



Optimisation of Fertility Levels and Row Arrangements for Enhancing Growth and Yield in Mustard+Chickpea Intercropping System

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Abstract

A field experiment was conducted during the *rabi* season (November, 2025 to March, 2026 at the Crop Research Centre, ITM University, Gwalior, Madhya Pradesh, India to evaluate fertility levels and row arrangements on growth, yield and land-use efficiency of mustard-chickpea intercropping. The experiment was laid out in a Randomised Block Design with eleven treatments consisting of three fertility levels [F_1 : 50%, F_2 : 75% and F_3 : 100% Recommended dose of fertilisers (RDF)] and three row arrangements [R_1 : 3:1, R_2 : 3:2 and R_3 : 3:3 (mustard: chickpea)] and sole mustard and sole chickpea replicated thrice. The soil was sandy loam in texture with a slightly alkaline reaction. The results indicated that the fertility level F_3 (100% RDF) significantly improved the growth and productivity of both crops. Maximum dry matter accumulation at harvest was recorded in mustard (46.01 g plant⁻¹) and chickpea (38.86 g plant⁻¹) under F_3 . Similarly, the highest crop growth rate and relative growth rate were observed with 100% RDF. Among fertility levels, F_3 produced the highest grain yield (1580 and 981 kg ha⁻¹), straw yield (3626 and 1750 kg ha⁻¹), harvest index (30.32 and 35.71%) of mustard and chickpea, respectively, and the highest land equivalent ratio (1.25). Among the row arrangements, R_3 (3:3) recorded the highest growth attributes, chickpea grain yield (1197 kg ha⁻¹), straw yield (2131 kg ha⁻¹) and land equivalent ratio (1.20), while, R_1 (3:1) recorded the highest mustard grain yield (1528 kg ha⁻¹) and straw yield (3683 kg ha⁻¹). The study concluded that the application of 100% RDF with a 3:3 row arrangement maximised yield, growth and land-use efficiency in mustard-chickpea intercropping.

Keywords: CGR, chickpea, intercropping, LER, mustard and RGR

1. Introduction

Indian mustard (*Brassica juncea* L.) is one of the important oilseed crops grown in India as well as in several other countries of the world. It belongs to the family *Brassicaceae* and the genus *Brassica*. Mustard is a major crop in the edible oil economy of India for its wide adaptability, high oil content and various industrial uses. Globally, the area under mustard was 6.59 million hectares with production of 72.37 mt and average productivity of 1980 kg ha⁻¹ during the *rabi* season of 2023-24 (Anonymous, 2025). Mustard was grown in 9.18 million ha with a production of 13.26 mt and an average productivity of 1,444 kg ha⁻¹ in India. During the same period, Madhya Pradesh contributed an area of 1.34 mha, production of 1.96 mt and productivity of 1,470 kg ha⁻¹ (Anonymous, 2025). The mustard seeds are a good source of oil (38–42%) and protein (24–26%). The oil is highly valued for its good

fatty acid composition, such as linoleic acid, which is vital for human health and nutrition (Tian et al., 2023). Besides its nutritional value, mustard has significant industrial and medicinal uses. Chickpea (*Cicer arietinum* L.), also known as Bengal gram, is one of the most important pulse crops grown all over the world. It belongs to the *Fabaceae* family and is a major source of dietary protein, especially in vegetarian diets. Chickpea is grown on 14.73 mha globally with production of 18.11 mt and average productivity of 1.20 t ha⁻¹. In India, chickpea is grown in 9.59 mha with a production of 11.04 mt and a productivity of 1151 kg ha⁻¹. Madhya Pradesh is the leading chickpea-producing state, having an area of 2.11 mha, production of 2.91 mt and an average productivity of 1381 kg ha⁻¹. Chickpea seeds are of high nutritive value, with 18–24% of protein, 52–70% of carbohydrate, dietary fibre, essential amino acids, minerals and vitamins such as folate



