*International Journal of Environment and Climate Change*

***Volume 14, Issue 3, Page 638-649, 2024; Article no.IJECC.114387***
***ISSN: 2581-8627***
*(Past name: British Journal of Environment & Climate Change, Past ISSN: 2231–4784)*

# Evaluation of Yield Advantages, Competitiveness and Economic Benefits of Pigeonpea (*Cajanus cajan* L.) Based Intercropping Systems Under Different Date of Sowing

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***Authors' contributions***

*This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.*

***Article Information***

DOI:10.9734/IJECC/2024/v14i34072

**Open Peer Review History:**
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here:
https://www.sdiarticle5.com/review-history/114387

***Original Research Article***

***Received: 10/01/2024***
***Accepted: 17/03/2024***
***Published: 22/03/2024***

## ABSTRACT

The experiment conducted at the Department of Agronomy farm, VNMKV., Parbhani (MH), during the kharif seasons of 2016-2017 and 2017-2018, integrates key agro-environmental factors. The utilization of deep black (vertisol) soil with good drainage replicates prevalent soil conditions in the region, ensuring the relevance and applicability of the findings to tropical environments of Latin

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America [20,21]. The implementation of a split plot design with two replications, considering four sowing dates and seven cropping systems, enhances the experimental robustness, facilitating a comprehensive evaluation of the interactions between timing and cropping systems [6,22].The study's findings highlight the significance of sowing dates in maximizing pigeonpea equivalent yield and net monetary returns, with sowing within a week period after the regular commencement of the monsoon (D1) demonstrating superior performance. Furthermore, the pigeonpea + soybean intercropping system emerges as the most favorable [50], indicating its potential for enhancing agricultural productivity and economic returns in the region [17,19]. The study's insights into the competitiveness and economic benefits of different intercropping systems provide valuable guidance for agronomic management practices in tropical environments [50]. By identifying the superior performance of certain cropping systems, such as pigeonpea + soybean, and the influence of sowing dates on yield outcomes [51,45], the study informs farmers and agricultural practitioners on optimal strategies for maximizing productivity and profitability in pigeonpea cultivation [29,30].

The observed behavior of component crops within intercropping systems underscores the complexity of crop interactions and highlights the need for tailored management approaches. The dominance of the niger crop in intercropping systems over the pigeonpea base crop emphasizes the importance of understanding crop dynamics for optimizing yield outcomes [5,18]. Additionally, the study's evaluation of different sowing dates contributes to enhancing climate resilience [14] in agricultural systems by identifying optimal timing strategies for mitigating climate variability effects on crop performance [7,37,13].

*Keywords: Competitiveness; dates of sowing; economic; evaluation; pigeonpea; intercropping systems; yield advantages.*

## 1. INTRODUCTION

"Climate is the most influential factor for crop production. The farmer selects a crop races that is adapted to the regional area where it will be grown. However, it is the weather in the locality that will ultimately determine crop growth, development, and productivity. Unless the crop and cultivars are well adapted to a particular area where they are grown, their cultivation in that locality is uneconomical. Knowledge of agrometeorology and crop physiology is necessary for crop production as it is concerned with the interaction between meteorological, hydrological, and crop phenophases/ physiological factors on one hand and crop production on the other. Indian agriculture, to a large extent, depends on the South-west monsoon shower and associated weather phenomenon. The average annual rainfall of the country is about 4 x 103 $km^3$ (400 M ha m) out of global rainfall of 5 x 105 $km^3$" [26]. "India's share is only one per cent of global precipitation. The 74 % rainfall contribution is from South-west monsoon and the remaining 10 percent during North-East monsoon. The average annual rainfall of the country is 1200 mm (400 M ham). However distribution across the country varies from Western Rajasthan (< 100 mm), in North Eastern states (> 3600 mm) and 1000 mm from the East Coast to 2500- 3000 mm in the West Coast" [1].

