



International Journal of Research in Agronomy

E-ISSN: 2618-0618
P-ISSN: 2618-060X
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NAAS Rating (2025): 5.20
www.agronomyjournals.com
2025; 8(11): 425-432
Received: 21-09-2025
Accepted: 23-10-2025

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Production and profitability of pearl millet (*Pennisetum glaucum* (L.) R. Br.) based intercropping systems in lowland summer rice fallows

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DOI: <https://www.doi.org/10.33545/2618060X.2025.v8.i11f.4204>

Abstract

A field experiment was conducted during the summer season of 2024 - 2025 at the Integrated Farming Systems Research Station, Karamana, Thiruvananthapuram, Kerala. This study aims to evaluate the effect of legume intercropping on the growth, yield attributes and yield of pearl millet (*Pennisetum glaucum* L.) in lowland rice fallows and to assess the economics. The experiment comprised thirteen treatments intercropping pearl millet with bush cowpea, fodder cowpea, green gram and black gram in 1:1 and 2:1 planting ratios along with their respective sole crops, laid out in a Randomized Block Design replicated thrice. Growth and yield attributes of pearl millet were significantly influenced by intercropping systems. The tallest plants, higher number of tillers and maximum grain yield (2498 kg ha^{-1}) were observed in T_9 (sole crop of pearl millet). Growth and yield attributes of intercrops were significantly reduced under intercropping systems. Sole crop of bush cowpea (T_{10}), fodder cowpea (T_{11}), green gram (T_{12}) and black gram (T_{13}) recorded the tallest plants with the highest number of branches, leaf area and LAI followed by intercropping at 1:1 ratio. Yield attributes such as number of pods per plant, grain yield and haulm yield were also higher in sole cropping. The leaf: stem ratio (0.78 ± 0.03), green fodder yield ($8184 \pm 162 \text{ kg ha}^{-1}$) and dry fodder yield ($1042 \pm 40 \text{ kg ha}^{-1}$) were also higher in T_{11} followed by T_3 . Among the treatments, T_1 (pearl millet + bush cowpea in 1:1 ratio) recorded the highest pearl millet equivalent yield (3888 kg ha^{-1}) followed by T_7 (pearl millet + black gram in 1:1 ratio) with 3749 kg ha^{-1} . The highest net income ($\text{₹}90,246 \text{ ha}^{-1}$) and benefit: cost ratio (2.15) were also observed in T_7 , indicating profitability of the system. The lowest yield and economic return were recorded in T_{11} (sole crop of fodder cowpea). Overall, intercropping with short-duration legumes such as black gram and bush cowpea enhanced system productivity, economic efficiency and resource utilization compared to sole cropping. The study concluded that T_7 (pearl millet + black gram in 1:1 ratio) were the most productive, economically viable and sustainable intercropping systems for effective utilization of lowland summer rice fallows of Kerala.

Keywords: Economics, growth, intercropping, legumes, pearl millet, pearl millet equivalent yield

1. Introduction

Pearl millet (*Pennisetum glaucum* (L.) R. Br.) is one of the most important cereal crops in arid and semi-arid regions ranking sixth among the world's major cereals and fourth in India (FAO and ICRISAT, 1996) ^[1] where it occupies about 72.1 lakh hectares, producing 108.63 lakh tonnes with an average productivity of 1507 kg ha^{-1} (UPAG, 2025) ^[2]. In Kerala, rice-rice-fallow remains the dominant cropping system (John *et al.*, 2014) ^[3], leaving a large area fallow during the summer season that could be effectively used for short-duration crops to improve cropping intensity and profitability. Intercropping, the practice of growing two or more crops simultaneously in the same field (Andrew and Kassam, 1976) ^[4] is recognized as an efficient and sustainable approach for optimizing land use, reducing risk, and enhancing system productivity, especially in low-input farming systems (Ngwira *et al.*, 2012) ^[5]. Cereal-legume intercropping systems are particularly advantageous due to their ability to fix atmospheric nitrogen, improve soil structure and enhance nutrient use efficiency while minimizing weed growth and pest incidence (Silwana and Lucas, 2002 ^[6]; Hardarson and Atkins, 2003 ^[7]). Pearl millet being a short duration, drought tolerant crop fits well in summer lowland rice fallows when intercropped with legumes such as bush cowpea, fodder cowpea, green gram and black gram, which

complement the cereal component through biological nitrogen fixation and canopy coverage (Sharma and Singh, 2008) [8]. The inclusion of such intercrops improves soil fertility and ensures sustainable productivity in succeeding *virippu* rice crops. In this context, the present investigation entitled “Production and profitability of pearl millet (*Pennisetum glaucum* (L.) R. Br.) based intercropping systems in lowland summer rice fallows” was undertaken to evaluate the performance, resource-use efficiency and profitability of different pearl millet-legume intercropping systems for sustainable utilization of lowland summer rice fallows under Kerala’s humid tropical conditions.

