RESEARCH ARTICLE Legume Research- An International Journal, Volume 49 Issue 3: 435-442 (March 2026)

Evaluation of Pigeonpea Equivalent Yield and Intercropping Indices of Organically Cultivated Pigeonpea (*Cajanus cajan* L.) based Intercropping System

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10.18805/LR-5543

ABSTRACT

Background: Pigeonpea (*Cajanus cajan* L.) is the fifth most significant grain legume globally and ranks second in importance in India, following chickpea. Pigeonpea is an ideal base crop for intercropping with various cereal and pulse crops to enhance system productivity and soil health. This study aims to assess the performance of different pigeonpea based intercropping systems by computing PEY and various intercropping indices.

Methods: The field experiment was conducted on organically certified field at Organic Farming Research and Training Centre (OFRTC), MPKV, Rahuri, Ahilyanagar, (M.S.) during two consecutive *kharif* season of 2021-22 and 2022-23 to study the performance of different crops in pigeonpea based intercropping system in RBD design with 13 treatments replicated thricely. Intercropping indices of different systems were evaluated by using standard formulae.

Result: The pooled data over two years of research revealed that among the various intercropping systems, Pigeonpea + Soybean (1:5) intercropping system was identified as the most effective system and was found significantly highest in respect to pigeonpea equivalent yield. It was at par with Pigeonpea + Greengram (1:5). Similarly, Pigeonpea + Soybean (1:5) intercropping system recorded higher values of different intercropping indices *viz*., land equivalent ratio, area time equivalent ratio, relative crowding coefficient, system productivity, production efficiency, price equivalent ratio, relative value total when compared to Sole Pigeonpea and other intercropping systems. However, Pigeonpea + Greengram (1:5) intercropping system was found comparable with Pigeonpea + Soybean (1:5) in terms of these intercropping indices on two years mean basis.

Key words: Greengram, Intercropping system, Land equivalent ratio, PEY, Soybean.

INTRODUCTION

Pigeonpea [*Cajanus cajan* (L.) Millsp.] is a protein-rich annual pulse crop of significant importance, cultivated widely across tropical and subtropical regions of the world. It is particularly renowned for its exceptional drought tolerance, making it well-suited for rainfed upland ecosystems during the *kharif* season (Fanish *et al.,* 2023). India is world's largest producer of pigeonpea. In 2021, the country produced approximately 4.32 million tons of pigeonpea, cultivated over 5.2 million hectares, with an average productivity of 825 kg ha^{-1} (FAO Stat, 2021).

Intercropping is the practice of growing two or more crops together in the same area. It enhances spatial and temporal land-use efficiency, optimizes resource utilization, reduces risk, suppresses weed growth and stabilizes crop yields. These benefits contribute to increased productivity per unit of land. Among intercropping systems, legume-cereal combinations are particularly gaining popularity for diversifying traditional cereal-based farming and improving profitability. The growing interest in intercropping is largely due to its ability to achieve higher yields, improve solar energy utilization and maximize land productivity resulting in better economic returns.

Pigeonpea is an ideal base crop for intercropping with a wide range of crops, including cotton, sorghum, pearl millet, mungbean, urdbean, maize, soybean and groundnut. Its inclusion in intercropping systems enhances overall productivity and contributes to improved soil health. Acting as an effective cover crop, pigeonpea protects soil from erosion by reducing the impact of direct rainfall (Mula and Saxena, 2010). It's slow initial growth and deep root system make pigeonpea particularly suitable for intercropping with fast-growing, early-maturing, shallow-rooted crops (Nandhini *et al.,* 2015). When grown alone, pigeonpea has a relatively low harvest index and slow early development, but intercropping helps overcome these limitations by promoting more efficient use of resources (Willey, 1979).

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How to cite this article: Ghule, N.S., Surve, U.S., Bade, A.S., Kanade, A.K. and Shende, S.M. (2026). Evaluation of Pigeonpea Equivalent Yield and Intercropping Indices of Organically Cultivated Pigeonpea (*Cajanus cajan* L.) based Intercropping System. *Legume Research*. **49(3):** 435-442. doi: 10.18805/LR-5543.