"Dryland agriculture has a prominent place in Indian farming, occupying around 67% of the cultivated area, containing nearly 44% of the food basket, and supporting 40% of the human and 60 % of the livestock population. Most (80 to 90%) of the pulses, oilseeds and millets are confined to the dryland ecosystem. It is characterized by resource scarcity, small and marginal farmers, poor infrastructure and low investment in modern technology and proper inputs. The discrepancy between rainfall distribution and the water requirement is the major cause of the instability of certain crops in dryland areas of India. Most dryland areas of India are either mono-cropped or intercropped. Traditional dryland cropping systems are not necessarily the most suitable ones for the agro-climatic conditions as they are mostly subsistence in nature" [1]. "Crop production in arid and semiarid climates, with < 750 mm annual rainfall, is limited by moderate to severe soil moisture stress during the sustainable period of crop growth season. In arid and semiarid tropics with 4-5 months of crop growing season, the predominant cropping system is intercropping with short-season crops. If the cropping growing period is longer (>5-6 months), as in areas of bimodal rainfall distribution, intercropping is mostly taken with long-duration crop such as pigeonpea and cotton. Although, double cropping with sequential cropping of 3-4 months duration crop can be practiced, farmers prefer intercropping for several reasons" [41].

"Intercropping includes strip cropping, alley cropping, contour cropping, paired row cropping, skip cropping, parallel cropping, companion cropping, multi-story cropping and synergetic cropping in additive and replacement series. Pigeonpea-based intercropping systems with cereals crops are more popular in India" [2]. "The Amount of rainfall determines the cereal crop associated with pigeonpea and rice with 1000 to 1500 mm, maize with 750 to 1000 mm, sorghum with 500 to 750 mm and millets with 400 to 600 mm rainfall. Most cereals, depending on their growth and development period, reduce the normal growth of pigeonpea and can be ranked for competitiveness: maize > sorghum >pearlmillet>setaria" [42].

"Paired row planting can adjust full population of the base crop and leave adequate inter-space to accommodate two or more rows of intercrop. In this technique two adjacent rows of the base crop are paired by reducing the inter-row spacing in the pair, narrow enough to create some inter-space between pairs of base crop rows but wide enough to minimize competition among plants of the base crop. In the inter-space of 60-120 cm paired rows of pigeonpea, two or more rows of another short-statured intercrop can be planted. In other words, two rows of base crop and three rows of intercrop can be accommodated in 120 cm (60-120 cm paired) space instead of two rows of base crop alone with the usual planting method. This is often referred to as 60-120 cm paired row planting. In dryland agriculture, intercropping is practiced to minimize the risk of total crop failure due to vagaries in monsoon for yield and economic advantage over sole cropping. Studies in the recent past however, indicated the profitability of intercropping even under irrigation due to efficient use of natural resources as well as applied inputs. All India coordinated research projects on cropping systems indicated the productivity of several intercropping systems in different regions of the country in the recent past" [16,44,48].

"Pigeonpea is a highly drought-resistant crop. It can successfully grow in areas receiving only 65 cm annual rainfall, as the crop matures fast and pest damage is low. It is mostly photoperiodic sensitive, indeterminate and short days result in reduced vegetative phase and onset of flowering. Pigeonpea can be cultivated on a variety of soils from sand to heavy clay loams. However, well-drained medium-heavy loam soils are best suited. The inbuilt mechanism of biological nitrogen fixation enables pulse crops to meet 30 to 90% of their nitrogen requirements, hence a small dose of 15- 25 kg N/ha applied at sowing is sufficient to meet the requirement of most of the pulse crops" [25]. "Pigeonpea can be knitted into many cropping systems viz., intercropping, mixed cropping, sequential cropping, etc. The initial slow growth, deep rooting pattern, ability to tolerate drought and low soil moisture have made it a highly suitable crop for intercropping systems" [1]. Numerous short-duration legumes, cereals, and commercial crops are interplanted with it. Pigeonpea takes up more space in cropping systems than it does as a single crop because of its complimentary effects on soil fertility, improvement, nutrient recycling, weed smothering, and efficient use of soil moisture under various cropping systems.