and niacin (Kemal et al., 2018). Chickpea is a leguminous crop which increases soil fertility through biological nitrogen fixation and helps in a sustainable agricultural production system (Pandit et al., 2022). One of the most important factors determining the success of intercropping systems is nutrient management. Component crops in the mustard-chickpea intercropping system compete and complement each other for nutrients (Meena et al., 2024). Application of adequate fertility levels ensures availability of adequate nutrients throughout the crop growth period and promotes better root development, nutrient uptake and improves the yield and quality parameters (Barlog et al., 2022). Limited fertiliser application may limit crop growth and productivity, while excess fertiliser application may increase production costs and reduce nutrient-use efficiency (Govindasamy et al., 2023). Therefore, it is necessary to identify the optimum fertility level to maximise the performance of the intercropping system. Intercropping is the simultaneous cultivation of two or more crops in the same land area (Feng et al., 2021). It is well accepted as an efficient cropping system in rainfed and resource-limited agriculture systems because in the intercropping system, there is better use of available resources such as light, water, nutrients and space as compared to sole cropping. (Maitra et al., 2021). Mustard and chickpea are highly compatible in the various intercropping systems because of their contrasting growth habits and resource requirements. Mustard is an oilseed crop that grows fast and has shallow roots, whereas chickpea has deep roots (Kour et al., 2016). Atmospheric nitrogen is fixed by chickpea, which is beneficial for better growth and development of the mustard crop (Bhanu et al., 2019). The study aimed to optimise fertility levels and row arrangements to improve growth, yield, system productivity, resource-use efficiency, and profitability of the mustard+chickpea intercropping system under prevailing agro-climatic conditions. Mustard and chickpea intercropping systems often produce higher equivalent yield and land equivalent ratio than a sole cropping system (Singh et al., 2015).

2. Materials and Methods

The field experiment was conducted during the *rabi* season of 2025–26 at the Crop Research Centre, ITM University, Gwalior, Madhya Pradesh, located at 26°14' N latitude and 78°14' E longitude with an altitude of 206 m above mean sea level. The experimental site is situated in the subtropical agro-climatic zone of central India with hot summers and cold winters. The average annual rainfall of the region is about 700 mm, most of which occurs during the south-west monsoon period from mid-July to mid-October, with occasional showers during winter. The soil of the experimental field was sandy loam in texture, slightly alkaline in reaction (pH 7.9), low in organic carbon, medium in available nitrogen (168.2 kg ha⁻¹) and potassium (370.6 kg ha⁻¹) and low in available phosphorus (16.2 kg ha⁻¹). The experiment was laid out in Randomized Block Design

(RBD) with three replications and comprised of eleven treatments consisting of three fertility levels viz., F₁ (50% Recommended Dose of Fertilizers), F₂ (75% Recommended Dose of Fertilizers) and F₃ (100% Recommended Dose of Fertilizers) having three row arrangements viz., R₁: 3:1, R₂: 3:2 and R₃: 3:3 (mustard: chickpea) along with sole mustard and sole chickpea as separate treatments. The gross plot size was 4.5×4.2 m² (18.9 m²), and the net plot size was 3.9×3.6 m² (14.04 m²). The chickpea variety JAKI-9218 developed by Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola, Maharashtra and mustard variety RVM-2 developed by Rajmata Vijayaraj Scindia Krishi Vishwa Vidyalaya, Gwalior, Madhya Pradesh. Seeds were sown on 09 November 2025 at seed rates of 5 kg ha⁻¹ for mustard and 75 kg ha⁻¹ for chickpea with a spacing of 30×10 cm². The fertilizer doses recommended for mustard was 80 kg N, 40 kg P₂O₅, 40 kg K₂O and 20 kg S ha⁻¹ and for chickpea it was 20 kg N, 40 kg P₂O₅ and 20 kg K₂O ha⁻¹. Fertilisers were applied through urea, diammonium phosphate (DAP) and muriate of potash (MOP) as per treatment requirement. Mustard was harvested on 10th March, 2026, and chickpea was harvested on 29th March, 2026. All the other agronomic and plant protection practices were uniformly followed as per the recommended package of practices for the region to ensure proper crop growth and development and to accurately assess the effect of fertility levels and row arrangements on the growth, yield and quality of the mustard-chickpea intercropping system.

