



Revisiting Intercropping Indices in Pearl Millet-Pulse Intercropping System under Rainfed Condition

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ABSTRACT

Background: In the rainfed conditions of India, which is characterised with low and erratic rainfall conditions, growing of sole crop is often risky and results in low productivity. In this kind of circumstances, intensification and crop diversification strategies are crucial for achieving higher yields. Intercropping, which is the practice of growing several compatible crop species on the same piece of land at the same time, is a workable strategy to stabilize the production of rainfed crops.

Methods: A field experiment was carried out to evaluate suitable intercrop in pearl millet-based cropping system under two different row ratios, at Karunya Institute of Technology and Sciences, Coimbatore during *rabi* season of 2022-23. The experiment consisted of seven treatment combination which were tested in randomized block design with three replications.

Result: The results of the experiment proved that the pearl millet + blackgram (4:1) intercropping may provide viable intensification options, especially for smallholder farmers.

Key words: Economics, Intercropping indices, Intercropping, Pearl millet, Yield.

INTRODUCTION

The greatest challenge in a populous country like India in agriculture is food production. We are in need to lift our annual food production to 400 million tonnes by 2050 (ICAR, 2024) against the current level of 329.68 million tonnes to meet our growing demand of the population and increasing average income to give quality and nutritious food. On the other hand, climate change, erratic rainfall, scarcity of land resources and the diminishing fertility of the soil on a local and global scale have raised doubts about agriculture's capacity to meet the demands of the growing population.

In these conditions, implementing high-intensity cropping systems could be a practical way to boost overall agricultural production and productivity. It is not advantageous to grow a single crop a year or cereals as the only crop in order to satisfy the various needs of customers and farmers. Intercropping is a productive technique that increases productivity per unit area of land per unit time by cultivating multiple crops in one field. Its main goal is to make better use of the environmental resources that are available.

Millets - one of the oldest foods known to humans and owing to its high nutrient value they are now considered as "Nutri - cereals" or "Nutra-cereals". Pearl millet [*Pennisetum glaucum* (L.)] popularly known as *bajra*, *bajri*, *cumbu* etc. is an important major millet, which ranks as fourth most important cereal crop next to rice, wheat and sorghum in India.

Pulses and millets can be intercropped to increase production and profitability per unit area and time while reducing the need for nitrogenous fertilizers. One might minimize mutual rivalry by choosing crops with distinct growth tendencies, which can significantly lessen it. Owing to this, the present experiment therefore was planned to study

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the competitiveness of pearl millet with pulse grown under intercropping system.

However, the interactive competition among the companion crops in pearl millet-pulse intercropping systems and economic gains are only partially explored. The present experiment, therefore was planned to study the competitiveness of pearl millet with pulse crops grown in intercropping systems in two different row ratios (4:1 and 6:1 ratios).

MATERIALS AND METHODS

The experiment was carried out during *rabi* season of 2022-23 at Karunya Institute of Technology and sciences, Coimbatore, Tamil Nadu. The experiment was performed in triplicate in experimental plots measuring 7.2×5.5 m arranged in a RBD with seven treatments viz., T₁- sole crop of pearl millet, T₂- pearl millet + blackgram (4:1), T₃- pearl millet + blackgram (6:1), T₄- pearl millet + cowpea (4:1), T₅- pearl millet + cowpea (6:1), T₆- pearl millet + redgram (4:1) and T₇- pearl millet + redgram (6:1). The

tested cultivars of pearl millet (*Pennisetum glaucum* L.), blackgram (*Vigna mungo* L.), cowpea (*Vigna unguiculata* L.) and redgram (*Cajanus cajan* L.) were 'Co 10', 'VBN 8', 'VBN 3' and 'Co (Rg) 7', respectively. Economic benefits like net returns and B:C ratio was calculated according to market price of each crop. Both under pearl millet sole cropping and under intercropping situations uniform inter-row spacing of 0.45m and inter-hill spacing of 0.10 m (Fig 1) was adopted.