## 2. MATERIALS AND METHODS

The field experiment was conducted during the *kharif* season in 2016 and 2017 at Agronomy Research Farm, College of Agriculture, Parbhani (Maharashtra). The soil was clayey in texture with a pH 7.80. The soil was low in organic carbon (0.5 %), low in available nitrogen (198 kg/ha), phosphorus (14 kg/ha) and high in potash (492 kg/ha). The experiment consisted of twenty-eight treatment combinations i.e. 4 dates of sowing (($D_1$- sowing within a week after regular commencement of monsoon, $D_2$- sowing 15 days after $D_1$, $D_3$- sowing 15 days after $D_2$ and $D_4$- sowing 15 days after $D_3$) and 7 cropping systems i.e. $I_1$-pigeonpea+soybean (2:3), $I_2$- pigeon pea+ pearlmillet (2:1), $I_3$-pigeonpea+niger (2:3), $I_4$-sole pigeon pea, $I_5$- sole soybean, $I_6$- sole pearlmillet and $I_7$- sole niger in sub-plot. The experiment was laid out in a split-plot design and replicated twice. The gross (6.60 m x 6.00 m) and net plot size (5.40 m x 4.80 m) were taken. Pigeonpea variety 'BDN 711', soybean 'MAUS 71', pearlmillet 'ABPC 4-3' and niger variety 'PNS 6' were sown on 27 June 2016 and 24 June 2017 as first sowing date ($D_1$) and $D_2$, $D_3$ and $D_4$ sowing were done after 15 days interval between each sowing date in both the year respectively. The seeds were sown in 60 cm x 20 cm spacing for sole pigeonpea, 30 cm x 15 cm for sole soybean and sole niger and 60 cm x 15 cm for sole pearlmillet. In the intercrop situation, pigeonpea was sown in paired rows at 60 cm keeping a 120 cm distance between 2 pair to adjust 3 rows of intercrop for soybean and niger (2:3) and 1 row (2:1) for pearlmillet (60/120 cm). The plant-to-plant distance of 20 cm in pigeonpea and 15 cm in intercrops was maintained. The recommended seed rates of 12-15 kg $ha^{-1}$, 60-65 kg $ha^{-1}$, 4-5 kg $ha^{-1}$ and 3-4 kg $ha^{-1}$ of pigeonpea, soybean, pearlmillet and niger for sole and intercrops, respectively, were used in the experiment. The recommended dose of 25 kg N/ha through urea and 50 kg $P_2O_5$/ha through single superphosphate was applied to sole pigeonpea as well as in intercrops. Also the recommended dose of 30:60:30 NPK kg $ha^{-1}$ for soybean, RDF 60:30:30 NPK kg $ha^{-1}$for pearlmillet and RDF 20:20:0 NPK kg $ha^{-1}$ for niger crop through urea, SSP, and MOP were drilled before sowing as a basal application. To maintain a healthy and good crop stand follow the all recommended package of practices like thinning, weeding, and plant protection measures as and when required.

The yield advantages of different intercropping systems over sole pigeonpea were determined in terms of pigeonpea crop equivalent (CEY), land equivalent ratio (LER) area time equivalent ratio (ATER), Aggressivity, Relative crowding coefficient (RCC), Competition Index (CI), Competition ratio (CR) and Competition coefficient (CC).