Submitted: 11-07-2025 **Accepted:** 29-09-2025 **Online:** 29-10-2025

By enhancing productivity and profitability, pigeonpea-based intercropping systems provide a valuable strategy for many farming communities, especially in developing countries. As global demand for food, fuel, fiber and other resources continues to rise, particularly in regions with rapidly growing populations, land-based farming systems expected to provide over 90% of the food supply must adopt such sustainable and efficient practices (Sharmili *et al.,* 2025). The present study aimed to address the following objectives:

1. To evaluate the impact of intercropping different crops on the growth, yield and quality of pigeonpea.
2. To assess the performance of various intercrops in pigeonpea-based intercropping systems.
3. To determine the effects of pigeonpea-based intercropping systems on soil health.
4. To analyse the economic feasibility of pigeonpea-based intercropping systems.

MATERIALS AND METHODS

The field experiment was conducted during the *kharif* seasons of 2021-22 and 2022-23 on an organically certified field (since 2019-20) at the organic farming research and training centre (OFRTC), MPKV, Rahuri, Ahilyanagar, Maharashtra. The site is located at 19°23′26.48″N latitude and 74°38′59.24″E longitude, with an elevation of 602.6 m above MSL, situated in the scarcity zone of Western Maharashtra under the Western Plateau and Hilly Region. The soil was medium black Vertic (Haplustept, Inceptisol), clayey in texture, with a bulk density of 1.25 mg m^{-3}. Moisture content at field capacity and permanent wilting point was 41.79% and 19.42%, respectively. The soil reaction was moderately alkaline (pH 8.25), with EC of 0.25 dS m^{-1}. Nutrient status was low in available nitrogen (181.80 kg ha^{-1}), medium in phosphorus (15.62 kg ha^{-1}) and very high in potassium (469.85 kg ha^{-1}). The experiment was conducted in a randomized complete block design (RCBD) with thirteen treatments replicated thrice. Treatments included seven sole cropping systems-Sole pigeonpea, onion, cauliflower, greengram, soybean, sesame and pearlmillet- and six pigeonpea-based intercropping systems: Pigeonpea + Onion (1:8), Cauliflower (1:3), Greengram (1:5), Soybean (1:5), Sesame (1:5) and Pearlmillet (1:5). The pigeonpea variety 'Phule Rajeshwari' was dibbled at a spacing of 180 cm × 30 cm, while intercrops were sown as per their recommended row proportions. As the field was organically certified, all agronomic practices followed organic standards. To meet the recommended nitrogen dose, well-decomposed farmyard manure, neem cake and vermi-compost were applied in equal proportions. Protective irrigation was provided during extended dry spells.

Pigeonpea equivalent yield (kg ha^{-1})

Pigeonpea equivalent yield of intercrops (kg ha^{-1})

The pigeonpea equivalent yield of the intercropping system was calculated based on the prices prevalent in the local market.

$$\text{PEY (kg ha}^{-1}\text{)} = \frac{\text{Grain yield of intercrop} \times \text{Selling price of intercrop yield (₹ kg}^{-1}\text{)}}{\text{Selling price of pigeonpea grain (₹ kg}^{-1}\text{)}}$$

Here, grain yield of intercrop while grown under sole cropping.

Pigeonpea equivalent yield of system (kg ha^{-1})

$$\text{PEY (kg ha}^{-1}\text{)} = \text{PP yield} + \frac{\text{Grain yield of intercrop} \times \text{Selling price of intercrop yield (₹ kg}^{-1}\text{)}}{\text{Selling price of pigeonpea grain (₹ kg}^{-1}\text{)}}$$

Intercropping indices

Land equivalent ratio (LER)

LER indicates the efficiency of intercropping in using the resources of the environment compared with sole cropping (Mead and Willey 1980). LER was worked out as given below to find out the economics of individual intercropping system.

$$\text{Land equivalent ratio} = \frac{Yab}{Yaa} + \frac{Yba}{Ybb}$$

Where,

Yab= Yield of pigeonpea in association with intercrop.

Yba= Yield of intercrop in association with pigeonpea.

Yaa= Yield of sole pigeonpea.

