-seed weight (36.10 g) and seed yield per plant (5.91 g). Among crop geometries, 40 cm × 10 cm spacing was superior with plant height (56.09 cm), branches (7.40), dry matter (15.52 g plant^{-1}), pods (24.68) and seed yield (5.73 g plant^{-1}). Genotype PDM-139 performed better than RMG-975, recording higher plant height (55.01 cm), branches (7.28), dry matter (15.08 g plant^{-1}), pods (24.16) and seed yield (5.59 g plant^{-1}). Significant interaction between fertilizer levels and spacing was observed for major yield traits. The study suggests that 125% RDF with 40 cm × 10 cm spacing and genotype PDM-139 is most suitable for higher productivity under Jaipur agro-climatic conditions.

Key words : Growth, Yield, Phenology, Genotypes, Spacing, Fertilizer Levels, Green gram.

Introduction

Green gram (*Vigna radiata* L. Wilczek), commonly known as moong bean is a short-duration, self-pollinated pulse crop of the Fabaceae family. It thrives in tropical and subtropical climates with an optimum temperature of 25-35°C and completes its life cycle in 60-75 days. Due to its short duration, it fits well into cropping systems such as rice-green gram and maize-green gram rotations and is widely grown as a summer or catch crop, making it an important component of sustainable farming systems in India. India accounts for about 35-37% of the global pulse area and nearly 27% of total production. During 2024-25, green gram was grown on 31.49 lakh hectares with a production of 3.10 million tonnes and an average productivity of 984 kg ha^{-1}. In Rajasthan, it covered 23.15 lakh hectares with a productivity of 769 kg ha^{-1}, which is lower than the national average (Anonymous, 2024). Nutritionally, green gram contains 20-25% protein, about 56% carbohydrates and provides approximately 334 kcal per 100 g grain. It is also rich in essential amino acids and minerals. Being a leguminous crop, it enhances soil fertility through biological nitrogen fixation and improves the productivity of succeeding crops (Kumar *et al.*, 2022).

Fertilizer application is crucial for enhancing green gram productivity. A starter dose of 20 kg N ha^{-1} supports early growth and nodulation, while 45 kg P_2O_5 ha^{-1} improves seed yield and returns. Application of 100% RDF enhances growth, yield, nutrient uptake and protein content under semi-arid conditions. Jagtap *et al.* (2019) and Chavan *et al.* (2022) reported that 100% RDF resulted in maximum growth and grain yield, while Patel *et al.* (2020) found that 75% RDF combined with sulfur improved plant height, yield and nutrient uptake. Selection of high-yielding and adaptable varieties is crucial under semi-arid conditions. Improved cultivars can enhance yield by 20-25% and provide better resistance to YMV. However, the use of traditional low-yielding varieties remains a constraint. Varieties like Virat, Samrat (PDM-139), and RMG-268 show superior performance and Shivran *et al.* (2010) reported that RMG-268 performs well under rainfed and moisture-stressed conditions in Rajasthan.

Crop geometry also plays a vital role in maximizing productivity. Optimum plant population ensures efficient use of light, nutrients and moisture, leading to better growth and yield. Both overcrowding and wider spacing can reduce yield potential, whereas proper inter- and intra-row spacing improves crop performance. Therefore, integration of appropriate fertilizer levels, improved varieties and optimum crop geometry is essential for enhancing green gram productivity under semi-arid regions like Rajasthan. Proper crop geometry is essential for maximizing resource use efficiency and yield. Patel *et al.* (2016) and Rathore *et al.* (2018) reported that appropriate spacing improves crop growth and productivity. A spacing of 30 cm × 10 cm was found most suitable for semi-arid and arid regions, respectively as it ensures optimum plant population and better physiological efficiency.