### 2.1 Pigeonpea Crop Equivalent Yield(CEY)

Base on the basis of Govt. the minimum support prices (MSP)of pigeonpea, soybean, pearlmillet and niger seed the yield of each treatment for both component crops converted into crop equivalent yield of pigeonpea crop [3]. The pigeonpea equivalent yield(PEY)(kgha-1) is calculated as follows:

$$PEY = \sum_{i-0}^{n} Yi\ ei$$

Where,

Yi is the yield of $i^{th}$ component
ei is an equivalent factor of $i^{th}$ component of price $i^{th}$ crop
or

$$\mathrm{PEY} = \mathrm{P_{ab}} + \frac{\mathrm{N_{ab}} \times \mathrm{N_{mp}}}{\mathrm{P_{mp}}}$$

Where,

PEY=Pigeonpea equivalent yield ($kgha^{-1}$)
Pab=Yield of pigeonpea in the intercropping system (kg $ha^{-1}$)
Nab=Yield of soybean, pearlmillet and niger in the intercropping system ($kgha^{-1}$)
Nmp=Soybean, pearlmillet and niger market price (kg $ha^{-1}$)
Pm=Pigeonpea market price (kg $ha^{-1}$)

### 2.2 Land Equivalent Ratio(LER)

The land equivalent ratio is defined as the relative land area under a sole crop that is required to produce the equal amount of yield from the intercropping system under the same management level. The LER was worked out by using the formula of Willey [47].

For studying the best utilization of land, the land equivalent ratio for various treatments was calculated by using the given formula.

$$\mathrm{LER} = \sum_{\mathrm{i=1}}^{\mathrm{m}} \frac{\mathrm{Yj}}{\mathrm{Yij}}$$

Where,

Yi is the yield of $i^{th}$ component from a unit area grown as intercrop
Yij is the yield of $i^{th}$ component grown as a sole crop over the same area.
In brief, LER is the summation of ratios of yields of intercrop to the yield of sole crop.

Or

$$LER = \frac{Yab}{Yaa} + \frac{Yba}{Ybb}$$

Where,

Yab=Yield of ‘a’ component intercropped with ‘b’
Yaa=Yield of ‘a’ component in sole planting
Yba=Yield of ‘b’ component intercropped with ‘a’
Ybb=Yield of ‘b’ component in sole planting

### 2.3 Area Time Equivalent Ratio

The LER method was modified by Hiebsch and McCollum [23] to include the duration of the crop present on the land from planting to harvest. This method is known as the area time equivalent ratio (ATER).

$$\mathrm{ATER} = \frac{\mathrm{Y_p D_p + Y_n D_n}}{\mathrm{T_d}}$$

Where,

Yp=Yield of pigeonpea ($kgha^{-1}$)
Yn=Yield of soybean, pearlmillet and niger ($kgha^{-1}$)
Dp=Duration of pigeonpea
Dn=Duration of soybean, pearlmillet and niger
Td=Total duration of crop

Or

Area time equivalent ratio was calculated by using the following formula suggested by Mendhe et al.
[28].

$$ATER = \frac{1}{ti} = \sum_{1}^{n} \left[\frac{d\ -\ Yi}{Ym}\right]$$

Where,

d=Growth period of crops in days
t=Time in days for which the field remained occupied
(i.e. the growth period of the longest-duration crop)
Yi=Yields of component crops in the inter-cropping system
Ym=Yield of component crops in monoculture cropping system
n=Number of crops involved

### 2.4 Aggressivity

This method was proposed by Mc Gilchrist [27]. It is the mixture of how much the relative yield increase in component a crop is greater than that for component b crop.

$$A_{ab} = \frac{Y_{ab}}{Y_{aa} \times Z_{ab}} - \frac{Y_{ba}}{Y_{bb} \times Z_{ba}}$$

Where,

Yab=Yield of ‘a’ component intercropped with ‘b’
Yaa=Yield of ‘a’ component in sole planting
Yba=Yield of ‘b’ component intercropped with ‘a’
Zab= Row proportion of ‘a’ component intercropped in ‘b’
Zba= Row proportion of ‘b’ component intercropped in ‘a’
Ybb= Yield of ‘b’ component in sole planting
$A_{ab}$= Negative means get dominated
$A_{ab}$= Bigger value either positive or negative means bigger difference in competitive abilities
Aab= 0 (component crops are equally competitive)
Aab= <0 (component a crop dominated)
Aab= >0 (component a crop dominant)

### 2.5 Relative Crowding Coefficient (RCC)

It was proposed by Dewit [9]. It is used in replacement series of intercropping. It indicates whether a species or crops, when grown in mixed population, has produced more or less yield than expected in pure stand.

