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Assessment of intercropping indices in finger millet and green gram systems under varied nutrient regimes

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Abstract

A field investigation entitled “Performance of Finger Millet and Green Gram Intercropping under Different Nutrient Levels” was conducted during the Kharif season of 2024 at the Zonal Agricultural Research Station, Shendapark, Kolhapur. The experiment was laid out in a Factorial Randomized Block Design (FRBD) with three replications, comprising a total of 18 treatment combinations. The study included two factors: the first factor consisted of three cropping systems, namely C₁-Sole finger millet, C₂-Finger millet + green gram (4:2), and C₃-Sole green gram, whereas the second factor comprised six nutrient management treatments (N₁-N₆). The experimental findings indicated that the finger millet + green gram (4:2) intercropping system supplied with 50% RDF along with 50% RDN through FYM (C₂N₆) recorded the highest values of Land Equivalent Ratio (LER), Relative Crowding Coefficient (RCC), Area Time Equivalent Ratio (ATER), and Monetary Advantage Index (MAI). However, the highest Finger Millet Equivalent Yield (FMEY) and Green Gram Equivalent Yield (GGEY) were obtained under the finger millet + green gram (4:2) intercropping system fertilized with 100% RDF (C₂N₁).

Keywords: Finger Millet, Green gram, Intercropping, Interaction, Fertilizers, Nutrient Levels, Indices

Introduction

Intercropping cereals with legumes is a sustainable agricultural strategy that enhances cropping system performance by maximizing the efficient use of vital resources such as sunlight, soil water, temperature, and soil nutrients (Foley *et al.*, 2011) [2]. This system not only improves resource-use efficiency but also functions as an eco-functional practice that contributes to diversified diets, lowers the risk of crop losses under biotic and abiotic stress conditions, improves yield stability, and delivers greater economic returns compared with monocropping systems (Tsubo *et al.*, 2005; Bitew *et al.*, 2019) [1, 8]. Due to their inherent drought tolerance, finger millet (FM) and green gram (GG) are considered a suitable crop combination for intercropping in drought-affected environments. Finger millet (*Eleusine coracana* L.), popularly known as ragi, is an important small millet that is widely cultivated under rainfed and dryland conditions across India. Green gram (*Vigna radiata* L. Wilczek), popularly known as moong, is a protein-rich legume with high digestibility and serves as an important component of human and animal diets. With the rising demand for nutritious food and the increasing emphasis on sustainable agriculture, maintaining soil fertility has become a major concern. Nevertheless, the continuous and imbalanced use of chemical inputs has accelerated nutrient exhaustion, degraded soil quality, and adversely affected crop productivity, threatening the sustainability of modern farming systems. Chemical fertilizers alone cannot sustain long-term soil productivity (Perli *et al.*, 2022) [5]. Integrating organic inputs such as farmyard manure (FYM), vermicompost, biofertilizers, and liquid formulations like Panchagavya, Jivamrut, and Sanjivak with inorganic fertilizers improves nutrient availability, soil fertility, and crop productivity. Therefore, integrated nutrient management is essential for sustainable agriculture. Keeping this in view, the present study was conducted during the kharif season to evaluate the performance of finger millet-green gram intercropping under different nutrient management levels.

Material and Methods experimental site

The field experiment was carried out during *Kharif*, 2024 at the Zonal Agricultural Research

Station, Shendapark, Kolhapur. The average annual rainfall is 1151.6 mm, with 67 rainy days. The annual mean maximum temperature ranges between 25.4 °C to 33.7°C while, the annual mean minimum temperature varies from 12.5 °C to 21.9 °C.

Soil characters

The soil of the experimental plot was sandy clay loam, low in available Nitrogen (196 kg ha⁻¹), medium in available phosphorus (35.3 kg ha⁻¹) and low in available potassium (194 kg ha⁻¹). The status of organic carbon content (0.67%) was high. The electrical conductivity and pH values were 0.11 dSm⁻¹ and 6.74 respectively.

Experimental details

The experiment was laid out in a Factorial Randomized Block Design (FRBD) comprising eighteen treatment combinations, each replicated three times in which first factor is intercropping C₁ : Sole Finger millet, C₂ : Finger millet + Green gram (4:2) and C₃: Sole Green gram, while N₁, N₂, N₃, N₄, N₅, N₆ nutrient levels as a second factor. For the sowing of seed, very small furrow lines were opened with the help of marker at a distance of 30 cm between the row and sowing of the crop was done on 13th July, 2024. The recommended seed rate of 15 kg ha⁻¹ for green gram and 5 kg ha⁻¹ for finger millet was used. Each gross plot measured 4.8 m × 6.0 m, and the net plot area was maintained at 3.6 m × 4.8 m.