2. Materials and Methods

The field experiment was conducted during the summer season of 2024-2025 at the Integrated Farming System Research Station, Kerala Agricultural University. The experimental site is situated at 8°28'25" N latitude, 76°59'32" E longitude and 5 m above mean sea level. During the crop growth period (23rd January to 9th May 2025), the mean maximum and minimum temperatures were 32.1 °C and 24.7 °C, respectively. The mean relative humidity was 88.2% in the forenoon and 70.4% in the afternoon. A total rainfall of 354.07 mm was received over 10 rainy days with an average wind speed of 6.1 km h⁻¹. The soil of the experimental field was sandy clay loam, slightly acidic in reaction (pH - 6.23), normal in electrical conductivity (0.181 dS m⁻¹), medium in organic carbon (1.42%), medium in available nitrogen (338.69 kg ha⁻¹), high in available phosphorus (63.05 kg ha⁻¹) and medium in available potassium (182.00 kg ha⁻¹). The experiment was laid out in a Randomized Block Design (RBD) with thirteen treatments replicated thrice. The treatments consisted of T₁: pearl millet + bush cowpea in 1:1 ratio, T₂: pearl millet + bush cowpea in 2:1 ratio, T₃: pearl millet + fodder cowpea in 1:1 ratio, T₄: pearl millet + fodder cowpea in 2:1 ratio, T₅: pearl millet + green gram in 1:1 ratio, T₆: pearl millet + green gram in 2:1 ratio, T₇: pearl millet + black gram in 1:1 ratio, and T₈: pearl millet + black gram in 2:1 ratio, T₉: sole crop of pearl millet, T₁₀: sole crop of bush cowpea, T₁₁: sole crop of fodder cowpea, T₁₂: sole crop of green gram and T₁₃: sole crop of black gram. Each plot measured 4.5 m × 3.0 m (13.5 m²) in size. Pearl millet (var. CO 10) was raised as main crop and bush cowpea (var. Bhagyalakshmi), fodder cowpea (var. Aiswarya), green gram (var. CO 8) and black gram (var. Sumanjana) were raised as intercrops in an additive series. Pearl millet was raised as per recommendations of TNAU (CPG, 2020) [9] and intercrops as per KAU package of practices recommendations (KAU, 2024) [10]. Observations on growth parameters such as plant height, number of tillers per m², leaf area per plant and leaf area index (LAI) were recorded at 30 and 60 days after sowing (DAS) and at harvest. Yield attributes such as number of productive tillers per plant, grain yield and stover yield were measured and expressed in kg ha⁻¹. The pearl millet equivalent yield (PMEY) was calculated using the formula (De Wit and Bergh, 1965) [11].

$$\text{PMEY (kg ha}^{-1}\text{)} = Y_i \times \frac{P_i}{P_m}$$

where Y_i is the yield of the intercrop (kg ha⁻¹), P_i is the price of the intercrop (₹ kg⁻¹), and P_m is the price of pearl millet (₹ kg⁻¹). Economic parameters such as gross return, net return and benefit-cost ratio (BCR) were computed based on the prevailing market prices. The Monetary Advantage Index (MAI) was

calculated as per Willey (1979) [12]:

$$\text{MAI} = \frac{\text{Gross return of intercropping} \times (\text{LER}-1)}{\text{LER}}$$

The Land Equivalent Ratio (LER) was estimated using the equation (Willey and Osiru, 1972) [13].

$$\text{LER} = \frac{Y_{pm}}{Y_p} + \frac{Y_{lg}}{Y_l}$$

where Y_{pm} and Y_{lg} represent the yields of pearl millet and legume in intercropping, and Y_p and Y_l are their respective yields under sole cropping.

The entire statistical analysis was performed using R and AI Solutions for Inferential Statistics (RAISINS), the online statistical analysis platform developed by Kerala Agricultural University (Hisham *et al.*, 2025 [14]; R Core Team, 2024 [15]).

3. Results and Discussion

Growth attributes of pearl millet

Growth attributes of pearl millet were significantly influenced by different intercropping systems (Table 1). At 30 DAS, the tallest plants were observed in T₉: sole crop of pearl millet (78.60 ± 1.06 cm), followed by T₈: pearl millet + black gram in 2:1 ratio (69.50 ± 2.69 cm), while the shortest plants were recorded in T₁: pearl millet + bush cowpea in 1:1 ratio (44.72 ± 2.04 cm). Likewise, at 60 DAS, T₉ recorded taller plants (189.00 ± 5.79 cm), followed by T₆ (172.00 ± 5.27 cm) and T₇ (170.00 ± 4.90 cm). At harvest, the tallest plants were again noted in T₉ (218.00 ± 7.66 cm), followed by T₈ (197.00 ± 6.57 cm) and T₆ (182.00 ± 0.66 cm). The higher plant height observed in the sole pearl millet might be attributed to the absence of competition for light, nutrients and moisture, which enabled better vegetative growth. Similar observations were reported by Choudhary *et al.* (2012) [16], Yadav *et al.* (2015) [17], Bana *et al.* (2016) [18], Kamani and Arvadiya (2023) [19] and Priya *et al.* (2023) [20] and Sowmiya *et al.* (2024) [21] who collectively emphasized that wider spacing, reduced interspecific competition and improved fertility conditions enhanced pearl millet height and overall vegetative growth.

The number of tillers per m² (Table 2) also followed a similar trend. At 30 DAS, T₉ recorded higher number of tillers (43.33 ± 0.74), followed by T₆ (41.11 ± 0.41) and T₈ (34.44 ± 1.03). At 60 DAS, the highest tiller count was again in T₉ (82.21 ± 2.96) followed by T₆ (78.88 ± 2.92) and T₇ (77.77 ± 1.54). At harvest, the highest tillers were recorded in T₉ (104.44 ± 2.26), followed by T₆ (102.21 ± 2.40) and T₇ (97.77 ± 4.32). These results are in agreement with Ram and Meena (2014) [22] and Kamani and Arvadiya (2023) [19], who reported enhanced tillering in sole millet compared to intercropped systems with legumes.