### 2.6 In 50:50 Mixture

$$Kab\ (RCC) = \frac{Mix.Yield\ of\ a}{Pure\ stand\ yield\ of\ a -\ Mix.Yield\ of\ a}$$

$$Kab = \frac{Y_{ab}}{Y_{aa} \times Yab}$$

$$For\ all\ mixture: Kab = \frac{Yab\ X\ zba}{(Yaa - Yab)\ Zab}$$

Where

Yab= mix. yield of a crop grown with b
Yaa= yield of pure stand crop a
Zab= proportion of sown spp. a in mix. With b
Zba= proportion of sown spp. b in mix. With a
K > 1 Yield advantage
K = 1 No difference
K < 1 Yield disadvantage

### 2.7 Competition Index (CI)

It is a measure to find out the yield of various crops when grown together as well as separately. It was proposed by Donald [11].

$$CI = \frac{(Yaa - Yab)\ X\ (Ybb - Yba)}{Yaa\ X\ Ybb}$$

### 2.8 Competition Ratio (CR)

Competition ratio is measure of intercrop competition, to indicate number of times by which the component crop is more competitive with than the other. The CR values for different replacement treatments were calculated by the equation given by Willey and Rao [46].

$$Cra = \frac{Yab}{Yaa\ x\ Zab} \div \frac{Yba}{Ybb\ x\ Zba}$$

Cra=Competition ratio for component ‘a’
Zab=Row proportion of ‘a’ component intercropped in ‘b’
Zba=Row proportion of ‘b’ component intercropped in ‘a’

### 2.9 Statistical Analysis and Interpretation of Data

The experimental data obtained on various selected variables were analyzed by the standard method of statistical analysis [34] for split plot design. The mean values of different treatments were then worked out along with corresponding standard error of mean (SEm). The critical difference at 5 per cent level of significance was computed by the formula.

$$CD = SEm \times \sqrt{2} \times t \text{ value at respective d.f.}$$

Results obtained have been presented in the form of summary tables, providing SEm in each case and CD at 5 per cent level wherever significant. The values of CD have been taken into account for concluding.

## 3. RESULTS AND DISCUSSION

The data regarding the assessment of yield advantage of inter cropping system viz. Pigeonpea equivalent yield (PEY),Land equivalent ratio(LER), Aggressivity, Area time equivalent ratio (ATER), relative crowding coefficient (RCC), competition index (CI) competition ratio (CR) and net monitory return (NMR) of pigeonpea influenced by sowing dates and different cropping systems treatments were presentedinTable1.

### 3.1 Sowing Dates

Sowing date ($D_1$) was found significantly superior for system pigeonpea equivalent yield (1661 kg $ha^{-1}$) than other sowing dates ($D_3$ and $D_4$) during both years and it was at par with $D_2$ (1508 kg $ha^{-1}$) in pooled analysis.

The land equivalent ratio was significantly influenced due to sowing dates during both years. Third sowing date ($D_3$) in pigeonpea recorded higher land equivalent ratio (1.19) as compared $D_1$, $D_2$ and $D_4$ sowing date, during first year. In the second year fourth sowing date ($D_4$) recorded higher LER (1.33) than other sowing dates. These results conform with those reported by [40,15,4].

ATER during the year 2016-17 was observed higher in sowing dates $D_3$(1.05).In next year it was found in sowing dates $D_4$ (1.13)but less difference were seen between all sowing dates. ATER is the ratio of the sum of yield of main crops and yield of component crop multiplied with duration of both crops to the total duration (days) of intercropping system. Delayed sowing reduces their crop duration also utilizes time effectively as compared to early sowing dates.