Materials and Methods

The experiment was conducted at the Agronomy Research Farm, School of Agricultural Sciences, Jaipur National University, Jaipur, Rajasthan, India, located at 26°85′ N latitude and 75°87′ E longitude at an altitude of about 390 m above mean sea level. The site falls under Agro-climatic Zone IIIa (Semi-Arid Eastern Plain Zone) of Rajasthan with a hot semi-arid climate (5-45°C) and average annual rainfall of about 527 mm. Relative humidity ranges from 20-30% in summer to 60-80% during the monsoon with wind speed of 5-15 km h^{-1} and occasional dust storms up to 40 km h{ ¹. During the kharif 2025-26 season, temperatures ranged from 43.1°C to 22.0°C with sporadic rainfall. The soil was sandy loam (69.14% sand, 22.12% silt, 8.74% clay), slightly alkaline (pH 7.88), low in organic carbon (0.49%), medium in available N (149.60 kg ha^{-1}) and P (19.15 kg ha^{-1}), and high in K (188.45 kg ha^{-1}) with bulk density 1.37 Mg m^{-3}, particle density 2.63 Mg m^{-3} and porosity 36.82%. Soil analysis was done using standard methods (Piper, 1950; Black, 1950; Olsen *et al.*, 1954; Richards, 1954; Subbaiah and Asija, 1956; Jackson, 1973).

The experiment was laid out in a split-plot design with four replications and eighteen treatment combinations. The main plots consisted of three fertilizer levels: 75% RDF (15 kg N and 30 kg P_2O_5 ha^{-1}), 100% RDF (20 kg N and 40 kg P_2O_5 ha^{-1}) and 125% RDF (25 kg N and 50 kg P_2O_5 ha^{-1}). The subplots included three spacings (30 cm × 10 cm, 40 cm × 10 cm and 50 cm × 10 cm) and two genotypes (PDM-139 and RMG-975). All standard agronomic practices were followed. Growth parameters were recorded from five randomly selected plants per plot and crop and weed dry matter was measured using a 1.0 m² quadrat at two locations. Plant population (000 ha^{-1}) was estimated from a 1 m² area. Plant height (cm) was recorded at different growth stages using a meter scale and branches per plant were counted from selected plants. Dry matter accumulation (g plant^{-1}) was determined by oven-drying samples at 65±5°C to constant weight. Days to 50% flowering and physiological maturity were recorded on a plot basis. Yield attributes, including pods per plant, pod length, seeds per pod, 1000-seed weight and seed yield per plant, were measured using standard methods. The mean data were analyzed using Analysis of Variance (ANOVA) for a split-plot design and tested at a 5% level of significance (P d" 0.05). Statistical analysis was carried out as per Gomez and Gomez (1984) and simple correlation coefficients (r) were computed to study relationships among characters.

Results and Discussion

Effect of Fertilizer levels

The data presented in Table 1 indicate that fertilizer levels had no significant effect on plant population at 20 DAS and at maturity, suggesting that crop establishment was primarily governed by seed germination and field emergence rather than nutrient application. Although 125% RDF (F_3) recorded the highest plant population (258.46 plants plot^{-1} at 20 DAS and 250.17 plants plot^{-1} at maturity), it remained statistically at par with 100% RDF (F_2) and 75% RDF (F_1). Application of 125% RDF (F_3) recorded maximum plant height at all stages (17.47, 46.61, 53.95 and 57.21 cm at 30, 45, 60 DAS and maturity, respectively) showing an increase of 7.18-17.86% over 75% RDF (F_1). Similarly, branches plant^{-1} increased by 12.01%, 17.73% and 13.68% at 30 DAS, 45 DAS and

Table 1 : Plant population (000 ha^{-1}) and plant height (cm) of green gram as influenced by different fertilizer levels, spacing and genotypes.