Evaluation of intercropping systems

Assessment of the biological efficiency of pearl millet-pulse intercropping system

The biological efficiency of the pearl millet pulse-based intercropping system was assessed using following indices.

The land equivalent ratio (LER) (Willey, 1979) is the relative size of land under a sole crop system which will be necessary for obtaining the same yield as in intercropping system.

$$LER = LERa + LERb$$

$$LERa = \frac{Yab}{Yaa} \text{ and } LERb = \frac{Yba}{Ybb}$$

Where,

LERa and LERb = Partial LER of main crop and intercrop, respectively.

Yaa and Ybb = Yield of 'a' and 'b' in sole crop situation.

Yab and Yba = Yield of 'a' and 'b' in intercropping situation.

LER > 1 = Yield advantage, LER value equal to 1 is neither advantage or disadvantage.

Land equivalent coefficient (LEC) is a product of LERa and LERb and was assessed using the following formulas as given by Adetiloye *et al.* (1983). Where, LEC > 0.25 = Advantageous.

$$LEC = LERa * LERb$$

Mead and Willey (1980) proposed area time equivalent ratio (ATER) as a modification to LER. It is used to compare the yield benefits of intercropping to monocropping, taking into account the time required from planting and harvesting (Doubi *et al.*, 2016).

$$ATER = \frac{(LERa * ta) + (LERb * TB)}{T}$$

Where,

ta and tb = Growth period in days between planting and maturity for main and intercrop.

T = Component crop with longest growing period.

Land use efficiency (LUE) refers to the land use during the agricultural year (Mead and Willey, 1980) and expressed in percentage

$$LUE = \left(LER + \frac{ATER}{2} \right) * 100$$

The system productivity index (SPI) (Odo, 1991) evaluated the productivity and stability of intercropping systems by standardizing intercrop yield in relation to main crop.

$$SPI = Yab + \left(\frac{Yaa}{Ybb} \right) * Yba$$

Competition indices of the intercropping system

Following indices are used to evaluate the competitive effect of pearl millet - pulse intercropping systems.

De Wit (1960) first proposed the relative crowding coefficient (RCC or K) in plant competition theory. It is used for the evaluation and comparison of one crop species competitive ability to another in a mixture (RCC is > 1 = yield advantage).

$$RCC = \frac{Yab * Zba}{(Yaa - Yab) * Zab}$$

Where,

Zab and Zba = Sown proportion of 'a' in combination with 'b' and 'b' in combination with 'a'.

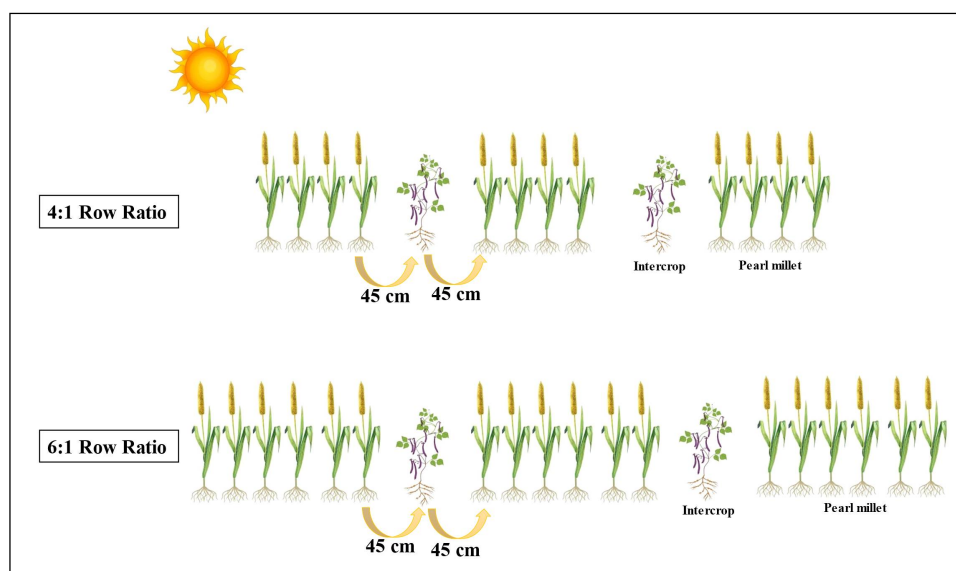


Fig 1: A schematic representation of intercropping ratios.

