



# Plant Archives

Journal homepage: <http://www.plantarchives.org>DOI Url : <https://doi.org/10.51470/PLANTARCHIVES.2025.v25.no.2.417>

## INTERCROPPING INDICES AND LAND USE EFFICIENCY IN PIGEONPEA-BASED CROPPING SYSTEMS IN EASTERN DRY ZONE OF KARNATAKA, INDIA

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(Date of Receiving-14-08-2025; Date of Acceptance-30-10-2025)

### ABSTRACT

The study aimed to evaluate the resource-use efficiency, and competitive dynamics of pigeonpea-based intercropping systems under rainfed conditions of Karnataka. A field experiment was conducted to examine the biological indices of various intercropping systems, using a randomized block design with 15 treatments, including sole crops and pigeonpea intercropped with cereals, legumes, and pseudo-cereals in 1:2 row proportion. Intercropping indices such as, pigeonpea equivalent yield (PEY), actual yield loss (AYL), intercropping advantage (IA), land equivalent ratio (LER), area time equivalent ratio (ATER), and land-equivalent coefficient (LEC) were analysed. Results revealed that all intercropping systems outperformed sole pigeonpea in terms of PEY and biological efficiency with higher PEY observed in pigeonpea + sweetcorn (2724 kg ha<sup>-1</sup>). Intercropping proved to be advantageous with reduced AYL in pigeonpea when intercropped with legumes compared to exhaustive cereals. The pigeonpea + fieldbean recorded the highest LER (1.43), ATER (1.19), LUE (131) and LEC (0.45) indicating higher resource-use and system productivity in legume-based intercropping. Thus, the findings underscore the potential of pigeonpea–legume intercropping to enhance land productivity, economic viability, and sustainability in rainfed agroecosystems.

**Key words :** Competition indices, Intercropping, Land equivalent ratio, Pigeonpea equivalent yield, Yield advantage.

### Introduction

Intercropping is a traditional agricultural practice that involves growing two or more crop species simultaneously, wherein they coexist with each other during part of their growth cycle. Historically, it was employed as a strategy to integrate legumes into cropping systems that were predominantly occupied by green revolution staples such as rice and wheat (Willey, 1979). In India, majority of marginal farmers in rainfed regions adopt this multi-cropping system to mitigate the risk of crop failure and to stabilize production against aberrant weather conditions. Due to its efficient resource optimisation, intercropping has the potential to produce higher yields than monoculture systems and has therefore continued to gain popularity in resource-constrained agriculture.

Furthermore, to address the challenges of agricultural sustainability in modern food systems, intercropping when adopted as a part of crop intensification and diversification enhances agroecosystem services by improving productivity and increasing resilience to external perturbations (Gitari *et al.*, 2018). The inclusion of legumes in cereal-based cropping systems is considered one of the most efficient intercropping and is widely practiced across the globe. The legumes improve the soil organic matter, and enhance soil fertility through biological nitrogen fixation, hence the intercropped cereals are less reliant on nitrogen fertilisers (Khonde *et al.*, 2018). Intercropping cereals with legumes results in more than a 20% increase in yield compared to monoculture (Li *et al.*, 2021). Additional benefits include inter-row weed

suppression, reduced pest and diseases pressure and improved management of abiotic stress (Dhaka *et al.*, 2023).