Leaf area per plant (Table 3) and leaf area index (LAI) (Table 4) of pearl millet also showed significant variation among treatments. At 30 DAS, T₉ had the highest leaf area (1043.90 ± 39.52 cm²) and LAI (2.32 ± 0.04), followed by T₄ and T₃. At 60 DAS, leaf area was higher in T₉ (3416.40 ± 55.43 cm²) with LAI (7.59 ± 0.11), followed by T₆ and T₈. At harvest, T₉ maintained the highest leaf area (2417.76 ± 106.79 cm²) and LAI (5.37 ± 0.23), followed by T₆ and T₈. Similar findings were reported by Priya *et al.* (2023) [20], who observed that wider spacing and the absence of intercrop competition enhanced canopy development, photosynthetic area and overall biomass accumulation in pearl

millet.

Growth attributes of intercrops

Growth attributes of intercrops were significantly influenced by different intercropping systems (Table 5,6,7 & 8). Among the intercrops, the growth attributes were found to be highest in their respective sole cropping. Sole crop of bush cowpea (T₁₀) recorded the tallest plants at 30 DAS (46.10 ± 1.79 cm), 60 DAS (158.00 ± 4.98 cm) and harvest (165.00 ± 2.38 cm). It also exhibited the highest leaf area per plant (358.88 ± 0.97, 904.31 ± 19.57 and 425.25 ± 5.36 cm²) and LAI (0.80 ± 0.03, 2.01 ± 0.05 and 0.95 ± 0.01) at 30 DAS, 60 DAS and harvest, respectively. These findings were supported by Kumar *et al.* (2006) [23], who observed vigorous growth of bush cowpea in sole cropping due to unrestricted light interception and root spread. Yadav *et al.* (2015) [15] and Kamani and Arvadiya (2023) [19] also reported that bush cowpea performed best in monocropping due to the absence of interspecific competition.

Similarly, the sole crop of fodder cowpea (T₁₁) showed taller plants with 58.10 ± 1.20 cm at 30 DAS and 118.00 ± 0.21 cm at harvest and recorded the highest leaf area (729.49 ± 3.29 and 1487.81 ± 48.28 cm²) and LAI (1.62 ± 0.03 and 3.31 ± 0.14) at 30 DAS and at harvest. The similar results were also reported by Chaudhary *et al.* (2020) [24], who found that sole fodder cowpea performed better due to optimal light interception, better canopy development and greater photosynthetic efficiency.

The sole crop of green gram (T₁₂) also exhibited taller plants at 30 DAS (56.60 ± 0.81 cm), 60 DAS (93.81 ± 1.14 cm) and harvest (95.00 ± 0.60 cm) along with higher leaf area (257.40 ± 6.03, 1015.19 ± 14.64, and 649.23 ± 24.58 cm²) and LAI (0.57 ±

0.02, 2.26 ± 0.06 and 1.44 ± 0.01). These results align with the findings of Chaudhary *et al.* (2012) [16] and Yadav *et al.* (2015) [17] who highlighted that sole green gram grows vigorously due to sufficient radiation and nutrient availability.

Likewise, the sole crop of black gram (T₁₃) recorded taller plants at 30 DAS (45.50 ± 0.37 cm), 60 DAS (81.00 ± 1.39 cm) and at harvest (110.00 ± 0.10 cm) with the highest leaf area (164.99 ± 2.97, 952.37 ± 30.91 and 839.58 ± 15.14 cm²) and higher LAI (0.37 ± 0.01, 2.12 ± 0.01 and 1.87 ± 0.05) at 30 DAS, 60 DAS, and harvest, respectively. Kamani and Arvadiya (2023) [19] also reported similar results, with black gram in sole cropping expressing its full potential for vegetative growth under reduced competition.

Table 1: Effect of intercropping on plant height of pearl millet, cm

Treatments	Plant height		
	30 DAS	60 DAS	At harvest
T ₁ : PM + BCP in 1:1 ratio	44.72±2.04 ^a	153.00±6.23 ^d	174.00±1.74 ^{def}
T ₂ : PM + BCP in 2:1 ratio	60.00±2.00 ^d	158.00±1.71 ^{cd}	181.00±6.69 ^{cd}
T ₃ : PM + FCP in 1:1 ratio	65.80±1.19 ^c	152.00±1.23 ^d	167.00±2.86 ^f
T ₄ : PM + FCP in 2:1 ratio	53.22±1.58 ^e	144.00±5.97 ^e	168.00±1.82 ^{ef}
T ₅ : PM + GG in 1:1 ratio	63.89±0.39 ^c	154.00±1.11 ^{cd}	176.00±4.92 ^{de}
T ₆ : PM + GG in 2:1 ratio	64.00±1.04 ^c	172.00±5.27 ^b	182.00±0.66 ^{cd}
T ₇ : PM + BG in 1:1 ratio	51.50±1.21 ^e	170.00±4.90 ^b	189.00±1.87 ^{bc}
T ₈ : PM + BG in 2:1 ratio	69.50±2.69 ^b	161.00±1.02 ^c	197.00±6.57 ^b
T ₉ : Sole crop of PM	78.60±1.06 ^a	189.00±5.79 ^a	218.00±7.66 ^a
S.Em (±)	0.8	2.6	2.7
CD (0.05)	2.403	7.782	8.180

