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Performance of wheat-mustard-chickpea intercropping systems for improved productivity and economic returns in semi-arid Punjab

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Abstract

Global food demand and the escalating threat of climate variability are pressing agriculture to evolve toward systems that simultaneously optimise land productivity, resource-use efficiency and farm profitability. Intercropping the deliberate co-cultivation of two or more crops on the same plot represents a cornerstone of sustainable intensification, yet systematic evaluation of cereal-oilseed-legume combinations under semi-arid Punjab conditions remains limited. This study investigated the agronomic and economic performance of ten cropping arrangements involving wheat (*Triticum aestivum* L. cv. DBW 372), mustard (*Brassica juncea* L. cv. PBR 210) and chickpea (*Cicer arietinum* L. cv. PBG 8), laid out in a Randomised Block Design with three replications at Guru Kashi University Research Farm, Talwandi Sabo (29°59'N, 75°04'E; 213 m asl), Punjab, during the *rabi* season of 2024-2025 and 2025-26. Treatments spanned sole crops (T₁ -T₃) and binary/ternary intercropping at row ratios of 1:1, 2:1, 2:2 and 4:2:2. Sole cropping recorded the highest individual-crop growth attributes (plant height, tiller number, leaf area index, dry matter accumulation, crop growth rate) and yield parameters (grain yield: wheat 5.2 t ha⁻¹, mustard 1.85 t ha⁻¹, chickpea 2.10 t ha⁻¹), attributable to the absence of interspecific competition. Notwithstanding, intercropping systems substantially outperformed sole crops in system-level indices: the ternary system wheat + mustard + chickpea (4:2:2) achieved the highest crop equivalent yield (CEY 6.10 t ha⁻¹), land equivalent ratio (LER 1.30), net return (₹63,000 ha⁻¹) and benefit -cost ratio (2.01). The binary wheat + chickpea (2:1) system was a close second (LER 1.28, B:C 2.00). An LER >1.0 across all intercropping treatments confirms a consistent land-use advantage of 15 -30% over sole cropping. These findings highlight that integrating chickpea biological nitrogen-fixer into cereal -oilseed systems can enhance nutrient cycling, reduce synthetic fertiliser dependence and deliver superior profitability, making such systems viable pathways for climate-resilient agricultural intensification in the Indo-Gangetic Plain and analogous agro-ecologies.

Keywords: Wheat intercropping, mustard, chickpea, land equivalent ratio, crop equivalent yield, biological nitrogen fixation, semi-arid agroclimatic conditions, sustainable intensification

1. Introduction

Global agriculture is under increasing pressure to meet the food demands of a rapidly growing population while sustaining declining natural resources and environmental quality. In India, the challenge is particularly important during the *rabi* season, where wheat, mustard, and chickpea collectively contribute substantially to food, edible oil, and protein security. Continuous monocropping and intensive input use in the Indo-Gangetic Plains, especially in Punjab, have led to soil fertility depletion, reduced resource-use efficiency, and stagnation in crop productivity (FAO, 2023; Sharma *et al.*, 2022) ^[4, 19].

Wheat (*Triticum aestivum* L.) is the major cereal crop of India, whereas mustard (*Brassica juncea* L.) is an important oilseed crop contributing significantly to domestic edible oil production. Chickpea (*Cicer arietinum* L.), besides being a rich source of dietary protein, improves soil fertility through biological nitrogen fixation. The contrasting canopy structure, rooting pattern, and nutrient acquisition behaviour of these crops make them suitable candidates for intercropping systems (Rao, 2020; Gupta, 2023) ^[18, 7]. Intercropping, the simultaneous

cultivation of two or more crops on the same field, improves resource utilization, productivity, and system stability through complementary use of light, water, and nutrients (Willey, 1979)^[24]. Among different intercropping systems, cereal-oilseed-legume combinations have shown considerable potential for enhancing land-use efficiency, productivity, and profitability under semi-arid conditions. However, information regarding wheat-mustard-chickpea ternary intercropping systems under Punjab conditions remains limited. Therefore, the present investigation was undertaken to evaluate the effect of different intercropping row ratios on crop productivity, land-use efficiency, and economic returns under semi-arid conditions of Punjab

2. Materials and Methods

A field experiment was conducted during the *rabi* season of 2024-2025 and 2025-26 at the Students' Research Farm, Faculty of Agriculture, Guru Kashi University, Talwandi Sabo, Bathinda, Punjab, India (29°59'N, 75°04'E; 213 m above mean sea level). The experimental site falls under the semi-arid agro-climatic zone of south-western Punjab, characterized by hot summers and cool winters. During the crop season, temperature ranged from 17.1°C in January to 38.8 °C in June, while annual rainfall during the experimental period was 436.6 mm, mainly concentrated during the monsoon months.