The Eastern Dry Zone of Karnataka is predominantly a rainfed region characterised as hot, dry, and sub-humid receiving an annual rainfall of more than 850 mm. The major crops grown in this zone include sorghum, pearl millet, finger millet, maize, groundnut, sunflower, pigeonpea, chickpea, and cotton. Due to significant discrepancies between rainfall distribution and the crop water requirements, the yield potential is often not fully realized. As a result, intercropping systems, particularly cereal-legume combinations, are widely adopted to enhance productivity, improve soil health, and reduce the risk of crop failure in such rainfed areas (Maitra *et al.*, 2021). Pigeonpea is the second most important pulse crop in India, accounting for 15-20% of country's total pulse production (Anonymous, 2022). It is highly drought-resistant and heat-tolerant, and therefore grows well in arid regions with high temperatures ranging from 20-40°C (FAO, 2016). However, large areas of pigeonpea cultivated in rainfed and marginal lands of Karnataka suffer from low productivity primarily due to severe moisture stress caused by erratic rainfall and drought during critical growth stages. To address this, pigeonpea is commonly recommended as an intercrop with crops such as sorghum, cotton or short-duration pulse crop like blackgram, greengram, and cowpea, in order to enhance the overall system productivity than cultivated as sole crop (Bhadu *et al.*, 2020). Several studies also have documented the intercropping in pigeonpea with short-duration pulses and oilseed crops, taking advantage of its initially slow growth and wider spacing (Kumar *et al.*, 2022). This practice not only enhances overall pulse production but also offers the potential for additional income for marginal farmers. Moreover, the economic viability of intercropping system largely depends on the selection of crops that are compatible and exhibit minimal interspecific competition for resources. Therefore, significant effects of diverse crop species such as sweet corn, baby corn, short-duration pulses like vegetable soybean and field bean, and nutri-rich super foods like quinoa and grain amaranth have been evaluated within pigeonpea-based intercropping systems. However, the efficacy of intercropping system needs to be assessed. The competition and agronomic advantages of component crops in intercropping can be analysed using various indices such as crop equivalent yield (CEY), actual yield loss (AYL), intercropping advantage (IA), land equivalent ratio (LER) and area time equivalent ratio (ATER) (Willey, 1979; Mead and Willey, 1980; Adetiloye *et al.*, 1983;

Hiebsch and McCollum, 1987). The present study aimed to assess the biological indices of various pigeonpea-based intercropping systems with a particular focus on improved land-use efficiency and potential economic benefits for farmers under rainfed conditions.

## Materials and Methods

The field experiment was conducted during the *kharif* 2021, at the research farm of University of Agricultural Sciences, GKVK, Bengaluru. The experimental plot is analysed and characterized as red sandy loam soil with a pH of 6.4, organic carbon content of 0.4% and electrical conductivity (EC) of 0.16 dS m<sup>-1</sup>. The site falls under a semi-arid tropical climate, received a total rainfall of 1,328 mm during the experimental year, significantly exceeding the average annual rainfall of 921 mm. The experimental layout followed in the trial was randomized block design (RBD) with 15 distinct treatments, each replicated thrice. Pigeonpea (variety 'BRG-5') was sown as the main crop at a row spacing of 120 cm under sole cropping. The treatment combinations included sole crops of pigeonpea, sweet corn, baby corn, sorghum, soybean, quinoa, grain amaranth, and field bean as well as seven intercropping systems in 1:2 ratio: pigeonpea + sweet corn, pigeonpea + baby corn, pigeonpea + sorghum, pigeonpea + soybean, pigeonpea + quinoa, pigeonpea + grain amaranth and pigeonpea + field bean.

### Crop yield assessment

The yield advantage of different intercropping practices in pigeonpea was assessed using indices such as, pigeonpea equivalent yield (PEY), actual yield loss (AYL), intercrop advantage (IA), land equivalent ratio (LER), area time equivalent ratio (ATER), land-use efficiency (LUE), and land-equivalent coefficient (LEC). Due to the varying contributions of different intercrops to the total production in the intercropping system, the combined yield was expressed as PEY, calculated based on the individual yields of both the main and component crops, along with their prevailing market prices.

$$PEY = \frac{\text{Yield of intercrop} \times \text{Price of intercrop}}{\text{Price of Pigeonpea}} + \text{Yield of Pigeonpea}$$

The proportionate gain or loss in yield of component crops when intercropped with pigeonpea is evaluated by actual yield loss (AYL). It also accounts for the actual row proportions of the intercrops relative to their pure stands (Banik, 1996).

$$AYL = AYL_a + AYL_b$$

$$AYL_a = \left[ LER_a \times \left( \frac{Z_{aa}}{Z_{ab}} \right) - 1 \right]$$

$$AYL_b = \left[ LER_b \times \left( \frac{Z_{bb}}{Z_{ba}} \right) - 1 \right]$$

$Z_{ab}$  and  $Z_{ba}$  represent row proportions in intercropping, while  $Z_{aa}$  and  $Z_{bb}$  represent row proportions in pure stands. AYL compares yield on a per-plant basis, hence can be either positive or negative, indicating yield benefits or losses.