Aggressivity (A) is a competitive index that measures how much one crop component has a higher relative yield than another (McGilchrist, 1965). Aggressivity value >0 indicates that one crop is dominating over the other.

$$\text{Aggressivity} = \frac{Y_{ab}}{Y_{aa} * Z_{ab}} * \frac{Y_{ba}}{Y_{bb} * Z_{ba}}$$

Competition index (CI) is the product of two equivalent factors of each component crops. The value of the index less than one will be an advantage.

CI = Equivalent factor for 'a' × Equivalent factor for 'b'

Where,

Equivalent factor for 'a' = Per plant yield of 'b' / Per plant yield of 'a'

Equivalent factor for 'b' = Per plant yield of 'a' / Per plant yield of 'b'

The competitive ratio (CR) (Willey and Rao, 1980) was used to evaluate crop competitiveness in intercropping systems (CR <1 Intercropping is advantageous).

$$\text{Competition ratio} = \frac{LER_a * Z_{ba}}{LER_b * Z_{ab}}$$

Evaluation of the economic efficiency of intercropping systems

The economic efficiency of the intercropping systems was analysed using following indices.

Lal and Ray (1976), proposed economics of crop by converting grain/seed/fodder in terms of gross return for valid comparison as grain equivalent yield (GEY).

$$\text{GEY (kg/ha)} = \frac{Y_b * P_b}{P_a}$$

Where,

P_a and P_b = Market prices of pearl millet and pulse.

Y_a = Yield of intercrop.

Income equivalent ratio (IER) is also known as monetary equivalent ratio is the area needed for pure stand versus intercropping to generate the same gross income at the same management level. It uses similar concept as LER (Devasenapathy, 2008). However, unlike LER, which measures yield in terms of plant product productivity, IER uses gross income.

$$\text{IER} = \frac{Y_{ab} * P_a}{Y_{aa} * P_a} + \frac{Y_{ba} * P_b}{Y_{bb} * P_b}$$

The monetary advantage index (MAI) is used to assess the economic feasibility of intercropping against sole cropping. MAI is a crucial indicator for assessing the economic viability of intercropping. The higher MAI value will indicate more profitable cropping system over the other. It is calculated (Willey, 1979) as follows:

$$\text{MAI} = \frac{LER - 1}{LER} * VCI$$

Where, the value of the combined intercrops (VCI) was computed as shown in the following equation (Finney, 1990).

$$\text{VCI} = (Y_{ab} * P_a) + (Y_{ba} * P_b)$$

Although the LER is the most commonly used agronomy index, it does not consider the economic value of crops. Relative value total (RVT) given by Alabi and Esobhawan (2006) addresses this shortcoming. This index is especially useful for farmers looking to maximize the economic benefits of intercropping.

$$\text{RVT} = \frac{(Y_{ab} * P_a) + (Y_{ba} * P_b)}{Y_{aa} * P_b}$$

Relative net return index (RNRI) is an important function to find the profitability in intercropping system and it is calculated by the formula given by Mead and Willey (1980). (RNRI >1 = Intercropping system is advantageous)

$$\text{RNRI} = \frac{(Y_{ab} * P_a) + (Y_{ba} * P_b) \pm D_{ab}}{Y_{aa} * P_a}$$

Where,

D_{ab} = Difference in the cost of cultivation (variable cost) between pearl millet-pulse intercropping.

The data recorded on pearl millet and intercrops, were subjected to statistical analysis of variance method as suggested by Gomez and Gomez (1984).

