Indian Journal of Agronomy **69** (3): 311–319 (September 2024)
DOI: 10.59797/ija.v69i3.5527

Research Paper

Evaluation of barnyard millet intercropping systems in semi-arid zone of Hisar

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Received: July 2024; Revised accepted: August 2024

ABSTRACT

A field experiment was conducted at CCSHAU, Hisar during *Kharif seasons* of 2021–22 and 2022–23 in three times replicated randomized block design. The experiment was comprised of thirteen barnyard millet-based intercropping systems in replacement series with greengram and sesame as intercrop with row ratio of 5:1, 4:2, 3:3, 2:4, 1:5 in addition to their sole crops. Results revealed that the barnyard millet intercropped with greengram was found superior over sole barnyard millet in terms of different intercropping indices. But, barnyard millet intercrop with sesame was found uneconomical. The barnyard millet + greengram (1:5) recorded the highest land equivalent ratio (LER; 1.25), barnyard millet equivalent yield (BMEY; 2977 kg/ha), land use efficiency (LUE; 119.4%), area time equivalent ratio (ATER; 1.14), relative crowding coefficient (RCC; 1.79), monitory advantage index (MAI; ₹ 10,756/ha), system productivity index (SPI; 2903), intercropping advantage index (IAI; 34.6), net return (₹ 23,111/ha), benefit:cost (1.42) and per day return (₹ 300.3) which was closely followed by barnyard millet + greengram (4:2). Hence, barnyard millet + greengram (1:5) intercropping system is a suitable option for achieving higher monetary returns and resource use efficiency as compared to sole barnyard millet under semiarid region of India.

***Key words*:** Intercropping, Barnyard millet, Greengram, Sesame and Row ratio

Millets cultivation spread over 74 Mha of the globe with the production of millets is 89.17 million metric tonnes (FAO, 2022). India is the global leader in production of millet with a share of ~15% of the world's total production. In India, millets are cultivated majorly in 21 states over an area of 12.53 Mha, with production of 15.53 mt and productivity of 1237 kg/ha (FAO, 2022). Barnyard millet (*Echinochloa frumentacea)* is fourth most important minor millet, providing food security to many poor people across the world. In India, it is mainly cultivated in Orissa, Maharashtra, Madhya Pradesh, Tamil Nadu, Bihar, Punjab, Gujarat and hills of Uttarakhand (Kumar *et al*., 2000). Barnyard millet is the minor millet which is emerged as very essential dual-motive crop for feed and fodder. Despite barnyard millet's excellent nutritional and agronomic value, the lack of awareness has led this crop to be considered a neglected and underutilized crop. Low productivity of millets as compared to other cereal crops is also a reason for low interest of farmers about the millet's cultivations. The intercropping of millets with legumes can enhance the economic returns per unit area. Intercropping is considered the most suitable for sustaining crop productivity (Buttar *et al.,* 2023). Cereal association with legumes and oilseeds in polyculture is always noteworthy in terms of multiple benefits (Singh *et al.,* 2021). Furthermore, millets are suitable candidates for mixed and intercropping and offer the sustainable uses of natural resources and play a crucial role in improving the livelihood security of small marginal grower of the rainfed areas (Singh *et al.,* 2022). Intercropping is a beneficial system of crop production aimed at maximizing production and profits by effectivity utilizing the nutrients and water, and other resources (Kumar *et al.,* 2022; Ajibola and Kolawole, 2019). Growing cereals as sole crop is not a remunerative venture in present scenario, hence there is need to integrate pulses and oilseeds in cereals production system to fulfill food and nutritional demand of rapid growing population (Avasthe *et al.,* 2023). But success of intercrops depend on ultimate density, planting date, resources availability, soil and crop management practices and intercropping models (Kumar *et al.,* 2022; Singh *et al.,* 2021). Spatial arrangement and plant population in an intercropping system have important effects on the balance of competition between component crops and their overall productivity. It was hypothesized that the intercropping of barnyard millet with green gram

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and sesame may be robust option for yield enhancement because of their diverse morphology, growth rate and similar climatic requirements and such intercropping systems are quite popular in India. Therefore, current study was conducted to assess the effect of different inter cropping combination on farm productivity and profitability under semi-arid condition of India.