Prior to sowing, composite soil samples (0-15 cm depth) were collected and analysed using standard procedures. The soil was sandy loam in texture, containing 67.4% sand, 21.7% silt, and 14.6% clay, with near-neutral pH (6.76), low organic carbon (0.45%), and non-saline electrical conductivity (0.32 dS m⁻¹). The soil had medium available nitrogen (224 kg ha⁻¹) and potassium (128 kg ha⁻¹), but low available phosphorus (14 kg ha⁻¹). Soil texture was determined by the International Pipette Method (Piper, 1966)^[17], soil pH and EC by Jackson (1967, 1973)^[9, 10], organic carbon by Walkley and Black (1934)^[22], available nitrogen by Subbiah and Asija (1956)^[20], and available phosphorus by Olsen *et al.*, (1954)^[15].

The experiment was laid out in a Randomized Block Design (RBD) with ten treatments and three replications. Treatments consisted of sole cropping of wheat, mustard, and chickpea, along with different binary and ternary intercropping systems involving wheat + chickpea, wheat + mustard, and wheat + mustard + chickpea combinations under varying row ratios. The treatments included sole wheat (T₁), sole mustard (T₂), sole chickpea (T₃), wheat + chickpea at 1:1, 2:1, and 2:2 row ratios (T₄-T₆), wheat + mustard at 1:1, 2:1, and 2:2 row ratios (T₇-T₉), and wheat + mustard + chickpea in 4:2:2 row ratio (T₁₀). Each plot measured 5 m × 4 m. Recommended crop varieties suitable for Punjab conditions were used, namely wheat DBW 372, mustard PBR 210, and chickpea PBG 8. Wheat was sown at 100 kg ha⁻¹ seed rate with 22.5 cm row spacing, mustard at 5 kg ha⁻¹ with 45 cm spacing, and chickpea at 80 kg ha⁻¹ with 30 cm spacing. Fertilizer application followed Punjab Agricultural University recommendations. Wheat received 120 kg N, 60 kg P₂O₅, and 40 kg K₂O ha⁻¹, mustard received 80 kg N and 40 kg P₂O₅ ha⁻¹, while chickpea received 20 kg N and 40 kg P₂O₅ ha⁻¹. In intercropping treatments, nutrients were applied proportionately according to crop row allocation. Recommended irrigation, weed management, and plant protection measures were uniformly followed in all treatments.

Observations on plant height, tiller number, leaf area index (LAI), dry matter accumulation, crop growth rate (CGR), and relative growth rate (RGR) were recorded at different growth stages. Yield attributes and grain yield of component crops were

recorded at harvest. System productivity was evaluated through crop equivalent yield (CEY) and land equivalent ratio (LER) following the method of Mead and Willey (1980)^[13]. Economic analysis included gross return, net return, and benefit-cost ratio based on prevailing market prices. The experimental data were statistically analysed using analysis of variance (ANOVA) appropriate for RBD, and treatment means were compared using the critical difference (CD) test at 5% probability level (Gomez and Gomez, 1984)^[6].

3. Results and Discussion

Growth Parameters

Growth parameters of wheat, mustard, and chickpea were significantly influenced by different intercropping systems. Sole cropping recorded maximum plant height, tiller number, dry matter accumulation, and leaf area index (LAI) compared with intercropping treatments. Sole wheat produced the highest plant height (98.5 cm), total tillers (9.2 plant⁻¹), productive tillers (7.8 plant⁻¹), and LAI (5.1), whereas the ternary intercropping system wheat + mustard + chickpea (4:2:2) recorded comparatively lower values (Table 1). Reduction in growth parameters under intercropping may be attributed to interspecific competition for light, nutrients, moisture, and space. Wheat + chickpea systems, particularly the 2:1 row ratio, maintained comparatively better growth due to complementary rooting pattern and lower canopy competition than wheat + mustard combinations. Dry matter accumulation, crop growth rate (CGR), and relative growth rate (RGR) also followed a similar trend, with sole cropping showing higher biomass production than intercropping treatments. However, intercropping systems improved overall canopy utilization and resource-use efficiency through better light interception and complementary crop interaction. Similar findings were reported by Agegnehu *et al.*, (2006)^[1], Kumar *et al.*, (2020)^[11], and Pandey *et al.*, (2019)^[16], who observed that cereal-legume intercropping systems enhance overall system efficiency despite moderate reductions in individual crop growth.