Intercropping indices

Statistically analysis of intercropping indices such as LER, CEY, RCC, ATER and MAI are evaluated by using 3 x 6 factorial randomized block design in intercropping system

Land Equivalent Ratio (LER)

LER is defined as the relative land area under sole crop that is required to produce yields achieved in intercropping. The LER was worked out by using the following formula given by Willey (1979).

$$LER = \frac{Y_a}{S_a} + \frac{Y_b}{S_b}$$

Where,

Y_a and Y_b: Individual crop yields under intercropping S_a and S_b: Individual crop yields under sole cropping.

Crop Equivalent Yield (CEY)

Crop Equivalent Yield (CEY) is a standardized measure used in agriculture to compare the yields of different crops by converting them into the yield of a single reference crop, usually the main or most valuable crop in a cropping system. To assess the economic productivity of the intercropping systems, Crop Equivalent Yield (CEY) was calculated using the following formula:

$$CEY = \text{Yield of main crop} + \frac{\text{Yield of intercrop} \times \text{Market price of intercrop}}{\text{Market price of main crop}}$$

Where,

Yields are expressed in tons per hectare (t ha⁻¹) or (q ha⁻¹)

Market prices (in ₹ ton⁻¹) were obtained from the local agricultural market at the time of harvest

Relative crowding coefficient (RCC) (K)

Each crop in the intercropping has its RCC (K) which provides a measure of whether that component has produced more or fewer yields than expected. If the K value is >1, then there is a yield advantage of crop A in intercropping but if the K value is equal to or less than 1, it means there is no yield advantages or disadvantage respectively.

$$K_{ab} = \frac{Y_{ab} \times Z_{ba}}{(Y_{aa} - Y_{ab}) \times Z_{ab}}$$

$$K_{ba} = \frac{Y_{ba} \times Z_{ab}}{(Y_{bb} - Y_{ba}) \times Z_{ba}}$$

$$K = K_{ab} \times K_{ba}$$

Where,

- K_{ab} is the RCC of the component crop 'a' in the mixture K_{ba} is the RCC of the component crop 'b' in the mixture
- K is the RCC of the system
- Y_{aa} is the yield of the component crop 'a' as the sole crop Y_{bb} is the yield of the component crop 'b' as sole crop
- Y_{ab} is the yield of the component crop 'a' as intercrop in combination with 'b' Y_{ba} is the yield of the component crop 'b' as intercrop in combination with 'a', Z_{ba} is sown proportion of component 'b' in combination with 'a'
- Z_{ab} is sown proportion of component 'a' in combination with 'b'

Area Time Equivalent Ratio (ATER)

Area Time Equivalent Ratio (ATER) is an index used to evaluate the efficiency of intercropping systems by considering both land use and crop duration. It provides a more realistic measure of intercropping advantage than the Land Equivalent Ratio (LER), especially when the component crops differ in their growth durations.

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

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.

Monetary Advantage index (MAI)

In intercropping, the Monetary Advantage Index (MAI) is a metric used to evaluate the economic benefit of growing two or more crops together compared to growing them separately (i.e., in monoculture). It helps determine whether intercropping is more profitable than sole cropping The economic advantage of the cropping system can determine by the monetary advantage index

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

Result and Discussion

Table 1: Grain and straw yield (q ha⁻¹) of finger millet as influenced by various treatments

Treatments	Grain yield (q ha ⁻¹)	Straw yield (q ha ⁻¹)
Intercropping		
C ₁ - Sole finger millet	27.37	34.38
C ₂ - Finger millet + Green gram (4:2)	21.27	27.94
S.E.m±	0.34	1.08
CD @ 5%	1.01	3.17
Nutrient levels		
N ₁ -100% Recommended dose of fertilizer (RDF)	27.37	38.39
N ₂ -75% RDF + Soil application of <i>Azospirillum</i> @2 kg ha ⁻¹ and Phosphate solubilizing bacteria @ 2 kg ha ⁻¹	25.22	29.63
N ₃ -75% RDF + Soil application of <i>Azospirillum</i> (2 kg ha ⁻¹) and PSB (2 kg ha ⁻¹) + Foliar spray of 2% 19:19:19 @ 15 and 30 DAS	26.33	34.02
N ₄ -75% RDF + Soil application of <i>Azospirillum</i> (2 kg ha ⁻¹) and PSB (2 kg ha ⁻¹) + Foliar spray of Panchagavya 3% @ 15 and 30 DAS	24.31	33.07
N ₅ - 75% RDF + 25% RDN through FYM	23.32	29.23
N ₆ - 50% RDF + 50% RDN through FYM	19.95	22.62
S.E.m±	1.75	1.87
CD @ 5%	27.37	5.50
Interaction: C × N		
S.E.m±	0.84	2.65
CD @ 5%	2.48	7.77
General Mean	24.32	31.16

