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Economic assessment of mustard based intercropping system under semi-arid region of Rajasthan

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Abstract
A field experiment was conducted during the Rabi season of 2025–26 under the semi-arid conditions of Rajasthan to evaluate the performance of mustard (*Brassica juncea* L.)-based intercropping systems involving chickpea and field pea. The experiment comprised seven treatments, *viz.*, sole mustard, mustard + chickpea (1:1, 2:2 and 2:4 row ratios) and mustard + field pea (1:2, 2:2 and 2:4 row ratios) laid out in a Randomized Block Design with three replications. The results revealed that plant population, plant height, number of seeds per siliqua, test weight and harvest index of mustard were not significantly influenced by different intercropping systems. However, the number of primary branches, secondary branches, siliquae per plant and seed, stover and biological yields were significantly affected. Sole mustard recorded the highest seed yield (2120 kg ha^{-1}), stover yield (4750 kg ha^{-1}) and biological yield (6870 kg ha^{-1}), while among the intercropping systems, mustard + chickpea (2:4) produced the highest mustard seed yield (1325 kg ha^{-1}). The growth and yield of chickpea and field pea were superior under their respective sole cropping systems; however, among the intercropping treatments, mustard + chickpea (2:4) and mustard + field pea (1:2) recorded the highest seed yields of chickpea (1550 kg ha^{-1}) and field pea (868 kg ha^{-1}), respectively. The results indicate that although sole mustard produced the highest individual crop yield, mustard + chickpea in a 2:4 row ratio was the most productive intercropping system among the evaluated combinations because it maintained better growth and yield of both component crops and improved overall system productivity. Therefore, mustard–chickpea intercropping in a 2:4 row ratio can be considered a suitable production strategy for sustainable crop diversification under semi-arid agro-climatic conditions.

Keywords: Mustard, *Brassica juncea*, chickpea, field pea, intercropping, yield attributes, productivity, semi-arid region

Introduction

Mustard (*Brassica juncea* L.) is one of the most important oilseed crops cultivated during the rabi season and plays a vital role in ensuring edible oil security, nutritional sustainability and farmers' income in India. It occupies the second position among oilseed crops after soybean in terms of area and production. Mustard seed contains approximately 38–42% oil and 24–26% protein, making it an important source of edible oil, livestock feed and industrial raw material. India cultivates rapeseed–mustard over about 9.5 million hectares with an annual production exceeding 13 million tonnes; however, productivity remains lower than that of many developed countries due to poor resource-use efficiency, imbalanced nutrient management and climatic constraints (FAOSTAT, 2024; Government of India, 2024) [3, 4].

Intercropping is recognized as one of the most efficient cropping strategies for improving biological productivity, resource-use efficiency and farm profitability. It involves the simultaneous cultivation of two or more crops in the same field during the same growing season in a definite spatial arrangement. Properly designed intercropping systems improve utilization of sunlight, soil moisture, nutrients and growing space, reduce weed infestation, minimize pest and disease incidence and provide greater yield stability than monocropping. The biological advantage of intercropping is commonly assessed through the Land Equivalent Ratio (LER), where values greater than one indicate superior land-use efficiency over sole cropping (Willey, 1979) [10]. Recent studies have further confirmed that well-planned intercropping systems enhance sustainability and resilience of crop production under climate variability (Bedoussac *et al*., 2024) [1].

Among pulse crops, chickpea (*Cicer arietinum* L.) is one of the most important winter legumes cultivated in India. Besides being a rich source of dietary protein, vitamins and minerals, chickpea contributes substantially to soil fertility through biological nitrogen fixation and improves soil physical properties by adding organic residues. Similarly, field pea (*Pisum sativum* L.) is another valuable pulse crop widely cultivated under irrigated and limited irrigation conditions owing to its short duration, high nutritional value and excellent compatibility with oilseed crops. Integration of these legumes with mustard may improve overall system productivity while reducing dependence on synthetic nitrogen fertilizers (Yadav *et al*., 2023) [13].