Intercropping advantage with an economic aspect is derived using formula by Banik (2009).

$$IA = IA_a + IA_b$$

$$IA_a = AYL_a \times P_a$$

$$IA_b = AYL_b \times P_b$$

$P_a$  and  $P_b$  are the market prices of pigeonpea, and its respective intercrops.

Land equivalent ratio (LER) indicates the efficiency of intercropping in resource utilization to achieve maximum productivity compared to sole cropping. LER is the relative land area under sole crops that is required to produce the yields obtained in intercropping at the same level of management (Willey, 1979). It is calculated as follows:

$$LER = \frac{Y_{ab}}{Y_{aa}} + \frac{Y_{ba}}{Y_{bb}}$$

$Y_{ab}$  and  $Y_{ba}$  are yields of species a and b, respectively in intercropping. Moreover,  $Y_{aa}$  and  $Y_{bb}$  represent yields of species a and b, respectively in pure stands.  $LER > 1$  indicates yield advantage in intercropping compared to monoculture.

LER is the most commonly used index in intercropping system. However, it focuses solely on land area without consideration of crop duration in field which can lead to over estimation of resource utilisation. To address this limitation, area time equivalent ratio (ATER), developed by Hiebsch (1980), includes the time each crop occupies the land from planting to harvest. It is calculated as follows:

$$\text{Area time equivalent ratio} = (ATER_a + ATER_b)$$

$$ATER_a = \frac{Y_{ab}}{Y_{aa}} \times \frac{T_a}{T_i}$$

$$ATER_b = \frac{Y_{ba}}{Y_{bb}} \times \frac{T_b}{T_i}$$

$T_a$  and  $T_b$  represent the duration of crop cycle of species a and b, respectively.  $T_i$  is the duration of intercropping cycle.

Land-use efficiency (LUE) is evaluated from LER

and ATER to provide a more precise estimation of land utilisation in intercropping systems (Mason *et al.*, 1986).

$$LUE = [(LER + ATER)/2] \times 100$$

To determine the better productivity of a species in a mixture or intercropping system, land-equivalent coefficient was assessed (Adetiloye *et al.*, 1983):

$$LEC = \frac{Y_{ab}}{Y_{aa}} \times \frac{Y_{ba}}{Y_{bb}}$$

## Statistical analysis

Data was analysed using analysis of variance (ANOVA) following the RBD (Gomez and Gomez, 1984). For comparison between the treatment means, an appropriate value of critical difference (CD) was worked out wherever F- test was significant.

## Results and Discussion

### Assessment of yield advantages

#### Pigeonpea equivalent yield (PEY), Actual yield loss (AYL) and Intercropping advantage (IA)

The maximum seed yield of pigeonpea was observed under sole cropping. Among the intercropping systems, pigeonpea intercropped with field bean recorded the higher yield (Table 1). In contrast, intercropping cereals with pigeonpea reduced its yield due to intense competition from cereals for nutrients, moisture, space, and sunlight during the early growth stages of pigeonpea. Similarly, the pigeonpea equivalent yield (PEY) was significantly influenced by different intercropping systems due to higher combined yield of component crops. Pigeonpea intercropped with two rows of sweet corn recorded a significantly higher PEY (2724 kg ha<sup>-1</sup>), and was on par with pigeonpea + baby corn system (2662 kg ha<sup>-1</sup>). Conversely, a lower PEY was recorded in pigeonpea + grain amaranth compared to sole pigeonpea (Table 1). Higher yield of sweet corn and baby corn, along with their high market prices, enhanced the PEY of these high-value intercrops in cropping systems, making them more economically viable and profitable to farmers. The yield reduction in pigeonpea was compensated by increased yield of demand-driven crops, thus increasing the productivity of pigeonpea based cropping system. Furthermore, all intercropping systems recorded higher PEY than sole pigeonpea, indicating higher yield advantage and efficient land-use (Kumar *et al.*, 2022). Similarly, Sujatha and Babalad (2018) reported a higher pigeonpea equivalent yield (3,987 kg ha<sup>-1</sup>) in pigeonpea–blackgram intercropping compared to other intercrops and sole pigeonpea.