Ybb= Yield of sole intercrop.

If value of LER is >1, then intercropping is considered to be advantageous, if LER is <1, then intercropping is disadvantageous and if LER is = 1, then it indicates no profit, no loss from the intercropping.

Area time equivalent ratio (ATER)

ATER is the ratio of hectare-days required under sole cropping to those used in intercropping to produce equivalent yields of component crops. Unlike the LER, ATER accounts for the duration of each crop in the field, providing a more realistic measure of intercropping efficiency. ATER offers a better assessment of productivity, especially when crop growth periods differ (Hiebsch, 1987).

$$\text{ATER} = \frac{(La \times Da) + (Lb \times Db)}{\text{Total duration of intercropping system in days}}$$

$$La = \frac{\text{Grain yield of pigeonpea grown with intercrop}}{\text{Grain yield of sole pigeonpea}}$$

$$Lb = \frac{\text{Grain yield of intercrop grown with pigeonpea}}{\text{Grain yield of sole intercrop}}$$

Where,

Da= Duration of crop pigeonpea crop.

Db= Duration of intercrop.

The interpretation of ATER involves:

ATER = >1 implies yield advantage

ATER = 1 implies no effect of intercropping and ATER = < 1 shows yield disadvantage.

Aggressivity (A)

The aggressivity assesses the dominance of the crop species in intercropping. It indicates the relative yield increase in crop "a" than that of crop "b" in an intercropping situation (Mc Gilchrist, 1965). Aggressivity is used to determine the competitive relationship between two crops used in the mixed cropping (Willey 1979). The aggressivity of a pigeonpea + different crops intercropping system can be derived from the following formula:

$$Aab = \frac{Yab}{(Yaa \times Zab)} - \frac{Yba}{(Ybb \times Zba)}$$

Where,

Aab = Aggressivity value.

Yab = Yield of pigeonpea crop (a) grown with intercrop (b).

Yba = Yield of intercrop (b) grown with pigeonpea crop (a).

Yaa = Yield in pure (sole) stand of pigeonpea (a); LERa is partial LER for pigeonpea crop (La).

Ybb = Yield in pure (sole) stand of intercrop (b); LERb is partial LER for intercrop crop (Lb).

Zab = Sown proportion of pigeonpea crop in mixture with intercrop.

Zba = Sown proportion of intercrop in mixture with pigeonpea crop.

If, Aab = (+) Positive, then main crop is aggressive (Dominant).

Aab = (-) Negative, then main crop is suppressive (Dominated).

Aab = (0) Zero, then both crops are equally aggressive/ competitive.

When the value of Aggressivity becomes zero, none of the crops are considered aggressive or both crops are equal in competition. If the value becomes positive, the main crop (a) is considered as aggressive or dominant over intercrop and intercrop (b) is dominated crop. If the value becomes negative, then intercrop (b) is considered as aggressive or dominant over main crop and main crop (a) is suppressive or dominated crop.

Competition ratio (CR)

The competitive ratio gives a good measure of the competitive ability of the component crops in an intercropping system (Willey and Rao, 1980) and has some advantage over relative crowding coefficient and aggressivity. It is calculated as:

$$CR = \frac{Yab}{(Yaa \times Zab)} \div \frac{Yba}{(Ybb \times Zba)}$$

CRa = >1, then crop a is more competitive than crop b.

CRa, <1, then crop b is more competitive than crop a.

CRa = 1, then both the crops are equally competitive.

Relative crowding coefficient (RCC)

RCC indicates whether a crop when grown in intercropping system, has produced more or less yield than expected in pure (sole) crop. It provides an idea in yield advantage in intercropping of crops and evaluates the degree of competition between component crops in replacement series.

$$Kab = \frac{Yab \times Zba}{(Yaa - Yab) \times Zab}$$

$$Kba = \frac{Yba \times Zab}{(Ybb - Yba) \times Zba}$$

The value of K is calculated as:

$$K = Kab \times Kba$$

Where,

Kab = RCC of crop a intercropped with crop b.

Kba = RCC of crop b intercropped with crop a.

