J. Farm Sci., 38(3): (233-236) 2025

RESEARCH PAPER

Effect of buckwheat (*Fagopyrum esculentum* Moench.) intercropping on growth, yield and economics of pigeonpea [*Cajanus cajan* (L.) Millsp.] under rainfed conditions

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(Received: July, 2025 ; Accepted:September,2025)

DOI: 10.61475/JFS.2025.v38i3.08

Abstract: A field experiment was conducted at Agricultural Research Station, Hanumanamatti, Karnataka, during *kharif* 2024 to evaluate the influence of different buckwheat (*Fagopyrum esculentum* Moench.) intercropping row arrangements on growth, yield and economics of pigeonpea [*Cajanus cajan* (L.) Millsp.] under rainfed conditions. The treatments comprised of sole pigeonpea and pigeonpea intercropped with buckwheat in 2:1, 2:2, 3:1 and 4:2 row proportions. Results showed that sole pigeonpea achieved significantly higher seed (1,393 kg ha^{-1}) and haulm yields (3,666 kg ha^{-1}). Among intercropping systems, 3:1 row proportion recorded significantly greater pigeonpea equivalent yield (1,597 kg ha^{-1}), gross return (₹ 1,25,542 ha^{-1}), net return (₹ 82,993 ha^{-1}) and benefit-cost ratio (2.95). These findings highlight the effectiveness of 3:1 row arrangement for maximizing yield and economic returns in pigeonpea-buckwheat intercropping system under rainfed conditions during *kharif* in *alfisols.*

Key words: Buckwheat, Intercropping, Pigeonpea, Rainfed, Row ratios

Introduction

Pigeonpea (*Cajanus cajan* (L.) Millsp.) stands out as a staple pulse crop in Indian agriculture, offering essential protein to millions of people and playing a central role in soil enhancement due to its nitrogenfixing capability (Barod *et al*., 2017). India, as the world's leading producer, has steadily increased its pigeonpea production, reaching over 4 million metric tons between 2001 and 2023. Analytical studies relying on predictive cubic models have verified the steady and continuous increasing trend, underlining pigeonpea's importance in supporting national food security, particularly in rainfed regions (Singh and Kumar, 2025). Despite promising production levels, cultivating pigeonpea under rainfed conditions continues to face significant challenges. The crop's early slow growth and prolonged maturity period often result in large gaps between rows, leading to inefficient use of resources and enabling unchecked weed growth, both of which negatively impact on its yield potential (Barod *et al.,* 2017). Additionally, erratic rainfall patterns may lead to drought or waterlogging conditions, adversely affecting crop establishment and leading to inconsistent yields. These environmental stresses contribute to economic instability for smallholding farmers and jeopardize their livelihood security (Patel *et al.,* 1998).

Intercropping has been proven to be an effective agronomic practice to overcome these issues. By combining pigeonpea with fast-growing companion crops that demand fewer inputs, farmers can optimize the use of sunlight, water and nutrients within their fields (Willey, 1979 and Patel *et al.,* 1998). Buckwheat is particularly beneficial due to its rapid growth and dense canopy formation, which helps to suppress weeds and enhances productivity without competing aggressively with pigeonpea (Lakshmi *et al*., 2023 and Nandhini *et al.,* 2025). Thus, intercropping of buckwheat with pigeonpea provides Indian farmers a promising strategy for achieving consistent yields and higher income in rainfed farming systems. This study aims to assess the effect of buckwheat intercropping on the growth, yield and economic viability of pigeonpea, offering new insights for resilient and sustainable pulse production.

Material and methods

The study was conducted at Agricultural Research Station, Hanumanamatti, during *kharif* of 2024. The soil of the experimental site is red sandy with acidic pH (5.89), low organic carbon (0.40%) and available nitrogen (238.5 kg ha^{-1}), phosphorus (25.8 kg ha^{-1})and potassium (322.5 kg ha^{-1}). The previous crop grown was late-sown cowpea (*Vigna ungiculata* L.) during *kharif* 2023, followed by fallow during *rabi* 2023-24 and summer 2024. The average annual rainfall recorded for the area over 2002-2024 was 409.65 mm. A factorial experiment was laid out using a randomized complete block design, comprising three intercropping systems where buckwheat was combined with pigeonpea, greengram and fieldbean in different row ratios *viz.,* 2:1, 2:2, 3:1 and 4:2. Fertilizer doses applied were 40:20:10 kg ha^{-1} for buckwheat, 25:50:25 kg ha^{-1} for pigeonpea, 25:50:00 kg ha^{-1} each for greengram and 25:50:25 kg ha^{-1} for field bean. Sole crops of all species were included as controls.The experiment employed a replacement series design to evaluate crop combination in varying proportions, with buckwheat variety 'Dharwad selection-1' and pigeonpea variety 'GC-11-39' as the main components. Five plants per plot were tagged at random to record growth and yield parameters at harvest. To assess the productivity of intercropping systems, pigeonpea equivalent yield (PEY) was calculated using the formula:

$$\text{PEY} = \text{Seed yield of pigeonpea} + \frac{\text{Grain yield of component crop} \times \text{Price of the component crop (₹ kg}^{-1}\text{)}}{\text{Price of pigeonpea (₹ kg}^{-1}\text{)}}$$