Treatments	Plant Population (000 ha^{-1})		Plant height (cm)			
	20 DAS	At Maturity	30 DAS	60 DAS	90 DAS	At Maturity
Fertilizer Levels (F)						
F_1: 75% RDF	247.67	237.75	16.30	39.54	47.05	50.92
F_2: 100% RDF	249.17	240.29	16.97	43.66	50.82	54.41
F_3: 125% RDF	258.46	250.17	17.47	46.61	53.95	57.21
SEm±	6.47	6.60	0.15	0.88	1.04	1.21
C.D (p=0.05)	NS	NS	0.52	3.04	3.59	4.18
Spacing (S)						
S_1: 30 cm x 10 cm	308.21	299.17	16.57	41.99	48.97	52.09
S_2: 40 cm x 10 cm	251.50	242.63	17.23	44.63	52.54	56.09
S_3: 50 cm x 10 cm	195.58	186.42	16.94	43.20	50.32	54.36
SEm±	7.76	7.73	0.19	0.58	0.84	0.66
C.D (p=0.05)	22.10	299.17	NS	1.65	2.40	1.89
Genotypes (G)						
G_1: PDM-139	248.64	239.44	17.03	44.09	52.24	55.01
G_2: RMG-975	254.89	246.03	16.80	42.46	48.98	53.35
SEm±	6.34	6.31	0.16	0.47	0.69	0.54
C.D (p=0.05)	NS	NS	NS	1.35	1.96	1.54

maturity, respectively. Dry matter accumulation was also highest under F_3 (3.73, 10.10 and 16.05 g $plant^{-1}$ at 30 DAS, 45 DAS and maturity) showing an increase of 19.4-31.8% over F_1. However, 100% RDF (F_2) remained statistically at par with F_3 for most growth traits, indicating that the response beyond recommended dose was marginal (Fig. 1).

Fertilizer levels also significantly affected phenology, where 125% RDF delayed 50% flowering (36.83 days) and physiological maturity (65.38 days) compared to 75% RDF (31.75 and 57.13 days, respectively) with delays of 5.08 and 8.25 days due to prolonged vegetative growth under higher nutrient availability. Similarly, yield attributes were highest under F_3, including pods $plant^{-1}$ (25.44), pod length (7.52 cm), seeds pod^{-1} (9.38), test weight (36.10 g), and seed yield $plant^{-1}$ (5.91 g), with percentage increases of 22.31%, 23.68%, 38.35%, 12.67%, and 21.86% over F_1, respectively. However, in most cases, F_2 remained statistically at par with F_3 (Fig. 2).

The higher fertilizer levels improved growth, phenology and yield attributes due to better nutrient availability, enhanced photosynthesis and improved assimilate production and translocation. However, the lack of significant superiority of 125% RDF over 100% RDF indicates diminishing returns beyond the recommended dose, making 100% RDF the most efficient and economically viable option under semi-arid conditions. Similar findings have been reported by Jagtap *et al.*

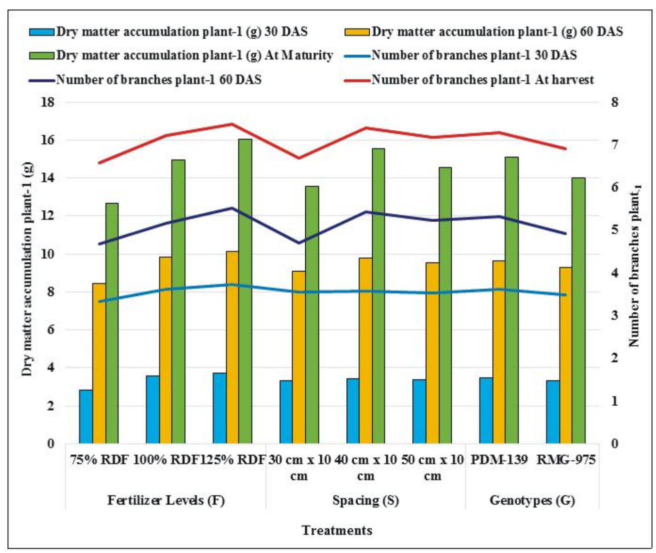

Fig. 1 : Number of branches $plant^{-1}$ and Dry matter accumulation $plant^{-1}$ (g) of green gram as influenced by different fertilizer levels, spacing and genotypes.