The interpretations of RCC

For crop a

Kab = <1, crop a produced less yield than expected.

Kab = 1, crop a produced same yield as expected.

Kab >1, crop a produced more yield than expected.

For crop b

Kba = <1, crop b produced less yield than expected.

Kba = 1, crop b produced same yield as expected.

Kba >1, crop b produced more yield than expected.

For intercropping system

If K <1, yield disadvantage in intercropping of crop a and b. (less yield than expected).

K = 1, no difference in yield between intercropping and sole crop (*i.e.* same yield as expected).

K >1, yield advantage in intercropping of crop a and b. (*i.e.* more yield in intercropping than expected).

System productivity (kg ha^{-1})

System productivity (kg ha^{-1}) =

Pigeonpea yield of respective treatment (kg ha^{-1}) + Pigeonpea grain equivalent yield of intercrop of respective treatment (kg ha^{-1})

Production efficiency (kg ha^{-1} day^{-1})

Production efficiency (PE) is worked out as given below to find out the economics of individual intercropping system.

Production efficiency (kg ha^{-1} day^{-1}) =

$$\frac{\text{System productivity of respective treatment (kg ha}^{-1})}{\text{Duration of intercropping system}}$$

Price equivalent ratio (PER)

The ratio obtained under the intercropping system as compared to the price that could have been obtained under sole cropping.

$$PER = \frac{(Yab \times Yap) + (Yba \times Ybp)}{½\,(Yaa \times Yap + Ybb \times Ybp)}$$

Where,

Yaa = Yield of the component crop 'a' as sole crop.

Ybb = Yield of the component crop 'b' as sole crop.

Yab = Yield of the component crop 'a' as intercrop in combination with 'b'.

Yba = Yield of the component crop 'b' as intercrop in combination with 'a'.

Yap = Market price of the produce of component crop 'a'.

Ybp = Market price of the produce of component crop 'b'.

Relative value total (RVT)

This index is especially useful for farmers looking to maximize the economic benefits of intercropping.

$$RVT = \frac{a \times P1 + b \times P2}{a \times M1}$$

Where,

a and b = Market price of main crop and intercrop, respectively.

P1 and P2 = Yield of main crop and intercrop, respectively in intercropping.

M1 = Yield of main crop as pure/sole crop.

If RVT is >1, the intercropping is economically preferable; whereas if RVT is <1, the pure cropping is preferable. If RVT =1, neither of the methods is economically superior to the other.

System profitability/Economic efficiency (₹ ha^{-1} day^{-1})

Economic efficiency (₹ ha^{-1} day^{-1}) =

$$\frac{\text{Net monetary returns over the year of respective treatment (₹ ha}^{-1}\text{)}}{\text{Duration of intercropping system of respective treatment (days)}}$$

RESULTS AND DISCUSSION

Pigeonpea equivalent yield (PEY) (kg ha^{-1})

The mean pigeonpea equivalent yield was 1971.32 kg ha^{-1} on pooled mean basis. Intercropping of various crops with pigeonpea significantly enhanced PEY compared to sole cropping systems (Fig 1). Among different intercropping systems, the PP + Soybean (1:5) intercropping system recorded 2943.98 kg ha^{-1} of PEY on pooled basis and it was found significantly higher over the Sole Pigonpea and all other sole crops and also some intercropping systems. However, this system was showed at par with PP + Greengram (1:5) intercropping system on pooled mean basis. Among different pigeonpea based intercropping systems, the PP + Pearlmillet (1:5) recorded lower pigeonpea equivalent yield (1907.81 kg ha^{-1}) on a pooled mean basis. Although it still performed better than Sole Pigeonpea but did not show as significant an increase as other intercrops. This may be due to higher competition for resources between Pigeonpea and Pearlmillet.

PP + Soybean (1:5) suggests a highly synergistic interaction between Pigeonpea and Soybean when grown under intercropping system. Furthermore, the combination of these crops (Greengram, Cauliflower, Onion and Sesame) with Pigeonpea likely leads to efficient resource utilization and reduced competition. Overall, the results suggest that intercropping Pigeonpea with certain crops can substantially improve yields due to complementary interactions and more efficient use of available resources. This can be a *via*ble strategy for farmers looking to maximize productivity and resource use efficiency in their cropping systems. These results are aligned with those reported by Kumar *et al.* (2015) and Deshmukh *et al.* (2020).