MATERIALS AND METHODS

A field experiment was carried out at CCS Haryana Agricultural University, Hisar, Haryana, India (29°10' N latitude, 75°46' E longitude and 215.2 M altitude) during *Kharif* season of 2022 and 2023 in three times replicated randomized block design. The experiment was comprised of thirteen treatments to evaluate barnyard millet based intercropping systems taking green gram and sesame as intercrop with barnyard millet + greengram/sesame with row ratio of 5:1, 4:2, 3:3, 2:4, 1:5 in addition to their sole crop. Experimental soil was sandy loam in texture, slightly alkaline in pH (7.6), low in organic carbon (0.38%), medium in available phosphorus (21.6 kg/ha), and low in available nitrogen (198 kg/ha) and available potassium (248 kg/ha). The maximum and minimum temperatures during the crop study period were congenial for the growth and development of crops. Sowing of sole and intercrops was done at 30 cm row to row distance. In intercropping treatments, barnyard millet rows were replaced with intercrops as per treatments in various row ratio of barnyard millet + intercrop varying from 5:1, 4:2, 3:3, 2:4 and 1:5. Barnyard millet variety VC 27 was intercropped with green gram (MH 1871) and sesame (HT 2). Crop was fertilized with 40 kg N/ha and 40 kg P^2O^5. Half dose of nitrogen along with full quantity of phosphorus was applied at the time of sowing. Remaining half quantity of nitrogen was applied at 25-30 days after sowing. Other crop management practices were followed as per the recommended package of practices. The economic yield of different crops was converted into barnyard millet equivalent yield (BEY) based on prevailing market price. Other input and output prices for economical calculation were used as given by department of agricultural economics, CCS Haryana Agricultural University, Hisar. Different indices like the relative yield, competitiveness, land use and economic performance of different intercropping systems were calculated and presented based on pooled analyzed data from two years as follows:

Relative Crowding Coefficient (RCC or K): It is a measure of the relative dominance of one species over the other in a mixture. The K was calculated as:

$K= (K_M \times K_I)$

$K_M = Y_{mi} \times Z_{im}/((Ym - Ymi) \times Zmi)$

$K_I = Yim \times Zmi/((Yi - Yim) \times Zim)$

where Zmi and Zim were the proportions of main crop and intercrop in the mixture, respectively. When the value of K is greater than 1, there is a yield advantage; when K is equal to 1, there is no yield advantage; and when it is less than 1, there is a disadvantage.

Aggressivity (A): The aggressivity was formulated as follows

$A_{intercrop} = (Yim/Yi \times Zim) - (Ymi/Ym \times Zmi)$

$A_{maincrop} = (Ymi/Ym \times Zmi) - (Yim/Yi \times Zim)$

Competitive Ratio (CR): The CR gives a better measure of competitive ability of the crops and is also advantageous as an index over K and A. The CR represents the ratio of individual LERs of the two component crops and considers the proportion of the crops in which they are initially sown. The CR is calculated according as per the following formula.

$CR_{maincrop} = (LER_{maincrop}/LER_{intercrop}) (Z_{intercrop\text{-}maincrop}/Z_{maincrop\text{-}intercrop})$

$CR_{intercrop} = (LER_{intercrop}/LER_{maincrop}) (Zmaincrop_{\text{-}intercrop}/Z_{intercrop\text{-}maincrop})$

$Z_{intercrop}$ and $Z_{maincrop}$ are the proportional sown area under inter and main crop in intercropping, respectively.

Actual Yield Loss (AYL): The AYL was calculated with the following euation.

$AYL = AYL_{maincrop} + AYL_{intercrop}$

$AYL_{maincrop} = ((Ymi/Zmi)/(Ym/Zm)) - 1$

$AYL_{intercrop} = ((Yim/Zim)/(Yi/Zi)) - 1$

Land Equivalent Ratio (LER)

$$LER = \sum_{i}^{m} \frac{Y_i}{Y_{ij}}$$

Y_i = Individual crop yield under intercropping system

Y_{ij} = Individual crop yield under sole cropping system

Land Equivalent Coefficient (LEC)

LEC= LA x LB

Where, LA = LER of main crop

LB = LER of intercrop

Area Time Equivalent Ratio (ATER): It considers the duration of the crops and permits an evaluation of crops on yield per day basis.

$$ATER = \frac{L_A \times T_A + L_B \times T_B}{T}$$

Where, L_A and L_B are partial LER of component crops A and B, T_A and T_B are duration of crops A and B and T is the total duration of the intercropping system.