Several investigators have demonstrated that mustard-based intercropping systems significantly improve resource-use efficiency and economic returns compared with sole cropping. Choudhary *et al*. (2023) [2] reported higher mustard equivalent yield and profitability under mustard–chickpea intercropping than monocropping. Likewise, Meena *et al*. (2023) [8] observed that appropriate row arrangements enhanced growth, yield attributes and overall productivity of component crops. Patel *et al*. (2023) [9] also reported that legume intercropping increased land equivalent ratio and economic returns by improving complementary utilization of available resources. Although considerable research has been conducted on mustard-based intercropping, information regarding suitable row arrangements of mustard with chickpea and field pea under the semi-arid agro-climatic conditions of Rajasthan remains limited. Identification of an optimum planting geometry capable of maximizing productivity of both component crops without causing excessive competition is therefore essential. The present investigation was undertaken to evaluate the effect of different mustard-based intercropping systems involving chickpea and field pea on the growth, yield attributes and yield of component crops, with the objective of identifying a biologically efficient and economically profitable production system for sustainable agriculture under semi-arid conditions.

Materials and Methods

Experimental site

A field experiment was conducted during the Rabi season of 2025–26 at the Agronomy Research Farm, Department of Agriculture, Vivekananda Global University, Jaipur, Rajasthan, India. The experimental site is situated at 26°51′ N latitude, 75°47′ E longitude and an altitude of approximately 390 m above mean sea level. The region falls under Agro-climatic Zone IIIA (Semi-arid Eastern Plain Zone) of Rajasthan and is characterized by a semi-arid climate with hot summers and cool winters.

Experimental design and treatments

The experiment was laid out in a Randomized Block Design (RBD) with seven treatments replicated three times.

The treatments were:

- **T_1:** Sole crop mustard
- **T_4:** Mustard + chickpea (1:1)
- **T_5:** Mustard + chickpea (2:2)
- **T_6:** Mustard + chickpea (2:4)
- **T_7:** Mustard + field pea (1:2)
- **T_8:** Mustard + field pea (2:2)
- **T_9:** Mustard + field pea (2:4)

For comparison of intercrop performance, observations were also recorded from the respective sole chickpea (T_2) and sole field pea (T_3) plots.

Crop establishment and management

The experimental field was prepared by one deep ploughing followed by two cross harrowings and planking to obtain a fine seedbed. Recommended agronomic practices were followed throughout the crop season.

Mustard, chickpea and field pea were sown during the first fortnight of November 2025 using the recommended seed rates and row spacing according to the respective treatment combinations. Fertilizers were applied uniformly to all treatments following the recommended package of practices for the region. Irrigation, weed management, plant protection measures and other intercultural operations were carried out as and when required to maintain a healthy crop.

Statistical analysis

The experimental data were statistically analysed using the analysis of variance (ANOVA) appropriate for a Randomized Block Design as described by Panse and Sukhatme (1985). The significance of treatment differences was tested using the F-test at the 5% probability level. Wherever the treatment effects were found significant, the Critical Difference (CD) at P = 0.05 was calculated for comparison of treatment means. Standard error of mean (SEm±) and coefficient of variation (CV%) were also computed to assess experimental precision.

Results and Discussion

Growth parameters and yield attributes of mustard

The growth parameters and yield attributes of mustard were influenced by different intercropping systems (Table 1). Plant population at 30 DAS and at harvest did not differ significantly among the treatments, indicating that crop establishment was uniform under all planting arrangements. The initial plant population ranged from 10.00 to 10.12 plants m^{-1}, while the final population varied between 8.30 and 8.60 plants m^{-1}. The absence of significant differences may be attributed to uniform seed quality, optimum germination conditions and similar crop management practices across treatments. Similar observations were reported by Yadav *et al*. (2022) [12] and Kumar *et al*. (2023) [5], who observed that intercropping had little influence on initial crop establishment in mustard-based systems. Likewise, plant height of mustard at 60 DAS and at harvest remained statistically unaffected by various intercropping systems, although numerically taller plants were observed under sole mustard (117.38 and 162.57 cm, respectively). Slight reductions in plant height under intercropping might be due to interspecific competition for light, moisture and nutrients; however, these differences were insufficient to attain statistical significance. Similar findings have been reported by Patel *et al*. (2023) [9] and Meena *et al*. (2024) [7], who concluded that compatible legume intercrops generally do not exert a significant influence on mustard plant height.