Yield Attributes and Yield

Yield attributes and grain yield of component crops were highest under sole cropping and declined under intercropping systems (Table 1). Sole wheat recorded maximum spikes plant⁻¹ (7.8), grains spike⁻¹ (48), 1000-grain weight (41.5 g), and grain yield (5.2 t ha⁻¹). Among intercropping treatments, wheat + chickpea (2:1) maintained higher yield attributes and grain yield compared with other combinations. The ternary system (4:2:2) showed comparatively lower individual crop yields because of increased interspecific competition and reduced assimilate availability during reproductive stages. Nevertheless, chickpea maintained relatively stable seed weight under intercropping, indicating efficient partitioning of assimilates even under competitive conditions. The reduction in yield attributes under mixed cropping systems mainly resulted from lower light availability, reduced leaf area expansion, and competition for nutrients and moisture. However, inclusion of chickpea likely improved nitrogen availability through biological nitrogen fixation, thereby partially compensating for competitive stress on wheat. Similar observations were reported by Lithourgdis *et al.*, (2011)^[12], Ghosh *et al.*, (2006)^[5], and Hauggaard-Nielsen and Jensen (2005)^[8].

System Productivity

Despite lower individual crop yields, intercropping systems exhibited superior overall system productivity compared with

sole cropping (Table 2). All intercropping treatments recorded land equivalent ratio (LER) values greater than 1.0, indicating efficient utilization of land and resources. The highest LER (1.30) and crop equivalent yield (6.10 t ha^{-1}) were recorded under the wheat + mustard + chickpea (4:2:2) system, followed by wheat + chickpea (2:1). Higher system productivity under intercropping may be attributed to complementary use of growth resources, differential canopy structure, temporal variation in nutrient demand, and biological nitrogen fixation by chickpea. The ternary system efficiently utilized vertical and horizontal space, resulting in improved radiation interception and enhanced productivity per unit area. Similar increases in LER and equivalent yield under cereal-legume and cereal-oilseed intercropping systems were also reported by Tesfaye *et al.*, (2020) ^[21], Choudhary *et al.*, (2023) ^[2], and Mead and Willey (1980) ^[13].

Economics

Economic analysis revealed that intercropping systems were

more profitable than sole cropping systems (Table 2). Although the cost of cultivation increased under ternary and binary intercropping treatments because of additional seed and management requirements, higher productivity and diversified marketable produce significantly enhanced economic returns. The wheat + mustard + chickpea (4:2:2) system recorded the highest gross return ($\text{₹}1,25,000 \text{ ha}^{-1}$), net return ($\text{₹}63,000 \text{ ha}^{-1}$), and benefit-cost ratio (2.01), closely followed by wheat + chickpea (2:1). Inclusion of chickpea contributed substantially to profitability because of its higher market price and nitrogen-fixing ability, which also improves soil fertility and reduces fertilizer dependency in subsequent crops. Intercropping systems additionally provided economic stability by minimizing production risks associated with climatic variability and market fluctuations. These findings are in close agreement with the results of Wasaya *et al.*, (2013) ^[23], Meena and Kumhar (2017) ^[14], and Davis *et al.*, (2021) ^[3], who reported higher profitability and resource-use efficiency in cereal-legume intercropping systems under semi-arid environments.