PM- pearl millet, BCP- Bush cowpea, FCP- Fodder cowpea, GG - Green gram and BG- black gram

Table 2: Effect of intercropping on number of tillers per m² of pearl millet

Treatments	Number of tillers per m ²		
	30 DAS	60 DAS	At harvest
T ₁ : PM + BCP in 1:1 ratio	30.00±0.52 ^g	58.88±1.86 ^d	79.99±1.95 ^{gh}
T ₂ : PM + BCP in 2:1 ratio	35.55±0.48 ^c	66.66±0.14 ^c	91.10±0.99 ^{de}
T ₃ : PM + FCP in 1:1 ratio	27.78±1.13 ^h	55.55±1.90 ^d	75.55±3.06 ^h
T ₄ : PM + FCP in 2:1 ratio	33.33±0.12 ^{de}	68.88±2.24 ^c	88.88±2.40 ^{ef}
T ₅ : PM + GG in 1:1 ratio	31.11±0.03 ^{fg}	65.55±1.42 ^c	84.44±3.65 ^{fg}
T ₆ : PM + GG in 2:1 ratio	41.11±0.41 ^b	78.88±2.92 ^{ab}	102.21±2.40 ^{ab}
T ₇ : PM + BG in 1:1 ratio	32.22±1.31 ^{ef}	77.77±1.54 ^b	97.77±4.32 ^{bc}
T ₈ : PM + BG in 2:1 ratio	34.44±1.03 ^{cd}	76.66±1.73 ^b	94.43±0.85 ^{cd}
T ₉ : Sole crop of PM	43.33±0.74 ^a	82.21±2.96 ^a	104.44±2.26 ^a
S.Em (±)	0.46	1.15	1.59
CD (0.05)	1.390	3.447	4.766

Table 3: Effect of intercropping on leaf area per plant of pearl millet, cm²

Treatments	Leaf area per plant		
	30 DAS	60 DAS	At harvest
T ₁ : PM + BCP in 1:1 ratio	243.24± 0.01 ^g	2242.56±38.41 ^e	1219.39± 10.99 ^{de}
T ₂ : PM + BCP in 2:1 ratio	412.89± 6.33 ^f	2719.98±71.10 ^b	1378.68± 53.43 ^{bc}
T ₃ : PM + FCP in 1:1 ratio	702.63±27.87 ^b	1541.76±44.47 ^g	1245.09± 12.34 ^d
T ₄ : PM + FCP in 2:1 ratio	722.70±11.73 ^b	1735.94±67.29 ^f	1332.40± 33.62 ^c
T ₅ : PM + GG in 1:1 ratio	604.44± 5.99 ^d	2568.87±39.36 ^c	1333.71± 25.25 ^{bc}
T ₆ : PM + GG in 2:1 ratio	657.00± 9.47 ^c	2619.24±96.80 ^{bc}	1412.11± 8.91 ^b
T ₇ : PM + BG in 1:1 ratio	545.31±16.71 ^e	2391.48±53.89 ^d	1139.97± 36.99 ^e
T ₈ : PM + BG in 2:1 ratio	700.80± 2.52 ^b	2611.21±91.80 ^{bc}	1382.91± 41.14 ^{bc}
T ₉ : Sole crop of PM	1043.90±39.52 ^a	3416.40±55.43 ^a	2417.76±106.79 ^a
S.Em (±)	10.91	38.06	26.53
CD (0.05)	32.71	114.09	79.53

Table 4: Effect of intercropping on leaf area index of pearl millet

Treatments	LAI		
	30 DAS	60 DAS	At harvest
T ₁ : PM + BCP in 1:1 ratio	0.54±0.01 ^g	4.98±0.04 ^e	2.71±0.02 ^d
T ₂ : PM + BCP in 2:1 ratio	0.92±0.01 ^f	6.04±0.12 ^b	3.06±0.08 ^{bc}
T ₃ : PM + FCP in 1:1 ratio	1.56±0.01 ^b	3.43±0.01 ^g	2.77±0.04 ^d
T ₄ : PM + FCP in 2:1 ratio	1.61±0.02 ^b	3.86±0.04 ^f	2.96±0.03 ^c
T ₅ : PM + GG in 1:1 ratio	1.34±0.03 ^d	5.71±0.14 ^c	2.96±0.03 ^c
T ₆ : PM + GG in 2:1 ratio	1.46±0.01 ^c	5.82±0.13 ^c	3.14±0.02 ^b
T ₇ : PM + BG in 1:1 ratio	1.21±0.05 ^e	5.31±0.00 ^d	2.53±0.04 ^e
T ₈ : PM + BG in 2:1 ratio	1.56±0.05 ^b	5.80±0.08 ^c	3.07±0.02 ^{bc}
T ₉ : Sole crop of PM	2.32±0.04 ^a	7.59±0.11 ^a	5.37±0.23 ^a
S.Em (±)	0.02	0.05	0.05
CD (0.05)	0.051	0.164	0.153