The number of primary and secondary branches per plant was significantly influenced by the intercropping systems. Sole mustard produced the maximum number of primary (6.17) and secondary (12.39) branches per plant, which remained statistically at par with mustard + chickpea (1:1). In contrast, mustard intercropped with field pea (1:2) and mustard + chickpea (2:2) recorded significantly lower

branching. Better branching under sole cropping may be attributed to the absence of interspecific competition, resulting in greater interception of solar radiation, efficient nutrient uptake and increased assimilate production. These results corroborate the findings of Choudhary *et al*. (2023) [2], Yadav *et al*. (2023) [13] and Kumar and Verma (2024) [6], who also reported superior vegetative growth of mustard under sole cropping compared with intercropping systems.
Yield attributes exhibited variable responses to different row arrangements. The number of seeds per siliqua and test weight were not significantly affected, indicating that these traits are relatively stable and largely controlled by genetic factors. However, the number of siliquae per plant differed significantly among the treatments. Sole mustard recorded the highest number of siliquae per plant (286.52), followed closely by mustard + chickpea (2:4) (278.16), whereas the minimum value (217.45) was recorded under mustard + chickpea (2:2). The higher number of siliquae under sole cropping and wider chickpea row arrangements may be attributed to reduced competition for growth resources, resulting in improved flowering and siliqua development. Similar observations were reported by Meena *et al*. (2023) [8], Patel *et al*. (2023) [9] and Meena *et al*. (2024) [7].

Yield of mustard
Seed yield, stover yield and biological yield of mustard were significantly influenced by the intercropping systems (Table 2). Sole mustard produced the highest seed yield (2120 kg ha^{-1}), stover yield (4750 kg ha^{-1}) and biological yield (6870 kg ha^{-1}). The superior performance of sole mustard was mainly due to the absence of interspecific competition, enabling efficient utilization of available moisture, nutrients, sunlight and growing space throughout the crop growth period.
Among the intercropping systems, mustard + chickpea (2:4) produced the highest mustard seed yield (1325 kg ha^{-1}), followed by mustard + chickpea (1:1) (1180 kg ha^{-1}) and mustard + field pea (2:2) (1105 kg ha^{-1}). In contrast, mustard + chickpea (2:2) recorded the lowest seed yield (780 kg ha^{-1}). The relatively higher productivity of the 2:4 row arrangements may be attributed to reduced competition between component crops and better complementary utilization of growth resources. Wider spacing between mustard rows likely improved light penetration and facilitated efficient utilization of soil moisture and nutrients by both crops. These findings are in close agreement with those reported by Choudhary *et al*. (2023) [2], Meena *et al*. (2024) [7] and Yadav *et al*. (2024) [11], who observed that wider row arrangements of mustard-legume intercropping improved mustard productivity compared with closer planting geometries.
Harvest index remained statistically unaffected by different treatments, varying only from 30.12 to 30.86%. The stability of harvest index suggests that intercropping influenced total biomass production more than dry matter partitioning towards economic yield. Similar observations have also been reported by Kumar *et al*. (2023) [5] and Patel *et al*. (2023) [9].

Performance of chickpea under mustard-based intercropping systems
The growth, yield attributes and yield of chickpea were markedly influenced by different mustard-based intercropping systems (Table 2). Sole chickpea consistently recorded superior growth and productivity compared with the intercropped treatments. Plant population at 30 DAS and at harvest was highest under sole chickpea (10.78 and 8.20 plants m^{-1}, respectively), whereas the lowest values were recorded under mustard + chickpea (2:2). The slight reduction in plant stand under intercropping may be attributed to increased competition for available space and growth resources. Similar findings were reported by Meena *et al*. (2023) [8] and Kumar *et al*. (2023) [5]. Plant height of chickpea followed a trend similar to plant population. Sole chickpea produced the tallest plants, recording 28.95 cm at 60 DAS and 58.76 cm at harvest. Among the intercropping treatments, mustard + chickpea (2:4) recorded comparatively greater plant height (27.40 and 58.20 cm at 60 DAS and harvest, respectively), while the shortest plants were observed under mustard + chickpea (2:2). Reduced plant height under intercropping could be attributed to competition for light, nutrients and soil moisture imposed by the associated mustard crop. Comparable results were also observed by Patel *et al*. (2023) [9] and Meena *et al*. (2024) [7].
Yield attributes of chickpea were significantly influenced by intercropping. Sole chickpea produced the highest number of branches per plant (6.01), pods per plant (26.02), grains per pod (1.32) and seed index (21.09 g). Among the intercropping treatments, mustard + chickpea (2:4) recorded the highest values for these parameters, whereas mustard + chickpea (2:2) produced the lowest. The better performance of the 2:4 row arrangement may be attributed to reduced competition and improved availability of growth resources due to wider spatial arrangement. Similar findings have been reported by Yadav *et al*. (2024) [11] and Choudhary *et al*. (2023) [2].
Seed yield, stover yield and biological yield of chickpea declined under intercropping compared with sole cropping. Sole chickpea recorded the highest seed yield (1825 kg ha^{-1}), stover yield (2295 kg ha^{-1}) and biological yield (4120 kg ha^{-1}). Among the intercropping treatments, mustard + chickpea (2:4) produced the highest seed yield (1550 kg ha^{-1}), followed by mustard + chickpea (1:1) (1485 kg ha^{-1}), while the lowest seed yield (1350 kg ha^{-1}) was recorded under mustard + chickpea (2:2). Similar trends were observed for stover and biological yields. The higher productivity of the 2:4 row ratio indicates better compatibility between mustard and chickpea due to efficient utilization of sunlight, moisture and nutrients. These findings are in agreement with those of Meena *et al*. (2024) [7], Patel *et al*. (2023) [9] and Kumar and Verma (2024) [6].
Harvest index varied only slightly among the treatments, ranging from 43.20 to 44.30%, indicating that intercropping had little effect on dry matter partitioning in chickpea. The relatively stable harvest index suggests that although total biomass production decreased under intercropping, the proportion of economic yield remained almost unchanged. Similar observations have been reported by Kumar *et al*. (2023) [5] and Yadav *et al*. (2023) [13].