(2019), Patel *et al.* (2020), Chaudhari *et al.* (2021), Khatana *et al.* (2021), Chavan *et al.* (2022), Arya *et al.* (2024) and Kankarwal *et al.* (2024), who also confirmed that 100% RDF performs at par with or close to higher fertilizer doses under similar agro-climatic conditions.

Effect of Spacing

The data presented in Tables 1, 2 and 3 clearly indicate that spacing significantly influenced plant population, growth and yield attributes of green gram. At 20 DAS

Table 2 : Number of branches plant^{-1} and Dry matter accumulation plant-1 (g) of green gram as influenced by different fertilizer levels, spacing and genotypes.

Treatments	Number of branches plant^{-1}			Dry matter accumulation plant^{-1} (g)		
	30 DAS	60 DAS	At harvest	30 DAS	60 DAS	At Maturity
Fertilizer Levels (F)						
F_1: 75% RDF	3.33	4.68	6.58	2.83	8.46	12.66
F_2: 100% RDF	3.61	5.17	7.21	3.56	9.84	14.92
F_3: 125% RDF	3.73	5.51	7.48	3.73	10.10	16.05
SEm±	0.09	0.14	0.08	0.10	0.11	0.43
C.D (p=0.05)	0.30	0.47	0.29	0.34	0.39	1.49
Spacing (S)						
S_1: 30 cm x 10 cm	3.55	4.70	6.69	3.34	9.07	13.57
S_2: 40 cm x 10 cm	3.58	5.43	7.40	3.41	9.78	15.52
S_3: 50 cm x 10 cm	3.53	5.23	7.18	3.36	9.55	14.54
SEm±	0.07	0.12	0.11	0.07	0.11	0.39
C.D (p=0.05)	NS	0.35	0.33	NS	0.33	1.11
Genotypes (G)						
G_1: PDM-139	3.62	5.31	7.28	3.45	9.65	15.08
G_2: RMG-975	3.49	4.93	6.91	3.30	9.28	14.00
SEm ±	0.05	0.10	0.09	0.06	0.09	0.32
C.D (p=0.05)	NS	0.29	0.27	NS	0.27	0.91

and maturity, the closest spacing of 30 cm × 10 cm (S_1) recorded the highest plant population (308.21 and 299.17 plants plot^{-1}), which was significantly superior to wider spacings, while the lowest population was observed under 50 cm × 10 cm (S_3) (195.58 and 186.42 plants plot^{-1}, respectively). The reduction under wider spacing was due to fewer rows and plants per unit area, directly lowering plant stand density.

Growth parameters showed no significant difference at 30 DAS; however, significant variation was observed at later stages. At 45 DAS, S_2 (40 cm × 10 cm) recorded the highest number of branches (5.43 plant^{-1}), which was 15.53% higher than S_1 (4.70) and remained statistically at par with S_3 (5.31). At maturity, S_2 recorded 7.40 branches plant^{-1}, which was 10.61% higher than S_1(6.69) and again statistically at par with S_3 (7.28). Similarly, dry matter accumulation at 45 DAS was highest under S, (9.78 g plant^{-1}), which was 7.83% higher than S_1 (9.07 g) and at par with S_3 (9.62 g). At maturity, S_2 recorded 15.52 g plant^{-1} dry matter, which was 14.37% higher than S_1 (13.57 g) and statistically at par with S_3 (15.21 g). This indicates that optimum spacing reduced inter-plant competition and improved resource availability, enhancing biomass production (Fig. 1).

Phenological stages were not significantly influenced by spacing. The crop attained 50% flowering within a narrow range of 34.38-34.75 days and physiological maturity between 59.58-63.08 days, indicating that spacing did not alter crop duration due to similar genetic development irrespective of plant density. Yield attributes were significantly affected by spacing. The optimum spacing S_2 recorded the highest pod length (7.24 cm), which was 10.7% higher than S_1 (6.54 cm) and statistically at par with S_3 (7.18 cm). Seeds per pod were also highest under S_2 (8.79), which was 15.66% higher than S_1 (7.60) and at par with S_3 (8.62). Although 1000-seed weight showed no significant difference across treatments (33.95-34.70 g), indicating genetic stability of seed size, seed yield per plant was significantly higher under S_2 (5.73 g plant^{-1}), which was 15.29% higher than S_1 (4.97 g) and statistically at par with S_3 (5.53 g plant^{-1}) (Fig. 2).