**Table 1 :** Pigeonpea Equivalent Yield (PEY), Actual yield loss (AYL), and Intercropping advantage (IA) as influenced by different intercrops in pigeonpea based cropping system.

| Treatments | Main crop yield (kg ha <sup>-1</sup> ) | Intercrop yield (kg ha <sup>-1</sup> ) | PEY (t ha <sup>-1</sup> ) | Actual yield loss |                  |       | Intercrop Advantage |                 |        |
|------------|----------------------------------------|----------------------------------------|---------------------------|-------------------|------------------|-------|---------------------|-----------------|--------|
|            |                                        |                                        |                           | Pigeonpea (AYLa)  | Intercrop (AYLb) | Total | Pigeonpea (IAa)     | Intercrop (IAb) | Total  |
| PP + SC    | 574                                    | 4816                                   | 2724                      | 0.70              | -0.12            | 0.58  | 52.62               | -24.38          | 28.24  |
| PP + BC    | 605                                    | 960                                    | 2662                      | 0.79              | -0.21            | 0.58  | 59.51               | -31.84          | 27.67  |
| PP+ S      | 642                                    | 842                                    | 1769                      | 0.90              | -0.28            | 0.62  | 67.74               | -11.15          | 56.59  |
| PP+ VS     | 798                                    | 4013                                   | 1357                      | 1.37              | -0.08            | 1.28  | 102.42              | -1.65           | 100.77 |
| PP + Q     | 735                                    | 607                                    | 1820                      | 1.18              | -0.14            | 1.04  | 88.41               | -2.73           | 85.69  |
| PP + GA    | 765                                    | 603                                    | 1303                      | 1.27              | -0.03            | 1.24  | 95.08               | -12.54          | 82.54  |
| PP + FB    | 852                                    | 471                                    | 1542                      | 1.53              | -0.12            | 1.41  | 114.43              | -35.30          | 79.13  |
| Sole PP    | 1012                                   | -                                      | 1012                      | -                 | -                | -     | -                   | -               | -      |
| Sole SC    | -                                      | 8227                                   | 4685                      | -                 | -                | -     | -                   | -               | -      |
| Sole BC    | -                                      | 1828                                   | 4929                      | -                 | -                | -     | -                   | -               | -      |
| Sole S     | -                                      | 1750                                   | 3356                      | -                 | -                | -     | -                   | -               | -      |
| Sole VS    | -                                      | 6560                                   | 1926                      | -                 | -                | -     | -                   | -               | -      |
| Sole Q     | -                                      | 1055                                   | 2896                      | -                 | -                | -     | -                   | -               | -      |
| Sole GA    | -                                      | 933                                    | 1845                      | -                 | -                | -     | -                   | -               | -      |
| Sole FB    | -                                      | 801                                    | 2185                      | -                 | -                | -     | -                   | -               | -      |
| S.Em. ±    | 22.83                                  | -                                      | 93.61                     | -                 | -                | 0.071 | -                   | -               | 5.29   |
| C.D. at 5% | 69.27                                  | -                                      | 271.17                    | -                 | -                | 0.217 | -                   | -               | 16.31  |