Land equivalent ratio (LER)

In present investigation all intercropping systems recorded LER value of greater than 1 on pooled mean basis, which indicates a yield advantage from intercropping systems and intercropping is more efficient in using land resources compared to sole cropping (Table 1). The LER for all sole cropping systems is consistently 1.00 on mean basis. This value signifies that sole cropping systems are considered the baseline for comparison and indicating that the intercropping system uses the same amount of land as sole cropping to produce the same yield. Among different intercropping systems, the PP + Soybean (1:5) and PP + Greengram (1:5), recorded numerically highest mean total LER (1.68 and 1.68) and which was followed by PP + Sesame (1:5), PP + Pearlmillet (1:5), PP + Cauliflower (1:3) and PP + Onion (1:8) intercropping systems (recorded mean total LER of 1.61, 1.57, 1.32 and 1.25, respectively).

The mean LER values for intercropping systems were ranges from 1.24 to 1.68, indicating a significant yield advantage over all sole cropping systems. This yield

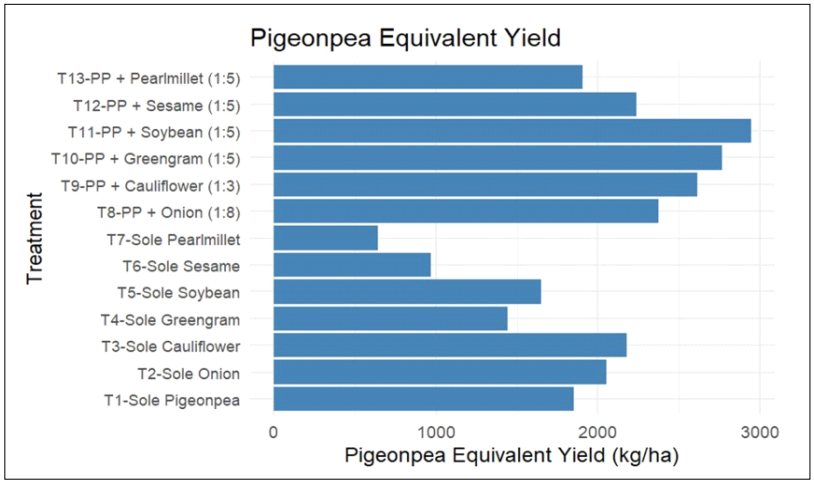


Fig 1: Pigeonpea equivalent yield as influenced by intercropping of different crops.

Table 1: Pigeonpea equivalent yield, partial land equivalent ratio of pigeonpea and intercrops, area time equivalent ratio, aggressivity and competition ratio of pigeonpea and intercrops as influenced by pigeonpea based intercropping system.