Table 1: Effect of intercropping systems on growth attributes, yield attributes and yield of wheat crop (pooled date 2024-25 and 2025-26)

Trt.	Combination	Plant Height (cm)			Total tillers plant ⁻¹	Productive tillers plant ⁻¹	LAI (Anthesis)	Wheat spikes plant ⁻¹	Grains spike ⁻¹	1000-grain wt (g)	Wheat BY (t ha ⁻¹)	Wheat GY (t ha ⁻¹)	Mustard GY (t ha ⁻¹)	Chickpea GY (t ha ⁻¹)
		Wheat	Mustard	Chickpea										
T ₁	Sole Wheat	98.5	-	-	9.2	7.8	5.1	7.8	48	41.5	12.4	5.2	-	-
T ₂	Sole Mustard	-	156.2	-	-	-	-	-	-	-	9.2	-	1.85	-
T ₃	Sole Chickpea	-	-	52.4	-	-	-	-	-	-	6.8	-	-	2.10
T ₄	W + C (1:1)	95.8	-	55.6	8.5	7.2	4.8	7.2	45	40.8	11.3	4.6	-	1.55
T ₅	W + C (2:1)	96.7	-	54.8	8.8	7.4	4.9	7.4	46	41.0	11.8	4.8	-	1.60
T ₆	W + C (2:2)	94.9	-	53.9	8.1	6.9	4.6	6.9	44	40.2	10.9	4.4	-	1.48
T ₇	W + M (1:1)	93.6	150.8	-	7.9	6.6	4.4	6.6	43	40.1	10.7	4.2	1.30	-
T ₈	W + M (2:1)	94.7	152.3	-	8.0	6.8	4.5	6.8	44	40.4	11.1	4.3	1.38	-
T ₉	W + M (2:2)	92.8	149.5	-	7.6	6.4	4.3	6.4	42	39.8	10.4	4.0	1.25	-
T ₁₀	W+M+C (4:2:2)	91.4	148.7	52.1	7.2	6.0	4.1	6.1	41	39.2	9.9	3.8	1.10	1.20
CD (P=0.05)		3.8	5.6	2.4	0.8	0.8	0.4	0.70	3.00	1.20	0.9	0.40	0.20	0.30
SEm±		1.34	1.98	0.85	0.28	0.28	0.14	0.25	1.06	0.42	0.32	0.14	0.07	0.11

Table 2: System productivity and economic returns under different intercropping systems

Trt.	Combination	HI Wheat (%)	CEY (t ha ⁻¹)	LER	Gross Return (₹ ha ⁻¹)	Net Return (₹ ha ⁻¹)	B:C Ratio
T ₁	Sole Wheat	41.2	5.20	1.00	1,04,000	49,000	1.89
T ₂	Sole Mustard	32.5	4.95	1.00	92,500	44,500	1.92
T ₃	Sole Chickpea	33.8	5.10	1.00	98,000	48,000	1.96
T ₄	W+C (1:1)	40.1	5.85	1.24	1,18,500	58,500	1.97
T ₅	W+C (2:1)	40.4	6.02	1.28	1,22,000	61,000	2.00
T ₆	W+C (2:2)	41.0	5.70	1.21	1,16,000	55,500	1.91
T ₇	W+M (1:1)	39.2	5.60	1.18	1,13,000	54,000	1.92
T ₈	W+M (2:1)	39.9	5.75	1.22	1,16,500	57,000	1.96
T ₉	W+M (2:2)	38.8	5.40	1.15	1,10,000	51,500	1.88
T ₁₀	W+M+C (4:2:2)	39.5	6.10	1.30	1,25,000	63,000	2.01
CD (P=0.05)		1.20	0.34	0.08	NS	NS	NS
SEm±		0.42	0.12	0.03	-	-	-

4. Conclusion

The present study demonstrated that intercropping systems were superior to sole cropping in terms of land-use efficiency, productivity, and profitability under semi-arid Punjab conditions. Among all treatments, the wheat + mustard + chickpea (4:2:2) system proved most effective, recording the highest crop equivalent yield (6.10 t ha^{-1}), land equivalent ratio (1.30), net return ($\text{₹}63,000 \text{ ha}^{-1}$), and benefit-cost ratio (2.01). The higher LER indicated better utilization of available resources and greater productivity per unit area compared with sole cropping. Among binary systems, wheat + chickpea (2:1)

also performed well and emerged as a promising alternative. The inclusion of chickpea in intercropping systems improved overall system productivity through biological nitrogen fixation, enhanced nutrient-use efficiency, and reduced dependence on synthetic fertilizers. In addition, intercropping provided diversified income and reduced production risk under variable climatic conditions. Therefore, the wheat + mustard + chickpea (4:2:2) system may be recommended as a sustainable and economically viable cropping strategy for semi-arid regions of Punjab and similar agro-ecological conditions.

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