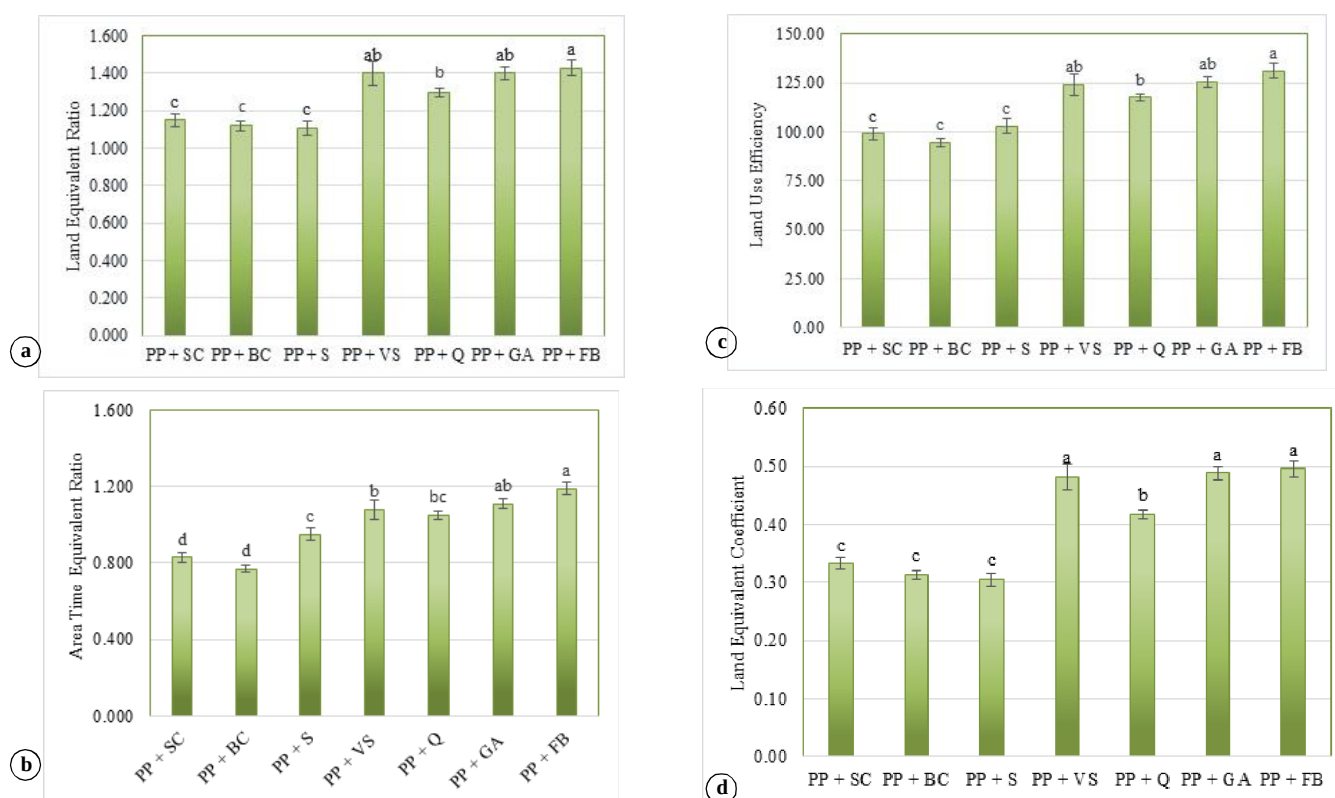
PP: Pigeonpea, SC: Sweet corn, BC: Baby corn, S: Sorghum, VS: Vegetable soybean, Q: Quinoa, GA: Grain amaranth, FB: field bean.

Actual yield loss (AYL) gives a more precise information about the intra- and inter-specific competition of component crops in intercropping system (Khonde *et al.*, 2018). It considers the actual sown proportion of component crops in field, in addition to LER, thereby giving more importance to yield gain or loss on a per-plant basis in an intercropping system compared to its pure stand. A positive value indicates dominant species, whereas a negative value suggests yield penalty of intercrops in cropping system due to dominant main crop (Gitari *et al.*, 2020). The study revealed the dominance of pigeonpea as a main crop with positive AYL values. Pigeonpea + field bean (1:2) recorded significantly the higher AYL<sub>a</sub> (+1.53 i.e. 153%) followed by pigeonpea + vegetable soybean (+1.37 i.e. 137%), while least AYL<sub>a</sub> (+0.70 i.e. 70%) was recorded in pigeonpea + sweet corn intercropping system (Table 1). The maximum yield gain in pigeonpea in legume-based pigeonpea intercropping could be probably due to complementary legume-legume interactions, whereas the initial growth rate of pigeonpea was suppressed by exhaustive cereal crops. On the other hand, the intercrops were dominated by pigeonpea and recorded negative partial AYL<sub>b</sub> values, with sorghum recording the maximum yield loss (-0.28 i.e. 28%). However, the yield penalty was compensated by the

positive yield gain of pigeonpea in the intercropping system (Yang *et al.*, 2017; Banik *et al.*, 2000). Similar trend was observed in intercropping advantage (IA), with legume-based intercropping in pigeonpea found to be more advantageous than cereals as intercrops (Bhadu *et al.*, 2021). Nonetheless, all the treatments had positive IA values, which indicates pigeonpea intercropping is not only agronomically viable but also highly advantageous and remunerative to marginal and smallholder farmers.