Table 5: Effect of Intercropping on plant height (cm) of intercrops

Treatments	Crop	30 DAS	60 DAS	At Harvest
T ₁ : PM + BCP in 1:1 ratio	Bush cowpea	38.70±1.24 ^b	87.00±3.53 ^c	90.00±0.32 ^c
T ₂ : PM + BCP in 2:1 ratio	Bush cowpea	44.00±1.43 ^a	117.00±1.37 ^b	125.00±0.11 ^b
T ₁₀ : Sole crop of BCP	Bush cowpea	46.10±1.79 ^a	158.00±4.98 ^a	165.00±2.38 ^a
S.Em (±)	-	1.03	2.26	0.76
CD (0.05)	-	4.063	8.879	2.973
T ₃ : PM + FCP in 1:1 ratio	Fodder cowpea	42.00±1.58 ^b	-	94.00±0.85 ^c
T ₄ : PM + FCP in 2:1 ratio	Fodder cowpea	44.00±0.08 ^b	-	112.00±3.13 ^b
T ₁₁ : Sole crop of FCP	Fodder cowpea	58.10±1.20 ^a	-	118.00±0.21 ^a
S.Em (±)	-	0.68	1.22	-
CD (0.05)	-	2.675	4.775	-
T ₅ : PM + GG in 1:1 ratio	Green gram	48.00±1.25 ^b	83.69±0.85 ^c	86.00±0.34 ^b
T ₆ : PM + GG in 2:1 ratio	Green gram	47.50±0.15 ^b	90.00±0.25 ^b	93.00±3.60 ^a
T ₁₂ : Sole crop of GG	Green gram	56.60±0.81 ^a	93.81±1.14 ^a	95.00±0.60 ^a
S.Em (±)	-	0.55	0.47	1.32
CD (0.05)	-	2.149	1.837	5.169
T ₇ : PM + BG in 1:1 ratio	Black gram	37.40±1.42 ^c	71.00±2.88 ^b	78.00±3.45 ^c
T ₈ : PM + BG in 2:1 ratio	Black gram	41.00±1.74 ^b	72.00±0.65 ^b	90.00±3.81 ^b
T ₁₃ : Sole crop of BG	Black gram	45.50±0.37 ^a	81.00±1.39 ^a	110.00±0.10 ^a
S.Em (±)	-	0.86	1.18	2.10
CD (0.05)	-	3.363	4.648	8.234

Table 6: Effect of Intercropping on number of branches of intercrops

Treatments	Crop	30 DAS	60 DAS	At Harvest
T ₁ : PM + BCP in 1:1 ratio	Bush cowpea	2.20±0.03 ^c	3.20±0.12 ^c	4.20±0.12 ^b
T ₂ : PM + BCP in 2:1 ratio	Bush cowpea	2.50±0.01 ^b	3.50±0.12 ^b	4.00±0.13 ^b
T ₁₀ : Sole crop of BCP	Bush cowpea	3.50±0.12 ^a	4.50±0.11 ^a	5.00±0.21 ^a
S.Em (±)	-	0.04	0.07	0.11
CD (0.05)	-	0.150	0.281	0.434
T ₃ : PM + FCP in 1:1 ratio	Fodder cowpea	4.00±0.02 ^c	-	8.00±0.31
T ₄ : PM + FCP in 2:1 ratio	Fodder cowpea	4.50±0.15 ^b	-	8.00±0.31
T ₁₁ : Sole crop of FCP	Fodder cowpea	5.50±0.07 ^a	-	8.00±0.01
S.Em (±)	-	0.04	-	0.17
CD (0.05)	-	NS	-	NS
T ₅ : PM + GG in 1:1 ratio	Green gram	2.00±0.02	4.00±0.06	4.10±0.04 ^b
T ₆ : PM + GG in 2:1 ratio	Green gram	2.00±0.07	4.00±0.01	4.30±0.15 ^b
T ₁₂ : Sole crop of GG	Green gram	2.00±0.06	4.00±0.01	5.00±0.02 ^a
S.Em (±)	-	0.02	0.02	0.05
CD (0.05)	-	NS	NS	0.207
T ₇ : PM + BG in 1:1 ratio	Black gram	2.00±0.08	3.00±0.12	3.90±0.10
T ₈ : PM + BG in 2:1 ratio	Black gram	2.00±0.04	3.00±0.08	3.80±0.07
T ₁₃ : Sole crop of BG	Black gram	2.00±0.05	3.00±0.10	4.00±0.14
S.Em (±)	-	0.04	0.06	0.04
CD (0.05)	-	NS	NS	NS

NS - Non significant, PM- pearl millet, BCP- Bush cowpea, FCP- Fodder cowpea, GG - Green gram and BG- black gram