Crop growth rate (CGR), is the increase in dry matter per unit area per unit time. The mean crop growth rate is calculated using the following formula:

$$CGR = (w_2 - w_1) / (t_2 - t_1) \times 1/A$$

Where,

W₁ and W₂ are dry weight (g m⁻²) at first and second taken at times t₁ and t₂ respectively.

Relative growth rate (RGR), increase in dry matter per unit dry matter present in per unit time. Mean relative growth rate calculate by-

$$RGR = (\log w_2 - \log w_1) / t_2 - t_1$$

Where,

W₁ and W₂ are dry weight (g m⁻²) at times t₁ and t₂ respectively.

The harvest index was calculated by dividing the economic yield by the biological yield.

$$\text{Harvest index (\%)} = \text{Economic yield (kg ha}^{-1}\text{)} / \text{Biological yield (kg ha}^{-1}\text{)} \times 100$$

The land equivalent ratio is the relative land area required under sole cropping to produce the same yield as obtained from an intercropping system. It is used to measure the efficiency and advantage of intercropping over monocropping.

$$\text{Land equivalent ratio (LER)} = (\text{Intercrop yield of crop A} / \text{Sole yield of crop A}) + (\text{Intercrop yield of crop B} / \text{Sole yield of crop B})$$

Recorded data were analysed using the appropriate method



of “Analysis of variance” (ANOVA) given by Gomez and Gomez (1984).

3. Results and Discussion

3.1. Growth attributes

3.1.1. Dry matter accumulation

Dry matter accumulation in mustard and chickpea increased progressively with the growth of crops and was significantly affected by the fertility levels and row arrangements at most of the growth stages (Table 1). In both mustard and chickpea, the highest dry matter accumulation was recorded in 100% RDF (F_3) among the fertility levels. F_3 produced significantly higher mustard and chickpea dry matter (46.01 and 38.86 g plant⁻¹, respectively), over F_1 (50% RDF) at harvest. Higher levels of fertility increased the dry matter production possibly due to the availability of nutrients for cell division, leaf area development, photosynthetic activity and nutrient uptake leading to more biomass accumulation (Jadon et al., 2019 and Jinger et al., 2022).

Row arrangements also significantly affected dry matter accumulation. The 3:3 row arrangement (R_3) recorded the highest dry matter accumulation in mustard (45.52 g plant⁻¹) and chickpea (38.52 g plant⁻¹) at harvest, followed by R_2 (3:2), while the lowest values were recorded under R_1 (3:1). The better performance of R_3 may be due to better spatial distribution of plants and lower interspecific competition for light, moisture and nutrients. The balanced crop geometry

probably enhanced canopy development and photosynthetic efficiency, leading to higher biomass production (Evers et al., 2019; Raza et al., 2020).

The dry matter accumulation of sole chickpea was significantly higher than intercropped chickpea among sole crops at all growth stages and was 39.37 g plant⁻¹ at harvest.

3.1.2. Crop growth rate (CGR)

Mean crop growth rate (CGR) of mustard and chickpea was influenced by fertility levels and row arrangements during different growth periods (Table 2). The maximum CGR was observed in the application of 100% RDF among the fertility levels in both crops during the crop growth period. The highest CGR was observed in mustard during 60–90 DAS (19.84 g m⁻² day⁻¹), followed by 30–60 DAS (14.94 g m⁻² day⁻¹) and at harvest (10.80 g m⁻² day⁻¹) under F_3 . Similarly, chickpea recorded the highest CGR in F_3 at 30–60 DAS (14.40 g m⁻² day⁻¹), 60–90 DAS (13.40 g m⁻² day⁻¹) and 90 DAS to harvest (9.30 g m⁻² day⁻¹). The increase in CGR at higher fertility levels might be due to improved nutrient availability, increased photosynthetic activity, greater leaf area development and efficient accumulation of dry matter (Jain et al., 2018 and Waqar et al., 2022). While the fertility levels did not show a significant effect of mustard CGR during 0–30 DAS.