Data was statistically analyzed using Student's t-test, considering significance at 5% probability level according to Gomez and Gomez (1984).

Results and discussion

At 30 days after sowing (DAS), sole pigeonpea recorded numericallyhigher plant height of 37.9 cm, which was not significantly different from any intercropping treatment, including 2:1 (33.9 cm), 2:2 (32.5 cm), 3:1 (34.6 cm) and 4:2 (34.8 cm) row ratios. Throughout the crop growth period, plant heights measured at 60 DAS (ranged between 72.0 to 80.1 cm), 90 DAS (114.4–123.3 cm), 120 DAS (134.3–143.5 cm) and at harvest (143.6 - 152.6 cm) also showed no significant variation between sole and intercropped pigeonpea or among different row configurations, although sole crops consistently had slightly higher numerical values (Table 1). Only at 120 days after sowing, sole pigeonpea crop exhibited a significantly greater plant height (143.5 cm) compared to various intercropping treatments. These results suggest that cultivating pigeonpea with buckwheat does not notably influence its plant height, provided that appropriate row ratios and compatible crop combinations are employed. This finding is consistent with earlier research highlighting that well-planned intercropping systems tend to reduce competitive stress on legumes, as any competition is generally short-lived or minimal (Sharma and Guled, 2012; Shashidhara *et al.,* 2000; Maitra *et al.,* 2019). Furthermore, relatively short life cycle and lower competition level of buckwheat make it a suitable intercrop for pigeonpea, supporting sustainable agriculture in rainfed environments.

Across all growth stages, sole pigeonpea showed significantly higher total dry matter production compared to intercropped systems, except at 120 DAS where the difference was not statistically significant.

Table 1. Influence of different row proportionsof buckwheat on plant height of pigeonpea at different growth stages

Treatments	Plant height (cm)				
	30 DAS	60 DAS	90 DAS	120 DAS	At harvest
PP + BW (2:1)	33.9	74.1	116.2	137.8	146.5
PP + BW (2:2)	32.5	72.0	114.4	134.3	143.6
PP + BW (3:1)	34.6	75.9	119.2	138.9	146.4
PP + BW (4:2)	34.8	76.4	119.5	137.2	147.1
Sole PP	37.9	80.1	123.3	143.5	152.6

Treatments	t-test value (5%)									
	V	R	V	R	V	R	V	R	V	R
2:1 vs 2:2	0.69	NS	1.09	NS	1.28	NS	2.14	NS	0.33	NS
2:1 vs 3:1	0.38	NS	0.04	NS	0.18	NS	0.67	NS	0.01	NS
2:1 vs 4:2	0.40	NS	0.96	NS	0.82	NS	0.37	NS	0.06	NS
2:1 vs Sole	1.95	NS	0.88	NS	0.57	NS	3.49	S	0.71	NS
2:2 vs 3:1	1.09	NS	1.13	NS	1.46	NS	2.82	S	0.34	NS
2:2 vs 4:2	0.98	NS	0.09	NS	0.33	NS	1.78	NS	0.35	NS
2:2 vs Sole	2.52	NS	0.16	NS	0.60	NS	5.63	S	0.99	NS
3:1 vs 4:2	0.09	NS	0.99	NS	0.97	NS	1.04	NS	0.08	NS
3:1 vs Sole	1.70	NS	0.92	NS	0.73	NS	2.82	S	0.78	NS
4:2 vs Sole	1.31	NS	0.07	NS	0.25	NS	3.86	S	0.56	NS

DAS: Days after sowing PP: Pigeonpea BW: Buckwheat V: Value R: Result S: Significant NS: Not significant

Table 2. Influence of different row proportionsof buckwheat ontotal dry matter production of pigeonpea at different growth stages

Treatments	Total dry matter production (g plant^{-1})				
	30 DAS	60 DAS	90 DAS	120 DAS	At harvest
PP + BW (2:1)	3.15	11.80	30.72	74.35	113.64
PP + BW (2:2)	3.02	12.56	30.54	72.94	112.47
PP + BW (3:1)	3.22	12.89	31.02	76.82	118.20
PP + BW (4:2)	3.14	11.95	30.31	75.64	115.35
Sole PP	3.91	15.20	36.65	82.62	133.65