Treatment	Pigeonpea grain yield (kg ha^{-1})	Intercrops grain/ bulb/curd yield (kg ha^{-1})	Pigeonpea equivalent yield (kg ha^{-1})	Land equivalent ratio (LER)			Area time equivalent ratio (ATER)	Aggressivity (A)		Competition ratio (CR)	
	At harvest	At harvest	At harvest	Partial pigeonpea LER	Partial intercrops LER	Total LER		Pigeon-pea aggressivity	Intercrops CR	Pigeonpea	Intercrops CR
	Pooled mean	Mean	Pooled mean	Mean	Mean	Mean	Mean	Mean	Mean	Mean	Mean
T1- Sole pigeonpea	1849.50	-	1849.50	1.00	-	1.00	1.00	-	-	1.00	-
T2- Sole onion	-	8285.41	2053.54	-	1.00	1.00	1.00	-	-	-	1.00
T3- Sole cauliflower	-	7828.44	2175.70	-	1.00	1.00	1.00	-	-	-	1.00
T4- Sole greengram	-	1292.70	1443.66	-	1.00	1.00	1.00	-	-	-	1.00
T5- Sole soybean	-	2217.97	1651.05	-	1.00	1.00	1.00	-	-	-	1.00
T6- Sole sesame	-	796.81	971.07	-	1.00	1.00	1.00	-	-	-	1.00
T7- Sole pearlmillet	-	1756.17	641.05	-	1.00	1.00	1.00	-	-	-	1.00
T8- PP + onion (1:8)	1506.22	3501.98	2372.92	0.81	0.42	1.24	1.11	6.87	6.87	15.45	0.06
T9- PP + cauliflower (1:3)	1451.10	4186.47	2615.73	0.78	0.54	1.32	1.03	2.42	2.42	4.47	0.23
T10- PP + greengram (1:5)	1552.37	1085.19	2764.25	0.84	0.84	1.68	1.21	4.05	4.05	5.07	0.20
T11- PP + soybean (1:5)	1589.10	1819.62	2943.98	0.86	0.82	1.68	1.45	4.19	4.19	5.27	0.19
T12- PP + sesame (1:5)	1428.44	663.44	2236.93	0.77	0.84	1.61	1.22	3.66	3.66	4.71	0.22
T13- PP + pearlmillet (1:5)	1377.55	1452.21	1907.81	0.75	0.82	1.57	1.16	3.51	3.51	4.59	0.22
SE. m. (±)	34.48	-	64.56	-	-	-	-	-	-	-	-
C.D. at 5%	100.63	-	183.56	-	-	-	-	-	-	-	-
General mean	1536.33	-	1971.32	-	-	-	-	-	-	-	-

advantage was primarily due to development of both temporal and spatial complementarities between pigeonpea and different intercrops, improved resource use efficiency, soil health enhancement, microclimate modification and yield stability (Devika *et al.,* 2020; Pandey *et al.,* 2013).

Area time equivalent ratio (ATER)

All sole crops, including pigeonpea, recorded an ATER of 1.00, indicating no yield advantage over each other (Table 1). In contrast, intercropping systems showed ATER values above 1.00, reflecting improved productivity. The highest ATER was observed in PP + Soybean (1:5) (1.45), followed by PP + Sesame (1.22), Greengram (1.21), Pearlmillet (1.16), Onion (1.11) and Cauliflower (1.03). These results indicate that intercropping pigeonpea with soybean, greengram and sesame is more efficient in utilizing land and time resources than with onion or cauliflower. ATER values ranging from 1.03 to 1.45 confirm the overall advantage of intercropping systems. The increased efficiency is likely due to complementary growth habits and better resource utilization between pigeonpea and these intercrops. Similar observations were reported by Pujari (1996) and Nandhini and Latha (2014).

Aggressivity (A)

Pigeonpea was dominant in all intercropping systems as indicated by positive aggressivity (A) values (Table 1). The dominance was highest in the Pigeonpea + Onion intercropping system, suggesting that Pigeonpea was highly competitive over onion crop when grown under intercropping system. Onion crop was highly suppressed by Pigeonpea, which is evident from the highly negative aggressivity values. Further, intercropping systems involving PP + Soybean (1:5), PP + Greengram (1:5), PP + Sesame (1:5) and PP + Pearlmillet (1:5) showed that Pigeonpea had intermediate levels of competition with these crops. These intercrops are moderately competitive with Pigeonpea and can be considered based on resource availability. The lowest positive aggressivity (A) of pigeonpea was observed with cauliflower, suggesting a more balanced competition between pigeonpea and cauliflower. Cauliflower experienced the least suppression, indicating a better competitive ability compared to other intercrops when grown with pigeonpea. The dominance of Pigeonpea in most of the intercropping systems indicates its strong competitive nature, which can significantly influence the performance of different intercrops (Pezzopane *et al.,* 2024).

Competition ratio (CR)

Pigeonpea exhibited the highest competition ratio (CR) when intercropped with Onion (15.45), indicating strong dominance, while Onion had the lowest CR (0.06), reflecting significant suppression (Table 1). In combinations with soybean, greengram, sesame and pearlmillet, pigeonpea showed intermediate CRs of 5.27, 5.07, 4.71 and 4.59, respectively. The lowest CR for pigeonpea (4.47) was observed in the Cauliflower system, where cauliflower recorded a comparatively higher CR of 0.23. Overall, Pigeonpea demonstrated dominance in all intercropping systems, particularly with onion, highlighting its strong competitive ability and efficient resource utilization compared to the intercrops.