Crop Performance Ratio (CPR): Th CPR was calculated with the following equation. The CPR for species X, in an intercrop composed of species X and Y,

CPRx= Yix/(Pix*Ysx)

Where Yix and Ysx are its yields per unit area (g m^{-2}) in the intercrop and sole crop respectively, and Pix is the proportional sown area of species X in the intercrop.

CPRy=Yiy/(Piy*Ysy)

Where Yiy and Ysy are its yields per unit area (g m^{-2}) in the intercrop and sole crop respectively, and Piy is the proportional sown area of species Y in the intercrop.

Total CPRxy=Yix +Yiy/(Pix*Ysx) + (Piy*Ysy)

Where Yix, Ysx, Pix, Yiy, Ysy and Piy are as defined previously.

Income Equivalent Ratio (IER): It is calculated by the following formula.

$$IER = \frac{\text{Net return in intercropping system}}{\text{Net return in sole cropping system}}$$

Monetary Advantage Index (MAI): It is an index which tells the relative money value of produce under inter-cropping system.

$$MAI = \text{Value of combined yield of intercrop} \times \frac{LER - 1}{LER}$$

Where, LER is land equivalent ratio.

System Productivity Index (SPI): This was calculated with the following expression

SPI = (SA / LB × Lb) + Sa

Where: SPI =System productivity index,

SA and LB =Mean yield of main crop and intercrop in sole cropping,

Sa and Lb =Yield of main crop and inter crop in intercropping.

Land use efficiency (LUE):

LUE= (LER + ATER) × 100/2

Intercropping Advantage Index (IAI):

$IAI_{\text{main crop}} = AYL_{\text{maincrop}} P_{\text{maincrop}}$, and $IAI_{\text{intercrop}} = AYL_{\text{intercrop}} P_{\text{intercrop}}$

$IAI_{\text{Total}} = IAI_{\text{maincrop}} + IAI_{\text{intercrop}}$

Where, Pmaincrop and $P_{\text{intercrop}}$ are the commercial value of main crop and intercrop, respectively

Relative Net Returns Index (RNRI) (Jain and Rao, 1980):

RNRI= ((PiYi) + (PjYj) ± Dij) / (Pi Yii)

Where, Yi - Yield of the i^{th} major crop ha^{-1}, Yj - Yield of the j^{th} intercrop ha^{-1}, Pi - Unit price of the product of i^{th} major crop, Pj - Unit price of the product of j^{th} intercrop, Yii - Yield of i^{th} sole crop ha^{-1} and Dij - Differential cost of cultivation of ij^{th} crop combination in comparison to i^{th} sole crop.

Barnyard millet Equivalent yield (CEY): CEY was calculated to compare system performance by converting the yield of non-barnyard millet crops into equivalent barnyard millet yield on a price basis, using the formula

CEY=Yx (Px/Pr)

where Yx is the yield of non-barnyard millet crops (q ha^{-1}), Px is the price of non-barnyard millet crop (₹ q^{-1}) and Pr is the price of barnyard millet.

The observations recorded during the course of investigation were tabulated and subjected to analysis of variance techniques as described by Gomez and Gomez (1984).

RESULTS AND DISCUSSION

Barnyard millet seed yield and inter crop yield: Intercropping of greengram and sesame in replacement series with barnyard millet has significantly reduced the barnyard millet seed yield as compared to sole barnyard millet (Table 1). Irrespective of row ratios, sesame intercrop with barnyard millet recorded higher seed yield reduction as compared to barnyard millet intercrop with greengram. Irrespective of intercrops, intercropping of barnyard millet + intercrop in 5:1 and 1:5 row ratios recorded significantly lower and higher seed yield loss over sole barnyard millet, respectively. Intercropping of barnyard millet with greengram was found effective over barnyard millet + sesame intercropping at all row ratios. Replacement of barnyard millet with green gram in intercropping with row ratio of 5:1 to 1:5 reduced the seed yield of barnyard millet by 9.2 to 57.5%, while replacement of barnyard millet with sesame in intercropping with row ratio 5:1 to 1:5 resulted in 16.7 to 66.1% seed yield reduction of barnyard millet as compared to sole barnyard millet crop. Higher sole crop yield as compared to the intercrop under different crop combinations under different agro condition was also reported by Baldev *et al.* (2003) and Anishetra and Kalaghatagi (2020). Concerning to inter crop yield, seed yield of both intercrops in intercropping with barnyard millet at all row ratios of combination declined significantly over their sole planting (Table 1). Barnyard millet + greengram intercropping row ratios from 5:1 to 1:5 resulted in 90.5 to 25.5% reduction in seed yield of greengram over sole greengram crop. Replacement of sesame in with barnyard millet + from 5:1 to 1:5 row ratio declined sesame seed yield by 88.4 to 27.3% over sole sesame crop, respectively. These results were also in conformity with findings of Padhi *et al*. (2010).