#### **Land equivalent Ratio (LER), Area Time Equivalent Ratio (ATER), Land-Use Efficiency (LUE) and Land Equivalent coefficient (LEC)**

The results indicated that different intercrops had a significant impact on land equivalent ratio which serves as an indicator of system productivity. Among the various intercrop combinations, pigeonpea + field bean exhibited the higher LER of 1.43, significantly outperforming sole pigeonpea (LER = 1.00). In contrast, the pigeonpea + sorghum system recorded the lower LER (1.11) (Fig. 1a). It is likely because the initially slow-growing pigeonpea, with its long maturity period, could not compensate for the yield loss caused by highly competitive and robust cereal crops. However, it performed better when intercropped with legumes, with complementary effect throughout its life cycle. Thus, the enhanced land-



**Fig. 1:** a) LER, b) ATER, c) LUE, d) LEC of different pigeonpea based intercropping system. PP: Pigeonpea, SC: Sweet corn, BC: Baby corn, S: Sorghum, VS: Vegetable soybean, Q: Quinoa, GA: Grain amaranth, FB: field bean.

use efficiency in pigeonpea intercropping indicates an advantage of 11 to 43 per cent over the respective sole crops. This could also be attributed to the more effective utilisation of resources by early-maturity crops intercropped with slow establishing, long-duration pigeonpea crop. Supporting this, Pandey *et al.* (2013) reported that the pigeonpea + black gram intercropping system recorded a higher pigeonpea yield ( $1.85 \text{ t ha}^{-1}$ ), pigeonpea equivalent yield ( $2.17 \text{ t ha}^{-1}$ ), land equivalent ratio (LER) of 2.29, compared to both the pigeonpea + maize intercropping system and sole pigeonpea.

The findings also confirmed that pigeonpea-based intercropping system recorded higher ATER values over sole cropping, but necessarily lesser than LER values. This could perhaps be due to the long duration of pigeonpea (170-180 days in 'BRG-5') compared to its intercrops, which might have led to over-estimation of resources. ATER is free from such limitation. Among different intercropping systems, pigeonpea + field bean recorded higher ATER, followed by pigeonpea + grain amaranth. While, the least ATER was observed with pigeonpea + baby corn (Fig. 1b). Pigeonpea combinations with cereal crops recorded ATER values less than one, indicating a disadvantage in terms of field occupation time. In contrast, higher ATER values in combination with

legumes may be due to higher combined seed yield per unit area and the longer duration of the crops in the field (Bhadu *et al.*, 2021).

Land use efficiency in terms of LER tends to be over-estimated, while ATER tends to be under-estimated, hence more accurate land-use efficiency (LUE) can be determined by averaging the two indices, rather than relying on either one or alone. LUE of the pigeonpea cropping system increased by 24-31% when intercropped with pseudo-cereals and legumes, with higher LUE observed in pigeonpea + field bean intercropping, which was on par with pigeonpea + grain amaranth, compared to sole pigeonpea (Fig. 1c). However, intercropping with cereals resulted in lower LUE. Similar finding was observed in land equivalent coefficient (LEC) with higher LEC recorded in the pigeonpea + field bean system, while pigeonpea + sorghum system recorded the least land equivalent coefficient (Fig. 1d). It indicates that inter-specific facilitation is greater than inter-specific competition in legume-legume intercropping system, which could be attributed to biological nitrogen fixation, optimal resources sharing, and improved soil health. However, when pigeonpea was intercropped with cereal crops (such as maize, sorghum or millet), the system demonstrated a marked increase in overall productivity



due to canopy stratification and differential root architecture while maximizing total biomass and grain yield (Gitari *et al.*, 2020).

## Conclusion

The present study revealed that pigeonpea-based intercropping systems significantly enhance biological efficiency, and system productivity under rainfed conditions. Assessment of various intercropping indices indicated the superiority of the pigeonpea + field bean combination in terms of LER, ATER and LUE, reflecting more efficient resource utilization and reduced interspecific competition. However, intercropping pigeonpea with high-value crops such as sweet corn and baby corn proved to be the most economically profitable, owing to higher system productivity and market returns. These findings highlight the yield advantage and biological efficiency of integrating pigeonpea with short-duration intercrops, presenting a viable strategy to enhance farm productivity and resilience in rainfed and semi-arid agroecosystems compared to sole cropping.

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