The row arrangements also had a significant effect on the CGR. The maximum CGR for mustard and chickpea was recorded in the row arrangement of 3:3 (R_3) during most of the growth periods. In mustard, R_3 resulted in CGR of 15.18, 19.75 and

Table 1: Effect of different fertility levels and row arrangement on dry matter accumulation in mustard+ chickpea intercropping

Treatments	30 DAS		60 DAS		90 DAS		At harvest stage	
	Mustard	Chickpea	Mustard	Chickpea	Mustard	Chickpea	Mustard	Chickpea
A. Fertility levels								
F_1 : 50% RDF	3.77	2.61	13.75	14.16	29.96	24.15	36.81	32.26
F_2 : 75% RDF	4.04	2.65	16.27	14.88	31.16	25.13	40.45	33.73
F_3 : 100% RDF	4.34	2.68	17.78	15.64	35.64	27.70	46.01	38.86
SEm±	0.16	0.02	0.83	0.29	0.38	0.47	0.57	0.51
LSD ($p=0.05$)	NS	0.05	2.47	0.86	1.12	1.39	1.69	1.53
B. Row arrangements (Mustard: Chickpea)								
R_1 : (3:1)	3.93	2.61	14.63	14.07	30.03	23.80	37.96	31.74
R_2 : (3:2)	4.02	2.65	15.33	14.81	31.11	25.55	39.79	34.59
R_3 : (3:3)	4.19	2.67	17.85	15.79	35.62	27.63	45.52	38.52
SEm±	0.16	0.02	0.83	0.29	0.38	0.47	0.57	0.51
LSD ($p=0.05$)	NS	0.05	2.47	0.86	1.12	1.39	1.69	1.53
Sole								
Mustard	3.85	-	14.22	-	28.93	-	36.17	-
Chickpea	-	2.77	-	16.08	-	28.33	-	39.37
SEm±	0.29	0.03	1.52	0.53	0.69	0.86	1.04	0.94
LSD ($p=0.05$)	NS	0.09	NS	1.56	2.05	2.55	3.09	2.79



Table 2: Effect of different fertility levels and row arrangement on mean crop growth rate ($\text{g m}^{-2} \text{day}^{-1}$) in mustard+chickpea intercropping

Treatments	30 DAS		60 DAS		90 DAS		At harvest stage	
	Mustard	Chickpea	Mustard	Chickpea	Mustard	Chickpea	Mustard	Chickpea
A. Fertility levels								
F_1 : 50% RDF	4.19	2.90	11.09	12.83	18.01	11.10	7.13	6.76
F_2 : 75% RDF	4.49	2.95	13.59	13.59	16.55	11.39	9.67	7.17
F_3 : 100% RDF	4.82	2.97	14.94	14.40	19.84	13.40	10.80	9.30
SEm $\pm$	0.18	0.02	0.96	0.32	0.85	0.61	0.78	0.58
LSD ($p=0.05$)	NS	0.05	2.86	0.95	2.52	1.80	2.33	1.72
B. Row arrangements (Mustard: Chickpea)								
R_1 : (3:1)	4.37	2.90	11.88	12.74	17.11	10.81	8.26	6.61
R_2 : (3:2)	4.47	2.95	12.56	13.51	17.54	11.93	9.04	7.53
R_3 : (3:3)	4.65	2.97	15.18	14.57	19.75	13.15	10.30	9.08
SEm $\pm$	0.18	0.02	0.96	0.32	0.85	0.61	0.78	0.58
LSD ($p=0.05$)	NS	0.05	2.86	0.95	2.52	1.80	NS	1.72
Sole								
Mustard	4.28	-	11.52	-	16.34	-	7.53	-
Chickpea	-	3.08	-	14.78	-	13.50	-	10.03
SEm $\pm$	0.32	0.03	1.76	0.59	1.55	1.10	1.43	1.06
LSD ($p=0.05$)	NS	0.10	NS	NS	NS	NS	NS	3.14