Barnyard millet Equivalent Yield (BEY): Intercropping of barnyard millet with greengram and sesame affected barnyard millet equivalent yield significantly (Table 1). Among intercrops, greengram as sole and intercropping with barnyard millet recorded significantly higher BEY than sole barnyard millets which may be due to its higher market price and yield obtained compared to sesame. Sesame as sole crop and intercrop with barnyard millet at all row ratios recorded significantly lower BEY than sole barnyard millet crop. Among all intercropping systems, barnyard millet + greengram (1:5) recorded highest BEY (2977 kg/ha) (Table 1), which was 26.9% higher than sole barnyard millet crop. Anishetra and Kalaghatagi (2020), also recorded significantly higher sesame equivalent yield with sesame + foxtail millet of 2:4 (703 kg/ha). These results are also corroborated with the findings of Kiranmai *et al*. (2021) and Choudhary (2012).

Land use efficiency (LUE) and land equivalent coefficient (LEC): Significant variation among intercropping systems was found regarding LUE and LEC (Table 1). Barnyard millet intercrop with greengram with all row ratios recorded LUE more than hundred, which showed better and efficient use of land as a resource in intercropping compared to sole planting. Barnyard millet + sesame intercrop with all row ratios except barnyard millet + sesame (1:5) recorded LUE less than hundred, hence found uneconomical. Irrespective of row ratios, barnyard millet intercrop with greengram recorded higher LEC than barnyard millet + sesame intercropping among other intercropping systems, barnyard millet + green gram (1:5) closely followed by barnyard millet + green gram (2:4) recorded significantly higher LUE (119.4 percent) and LEC (0.37). Higher land use efficiency of lupine +wheat (75:100 ratio) followed by lupine +finger millet mixtures (75:100 ratios) was also reported by Yayeh *et al*. (2014). Higher productivity of intercropping over sole cropping was also reported by Kumar *et al.* (2023).

Land equivalent ratio (LER) and area-time equivalency ratio (ATER): LER and ATER were significantly affected with intercropping systems (Tables 1 and 2). Irrespective to intercrops, LER for barnyard millet crop was declined with decline in plant population compared to intercrop. Higher LER for barnyard millet (0.91 and 0.85) was recorded with row ratio of 5:1 when barnyard millet was intercropped with greengram and sesame, respectively, which may be due to higher barnyard millet yield in these intercropping treatments compared to others. Higher LER for intercrop (0.82 and 0.71) was recorded with row ratio of 1:5 when barnyard millet was intercrop with greengram and sesame, respectively. Intercropping of barnyard millet with greengram with all row ratios was recorded with LER values more than one, hence proved more economical than sole planting of barnyard millet. Barnyard millet intercrop with sesame in all row combinations except 1:5 recorded LER less than one, hence uneconomical over sole barnyard millet crop. Similarly, intercropping of barnyard millet with greengram with all row ratios was recorded with ATER values more than one, while Barnyard millet intercropping with sesame in all row combinations recorded ATER less than one, hence found uneconomical over sole barnyard millet. Among all the intercropping systems, barnyard millet + green gram (1:5) closely followed by barnyard millet + green gram (2:4) recorded significantly higher LER (1.25) and ATER (1.14). This might be because component crops differed in utilizing growth and other resources and converting them into sink more efficiently resulting in higher yield per unit area compared to sole crop. Anishetra and Kalaghatagi (2020) reported that

Table 1. Yield performance and Land use intercropping indices of Barnyard millet-based intercropping systems.