Table 7: Effect of Intercropping on Leaf area per plant (cm²) of intercrops

Treatments	Crop	30 DAS	60 DAS	At Harvest
T ₁ : PM + BCP in 1:1 ratio	Bush cowpea	282.94±1.02 ^c	834.75±9.03 ^c	307.80±9.99 ^c
T ₂ : PM + BCP in 2:1 ratio	Bush cowpea	315.84±11.67 ^b	874.50±14.98 ^b	364.50±4.27 ^b
T ₁₀ : Sole crop of BCP	Bush cowpea	358.88±0.97 ^a	904.31±19.57 ^a	425.25±5.36 ^a
S.Em (±)	-	3.91	3.65	3.01
CD (0.05)	-	15.365	14.323	11.804
T ₃ : PM + FCP in 1:1 ratio	Fodder cowpea	585.71±18.48 ^c	-	1346.62±32.77 ^b
T ₄ : PM + FCP in 2:1 ratio	Fodder cowpea	652.50±24.70 ^b	-	1423.13±34.63 ^{ab}
T ₁₁ : Sole crop of FCP	Fodder cowpea	729.49±3.29 ^a	-	1487.81±48.28 ^a
S.Em (±)	-	10.65	21.06	-
CD (0.05)	-	41.830	82.690	-
T ₅ : PM + GG in 1:1 ratio	Green gram	204.93±2.21 ^c	855.36±12.34 ^b	546.64±5.42 ^b
T ₆ : PM + GG in 2:1 ratio	Green gram	237.60±5.57 ^b	841.43±37.16 ^b	541.73±0.49 ^b
T ₁₂ : Sole crop of GG	Green gram	257.40±6.03 ^a	1015.19±14.64 ^a	649.23±24.58 ^a
S.Em (±)	-	3.23	15.6	9.12
CD (0.05)	-	12.691	61.257	35.790
T ₇ : PM + BG in 1:1 ratio	Black gram	138.65±5.87 ^b	782.34±5.64 ^c	511.19±13.82 ^c
T ₈ : PM + BG in 2:1 ratio	Black gram	155.31±6.30 ^a	889.96±15.24 ^b	681.48±27.03 ^b
T ₁₃ : Sole crop of BG	Black gram	164.99±2.97 ^a	952.37±30.91 ^a	839.58±15.14 ^a
S.Em (±)	-	2.18	11.34	12.17
CD (0.05)	-	8.570	44.540	47.786

Table 8: Effect of Intercropping on LAI of intercrops

Treatments	Crop	30 DAS	60 DAS	At Harvest
T ₁ : PM + BCP in 1:1 ratio	Bush cowpea	0.63±0.02 ^c	1.85±0.04	0.68±0.01 ^c
T ₂ : PM + BCP in 2:1 ratio	Bush cowpea	0.70±0.01 ^b	1.94±0.09	0.81±0.03 ^b
T ₁₀ : Sole crop of BCP	Bush cowpea	0.80±0.03 ^a	2.01±0.05	0.95±0.01 ^a
S.Em (±)	-	0.01	0.04	0.01
CD (0.05)	-	0.053	NS	0.035
T ₃ : PM + FCP in 1:1 ratio	Fodder cowpea	1.30±0.03 ^c	-	2.99±0.12
T ₄ : PM + FCP in 2:1 ratio	Fodder cowpea	1.45±0.01 ^b	-	3.16±0.02
T ₁₁ : Sole crop of FCP	Fodder cowpea	1.62±0.03 ^a	-	3.31±0.14
S.Em (±)	-	0.02	0.06	-
CD (0.05)	-	0.071	NS	-
T ₅ : PM + GG in 1:1 ratio	Green gram	0.45±0.01 ^c	1.90±0.04 ^b	1.22±0.01 ^b
T ₆ : PM + GG in 2:1 ratio	Green gram	0.53±0.01 ^b	1.87±0.07 ^b	1.20±0.03 ^b
T ₁₂ : Sole crop of GG	Green gram	0.57±0.02 ^a	2.26±0.06 ^a	1.44±0.01 ^a
S.Em (±)	-	0.01	0.01	0.01
CD (0.05)	-	0.037	0.056	0.050
T ₇ : PM + BG in 1:1 ratio	Black gram	0.31±0.01 ^b	1.74±0.05 ^c	1.14±0.02 ^c
T ₈ : PM + BG in 2:1 ratio	Black gram	0.34±0.01 ^a	1.98±0.02 ^b	1.52±0.01 ^b
T ₁₃ : Sole crop of BG	Black gram	0.37±0.01 ^a	2.12±0.01 ^a	1.87±0.05 ^a
S.Em (±)	-	0.01	0.02	0.02
CD (0.05)	-	0.021	0.069	0.072

NS- Non significant

Yield attributes of pearl millet

The number of productive tillers per plant, grain yield and stover yield of pearl millet (Table 9) were significantly influenced by different intercropping systems (Table 13). The higher number of productive tillers per plant was recorded in the sole crop of pearl millet (T₉) with 3.60, followed by pearl millet + black gram in 2:1 ratio (T₈) and pearl millet + green gram in 2:1 ratio (T₆). The lowest tiller count (2.70) was observed in pearl millet + fodder cowpea in 1:1 ratio (T₃). The greater tiller formation in the sole crop might be attributed to the absence of interspecific competition and the efficient utilization of available growth resources. Similar results were reported by Ram and Meena (2014) [22] and Kamani and Arvadiya (2023) [19], Priya *et al.* (2023) [20] and Sowmiya *et al.* (2024) [21] who observed that sole pearl millet produced more tillers due to better access to light, moisture and nutrients compared to intercropped systems.

The sole crop of pearl millet (T₉) recorded the maximum grain yield (2498 kg ha⁻¹) and stover yield (4400 kg ha⁻¹), which could be attributed to the absence of competition and greater

canopy efficiency leading to improved photosynthetic activity. In contrast, the lowest grain (2018 kg ha⁻¹) and stover yields (3212 kg ha⁻¹) were obtained in pearl millet + bush cowpea in 1:1 ratio (T₁), possibly due to excessive competition between the component crops for growth factors. Similar observations were made by Choudhary *et al.* (2012) [16], Barod *et al.* (2017) [25], Kamani and Arvadiya (2023) [19], Victor *et al.* (2023) [26] and Sowmiya *et al.* (2024) [21], who emphasized that intense interspecific competition could suppress yield.