RESULTS AND DISCUSSION

Effect of pearl millet-pulses intercropping on yield and economics

Different pearl millet - pulses intercropping treatments significantly influenced the yields of pearl millet and pulse intercrops (Table 1). The higher and lower pearl millet yield were obtained under pearl millet sole crop (2503 kg/ha) and pearl millet + cowpea (4:1) (1807.8 kg/ha). Additionally, higher pearl millet yield under intercropping situation was obtained under pearl millet + blackgram intercropping (4:1) (2485.3 kg/ha) compared to other intercropping systems. Flavia *et al.*, (2023) also recorded higher yield under maize sole crop followed by maize + greengram in 4:1 row ratio.

Gross income, net income and B:C ratio followed an analogous trend (Table 1). For instance, with respect to blackgram (4:1) intercropping treatment (Rs. 1,40,978/ha) resulted in higher gross income compared to other intercropping systems. Whereas, pure stand of pearl millet fetched a gross income of Rs. 1,32,540/ha. Benefit: cost ratio differed substantially between treatments with the higher values noted in pearl millet + blackgram (4:1) (2.45), whereas pearl millet + cowpea (4:1) had the least ratio of 1.78. It might be due to pearl millet + blackgram 4:1 row proportion produced higher grain yield which has contributed to more economics. These results were corroborated with the findings of Kumar *et al.* (2022).

Biological efficiency of pearl millet-pulses intercropping system

The biological efficiency of various intercropping systems was assessed by different evaluation indices (Fig 2). The combined land equivalent ratio (LER) was derived by summing the LER of pearl millet and pulses. The results showed that pearl millet + redgram (4:1) resulted in the

higher LER of 1.23. Jan *et al.* (2016) found that intercropping system of maize and black gram resulted in LER values greater than unity, indicating a yield advantage. The LER values the intercropping treatments with pearl millet + blackgram (6:1) (0.93) and pearl millet + cowpea in both 4:1 (0.95) and 6:1 (0.97) ratio showed lower LER (<1) which proved these additive series of intercropping system was not beneficial in terms of total yield from a unit area. These results also align with previous research works conducted by Arif *et al.* (2022).

From the LEC values shown in Table (2), the cultivation system (4:1) pearl millet + redgram intercropping system produced a higher LEC (0.32), indicating that this system has greater yield advantage. They made better use of the growth elements and turned them into an economic crop for the two crops, avoiding competition and deception when planting them together. In other intercropping systems, LEC values were less than 0.25. These results are in agreement with the findings of Ahmed and Aziz (2023).

According to Maitra *et al.* (2021), the LER overestimates intercropping system efficiency, while the ATER underestimates it when time is factored in. In terms of

ATER, pearl millet + redgram (4:1) had the highest value (1.18), indicating a time and space advantage over the other treatments. Furthermore, treatments such as pearl millet + blackgram (4:1) and pearl millet + redgram (6:1) produced ATER values greater than one, indicating their effectiveness. These findings are consistent with previous studies by Priya *et al.* (2023). Similar, differences were obtained for LUE and SPI with respective higher values of 185.5 and 3124.9 (kg/ha) in treatment with pearl millet + redgram with ratio of 4:1.

One effective indicator that can be used to evaluate the total production potential of intercropping systems is crop equivalent yield. Pearl millet equivalent yield (PMGEY) (Table 1) was calculated for comparing different intercropping combinations. The higher pearl millet grain equivalent yield (5467.7 kg/ha) was recorded in 6:1 row ratio of pearl millet + black gram (4:1) which was closely followed by 4:1 row proportion of pearl millet + redgram (4:1) (5105.3 kg/ha). Similar results were also reported by Reddy *et al.* (2023) in finger millet based intercropping system.

Table 1: Yield and economics of pure stands and pearl millet-pulse intercropping systems.