Treatments	Seed yield ($kg\ ha^{-1}$)		Biological yield ($kg\ ha^{-1}$)		Land Equivalent Ratio (LER)			Barnyard millet Seed Equivalent yield ($kg\ ha^{-1}$)	Land Use Efficiency (LUE %)	Land Equivalent Coefficient (LEC)
	Barnyard millet	Inter crop	Barnyard millet	Inter crop	Barnyard millet	Inter crop	System			
Sole Barnyard millet	2345		15179					2345		
Sole Greengram		804		3352				2659		
Sole Sesame		538		3095				1795		
Barnyard + Greengram (5:1)	2,130	76	13580	394	0.91	0.11	1.02	2380	101.2	0.10
Barnyard + Greengram (4:2)	1,889	144	11668	709	0.81	0.21	1.01	2364	100.0	0.17
Barnyard + Greengram (3:3)	1,535	291	9703	1291	0.65	0.43	1.08	2496	105.6	0.27
Barnyard + Greengram (2:4)	1,282	458	7565	1930	0.55	0.65	1.20	2796	115.7	0.37
Barnyard + Greengram (1:5)	997	599	5520	2525	0.43	0.82	1.25	2977	119.4	0.37
Barnyard + Sesame (5:1)	2,001	62	12494	446	0.85	0.12	0.97	2207	87.6	0.10
Barnyard + sesame (4:2)	1,781	105	10949	747	0.76	0.21	0.96	2131	88.0	0.15
Barnyard + sesame (3:3)	1,435	185	8824	1237	0.61	0.35	0.96	2050	89.5	0.22
Barnyard + Sesame (2:4)	1,122	286	6761	1759	0.48	0.52	1.00	2076	94.6	0.25
Barnyard + Sesame (1:5)	794	391	4859	2303	0.34	0.71	1.05	2096	101.2	0.24
CD (5%)	76		1289		0.03	0.16	0.06	327	5.1	0.10
SEm (±)	25		434		0.01	0.05	0.02	111	1.7	0.03

Table 2. Area Time Equivalent Ratio and Competition intercropping indices for Barnyard millet-based intercropping systems.

Treatments	ATER			CPR			Aggressivity (A)		RCC			Competitive Ratio		Actual Yield Loss (AYL)		
	Barnyard millet	Intercrop	System	Barnyard millet	Intercrop	System	Barnyard millet	Intercrop	K_{CP} (Barnyard millet)	K_{IM} (Intercrop)	$K = K_{MI} * K_{IM}$	Barnyard millet	Intercrop	Barnyard millet	Intercrop	Total
Sole Barnyard millet	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sole Greengram	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sole Sesame	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Barnyard + Greengram (5:1)	0.91	0.10	1.00	1.09	0.64	1.06	0.68	-0.68	2.21	0.64	1.49	1.99	0.60	0.09	-0.35	-0.26
Barnyard + Greengram (4:2)	0.81	0.18	0.99	1.20	0.63	1.11	0.62	-0.62	2.14	0.57	1.19	2.34	0.52	0.20	-0.37	-0.17
Barnyard + Greengram (3:3)	0.65	0.38	1.03	1.31	0.85	1.17	0.40	-0.40	1.91	2.52	3.69	1.91	0.68	0.31	-0.14	0.16
Barnyard + Greengram (2:4)	0.55	0.57	1.12	1.66	0.97	1.36	0.18	-0.18	2.51	0.08	-0.62	1.93	0.58	0.66	-0.03	0.63
Barnyard + Greengram (1:5)	0.43	0.72	1.14	2.52	0.99	1.59	0.26	-0.26	4.02	0.43	0.79	2.81	0.39	1.52	-0.01	1.51
Barnyard + Sesame (5:1)	0.66	0.12	0.78	1.03	0.70	1.01	0.55	-0.55	1.28	0.68	0.82	1.48	0.71	0.03	-0.30	-0.27
Barnyard + sesame (4:2)	0.59	0.21	0.79	1.13	0.63	1.08	0.55	-0.55	1.65	0.53	0.82	1.93	0.55	0.13	-0.37	-0.24
Barnyard + sesame (3:3)	0.47	0.35	0.83	1.22	0.70	1.12	0.36	-0.36	1.59	0.55	0.86	1.76	0.58	0.22	-0.29	-0.07
Barnyard + Sesame (2:4)	0.37	0.52	0.89	1.45	0.78	1.25	0.21	-0.20	1.86	0.55	1.02	1.86	0.55	0.45	-0.22	0.23
Barnyard + Sesame (1:5)	0.26	0.71	0.97	2.00	0.86	1.42	0.24	-0.24	2.60	0.55	1.38	2.45	0.43	1.00	-0.14	0.85
CD (5%)	0.03	0.14	0.15	0.12	0.08	0.21	0.15	0.14	0.45	0.45	0.18	0.50	0.06	0.12	0.06	0.30
SEm (±)	0.01	0.05	0.05	0.04	0.64	0.07	0.05	0.05	0.15	0.15	0.06	0.17	0.02	0.04	0.02	0.10

intercropping of sesame + foxtail millet in 2:4 ratio recorded significantly higher LER (1.33) and ATER (1.28) compared to sole crops. The intercropping systems recorded with LER values less than 1.0 indicates the disadvantage of intercropping (Dass and Sudhishri, 2010, Habib *et al*., 2016).