Among the intercropping systems, pearl millet + black gram in 2:1 ratio (T₈) produced higher grain yield (2353 kg ha⁻¹) and stover yield (4130 kg ha⁻¹), followed by pearl millet + green gram in 2:1 ratio (T₆). These results indicate that wider row spacing and compatible legume intercrops promoted complementary utilization of resources and minimized interspecific competition. The increased productivity under these systems may also be attributed to biological nitrogen fixation by legumes and improved soil fertility. These findings are supported by Kumar *et al.* (2006) [23], Ram and Meena (2014) [22],

Ghilotia *et al.* (2015)^[27] and Sowmiya *et al.* (2024)^[21], reported enhanced yield performance of cereal-legume intercropping

systems due to efficient nutrient and moisture use.

Table 9: Effect of intercropping on yield attributes of pearl millet

Treatments	Number of productive tillers per plant	Grain yield (kg ha ⁻¹)	Stover yield (kg ha ⁻¹)
T ₁ : PM + BCP in 1:1 ratio	2.80±0.07 ^f	2018±38 ^f	3212 ±186 ^f
T ₂ : PM + BCP in 2:1 ratio	3.30±0.04 ^{cd}	2202±43 ^d	3860±56 ^{cd}
T ₃ : PM + FCP in 1:1 ratio	2.70±0.02 ^f	2197±17 ^{de}	3050±109 ^f
T ₄ : PM + FCP in 2:1 ratio	3.20±0.13 ^d	2231±70 ^{cd}	3752±171 ^{de}
T ₅ : PM + GG in 1:1 ratio	3.00±0.09 ^e	2124±40 ^e	3590±24 ^e
T ₆ : PM + GG in 2:1 ratio	3.50±0.05 ^{ab}	2289± 8 ^{bc}	4022±78 ^{bc}
T ₇ : PM + BG in 1:1 ratio	3.50±0.15 ^{ab}	2157±70 ^{de}	3900±194 ^{cd}
T ₈ : PM + BG in 2:1 ratio	3.40±0.12 ^{bc}	2353±27 ^b	4130±153 ^b
T ₉ : Sole crop of PM	3.60±0.13 ^a	2498±26 ^a	4400±53 ^a
S.Em (±)	0.05	25.82	68.29
CD (0.05)	0.160	77.391	204.720

PM- pearl millet, BCP- Bush cowpea, FCP- Fodder cowpea, GG - Green gram and BG- black gram

Yield attributes of intercrops

Among the intercrops, sole crop of bush cowpea (T₁₀) (Table 10) recorded the highest number of pods per plant, grain yield and haulm yield in sole cropping (15 pods, 2021 ± 61 kg ha⁻¹), followed by pearl millet + bush cowpea (1:1) and 2:1 intercropping systems. Similar findings were reported by and Kumar *et al.* (2006)^[23], who observed that sole cowpea exhibited superior yield attributes owing to the absence of interspecific competition. Yadav *et al.* (2015)^[17] and Kamani and Arvadiya (2023)^[19] also confirmed that sole crop of cowpea produced greater pod number and seed yield due to better canopy development and light interception efficiency.

Sole crop of fodder cowpea (T₁₁) (Table 10) produced the maximum green fodder and dry fodder yields (8184 kg ha⁻¹ and 1042 kg ha⁻¹, respectively), followed by pearl millet + fodder cowpea (1:1) and 2:1 intercropping systems. This was supported by Choudhary *et al.* (2020)^[24] who noted that fodder cowpea grown alone performed better due to full exploitation of resources and lack of competition for moisture and nutrients.

Sole crop of green gram (T₁₂) (Table 10) recorded the highest

number of pods per plant, grain yield (35 pods, 633 ± 21 kg ha⁻¹) and haulm yield followed by intercropping systems. Similar trends were reported by Choudhary *et al.* (2012)^[16] and Barod *et al.* (2017)^[25], who emphasized that sole cropping of green gram ensured better partitioning of assimilates toward the reproductive phase. Ram and Meena (2014)^[22], Ghilotia *et al.* (2015)^[25] and Yadav *et al.* (2015)^[27] also documented that the absence of competition in sole legumes enhanced pod formation and grain yield.

Likewise, sole crop of black gram (T₁₃) (Table 10) produced the maximum pods per plant and grain yield (36 pods, 1173 ± 29 kg ha⁻¹) and haulm yield, compared to pearl millet + black gram (1:1) and 2:1 ratio. This agrees with the observations of Kamani and Arvadiya (2023)^[19], who reported that the yield of black gram was reduced under intercropping due to competition for space and nutrients, further emphasized that although legume yield decreased in intercropping, the overall system productivity improved due to complementary interactions between the base and intercrop species.