The results demonstrate that closer spacing increased plant population but created higher inter-plant competition for light, nutrients and moisture, thereby reducing individual plant performance. In contrast, wider spacing reduced competition but lowered total plant stand, while optimum spacing (40 cm × 10 cm) achieved a balance between plant density and resource utilization. This resulted in improved branching, biomass accumulation and reproductive efficiency. The statistical parity of S_2 with S_3 in many traits indicates that both spacings supported better per-plant growth; however, 40 cm × 10 cm (S_2) proved agronomically superior due to better balance between population and productivity. These

Table 3 : Phenological and yield attributes of green gram as influenced by different fertilizer levels, spacing and genotypes.

Treatments	Phenological Parameters		Yield attributes				
	Days taken to 50% flowering	Days taken to physiological maturity	Number of pods per plant	Pod length (cm)	Number of seeds per pod	1000 seed weight (g)	Seed yield per plant (g)
Fertilizer Levels (F)							
F_1: 75% RDF	31.75	57.13	20.80	6.08	6.78	32.04	4.85
F_2: 100% RDF	35.13	61.96	23.70	7.19	8.65	35.04	5.47
F_3: 125% RDF	36.83	65.38	25.44	7.52	9.38	36.10	5.91
SEm±	0.58	1.26	0.59	0.10	0.27	0.65	0.14
C.D (p=0.05)	2.01	4.37	2.06	0.35	0.92	2.24	0.48
Spacing (S)							
S_1: 30 cm x 10 cm	34.38	59.58	21.46	6.54	7.60	33.95	4.97
S_2: 40 cm x 10 cm	34.75	61.79	24.68	7.24	8.79	34.53	5.73
S_3: 50 cm x 10 cm	34.58	63.08	23.80	7.01	8.42	34.70	5.53
SEm±	0.44	1.62	0.49	0.11	0.15	0.50	0.12
C.D (p=0.05)	NS	NS	1.39	0.32	0.43	NS	0.34
Genotypes (G)							
G_1: PDM-139	33.08	58.92	24.16	7.12	8.62	34.75	5.59
G_2: RMG-975	36.06	64.06	22.47	6.74	7.92	34.03	5.23
SEm±	0.36	1.32	0.40	0.09	0.12	0.41	0.10
C.D (p=0.05)	1.02	3.77	1.13	0.26	0.35	NS	0.28

findings are strongly supported by Kalsaria *et al.* (2016), Jagadale *et al.* (2017), Worku *et al.* (2018), Kumar *et al.* (2021) and Kumar *et al.* (2022), who also reported that optimum spacing improves resource use efficiency, enhances yield attributes and maximizes productivity under semi-arid conditions.

Effect of Genotypes

The data presented in Tables 1, 2 and 3 indicate that genotypic differences had no significant effect on plant population at 20 DAS and at maturity. However, numerically higher plant population was recorded in RMG-975 (G_2) compared to PDM-139 (G_1), indicating similar germination and establishment ability of both genotypes under the given conditions. Growth parameters (plant height, number of branches and dry matter accumulation) did not differ significantly at 30 DAS. However, significant differences were observed from 45 DAS onwards. PDM-139 (G_1) recorded higher plant height at 45 DAS (3.84% higher), 60 DAS (6.66% higher) and at maturity (3.11% higher) over RMG-975 (G_2). Similarly, number of branches plant^{-1} was significantly higher in G_1 with increases of 7.71% at 45 DAS and 5.35% at maturity over G_2. Dry matter accumulation was also significantly higher in PDM-139, showing increases of 3.99% at 45 DAS and 7.71% at maturity compared to G_2. These results clearly indicate that although early growth was similar, PDM-139 exhibited superior vegetative growth due to better photosynthetic efficiency, stronger assimilate production and improved biomass partitioning at later stages (Fig. 1).