The aggressivity of sowing date $D_4$ was found higher (0.55) during first year. In next year it was seen in sowing dates $D_3$ (0.51). Aggressivity (Aab) was greater than (> 0) means all the sowing dates had difference in competitive ability.This might be due to delayed sowing increases the competition for soil moisture, nutrients, space and PAR within plant to plant and between two intercrops.[39,10].

Relative crowding coefficient of sowing date $D_2$ (1.51) was confirmed higher during 2016-17 and it was found higher in sowing date $D_1$ (2.28) during 2017-18. As RCC i.e. K value was greater than one (> 1) means more yield advantages than other sowing dates. As it was depends upon the row proportion of crops and yield of both the crops.

Competition index and Competition ratio during both the year of experimentation were observed in sowing dates $D_4$ i.e. 0.46, 2.03 and 0.40, 1.80 respectively except CR was seen higher in sowing dates $D_3$ (1.80) during next year. CI measures the yield of various crops when grown together as well as separately. Here CR was the ratio of individuals LER'S of the two component crops, corrected by multiplying with their sowing proportion.

The system net monetary returns were significantly influenced due to sowing dates during pooled analysis. First sowing date ($D_1$) in pigeonpea observed significantly higher net monetary returns (Rs. 43275 $ha^{-1}$) as compared $D_2$, $D_3$ and $D_4$ sowing date, during pooled analysis. A lowest system net monetary return was seen in sowing date $D_4$(Rs.1817 $ha^{-1}$). Islam et al. [24] also obtained higher net returns in early sown crop of pigeonpea.

### 3.2 Cropping Systems

The different cropping systems markedly influenced the indices of intercropping system viz. pigeonpea equivalent yield (PEY), land equivalent ratio (LER), Aggressivity, Area time equivalent ratio (ATER), relative crowding coefficient (RCC), competition index (CI) competition ratio (CR) and net monitory return (NMR) of pigeonpea were depicted in Table 1.

Total pigeonpea equivalent yield (PEY) is the best tool to determine the overall productivity potential of an intercropping system. The data presented in Table 1 reflected that Systempigeonpea equivalent yield of pigeonpea + soybean ($I_1$) found superior i.e.1958 kg $ha^{-1}$ over pigeonpea + pearlmillet ($I_2$), pigeonpea +

**Table 1. PEY, LER, ATER, Aggressivity, RCC, CI and CR as influenced by dates of sowing and different cropping systems during 2016-17 and 2017-18**

| Treatments | Yield advantage in intercropping | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | PEY (Kg ha$^{1}$) | LER | | ATER | | Aggri. | | RCC | | CI | | CR | | NMR |
| | | 2016-17 | 2017-18 | 2016-17 | 2017-18 | 2016-17 | 2017-18 | 2016-17 | 2017-18 | 2016-17 | 2017-18 | 2016-17 | 2017-18 | (Rs.ha$^{-1}$) |
| **A) Dates of sowing** | | | | | | | | | | | | | | |
| $D_1$ | 1661 | 1.17 | 1.19 | 1.02 | 1.05 | 0.46 | 0.49 | 1.41 | 2.28 | 0.35 | 0.31 | 1.39 | 1.46 | 43,275 |
| $D_2$ | 1508 | 1.15 | 1.15 | 1.00 | 1.00 | 0.46 | 0.50 | 1.51 | 1.87 | 0.36 | 0.32 | 1.57 | 1.51 | 35,750 |
| $D_3$ | 1181 | 1.19 | 1.14 | 1.05 | 1.00 | 0.51 | 0.51 | 1.24 | 1.44 | 0.39 | 0.36 | 1.85 | 1.80 | 18,174 |
| $D_4$ | 876 | 1.12 | 1.33 | 0.99 | 1.13 | 0.55 | 0.37 | 1.15 | 1.15 | 0.46 | 0.40 | 2.03 | 1.66 | 1,817 |
| **B) Cropping systems** | | | | | | | | | | | | | | |
| $I_1$- PP+SOY | 1958 | 1.26 | 1.31 | 1.08 | 1.12 | 0.43 | 0.33 | 2.40 | 2.52 | 0.10 | 0.10 | 3.01 | 2.59 | 54,449 |
| $I_2$- PP+PM | 1616 | 1.28 | 1.39 | 1.15 | 1.25 | 1.04 | 0.45 | 1.17 | 2.09 | 0.30 | 0.21 | 1.39 | 1.58 | 46,647 |
| $I_3$- PP + NIG | 1624 | 1.10 | 1.11 | 0.84 | 0.81 | -0.50 | 0.08 | 0.74 | 1.12 | 0.16 | 0.09 | 1.45 | 1.26 | 42,307 |
| $I_4$- SOLE PP | 1882 | 1.00 | 1.00 | 1.00 | 1.00 | -- | -- | -- | -- | -- | -- | -- | -- | 46,706 |
| $I_5$- SOLE SOY | 831 | 1.00 | 1.00 | 1.00 | 1.00 | -- | -- | -- | -- | -- | -- | -- | -- | -6,807 |
| $I_6$- SOLE PM | 587 | 1.00 | 1.00 | 1.00 | 1.00 | -- | -- | -- | -- | -- | -- | -- | -- | -7,001 |
| $I_7$- SOLE NIG | 648 | 1.00 | 1.00 | 1.00 | 1.00 | -- | -- | -- | -- | -- | -- | -- | -- | -3,024 |
| S.E. (m) | 30 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 1232 |
| C.D. @ 5% | 89 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 3590 |