Relative crowding coefficient (RCC/K)

The relative crowding coefficient (RCC or K) reflects yield advantage in intercropping systems by assessing the yield performance of each component crop. In Table 2, the

Table 2: Relative crowding coefficient (RCC/K) of pigeonpea and intercrops, system productivity, production efficiency, economic efficiency, price equivalent ratio and relative value total as influenced by pigeonpea based intercropping system.

Treatment	Relative crowding coefficient (RCC or K)			System productivity	Production efficiency	Economic efficiency	Price equivalent ratio (PER)	Relative value total (RVT)
	Kab	Kba	K (Kab × Kba)	(kg ha^{-1})	(kg ha^{-1} day^{-1})	(₹ ha^{-1} day^{-1})		
	Mean	Mean	Mean	Mean	Mean	Mean	Mean	Mean
T1- Sole pigeonpea	-	-	-	-	-	-	-	-
T2- Sole onion	-	-	-	-	-	-	-	-
T3- Sole cauliflower	-	-	-	-	-	-	-	-
T4- Sole greengram	-	-	-	-	-	-	-	-
T5- Sole soybean	-	-	-	-	-	-	-	-
T6- Sole sesame	-	-	-	-	-	-	-	-
T7- Sole pearlmillet	-	-	-	-	-	-	-	-
T8- PP + Onion (1:8)	35.10	0.09	3.21	2373	15.38	396.38	1.45	1.29
T9- PP + Cauliflower (1:3)	10.93	0.38	4.17	2616	16.91	527.63	1.43	1.41
T10- PP + Greengram (1:5)	26.21	1.05	27.49	2764	17.73	747.06	1.72	1.50
T11- PP + Soybean (1:5)	30.65	0.91	28.18	2944	19.01	853.65	1.74	1.59
T12- PP + Sesame (1:5)	17.04	0.99	16.97	2237	14.47	577.21	1.61	1.21
T13- PP + Pearlmillet (1:5)	14.64	0.96	14.03	1908	12.39	476.44	1.61	1.03

highest Kab value for pigeonpea (35.10) was observed in the PP + Onion (1:8) system, indicating that pigeonpea outperformed expectations, while onion showed low Kba (0.09), likely due to shading. In contrast, PP + Soybean (1:5) and PP + Greengram (1:5) exhibited high Kab values (30.65 and 26.21) along with relatively better Kba values of 0.91 and 1.05, respectively, suggesting strong mutual performance. Among intercrops, Greengram recorded the highest Kba, followed by Sesame (0.99), Pearlmillet (0.96), Soybean and Cauliflower (0.38), with Onion the lowest. The combined RCC (K) values were highest in PP + Soybean (28.18) and PP + Greengram (27.49), indicating excellent compatibility and resource utilization. Moderate RCCs were recorded in PP + Sesame (16.97) and PP + Pearlmillet (14.03), while PP + Onion and PP + Cauliflower had lower yet favorable values (3.21 and 4.17). As all intercropping systems showed RCC >1, they conferred a yield advantage compared to sole cropping (Ekeledo *et al.,* 2024).

System productivity (kg ha^{-1})

System productivity in intercropping systems refers to the total yield or output obtained from a given area (usually expressed in kilograms per hectare) when multiple crops are grown together in a specified pattern. It measures the combined yield of all crops in the intercropping system, reflecting the efficiency and effectiveness of the cropping strategy.