Phenological observations (Table 3) revealed significant genotypic variation. RMG-975 (G_2) took significantly more days to attain 50% flowering (36.06 days), which was 2.98 days (9.0%) later than PDM-139 (33.08 days). Similarly, physiological maturity was delayed in G_2 (64.06 days), which was 5.14 days (8.72%) later than G_1 (58.92 days). This indicates that RMG-975 is a relatively late-maturing genotype, likely due to prolonged vegetative phase and slower transition to reproductive stage.

Yield attributes (Table 3) were significantly influenced by genotypes. PDM-139 (G_1) recorded significantly higher pods plant^{-1} (24.16), which was 7.5% higher than RMG-975 (22.47). Pod length was also higher in G_1(7.12 cm), showing a 5.64% increase over G_2 (6.74 cm), while seeds pod^{-1} were 8.62 in G_1 compared to 7.92 in G_2, reflecting an 8.84% improvement. However, 1000-seed weight showed no significant difference between genotypes, remaining statistically at par (34.75 g in G_1 and 34.03 g in G_2), indicating genetic stability of seed size irrespective of genotype. Consequently, seed yield per plant was significantly higher in PDM-139 (5.59 g),

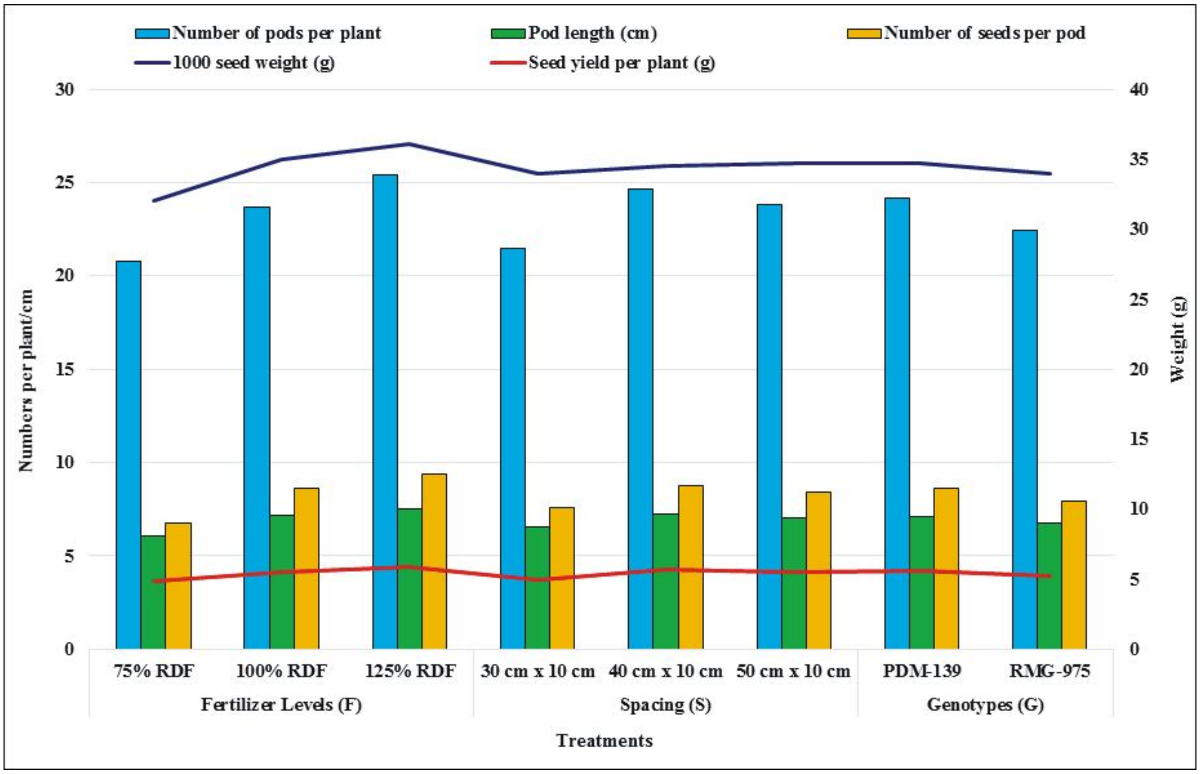

Fig. 2 : Yield attributes of green gram as influenced by different fertilizer levels, spacing and genotypes.