10.30 $\text{g m}^{-2} \text{day}^{-1}$ at 30-60 DAS, 60-90 DAS and at harvest, respectively. Chickpea also registered the highest CGR under R_3 with values of 14.57, 13.15 and 9.08 $\text{g m}^{-2} \text{day}^{-1}$ during the respective growth periods. The better performance of R_3 might be attributed to better crop geometry and effective utilisation of available resources, resulting in reduced competition between component crops (Shao et al., 2025).

3.1.3. Relative growth rate (RGR)

Relative growth rate (RGR) of mustard and chickpea declined with the advancement of crop age, reflecting a reduction in growth efficiency during later stages of development (Table 3). Among the fertility levels, 100% RDF (F_3) exhibited maximum RGR values in both crops at most of the growth periods. F_3 produced significantly higher RGR of 0.0588 $\text{g g}^{-1} \text{day}^{-1}$ in chickpea during 30–60 DAS over F_1 (0.0563 $\text{g g}^{-1} \text{day}^{-1}$). Again, maximum RGR of 0.0467, 0.0235 and 0.0079 $\text{g g}^{-1} \text{day}^{-1}$ were recorded in mustard during 30-60 DAS, 60–90 DAS and 90 DAS to harvest, respectively, under F_3 , though statistically non-significant differences were observed. The higher RGR under increased fertility levels could be due to enhanced nutrient availability, improved photosynthetic activity and more biomass production (Tripathy et al., 2023).

Row arrangements also affected RGR, with the 3:3 (mustard: chickpea) row arrangement (R_3) showing the highest values for both crops. In chickpea, R_3 had significantly higher RGR (0.0591 $\text{g g}^{-1} \text{day}^{-1}$) during 30–60 DAS and the differences at

later stages were non-significant. The 3:3 row arrangement created a favourable microenvironment that was conducive to dry matter production and hence increased RGR during the early growth stages (Arya et al., 2007). Sole mustard and sole chickpea showed RGR values comparable to intercropped treatments.

3.2. Yield

3.2.1. Yield, harvest index and land equivalent ratio (LER)

Yield of mustard and chickpea was significantly influenced by fertility levels and row arrangements (Table 4). Among different fertility levels, 100% RDF (F_3) recorded significantly higher grain yield of mustard (1580 kg ha^{-1}) and chickpea (981 kg ha^{-1}) over 50% RDF (F_1). Likewise, straw yield was maximum under F_3 with 3626 and 1750 kg ha^{-1} for mustard and chickpea, respectively. The higher yields of grain and straw at higher fertility levels may be due to the increased availability of nutrients, better growth, more dry matter accumulation and better translocation of photosynthates from source to sink (Lal et al., 2019; Ramesh et al., 2022; and Rakshit et al., 2015). The highest harvest index values were observed under F_3 ; however, fertility levels did not significantly affect the harvest index of either crop. Land equivalent ratio (LER) increased significantly with increasing fertility levels and reached a maximum value of 1.25 under F_3 , indicating a 25% yield advantage of intercropping over sole cropping.

Row arrangements had a significant effect on grain and straw



Table 3: Effect of different fertility levels and row arrangement on mean relative growth rate ($\text{g m}^{-1} \text{day}^{-1}$) in mustard+chickpea intercropping