Table 2: Effect of interaction on grain and straw yield (q ha⁻¹) of finger millet as influenced by various treatment

Nutrient Levels \ Intercropping	Grain yield (q ha ⁻¹)			Straw yield (q ha ⁻¹)		
	C ₁	C ₂	Mean	C ₁	C ₂	Mean
N ₁	30.76	22.82	26.79	44.00	32.77	38.39
N ₂	27.82	20.79	24.31	33.89	25.36	29.63
N ₃	29.90	22.76	26.33	37.55	30.49	34.02
N ₄	28.52	21.93	25.22	36.46	29.68	33.07
N ₅	25.99	20.65	23.32	33.41	25.05	29.23
N ₆	21.20	18.70	19.95	20.97	24.28	22.62
Mean	27.37	21.27	24.32	34.38	27.94	31.16
S.E.m±		0.84			2.65	
CD @ 5 %		2.48			7.77	

Table 3: Seed and stover yield (q ha⁻¹) of green gram as influenced by various treatments

Treatments	Seed yield (q ha ⁻¹)	Stover yield (q ha ⁻¹)
Intercropping		
C ₃ - Sole Green gram	13.87	29.90
C ₂ - Finger millet + Green gram (4:2)	5.92	12.22
S.E.m±	0.23	0.48
CD @ 5%	0.68	1.40
Nutrient levels		
N ₁ -100% Recommended dose of fertilizer (RDF)	11.46	24.63
N ₂ -75% RDF + Soil application of <i>Azospirillum</i> @2 kg ha ⁻¹ and Phosphate solubilizing bacteria @ 2 kg ha ⁻¹	9.84	21.53
N ₃ -75% RDF + Soil application of <i>Azospirillum</i> (2 kg ha ⁻¹) and PSB (2 kg ha ⁻¹) + Foliar spray of 2% 19:19:19 @ 15 and 30 DAS	11.15	24.15
N ₄ -75% RDF + Soil application of <i>Azospirillum</i> (2 kg ha ⁻¹) and PSB (2 kg ha ⁻¹) + Foliar spray of Panchagavya 3% @ 15 and 30 DAS	10.66	22.60
N ₅ - 75% RDF + 25% RDN through FYM	9.04	18.50
N ₆ - 50% RDF + 50% RDN through FYM	7.20	14.93
S.E.m±	0.40	0.83
CD @ 5%	1.19	2.43
Interaction: C × N		
S.E.m±	0.57	1.17
CD @ 5%	1.68	3.43

General Mean	9.89	21.06
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Table 4: Effect of interaction on seed yield and stover yield after harvest of green gram as influenced by various treatments

After harvest \ Intercropping	Seed Yield (q ha ⁻¹)			Stover Yield (q ha ⁻¹)		
Nutrient levels	C ₃	C ₂	Mean	C ₃	C ₂	Mean
N ₁	16.10	6.82	11.46	34.14	15.12	24.63
N ₂	14.35	5.33	9.84	31.75	11.31	21.53
N ₃	15.59	6.71	11.15	34.06	14.24	24.15
N ₄	14.81	6.51	10.66	32.07	13.13	22.60
N ₅	12.91	5.17	9.04	26.71	10.29	18.50
N ₆	9.43	4.97	7.20	20.65	9.21	14.93
Mean	13.87	5.92	9.89	29.90	12.22	21.06
S.Em±		0.57			1.17	
CD @ 5 %		1.68			3.43	

Intercropping Indices**Land Equivalent Ratio**

The effect of finger millet and green gram intercropping on the Land Equivalent Ratio (LER) is presented in Table 3. The maximum LER (1.41) was recorded under the treatment combination of finger millet + green gram (4:2) with application of 50% RDF + 50% RDN through FYM (C₂N₆), followed by finger millet + green gram (4:2) with 75% RDF along with soil application of *Azospirillum* (2 kg ha⁻¹) and PSB (2 kg ha⁻¹) + foliar spray of 3% Panchagavya at 15 and 30 DAS (C₂N₄). In contrast, the lowest LER (1.12) was observed under finger millet + green gram (4:2) with 75% RDF + soil application of *Azospirillum* (2 kg ha⁻¹) and PSB (2 kg ha⁻¹) (C₂N₂). The higher LER values obtained under the intercropping treatments indicate better land use efficiency compared to the sole cropping system. These findings are in accordance with those reported by Padhi *et al.* (2010) [4].