niger ($I_3$), Sole soybean($I_5$), sole pearlmillet ($I_6$) and sole niger ($I_7$), but it was on par with sole pigeonpea ($I_4$) during pooled analysis.Pigeonpea equivalent yield (PEY) of intercropping system was recorded significantly higher except pigeonpea + pearlmillet ($I_2$), pigeonpea + niger ($I_3$) than sole pigeonpea system because of higher yield of both crops and more or less remunerative prices of intercrop than sole cropping system. The differential behavior in PEY was on account of productivity of crops in intercropping system and their relative market prices [43].

“The land equivalent ratio (LER) is the relative area of a sole crop required to produce the yield achieved in intercropping. If LER value is equal to one, it means that there is no yield advantage but when LER is more than one, then there is yield advantage. The data on LER of different intercropping systems indicated thatLER of cropping system pigeonpea + pearlmillet ($I_2$) (1.28 and 1.39) recorded maximum during 2016-17 and 2017-18 as compared to all other cropping systems. It means 28 % and 39 % more area or yield required to sole crops to obtain similar yield when grown in intercropping. Lowest LER obtained in all sole cropping systems”[12,49].

As the LER not take into account the time for which land is occupied by the component crops of an intercropping system, area-time equivalent ratio (ATER) was also calculated. The ATER provides a more realistic comparison of the yield advantage of intercropping over that of the sole cropping that the LER as it considers variation in time taken by the component crops of different intercropping systems. The ATER values shown in Table 1 revealed that ATER in all the intercropping systems was smaller than LER values indicating the over estimation of resource utilization in the latter. Hence contrary to LER, the ATER is free from the prediction of over estimation of resources utilization. Based on two year data, ATER value of pigeonpea + pearlmillet ($I_2$) (1.15 and 1.25) cropping system was found higher during both the year of research investigation. It confirmed that pigeonpea + pearlmillet ($I_2$) cropping system utilize area very efficiently as well as time also as compared to other systems. Lowest ATER was seen in pigeonpea + niger ($I_3$) (0.84 and 0.81) cropping system. “Higher ATER values in the above mentioned intercropped treatments were due to higher combined seed yield per plant of both the crops per unit area and longer duration of the crop present on the land from planting to harvest” [10,49].

## 3.3 Competition Functions

Competitive behavior of the component crops across different intercropping systems was determined in terms of aggressivity, relative crowding coefficient, competition index and Competition ratio.