Treatments	t-test value (5%)									
	V	R	V	R	V	R	V	R	V	R
2:1 vs 2:2	0.69	NS	1.01	NS	0.10	NS	0.31	NS	0.17	NS
2:1 vs 3:1	0.41	NS	1.67	NS	0.18	NS	0.62	NS	0.74	NS
2:1 vs 4:2	0.05	NS	0.19	NS	0.20	NS	0.26	NS	0.23	NS
2:1 vs Sole	3.75	S	4.37	S	3.07	S	1.84	NS	2.82	S
2:2 vs 3:1	1.12	NS	0.45	NS	0.27	NS	0.90	NS	0.87	NS
2:2 vs 4:2	0.56	NS	0.72	NS	0.11	NS	0.52	NS	0.36	NS
2:2 vs Sole	4.22	S	3.12	S	2.99	S	2.04	NS	2.83	S
3:1 vs 4:2	0.40	NS	1.23	NS	0.37	NS	0.25	NS	0.39	NS
3:1 vs Sole	3.57	S	3.04	S	3.08	S	1.36	NS	2.28	NS
4:2 vs Sole	3.39	S	3.72	S	2.93	S	1.35	NS	2.27	NS

DAS: Days after sowing PP: Pigeonpea BW: Buckwheat V: Value R: Result S: Significant NS: Not Significant

Table 3. Influence of different buckwheat row arrangements on pigeonpea yield parameters, yield and pigeonpea equivalent yield

Treatment	Number of pods per plant	Seed weight per plant (g.)	Test weight (g.)	Seed yield (kg ha^{-1})	Haulm yield (kg ha^{-1})	Pigeonpea equivalent yield (kg ha^{-1})
PP + BW (2:1)	161	20.15	10.78	944	2679	1506
PP + BW (2:2)	162	19.50	10.69	735	1955	1408
PP + BW (3:1)	159	19.89	10.72	1080	2983	1597
PP + BW (4:2)	158	20.04	10.76	965	2662	1532
Sole PP	165	21.01	10.81	1393	3666	1393

	t-test value (5%)											
Treatments	V	R	V	R	V	R	V	R	V	R	V	R
2:1 vs 2:2	0.10	NS	0.54	NS	0.14	NS	6.76	S	24.47	S	1.42	NS
2:1 vs 3:1	0.23	NS	0.24	NS	0.10	NS	5.21	S	6.81	S	1.66	NS
2:1 vs 4:2	0.29	NS	0.08	NS	0.03	NS	0.81	NS	0.62	NS	0.43	NS
2:1 vs Sole	0.43	NS	0.73	NS	0.05	NS	12.53	S	29.16	S	2.11	NS
2:2 vs 3:1	0.32	NS	0.34	NS	0.05	NS	14.82	S	23.32	S	3.19	S
2:2 vs 4:2	0.36	NS	0.39	NS	0.09	NS	9.88	S	26.79	S	1.89	NS
2:2 vs Sole	0.30	NS	1.22	NS	0.18	NS	19.45	S	51.83	S	0.26	NS
3:1 vs 4:2	0.10	NS	0.12	NS	0.06	NS	7.04	S	7.53	S	1.28	NS
3:1 vs Sole	0.69	NS	1.02	NS	0.16	NS	10.61	S	14.51	S	5.08	S
4:2 vs Sole	0.66	NS	0.72	NS	0.07	NS	14.51	S	32.29	S	2.82	S

PP: Pigeonpea BW: Buckwheat V: Value R: Result S: Significant NS: Non significant

At 30 DAS, sole pigeonpea accumulated 3.91g plant^{-1} of dry matter, outpacing the intercropping systems which ranged from 3.02 to 3.22g plant^{-1}. This trend continued at 60, 90 and at harvest, with sole cropping consistently exhibiting greater dry matter accumulation (80.1, 123.3, 152.6 g plant^{-1} at 60 DAS, 120 DAS and at harvest, respectively) (Table 2). Importantly, among various intercropping arrangements, there were no significant differences, underscoring that choice of intercrop arrangement has minimal effect when using less competitive crops like buckwheat.

This consistent outperformance in sole systems can be attributed to the absence of below and aboveground competition for light, water and nutrients, allowing the main crop to realize its full biomass potential (Barod *et al.*, 2017); similar observations have been made in comparative pigeonpea studies (Kumar *et al.,* 2005 and Rathod *et al*., 2004). Multiple studies have shown that while some reduction in biomass may result from competition for resources, overall growth and yield of the main crop generally remain largely unaffected when intercropping systems are thoughtfully designed with proper row spacing and compatible crop species (Lithourgidis *et al.,* 2011 and Willey, 1979).