Finger Millet Equivalent Yield

The data on finger millet equivalent yield (FMEY) as influenced

by intercropping of finger millet with green gram are presented in Table 3. Among the treatment combinations, finger millet + green gram (4:2) with the application of 100% RDF (C₂N₁) recorded the highest FMEY (36.61 q ha⁻¹). This was followed by finger millet + green gram (4:2) receiving 75% RDF along with soil application of *Azospirillum* (2 kg ha⁻¹) and PSB (2 kg ha⁻¹) in combination with foliar spray of 2% 19:19:19 at 15 and 30 DAS (C₂N₃). The superior finger millet equivalent yield recorded under the 100% RDF treatment may be attributed to the adequate supply of essential nutrients, which promoted better crop growth, enhanced photosynthetic activity, and increased biomass production. The slightly lower FMEY observed under the 75% RDF treatment supplemented with biofertilizers and foliar nutrition indicates that although biofertilizers improve nutrient availability and uptake, they may not completely offset the reduction in the recommended fertilizer dose. Similar findings were reported by Padhi *et al.* (2010) [4], Jena *et al.* (2000) [3], and Ramamoorthy *et al.* (2003) [7], who also emphasized the importance of balanced nutrient management for maximizing productivity in intercropping systems.

Table 5: Intercropping indices of cropping system as influenced by various treatment combination

Treatment combinations	Land Equivalent Ratio (LER)	Crop Equivalent Yield (q ha ⁻¹)		Relative crowding Coefficient (RCC)			Area Time Equivalent Ratio (ATER)	Monetary Advantage Index (MAI) (₹ ha ⁻¹)
		Finger millet equivalent yield (FMEY)	Green gram Equivalent Yield (GGEY)	Kfg	Kgf	K		
C1N1	1	30.76				-	-	-
C1N2	1	27.82				-	-	-
C1N3	1	29.90				-	-	-
C1N4	1	28.52				-	-	-
C1N5	1	25.99				-	-	-
C1N6	1	21.20				-	-	-
C2N1	1.17	36.61	18.09	1.44	1.47	2.11	0.96	23865
C2N2	1.12	31.59	15.61	1.48	1.18	1.75	0.92	15335
C1N3	1.19	36.35	17.96	1.59	1.51	2.41	0.98	26791
C2N4	1.21	35.09	17.34	1.66	1.57	2.61	1	27716
C2N5	1.19	31.11	15.37	1.93	1.34	2.58	0.98	23155
C2N6	1.41	28.77	14.21	3.73	2.23	8.34	1.16	38279
C3N1	1		16.10			-	-	-
C3N2	1		14.35			-	-	-
C3N3	1		15.59			-	-	-
C3N4	1		14.81			-	-	-
C3N5	1		12.91			-	-	-
C3N6	1		9.43			-	-	-
S.Em±	-	0.80	0.75			-	-	-
CD @ 5 %	-	2.31	2.14			-	-	-

Green gram Equivalent Yield

The data on Green Gram Equivalent Yield (GGEY) as affected

by intercropping of finger millet with green gram are presented in Table 3. Among the different treatment combinations, finger

millet + green gram (4:2) with the application of 100% Recommended Dose of Fertilizers (RDF) (C_2N_1) recorded the highest GGEY of 18.09 q ha^{-1} . The second highest GGEY was obtained with finger millet + green gram (4:2) receiving 75% RDF along with soil application of *Azospirillum* (2 kg ha^{-1}) and PSB (2 kg ha^{-1}) in combination with foliar spray of 2% 19:19:19 at 15 and 30 DAS (C_2N_3).

The superior GGEY recorded under the 100% RDF treatment could be attributed to the adequate and balanced availability of essential nutrients, which supported optimum crop growth and higher productivity of green gram in the intercropping system. Adequate nutrient supply enhanced physiological activities, improved nodulation, and promoted better grain filling in the legume crop. Although the integrated nutrient management treatment (C_2N_3) also produced higher GGEY, it remained slightly lower than the 100% RDF treatment, probably because the reduced fertilizer dose could not completely meet the crop's nutrient requirement. Similar findings were reported by Padhi *et al.* (2010)^[4], Jena *et al.* (2000)^[3], and Ramamoorthy *et al.* (2003)^[7], who emphasized the significance of balanced nutrient management for achieving higher legume productivity under intercropping systems.