Table 1: Growth and yield attribute as influenced by various treatments

Treatment	Plant population (Per metre row length)		Plant height (cm)		Number of primary branches/ plant	Number of secondary branches/ plant	Number of seeds per siliqua	Number of siliquae per plant	Test weight (g)
	30 DAS	At harvest	60 DAS	At harvest					
T_1: Sole crop mustard	10.12	8.60	117.38	162.57	6.17	12.39	11.52	286.52	5.20
T_4: Mustard + chickpea (1:1)	10.10	8.52	115.18	160.50	5.80	12.33	11.18	250.65	4.93
T_5: Mustard + chickpea (2:2)	10.00	8.55	114.35	159.05	4.87	10.01	10.16	217.45	4.60
T_6: Mustard + chickpea (2:4)	10.05	8.60	113.85	158.15	5.37	10.17	11.27	278.16	4.97
T_7: Mustard + field pea (1:2)	10.02	8.30	115.01	159.68	4.60	9.86	10.19	230.92	4.61
T_8: Mustard + field pea (2:2)	10.08	8.40	114.28	158.45	5.77	10.88	10.50	247.40	4.87
T_9: Mustard + field pea (2:4)	10.06	8.45	113.11	157.55	5.43	10.45	10.33	241.33	4.77
S.Em.±	0.46	0.27	4.51	6.54	0.30	0.46	0.36	13.68	0.27
C.D. (P = 0.05)	NS	NS	NS	NS	0.93	1.42	NS	42.16	NS
C.V. (%)	7.98	5.51	6.82	7.10	9.64	7.36	5.78	9.47	9.52

Table 2: Yield (kg/ha) and harvest index of mustard as influenced by various treatments

Treatment	Seed yield (kg/ha)	Stover yield (kg/ha)	Biological yield (kg/ha)	Harvest Index (%)
T_1: Sole crop mustard	2120.0	4750.0	6870.0	30.86
T_4: Mustard + chickpea (1:1)	1180.0	2680.0	3860.0	30.61
T_5: Mustard + chickpea (2:2)	780.0	1810.0	2590.0	30.12
T_6: Mustard + chickpea (2:4)	1325.0	3005.0	4330.0	30.48
T_7: Mustard + field pea (1:2)	860.0	1975.0	2835.0	30.34
T_8: Mustard + field pea (2:2)	1105.0	2515.0	3620.0	30.46
T_9: Mustard + field pea (2:4)	950.0	2185.0	3135.0	30.25
S.Em.±	79.56	110.08	162.40	1.27
C.D. (P = 0.05)	245.14	339.19	500.41	NS
C.V. (%)	11.59	7.05	7.23	7.22