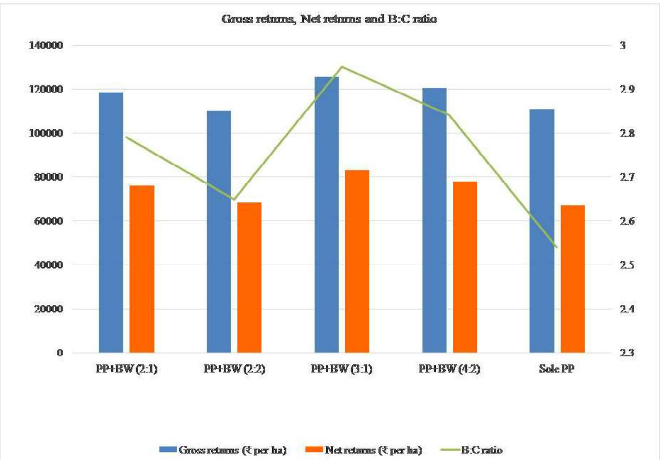

Fig 1. Gross returns (₹ ha^{-1}), net returns (₹ ha^{-1}) and B:C ratio of pigeonpea intercropping systems as influenced by different row proportions of buckwheat

While examining pigeonpea yield traits such as number of pods per plant, seed weight per plant and 100-seed weight, there were no significant differences between sole pigeonpea cropping and intercropping with buckwheat at various row proportions. The number of pods per plant ranged from 158 to 165, seed weight ranged from 19.50 to 21.01 grams and test weight stayed consistently between 10.69 and 10.81 grams across all treatments (Table 3). This lack of significant variation suggests that intercropping pigeonpea with buckwheat, regardless of row arrangement, does not adversely affect these critical yield components. This consistency in yield characteristics demonstrate the harmonious coexistence of buckwheat and pigeonpea within the intercropping system, making it a suitable combination that preserves the reproductive performance of pigeonpea.

There were significant differences in both seed and haulm yields among treatments, with sole crop yielding higher seed (1393 kg ha^{-1}) and haulm yield (3666 kg ha^{-1}). The superior yield under sole cropping is primarily due to higher plant density and absence of competition from other crops (Barod *et al.,* 2017 and Pandit *et al.,* 2020).

Among the intercropping patterns, 3:1 row ratio delivered comparatively better yields than other setups, emphasizing the importance of appropriate spacing (Marer *et al*., 2005). The pigeonpea–buckwheat intercropping system (3:1 row ratio) recorded higher pigeonpea equivalent yield (PEY), driven by strong yields from both crops and attractive market prices for pigeonpea and buckwheat. This well-balanced combination significantly improve the overall profitability of system and illustrates how strategic intercropping, combined with favourable economic conditions, can greatly enhance income, especially in rainfed agricultural environments (Megharani *et al.,* 2023).

Economic evaluation from the study further confirmed that 3:1 intercropping system delivered superior financial returns, with a gross return of ₹ 1,25,542 ha^{-1}, net returns of ₹ 82,993 ha^{-1}and benefit-cost (B:C) ratio of 2.95. By comparison, sole pigeonpea resulted in lower net returns of ₹ 67,074 ha^{-1} and B:C ratio of 2.54 (fig 1). The economic advantage of 3:1 system is from the combined revenues of both pigeonpea and buckwheat, which influence their better market values. Although sole cropping registered higher yields, complementary resource utilization in 3:1 intercropping design led to better overall returns under rainfed conditions. These results emphasize the crucial role of optimizing crop row arrangements and combinations to boost farm productivity and profitability (Darshan *et al.,* 2023; Lakshmi *et al.,* 2023 and Shivaramu *et al*., 1991).

Conclusion

The findings demonstrate that pigeonpea intercropped with buckwheat in 3:1 row ratio resulted in higher pigeonpea equivalent yield of 1,597 kg ha^{-1}, along with higher gross returns (₹ 1,25,542 ha^{-1}), net returns (₹ 82,993 ha^{-1})and benefit-cost ratio of 2.95, surpassing all other evaluated treatments. While sole pigeonpea produced maximum individual seed yield (1,393 kg ha^{-1}) and haulm yield (3,666 kg ha^{-1}), the 3:1 intercropping system achieved superior profitability by efficiently utilizing resources and combining the economic value of both crops. These results clearly indicate that 3:1 row ratio is optimal choice for enhancing both productivity and economic gains in pigeonpea-buckwheat intercropping systems.

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