Table 4 : Interaction Effect of fertilizer levels and spacing on plant height at maturity, number of branches per plant at 45 DAS, number of pods per plant and seed yield per plant (g) of green gram.

Treatments	Plant height at maturity			Number of branches at 45 DAS			Number of pods per plant			Seed yield per plant (g)		
Spacing (S)	S_1	S_2	S_3	S_1	S_2	S_3	S_1	S_2	S_3	S_1	S_2	S_3
Fertilizer levels (F)												
F_1: 75% RDF	46.82	55.18	50.76	4.00	4.93	5.13	19.90	21.00	21.50	4.10	5.13	5.33
F_2: 100% RDF	53.32	55.08	54.83	4.40	5.65	5.45	20.38	26.93	23.79	4.70	5.95	5.75
F_3: 125% RDF	56.13	57.99	57.50	5.70	5.71	5.10	24.11	26.15	26.10	6.11	6.11	5.50
SEm±		1.15			0.21			0.85			0.21	
C.D (p=0.05)		3.28			0.61			2.41			0.59	

Note: See Table 1 for treatment details.

which was 6.88% higher than RMG-975 (5.23 g) (Fig. 2).

This superiority is attributed to better source-sink relationship, higher assimilate production, improved pod setting efficiency and stronger physiological efficiency in PDM-139, leading to better reproductive performance under semi-arid conditions. Similar trends were observed by Kardile *et al.* (2018), Patel and Kumari (2018), Rathore *et al.* (2018), Sankhla *et al.* (2019), Tripathi *et al.* (2020), Yadav *et al.* (2020) and Kumawat *et al.* (2021).

Interaction effect

The interaction between fertilizer levels and spacing significantly influenced plant height, branching, pods per plant and seed yield per plant (Table 4). The tallest plants (57.99 cm) and maximum branches at 45 DAS (5.71 plant^{-1}) were recorded under 125% RDF with 40 cm × 10 cm spacing (F_3S_2), remaining at par with other higher fertility and moderate spacing combinations, while the lowest values were observed under 75% RDF with 30 cm × 10 cm (F_1S_1). For pods per plant, the highest value (26.93) was obtained under 100% RDF with 40 cm × 10 cm (F_2S_2), which was at par with F_3S_2 and F_3S_3 and showed about 35% increase over F_1S_1. Seed yield per plant was maximum (6.11 g) under F_3S_1 and F_3S_2, registering about 49% higher yield than F_1S_1 (4.10 g). Overall, combinations of 100-125% RDF with moderate to wider spacing (40-50 cm × 10 cm) enhanced growth and yield attributes due to better nutrient availability and reduced inter-plant competition.

Conclusion

Based on one year study, it can be concluded that balanced fertilization and appropriate crop geometry significantly improve growth, yield attributes and seed yield of green gram under semi-arid conditions. Application of 100% RDF was found statistically at par with 125% RDF for most growth and yield parameters, indicating that the recommended dose is sufficient for achieving optimum productivity without additional fertilizer input. Among spacing treatments, 40 cm × 10 cm proved most suitable as it ensured better resource utilization and higher yield per plant. Among genotypes, PDM-139 performed better than RMG-975 in terms of vegetative growth, phenology and yield attributes, resulting in higher seed yield and better adaptability. Therefore, it is concluded that integration of 100% RDF, optimum spacing of 40 cm × 10 cm and cultivation of genotype PDM-139 is most suitable for maximizing green gram productivity under semi-arid conditions.

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