When a crop is cultivated alongside another crop, its capacity to compete is determined in large part by its level of aggression. It was shown that component crops are equally competitive when the aggressivity value was zero. In a different scenario, both crops will have the same numerical value, but the dominant species' sign will be "positive" and the dominated species' sign "negative." The disparity in competitive capacities and the disparities between actual and expected yields are higher the larger the numerical value. The data shown in Table 1 revealed that aggressivity of pigeonpea + niger ($I_3$) cropping system (-0.50) was recorded negative value during first year. It means component crop show dominant effect on main crop. During second year pigeonpea + niger ($I_3$) was recorded not negative value (0.08) but near to 0 i.e. aggressivity = 0 that component crop (Niger) was equally competitive to main crop. Here pigeonpea + soybean ($I_1$) and pigeonpea + pearlmillet ($I_2$) cropping systems recorded aggressivity value more than 0; both the systems had different in competitive ability. These indices decide the suitability of intercropping systems for cultivation. Similar finding was confirmed by Yenebala [49].

Relative crowding coefficient (RCC) plays an important role in determining the competition effects and advantages of intercropping. According to Willey [47], in an intercropping system, each crop has its own RCC (K). The component crop with higher “K” value is the dominant and that with low “K” value is dominated. To determine if there is a yield advantage in intercropping, the product of the coefficient of both component crops is obtained and that is usually designated as “K”. If the product of RCC of the two species is equal, less or greater than one it means that the intercropping system has no advantage, disadvantage or advantage, respectively. RCC during both the year (2016-17 and 2017-18) confirmed greater in pigeonpea + soybean ($I_1$) i.e. 2.40 and 2.52, cropping system. As RCC value was greater than 1 means yield advantages over sole crops. Lower RCC was obtained in pigeonpea + niger ($I_3$) (0.74) cropping system means K <1 yield disadvantage confirmed over other treatments during first year. In second year it was slightly more than 1in pigeonpea + niger($I_3$) (1.12) cropping system i.e. RCC/ K = 1 no difference in yield of both the crops over rest of the systems.

Competition index (CI)) during 2016-17 year of experimentation was observed in pigeonpea + soybean ($I_1$) i.e. 0.10 cropping system. In next year pigeonpea + niger($I_3$) i.e. 0.09, was recorded lower CI. CI is the ratio of yield difference of both the crops grown in sole and intercropping to the sole yield of both the crops. As it measures the yield of various crops when grown together as well as separately. It indicates suitability of crops under intercropping.

Competition ratio (CR) is another way to know the degree with which one crop competes with the intercrop. Competition ratio (CR) during both the year of experimentation was observed in pigeonpea + soybean ($I_1$) (3.01 and 2.59) system. CR was the ratio of individuals LER'S of the two component crops, corrected by multiplying with their sowing proportion.

### 3.4 Economic Analysis

Economic analysis is essential as the farmers are often interested in profits and costs of a newly evolved technology. They also like to know about risks involved in the adoption of new practices**.** The data revealed that system net monetary returns of pigeonpea + soybean ($I_1$) found maximum Rs. 54,449 $ha^{-1}$ over pigeonpea + pearlmillet ($I_2$), pigeonpea + niger ($I_3$), sole pigeonpea ($I_4$), Sole soybean($I_5$), sole pearlmillet ($I_6$) and sole niger ($I_7$) during pooled analysis. Negative values of net monetary returns were confirmed in sole soybean $I_5$), sole pearlmillet ($I_6$) and in sole niger ($I_7$) during pooled analysis.

## 4. CONCLUSION

In conclusion, this study significantly contributes to advancing our understanding of agro-environmental factors, climate variability, soil dynamics, and agronomic management practices in tropical environments of Latin America [36,35]. By evaluating pigeonpea-based intercropping systems under different dates of sowing, the study provides actionable insights for enhancing agricultural productivity, economic benefits, and climate resilience in the region [38,32]. The findings have immediate implications for informing agronomic management decisions and guiding sustainable agricultural practices tailored to the specific challenges and opportunities of tropical environments in Latin America [8,33,31].

## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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