Relative crowding coefficient (RCC): Relative crowding coefficient is a measure of the relative dominance of one species over the other in a mixture. RCC was significantly affected by intercropping systems (Table 2). Barnyard millet recorded higher RCC values than intercrops at all row ratios of intercropping except barnyard millet + greengram (3:3) which shows the higher competitive ability and relative dominance of barnyard millet over intercrops. Among all intercropping systems, barnyard millet + greengram at all row ratios except 2:4 recorded higher RCC values over barnyard millet intercropping with sesame. Barnyard millet + greengram (3:3) closely followed by barnyard millet + greengram (1:5) with significantly higher system RCC values of 4.89 and 1.79, respectively. Among intercropping systems, barnyard millet + sesame intercropping with row ratio of 5:1, 4:2 and 3:3 was found non-advantageous as RCC of system recorded values less than one, while barnyard millet intercrop with greengram was recorded with system RCC values more than one at all row ratios. Varia and Sadhu (2011) also reported higher RCC value with pearl millet + greengram intercropping.

Competitive ratio (CR): Competitive ratio was significantly affected by intercropping treatments (Table 2). In intercropping systems, Barnyard millet recorded higher CR values compared to intercrops at all row ratios, which shows competitive nature of barnyard millet over intercrops (greengram and sesame). Barnyard millet intercrop with green gram recorded higher CR values compared to barnyard millet intercrop with sesame. Regarding relative competitiveness with barnyard millet, sesame as intercrop proved more competitive than green gram intercropping row ratio of 5:1, 4:2 and 1:5, while at 3:3 and 2:4 row ratio of intercropping of Barnyard millet + green gram proved more competitive than sesame. Among all intercropping systems, barnyard millet + green gram (1:5) followed by barnyard millet + sesame (1:5) was recorded with significantly higher $CR_{\text{barnyard millet}}$ (2.81), while maximum $CR_{\text{intercrop}}$ (0.71) was recorded by barnyard millet + sesame (5:1). Similar finding was also reported by Jakhar *et al.* (2015).

Aggressivity (A): Aggressivity was significantly affected with intercropping systems (Table 2). Barnyard millet recorded positive A values with all row ratios, while both intercrops recorded negative A values, which indicated more dominance and aggressivity of barnyard millet over greengram and sesame in intercropping. Higher A values for barnyard millet recorded in intercroping with greengram compared to barnyard millet + sesame intercropping showed that Barnyard millet was more aggressive or dominant with greengram than sesame. Among all intercropping systems, barnyard millet + green gram (5:1) followed by barnyard millet + green gram (4:2) was recorded with significantly higher values both for barnyard millet (+ 0.68) and intercrop (- 0.68), respectively (Table 2). Shalini *et al.* (2019) also reported that the aggressivity values for finger millet in finger millet + black gram and finger millet + pigeonpea intercropping at 3:2, 4:2, 5:2 and 6:2 row ratios were found negative which indicate that both the pulses have shown dominance over finger millet. While, Jakhar *et al.* (2015) studied the performance of finger millet and groundnut-based strip intercropping in ratios 6:4, 8:4, 10:4 and 12:4 and found negative aggressivity (A) values for groundnut which indicated that finger millet has shown dominance over groundnut. Similar trend was also observed by Ram and Meena (2014).