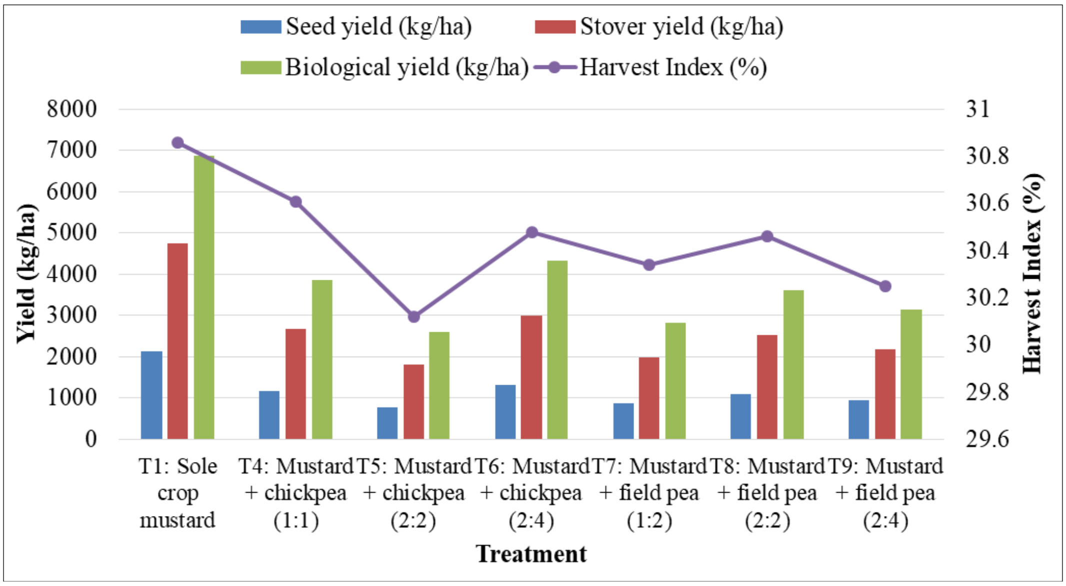

Fig 1: Yield (kg/ha) and harvest index of mustard as influenced by various treatments

Table 2 Effect of mustard on intercrops

Table 2.1: Growth parameters, yield and yield attributes of intercrop chickpea as influenced by various treatment

Treatment	Plant population per metre row length		Plant height (cm)		Number of branches per plant	Number of pods per plant	Number of grains per pod	Seed index (g)	Seed yield (kg/ha)	Stover yield (kg/ha)	Biological yield (kg/ha)	Harvest Index (%)
	30 DAS	Harvest	60 DAS	At harvest								
T_2: Sole crop chickpea	10.78	8.20	28.95	58.76	6.01	26.02	1.32	21.09	1825	2295	4120	44.30
T_4: Mustard + chickpea (1:1)	10.64	8.10	27.20	57.60	5.35	22.20	1.29	21.02	1485	1925	3410	43.55
T_5: Mustard + chickpea (2:2)	10.55	8.06	26.90	56.80	5.10	19.50	1.27	20.95	1350	1775	3125	43.20
T_6: Mustard + chickpea (2:4)	10.70	8.14	27.40	58.20	5.80	25.10	1.31	21.07	1550	2000	3550	43.66

Table 2.2: Growth parameters, yield and yield attributes of intercrop field pea as influenced by various treatments

Treatment	Plant population per metre row length		Plant height (cm)		Number of branches per plant	Number of pods per plant	Number of grains per pod	Seed index (g)	Seed yield (kg/ha)	Stover yield (kg/ha)	Biological yield (kg/ha)	Harvest Index (%)
	30 DAS	At harvest	60 DAS	At harvest								
T_3: Sole crop field pea	10.38	7.08	28.35	44.90	2.68	18.22	3.66	16.52	1035	1178	2213	46.77
T_7: Mustard + field pea (1:2)	10.30	6.72	27.95	43.55	2.48	17.35	3.64	16.44	868	1032	1900	45.68
T_8: Mustard + field pea (2:2)	10.18	6.55	26.65	41.18	2.02	15.30	3.37	16.18	715	838	1553	46.04
T_9: Mustard + field pea (2:4)	10.24	6.63	27.05	42.15	2.18	16.25	3.52	16.30	805	965	1770	45.48

Conclusion

The present study demonstrated that mustard-based intercropping systems significantly influenced the growth and productivity of component crops. Although sole mustard produced the highest individual seed yield (2120 kg ha^{-1}), intercropping with chickpea in a 2:4 row ratio proved to be the most efficient among the evaluated systems by maintaining superior growth, yield attributes and seed yield of both crops. Similarly, mustard + field pea (1:2) performed better than the other mustard–field pea combinations. Overall, the results indicated that appropriate row arrangements minimized interspecific competition and improved resource utilization. Therefore, mustard + chickpea (2:4) can be recommended as a productive and sustainable intercropping system for enhancing crop productivity under semi-arid conditions.

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