Treatments	Yield (kg/ha)		PMGEY (kg/ha)	Gross income (Rs/ha)	Cost of cultivation (Rs/ha)	Net income (Rs/ha)	B:Cratio
	Pearl millet	Intercrops					
T ₁ - Pearl millet sole crop	2503.0	-	-	132541	56577	75964	2.34
T ₂ - Pearl millet + blackgram (4:1)	2485.3	139.6	5467.7	140978	57557	83421	2.45
T ₃ - Pearl millet + blackgram (6:1)	2171.3	57.4	4776.9	119385	57377	62008	2.08
T ₄ - Pearl millet + cowpea (4:1)	1807.8	204.6	2892.5	102712	57677	45035	1.78
T ₅ - Pearl millet + cowpea (6:1)	2063.5	136.7	3301.6	114034	57377	56657	1.99
T ₆ - Pearl millet + redgram (4:1)	2219.7	309.1	5105.3	138007	57467	80541	2.40
T ₇ - Pearl millet + redgram (6:1)	2139.4	172.7	4920.6	125351	57287	68064	2.19
Sed	216.1		354.07				
CD (P=0.05)	451.5		739.68				

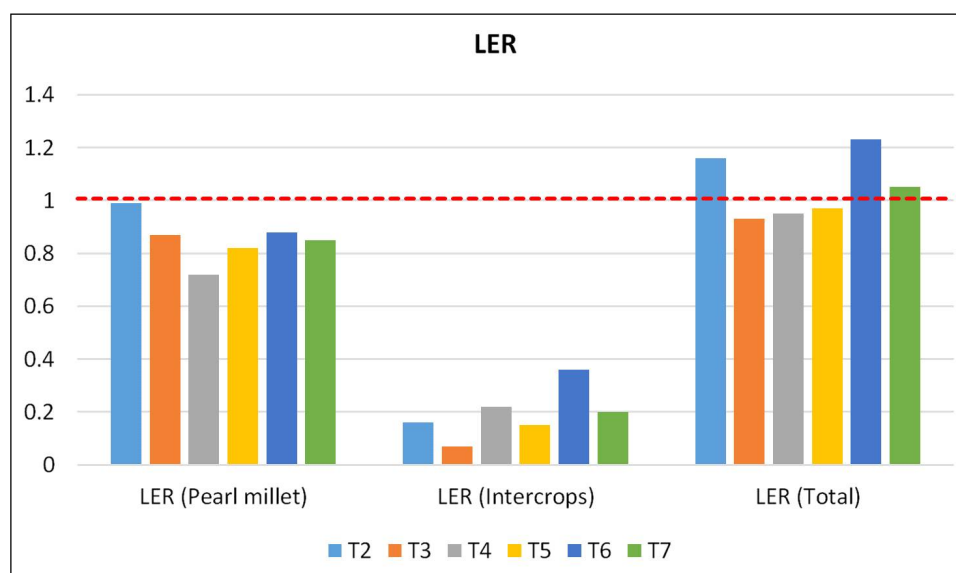


Fig 2: Land equivalent ratios (LERs) of pearl millet-pulses intercropping system. The dashed line denotes an LER equal to 1.

Table 2: Effect of pearl millet-pulse intercropping systems on various intercropping indices.

Treatments	LEC	ATER	LUE (%)	SPI (kg/ha)	RCC	CI	CR	VCI (Rs/ha)	MAI (Rs/ha)	RVT	RNRI
T ₂ - Pearl millet + blackgram (4:1)	0.16	1.12	172.0	2894.15	1.97	0.99	1.54	1,32,626	18,293	1.06	1.05
T ₃ - Pearl millet + blackgram (6:1)	0.06	0.93	139.0	2339.23	0.61	0.93	2.07	1,11,994	8,429	0.89	0.89
T ₄ - Pearl millet + cowpea (4:1)	0.16	0.94	140.2	2359.44	0.46	0.84	0.82	96,488	5,078	0.77	0.76
T ₅ - Pearl millet + cowpea (6:1)	0.12	0.97	144.3	2432.10	0.50	0.80	0.91	1,07,251	3,317	0.86	0.85
T ₆ - Pearl millet + redgram (4:1)	0.32	1.18	185.5	3124.94	1.00	0.85	0.61	1,31,041	24,504	1.05	1.03
T ₇ - Pearl millet + redgram (6:1)	0.17	1.02	157.5	2645.16	0.57	0.80	0.71	1,18,175	5,793	0.94	0.94

Competition indices under pearl millet-pulses intercropping system

The higher combined K value (RCC) was obtained with intercropping 4 row of pearl millet with one row of blackgram (1.97) which indicated higher yield advantages than other treatments. In terms of RCC, the above treatment was followed by pearl millet + redgram (4:1) (Table 2). This could be due to the complementary effects of the two crop species studied. Similar results were reported in earlier researches conducted by Arif *et al.* (2022) in pearl millet and cowpea intercropping system.