Actual yield loss (AYL) and crop performance ratio (CPR): AYL and CPR were significantly affected with intercropping systems (Table 2). $AYL_{\text{barnyard millet}}$ had positive values in intercropping with greengram and sesame at all row combinations, while negative $AYL_{\text{intercrop}}$ values were recorded in all intercropping systems with both intercrops. All barnyard millet-based intercropping systems with green gram and sesame except barnyard millet + green gram (5:1 and 4:2), barnyard millet + sesame (5:1, 4:2 and 3:3) recorded negative values of total AYL. Irrespective of row ratios CPR barnyard millet was recorded higher in barnyard + greengram intercropping as compared to barnyard millet + sesame intercropping. CPR for barnyard millet was increased with decline in number of rows compared to intercrop, while CPR for intercrop was increased with increase in number of rows compared to barnyard millet i.e. from 5:1 to 1:5 (Barnyard millet + intercrop). Among all intercropping systems, barnyard millet + green gram (5:1) recorded total AYL value more than one (1.51) and recorded significantly higher CPR system (1.59), maximum CPR barnyard millet (2.52) and $CPR_{\text{intercrop}}$ (0.99), which indicated an increment of 59 percent in crop performance in intercropping compared to barnyard millet as sole crop. Quantification of yield loss or gain due to intercropping with other species or the variation of the plant population could not be obtained through partial LERs, whereas partial AYL shows the yield loss or gain by its sign and as well as its value (Banik *et al*., 2000).

Monetary advantage index (MAI) and system productivity index (SPI): Intercropping systems significantly affected MAI and SPI (Table 3). Intercropping of barnyard millet with green gram recorded positive MAI values with all row combinations, while barnyard millet + sesame intercropping resulted negative MAI values at all row ratios except Barnyard millet + sesame (2:4 and 1:5), which showed relative monetary advantage of barnyard millet + greengram over barnyard millet + sesame intercropping. Barnyard millet intercrop with greengram recorded higher SPI than barnyard millet + sesame intercropping at all row ratios. Among intercropping systems, barnyard millet + green gram (1:5) followed by barnyard millet + greengram (2:4) recorded significantly higher MAI (10,756 ha^{-1}) and SPI (2903) (Table 3). Higher SPI in intercropping systems was also reported by Gupta *et al.* (2019) and Ahlawat and Gangaiah (2010).

Intercropping advantage index (IAI) and relative net returns index (RNRI): Intercropping systems significantly affected IAI and RNRI (Table 3). Barnyard millet intercropping with greengram and sesame recorded negative values of IAI at all row ratios except barnyard millet + greengram (4:2 and 1:5) and barnyard millet + sesame (1:5), which showed relative advantage of barnyard millet intercrop with greengram and sesame with these row ratios. Irrespective to row ratios barnyard millet + greengram recorded higher values of IAI compared to barnyard millet + sesame intercropping, which showed that greengram is more advantageous as intercrop with barnyard millet compared to sesame. Barnyard millet + greengram recorded RNRI values more than one at all row ratios except 5:1, while barnyard millet intercrop with sesame recorded RNRI less than one at all row ratios. Among intercropping systems, barnyard millet + green gram (1:5) followed by barnyard millet + greengram (2:4) and barnyard millet + sesame (1:5) recorded significantly higher IAI (34.6) and RNRI (1.23) (Table 3). The higher IAI is also an indicator of the economic feasibility of intercropping systems.

Relative economic efficiency (REE) and income equivalent ratio (IER): REE and IER were significantly affected by intercropping systems (Table 3). Barnyard millet intercrop with greengram and sesame recorded negative values of REE at all row ratios except barnyard millet + greengram (4:2 and 1:5). Similarly, except barnyard millet + greengram (4:2 and 1:5), all intercropping systems reported with IER values less than one, which showed relative higher economic efficiency and monetary returns of barnyard millet + greengram (4:2 and 1:5). Barnyard millet intercrop with greengram proved economical as it was recorded with higher values of REE and IER compared to barnyard millet intercrop with sesame. Among intercropping systems, barnyard millet + green gram (1:5) followed by barnyard millet + greengram (2:4) recorded significantly higher REE (22.1%) and IER (1.22).

Economics: Cost of cultivation (total and variable) for barnyard millet intercrop with greengram or sesame intercropping was less than sole barnyard millet crop (Table 3).

Table 3. System Productivity Index and Economics of Barnyard millet-based intercropping systems.