Table 10: Effect of intercropping on yield attributes of intercrops

Treatments	Crop	No. of pods per plant	Grain yield (kg ha ⁻¹)	Haulm yield (kg ha ⁻¹)
T ₁ : PM + BCP in 1:1 ratio	Bush cowpea	12.00±0.19 ^c	1052±27 ^b	2175±29 ^b
T ₂ : PM + BCP in 2:1 ratio	Bush cowpea	13.00±0.35 ^b	633±19 ^c	1330±51 ^c
T ₁₀ : Sole crop of BCP	Bush cowpea	15.00±0.51 ^a	2021±61 ^a	4244±168 ^a
S.Em (±)	-	0.21	24.97	56.10
CD (0.05)	-	0.823	98.059	220.291
		Leaf:stem ratio	Green fodder yield (kg ha ⁻¹)	Dry fodder yield (kg ha ⁻¹)
T ₃ : PM + FCP in 1:1 ratio	Fodder cowpea	0.77±0.01 ^a	4192±49 ^b	486±20 ^b
T ₄ : PM + FCP in 2:1 ratio	Fodder cowpea	0.64±0.03 ^b	3111±123 ^c	353±1.59 ^c
T ₁₁ : Sole crop of FCP	Fodder cowpea	0.78±0.03 ^a	8184±162 ^a	1042±40.38 ^a
S.Em (±)	-	0.01	84.53	16.66
CD (0.05)	-	0.056	331.888	65.426
	Crop	No. of pods per plant	Grain yield (kg ha ⁻¹)	Haulm yield (kg ha ⁻¹)
T ₅ : PM + GG in 1:1 ratio	Green gram	24.00±0.43 ^c	349±13.21 ^b	768±28.38 ^b
T ₆ : PM + GG in 2:1 ratio	Green gram	27.00±0.88 ^b	211±6.08 ^c	428±10.41 ^c
T ₁₂ : Sole crop of GG	Green gram	35.00±0.72 ^a	633±21.11 ^a	1271±51.5 ^a
S.Em (±)	-	0.41	7.91	16.86
CD (0.05)	-	1.623	31.06	66.196
T ₇ : PM + BG in 1:1 ratio	Black gram	20.00±0.89 ^c	651±17 ^b	1524±16 ^b
T ₈ : PM + BG in 2:1 ratio	Black gram	29.00±0.13 ^b	373±15 ^c	930±12 ^c
T ₁₃ : Sole crop of BG	Black gram	36.00±0.94 ^a	1173±29 ^a	2890±10 ^a
S.Em (±)	-	0.27	11.37	7.20
CD (0.05)	-	1.045	44.639	28.263

PM- pearl millet, BCP- Bush cowpea, FCP- Fodder cowpea, GG - Green gram and BG- black gram

Pearl millet equivalent yield (PMEY)

The maximum PMEY (Table 11) was recorded in T₁ (pearl millet + bush cowpea in 1:1 ratio), which was 56 per cent higher than the sole pearl millet (T₉), followed by T₇ (3749 kg ha⁻¹, 50% higher) and T₁₀ (3593 kg ha⁻¹, 43% higher). The higher PMEY observed in these treatments could be attributed to efficient utilization of growth resources, complementary interactions between component crops and the additional yield advantage from intercrops. Similar synergistic effects of cereal-legume intercropping systems were reported by Kumar *et al.* (2006) [23], Yadav *et al.* (2015) [17], Victor *et al.* (2023) [26] and Sowmiya *et al.* (2024) [21].

Economic evaluation

The economic analysis of the system (Table 11) revealed that T₇ (pearl millet + black gram in 1:1 ratio) registered the highest net income (₹ 90,246 ha⁻¹) and benefit-cost ratio (2.15), followed by T₈ (₹ 71,960 ha⁻¹; B:C ratio 1.96) and T₁ (₹ 67,499 ha⁻¹; B:C ratio 1.63). The increased profitability in these systems could be attributed to the combined benefit of higher yields and reduced fertilizer requirement due to biological nitrogen fixation by legumes. These results are in accordance with Chaudhary *et al.* (2012) [16], Victor *et al.* (2023) [26] and Sowmiya *et al.* (2024) [21], who observed improved economic returns under pearl millet-legume intercropping systems.

Table 11: Effect of intercropping on PMEY, Net income and B:C ratio

Treatments	PMEY (kg ha ⁻¹)	Net income (₹ ha ⁻¹)	B:C ratio
T ₁ : PM + BCP in 1:1 ratio	3888	67499	1.63
T ₂ : PM + BCP in 2:1 ratio	3327	54377	1.57
T ₃ : PM + FCP in 1:1 ratio	2477	33359	1.43
T ₄ : PM + FCP in 2:1 ratio	2439	33992	1.45
T ₅ : PM + GG in 1:1 ratio	3087	60327	1.77
T ₆ : PM + GG in 2:1 ratio	2871	54168	1.72
T ₇ : PM + BG in 1:1 ratio	3749	90246	2.15
T ₈ : PM + BG in 2:1 ratio	3265	71960	1.96
T ₉ : Sole crop of PM	2498	41371	1.58
T ₁₀ : Sole crop of BCP	3593	35343	1.28
T ₁₁ : Sole crop of FCP	546	-3	0.99
T ₁₂ : Sole crop of GG	1743	7769	1.11
T ₁₃ : Sole crop of BG	2867	58560	1.83

PM- pearl millet, BCP- Bush cowpea, FCP- Fodder cowpea, GG - Green gram, BG- black gram

4. Conclusion

From the study, it could be inferred that sole crops recorded superior growth parameters due to the absence of interspecific competition, while intercropping systems enhanced overall yield and profitability. Among the treatments, pearl millet + bush cowpea in 1:1 ratio produced the highest pearl millet equivalent yield (3,888 kg ha⁻¹), whereas pearl millet + black gram in 1:1 ratio recorded the higher net income (₹ 90,246 ha⁻¹) and B:C ratio (2.15). Thus, pearl millet + black gram (1:1) intercropping can be recommended as the most productive and economically viable system for sustainable utilization of lowland summer rice fallows in southern Kerala.

Acknowledgement

The authors sincerely acknowledge KAU for providing PG Fellowship for the successful execution of this research work.

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