The aggressivity of pearl millet showed positive values in intercropping treatments with blackgram in both 4:1 and 6:1 row ratios (+0.36 and +0.55, respectively). The positive value of aggressivity indicated pearl millet as dominant crop and cowpea as dominated crops in the said treatments (Fig 3). Comparatively higher value of aggressivity noted with pearl millet + blackgram (6:1) (+0.55) indicated greater difference in competitive ability between the competitive crops, resulting in wide variation between the actual and expected yield. The higher pearl millet population in the mixed stand with the replacement planting geometry was likely the reason of the observed increase in aggressiveness in the pearl millet + blackgram (6:1) ratio. The results are in conformity to the findings of Harati *et al.* (2023).

The competition index of pearl millet was persuaded by the various intercropping system. All the intercropping treatments produced the competition index of less than 1 (Table 2). This showed that growing the intercrops like blackgram, cowpea and red gram is of advantage in pearl millet intercropping systems. The results corroborate with the findings of Keerthapriya *et al.* (2019). The calculated competition ratio values show that when pearl millet is intercropped with blackgram at 6:1 ratio (2.07), the competitive ratio was highest among the intercropping systems. Red gram intercropping showed the lowest CR value at 4:1 ratio (0.61). The growth habit and early establishment of the crops had a significant impact on the CR, as noted concurrently by Sharmili *et al.* (2023).

Economic efficiency under pearl millet-pulses intercropping system

Income equivalent ratio in the treatments pearl millet + blackgram (4:1), pearl millet + redgram in both 4:1 and 6:1 row ratio (Fig 4) is greater than unity (>1), indicating the yield advantage over pure stand of pearl millet. The higher IER was recorded in pearl millet + redgram (4:1) (1.24) and the lowest IER was recorded in pearl millet + cowpea (4:1) (0.96). Similar results were also observed by Abinaya *et al.* (2020) in finger millet based intercropping system.

The higher value of combined crops index and monetary advantage index was recorded by pearl millet + blackgram (4:1) (Table 2). The probable reason for this result could be the greater yield potential of blackgram compared to other pulses and the difference in market price which resulted in more MAI in pearl millet intercropped with blackgram (Sain *et al.*, 2023).