Treatments	VC (ha^{-1})	TC (ha^{-1})	Gross return (ha^{-1})	Net Return (ha^{-1})	BCR	VCR	Per day return (ha^{-1}day^{-1})	MAI (ha^{-1})	RNRI	REE (%)	System Productivity Index (SPI)	Intercropping Advantage Index (IAI)	Income Equivalent Ratio (IER)
Sole Barnyard millet	28868	58168	78203	20036	1.34	0.34	260.0						
Sole Greengram	26585	55428	63649	8221	1.15	0.15	126.7						
Sole Sesame	25758	54435	43456	-10979	0.80	-0.20	-106.3						
Barnyard + Greengram (5:1)	28469	57674	76696	19023	1.33	0.33	247.0	774	1.01	-1.9	2384	-25.3	0.98
Barnyard + Greengram (4:2)	28098	57236	73422	16187	1.28	0.28	210.3	189	0.99	-14.3	2369	-24.1	0.86
Barnyard + Greengram (3:3)	27726	56798	73812	17014	1.30	0.30	220.7	2828	1.04	-12.5	2525	-3.9	0.88
Barnyard + Greengram (2:4)	27328	56304	77677	21373	1.38	0.38	277.0	8069	1.16	12.5	2789	13.0	1.12
Barnyard + Greengram (1:5)	26957	55866	78976	23111	1.42	0.42	300.3	10756	1.23	22.1	2903	34.6	1.22
Barnyard + Sesame (5:1)	28332	57509	70950	13441	1.23	0.23	136.0	-1413	0.93	-29.4	2281	-22.7	0.71
Barnyard + sesame (4:2)	27822	56905	66913	10008	1.18	0.18	101.3	-1805	0.89	-46.0	2263	-26.1	0.54
Barnyard + sesame (3:3)	27313	56301	62002	5701	1.10	0.10	58.3	-1916	0.84	-68.9	2258	-17.9	0.31
Barnyard + Sesame (2:4)	26777	55643	59671	4028	1.07	0.07	43.0	216	0.84	-72.4	2347	-6.7	0.28
Barnyard + Sesame (1:5)	26267	55039	57539	2500	1.05	0.05	28.3	2553	0.83	-82.4	2465	12.2	0.18
CD (5%)			8099	8099	0.14	0.15	114.2	3041	0.05	18.9	199	19.8	0.19
SEm (±)			2758	2758	0.05	0.05	38.9	1016	0.02	6.3	67	6.6	0.06

Variable Cost; TC, Total Cost; BCR, Benefit Cost Ratio; VLR, Value Lost Ratio; MAI, Monetary Advantage Index; RNRI, Relative Net Returns Index; REE, Relative Economics Efficiency

Barnyard millet intercrop with greengram recorded higher cost compared to barnyard millet + sesame intercropping at each row ratio. Decrement in rows of barnyard millet in comparison to intercrop from 5:1 to 1:5 declined the variable cost as well as total cost. All intercropping systems except barnyard millet + greengram (4:2 and 1:5) recorded fewer net returns compared to sole barnyard millet. Among all intercropping systems, significantly higher gross return (₹ 78,976 ha^{-1}) was recorded with barnyard millet + greengram (1:5). Among all intercropping systems, barnyard millet + greengram (1:5) closely followed by barnyard millet + greengram (4:2) recorded significantly higher net return (₹ 23,111ha^{-1}) (Table 3), which was 15.3% higher over sole barnyard millet crop. All intercropping systems except barnyard millet + greengram (4:2 and 1:5) recorded lower benefit: cost (BCR), value cost ratio (VCR) and per day return over sole barnyard millet crop. Barnyard millet + greengram (1:5) closely followed by barnyard millet + greengram (4:2) recorded significantly higher BCR (1.42), VCR (0.42) and per day return (₹ 300.3 ha^{-1} day^{-1}), which were 6.0,23.5 and 15.5% higher over sole barnyard millet crop. Similar results were also reported by Chaudhary (2012) and Kumar *et al.,* (2023).

Thus, the study concluded that sesame intercropping in barnyard millet was uneconomical over sole barnyard millet. Considering all intercropping indices calculated to assess the relative competitiveness, advantage and efficiency of different intercropping systems, Barnyard millet + greengram (1:5) closely followed by barnyard millet + greengram (4:2) was found most economical and suitable system with higher Land Equivalent Ratio (1.25), Barnyard millet Equivalent Yield (2977 kg/ha), Land Use Efficiency (119.4), Area Time Equivalent Ratio (1.14), Relative Crowding Coefficient (1.79), Monitory advantage Index (₹ 10,756/ha), System Productivity Index (-2903), Intercropping Advantage Index (34.6), Net Return (₹ 23,111 ha^{-1}), Benefit Cost Ratio (1.42) and per day return (₹ 300.3). Hence, barnyard millet intercrop greengram in row ratio of 1:5 and 4:2 is a viable option for higher productivity and profitability of millet growers in a sustainable way.

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