Treatments	30 DAS		60 DAS		90 DAS	
	Mustard	Chickpea	Mustard	Chickpea	Mustard	Chickpea
A. Fertility levels						
F ₁ : 50% RDF	0.0426	0.0563	0.0264	0.0178	0.0064	0.0073
F ₂ : 75% RDF	0.0465	0.0574	0.0219	0.0175	0.0081	0.0073
F ₃ : 100% RDF	0.0467	0.0588	0.0235	0.0190	0.0079	0.0084
SEm±	0.0024	0.0007	0.0018	0.0008	0.0007	0.0006
LSD ($p=0.05$)	NS	0.0020	NS	NS	NS	NS
B. Row arrangements (Mustard: Chickpea)						
R ₁ : (3:1)	0.0433	0.0561	0.0244	0.0174	0.0074	0.0072
R ₂ : (3:2)	0.0442	0.0573	0.0241	0.0182	0.0075	0.0075
R ₃ : (3:3)	0.0483	0.0591	0.0234	0.0186	0.0076	0.0083
SEm±	0.0024	0.0007	0.0018	0.0008	0.0007	0.0006
LSD ($p=0.05$)	NS	0.0020	NS	NS	NS	NS
Sole						
Mustard	0.0435	-	0.0238	-	0.0070	-
Chickpea	-	0.0586	-	0.0189	-	0.0082
SEm±	0.0044	0.0012	0.0032	0.0015	0.0012	0.0011
LSD ($p=0.05$)	NS	NS	NS	NS	NS	NS

Table 2: Effect of different fertility levels and row arrangement on mean crop growth rate ($\text{g m}^{-2} \text{day}^{-1}$) in mustard+chickpea intercropping

Treatments	Yield						
	Grain yield (kg ha ⁻¹)		Straw yield (kg ha ⁻¹)		Harvesting index (%)		Land equivalent ratio (LER)
	Mustard	Chickpea	Mustard	Chickpea	Mustard	Chickpea	
A. Fertility levels							
F ₁ : 50% RDF	1222	772	2977	1520	29.12	33.62	0.97
F ₂ : 75% RDF	1406	877	3298	1612	29.92	34.82	1.11
F ₃ : 100% RDF	1580	981	3626	1750	30.32	35.71	1.25
SEm±	46	36	45	39	0.60	0.96	0.02
LSD (<i>p</i> =0.05)	136	108	132	116	NS	NS	0.07
B. Row arrangements (Mustard: Chickpea)							
R ₁ : (3:1)	1528	484	3683	937	29.25	33.89	0.99
R ₂ : (3:2)	1390	949	3257	1813	29.89	34.32	1.14
R ₃ : (3:3)	1290	1197	2961	2131	30.22	35.94	1.20
SEm±	46	36	45	39	0.60	0.96	0.02
LSD (<i>p</i> =0.05)	136	108	132	116	NS	NS	0.07
Sole							
Mustard	1979	-	4810	-	29.13	-	1.00
Chickpea	-	2207	-	3810	-	36.65	
SEm±	83	66	81	71	1.10	1.76	0.04
LSD (<i>p</i> =0.05)	248	197	242	212	NS	NS	0.13



yields of both crops. The maximum mustard grain yield (1528 kg ha⁻¹) and straw yield (3683 kg ha⁻¹) were obtained with 3:1 row arrangement (R₁), while the maximum chickpea grain yield (1197 kg ha⁻¹) and straw yield (2131 kg ha⁻¹) were obtained with 3:3 row arrangement (R₃). Harvest index was not affected by row arrangements. However, the maximum LER (1.20) was noted with R₃, followed by R₂ (1.14), which showed the efficient use of resources under these row proportions (Alam et al., 2017; Chhetri and Sinha, 2019). Sole mustard and sole chickpea had higher individual crop yields than their intercropped counterparts due to the absence of interspecific competition (Layek et al., 2018).

4. Conclusion

Based on the results concluded that the highest dry matter accumulation, growth rate, grain yield, straw yield and land equivalent ratio (1.25) were observed with the application of 100% RDF. However, among the row arrangements, 3:3 (mustard: chickpea) was better in terms of growth, chickpea yield and land equivalent ratio (LER 1.20). Thus, 100% RDF with a 3:3 row arrangement is recommended for getting maximum productivity and profitability in the Gwalior region.

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