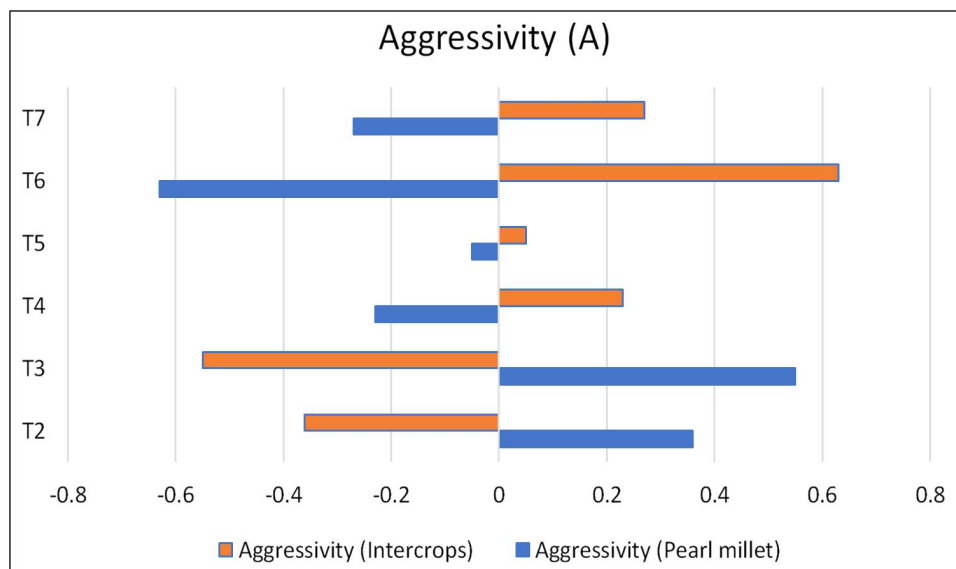


Fig 3: Aggressivity between pearl millet and pulse intercrops.

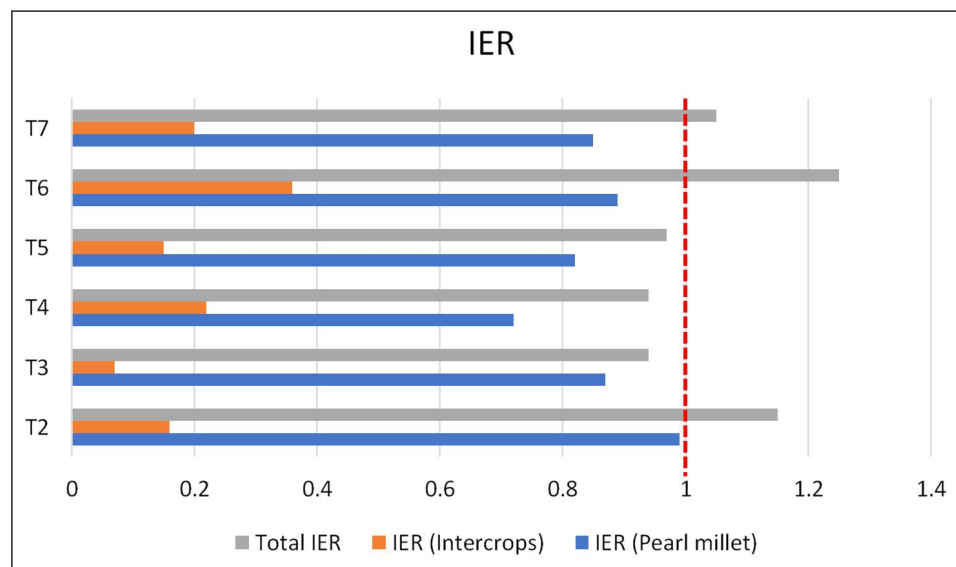


Fig 4: Income equivalent ratios (IERs) of pearl millet-pulses intercropping system. The dashed line denotes an IER equal to 1.

The relative value total of pearl millet recorded under pearl millet + blackgram (4:1), pearl millet + redgram in 4:1 row ratio was higher than all remaining intercropping treatments. This indicates that the economic advantage of pearl millet and blackgram/redgram intercropping (4:1 ratio) is more than the sole cropping of pearl millet. Similar results were also observed by Chavda *et al.* (2023). The RNRI value of all treatments except little millet + blackgram at 4:1 ratio (1.05) is found disadvantageous (Table 2). This is due to the spatial complementarity that was bound by substantial yield advantages from intercropping (Sharmili *et al.*, 2023).

CONCLUSION

The present study evaluated the biological and economic feasibility of pearl millet-pulse intercropping systems in

population ratios (4:1 and 6:1) against the corresponding pure stands. Following the assessment of these intercropping systems using 14 different indices, the study indicated that pearl millet + blackgram (4:1) intercropping is beneficial in increasing yield of the components crops resulting in higher land-use efficiency and is a viable farming technique, particularly for smallholder farmers. Additionally, it proved that intercropping yielded a larger economic return than pure stand.

Scope for future research

Growing interdisciplinary research endeavours could employ a systems-level perspective to comprehend the mechanisms functioning in intercropping systems and move beyond the traditional focus on resources by incorporating the functions of above-and below-ground plant interactions with other organisms.

Conflict of interest

All authors declare that they have no conflict of interest.

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