PP + Soybean (1:5) intercropping system recorded higher system productivity (2944 kg ha^{-1}) than oher intercropping systems on mean basis (Table 2). However, it was numerically followed by PP + Greengram (1:5), PP + Cauliflower (1:3), PP + Onion (1:8) and PP + Sesame (1:5) intercropping systems which were recorded mean system productivity of 2764, 2616, 2373 and 2237 kg ha^{-1}, respectively. The PP + Pearlmillet (1:5) intercropping system registered numerically minimum system productivity (1908 kg ha^{-1}) over all other intercropping systems on mean basis. The PP + Soybean (1:5) and PP + Greengram (1:5) intercropping systems demonstrated relatively highest system productivity over other treatments, likely due to complementary growth habits, effective nitrogen fixation and proper soil environment. Other intercropping systems showed varying degrees of lower productivity and it might be due to factors such as competition for space, nutrients and water, less effective nitrogen fixation and potential shading issues. Similar results are also reported by Jat and Ahlawat (2010); Tiwari *et al.* (2011) and Kumar *et al.* (2015).

Production efficiency (kg ha^{-1} day^{-1})

The results revealed that the PP + Soybean (1:5) intercropping system registered numerically higher production efficiency (19.01 kg ha^{-1} day^{-1}) over rest of the intercropping systems on mean basis (Table 2). However, it was numerically followed by PP + Greengram (1:5), PP + Cauliflower (1:3), PP + Onion (1:8) and PP + Sesame (1:5) intercropping systems and which were recorded mean production efficiency of 17.73, 16.91, 15.38 and 14.47, respectively. Further, the PP + Pearlmillet (1:5) intercropping system registered numerically lowest production efficiency (12.39 kg ha^{-1} day^{-1}) on mean basis. The intercropping systems involving leguminous crops (Soybean and Greengram) with pigeonpea exhibited the highest production efficiency and this can be attributed to the complementary benefits of nitrogen fixation and improved soil fertility by leguminous crops leading to better resource use efficiency. These results are confirmed by Pandey *et al.,* (2013) and Kumawat *et al.,* (2015).

Economic efficiency, price equivalent ratio (PER) and relative value total (RVT)

The PP + Soybean (1:5) intercropping system recorded the highest economic efficiency (₹ 853.65 ha^{-1} day^{-1}), followed by PP + Greengram (₹ 747.06), sesame, cauliflower and pearlmillet systems, while the lowest was observed in PP + Onion (₹ 396.38) (Table 2). The superior performance of Soybean and Greengram systems is attributed to higher yields, complementary growth habits and favorable market prices (Kumawat *et al.,* 2015). Similarly, the highest price equivalent ratio (PER) was recorded in PP + Soybean (1.74), followed closely by PP + Greengram (1.72), with the lowest in PP + Cauliflower (1.43). For relative value total (RVT), Soybean (1.59) and Greengram (1.50) systems again ranked highest, indicating strong economic returns, while Pearlmillet showed the lowest (1.03). The better performance of these legume-based systems reflects efficient resource use, nitrogen fixation and crop compatibility, whereas lower values in other systems may be due to competition and shading effects.

CONCLUSION

The present study demonstrated that pigeonpea-based intercropping systems significantly enhance productivity, resource use efficiency and economic returns under organic farming conditions. Among all treatments evaluated over two years, the Pigeonpea + Soybean (1:5) intercropping system consistently outperformed other systems in terms of pigeonpea equivalent yield, land equivalent ratio, area time equivalent ratio, system productivity, production efficiency, economic efficiency, price equivalent ratio and relative value total. It was closely followed by the Pigeonpea + Greengram (1:5) system, indicating a strong synergy between pigeonpea and these leguminous intercrops. All intercropping systems recorded land equivalent ratios greater than one, suggesting their superior land use efficiency compared to sole cropping. Looking ahead, future research should focus on long-term impacts of pigeonpea-based intercropping on soil health, nutrient dynamics and microbial activity. Further evaluation of diverse intercrop combinations, including oilseeds and vegetables, can help enhance system resilience and farmer income.

ACKNOWLEDGEMENT

The present study was supported by Organic Farming Research and Training Centre, Mahatma Phule Krishi Vidyapeeth, Rahuri, Ahilyanagar, India.

Disclaimers

The views and conclusions expressed in this article are solely those of the authors and do not necessarily represent the views of their affiliated institutions. The authors are responsible for the accuracy and completeness of the information provided, but do not accept any liability for any direct or indirect losses resulting from the use of this content.

Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this article. No funding or sponsorship influenced the design of the study, data collection, analysis, decision to publish or preparation of the manuscript.

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