Relative Crowding Coefficient (RCC)

The effect of finger millet-green gram intercropping on the Relative Crowding Coefficient (RCC) is presented in Table 3. Among the treatment combinations evaluated, finger millet + green gram (4:2) supplied with 50% RDF along with 50% RDN through FYM (C_2N_6) exhibited the highest RCC value of 8.34. The lowest RCC value (1.75) was recorded under the treatment receiving 75% RDF combined with soil application of *Azospirillum* (2 kg ha^{-1}) and PSB (2 kg ha^{-1}) (C_2N_2).

The higher RCC obtained under C_2N_6 reflects a more favourable competitive relationship and better complementary use of resources between finger millet and green gram. This could be attributed to the combined use of organic manure and inorganic fertilizers, which improved nutrient availability throughout the crop growth period and promoted efficient utilization of growth resources by both component crops. In comparison, the lower RCC observed in C_2N_2 may be associated with the reduced inorganic fertilizer level, which, despite the addition of biofertilizers, was insufficient to achieve optimum nutrient availability and competitive performance of the intercrops. These results are in agreement with the findings of Pradhan *et al.* (2024)^[6], who also reported that integrated nutrient management enhances crop compatibility, resource-use efficiency, and productivity in intercropping systems.

Area Time Equivalent Ratio

The results pertaining to the Area Time Equivalent Ratio (ATER) of finger millet-green gram intercropping are presented in Table 3. Among the various treatment combinations, finger millet + green gram (4:2) with the application of 50% RDF + 50% RDN through FYM (C_2N_6) recorded the highest ATER value of 1.16. The next highest ATER was obtained with finger millet + green gram (4:2) receiving 75% RDF along with soil application of *Azospirillum* (2 kg ha^{-1}) and PSB (2 kg ha^{-1}) followed by foliar spray of 3% Panchagavya at 15 and 30 DAS (C_2N_4). The lowest ATER (0.92) was observed under finger millet + green gram (4:2) supplied with 75% RDF in combination with soil application of *Azospirillum* (2 kg ha^{-1}) and PSB (2 kg ha^{-1}) (C_2N_2).

The superior ATER recorded under C_2N_6 and C_2N_4 reflects more efficient utilization of land as well as crop duration in the intercropping system. This improvement may be attributed to the combined effect of balanced nutrient supply, enhanced soil fertility through FYM and Panchagavya, and increased microbial activity resulting from biofertilizer application, which together promoted better crop growth and improved overall system productivity. In contrast, the lower ATER recorded under C_2N_2

indicates comparatively less efficient use of available land and time resources, which may be due to reduced nutrient availability and the absence of integrated nutrient sources.

Monetary Advantage Index (MAI)

The effect of finger millet-green gram intercropping on the Monetary Advantage Index (MAI) is presented in Table 3. Among the different treatment combinations, finger millet + green gram (4:2) receiving 50% RDF along with 50% RDN through FYM (C_2N_6) registered the highest MAI of ₹38,279 ha^{-1} . However, the lowest MAI was recorded under the treatment comprising finger millet + green gram (4:2) supplied with 75% RDF in combination with soil application of *Azospirillum* (2 kg ha^{-1}) and PSB (2 kg ha^{-1}) (C_2N_2). The higher MAI obtained under C_2N_6 reflects the greater economic advantage of this intercropping system. This may be attributed to the integrated use of organic and inorganic nutrient sources, which improved nutrient use efficiency, stimulated microbial activity, and ensured a steady supply of nutrients during the crop growth period. Consequently, these factors enhanced crop productivity and increased economic returns. In comparison, the lower MAI recorded under C_2N_2 may be associated with comparatively lower nutrient availability, resulting in reduced crop productivity and consequently lower economic benefits from the intercropping system. Thus, integrated nutrient management using both organic and inorganic sources play a key role in maximizing the monetary advantage in intercropping systems.

Conclusions

The experimental results revealed that the highest Land Equivalent Ratio (LER) of 1.41 was obtained under the treatment combination of finger millet + green gram (4:2) with the application of 50% RDF + 50% RDN through FYM (C_2N_6). The maximum Finger Millet Equivalent Yield (FMEY) of 36.61 q ha^{-1} and Green Gram Equivalent Yield (GGEY) of 18.09 q ha^{-1} were recorded under finger millet + green gram (4:2) receiving 100% RDF (C_2N_1). Likewise, the highest values of Relative Crowding Coefficient (RCC) (8.34), Area Time Equivalent Ratio (ATER) (1.16), and Monetary Advantage Index (MAI) (₹38,279 ha^{-1}) were also observed in the treatment comprising finger millet + green gram (4:2) with 50% RDF + 50% RDN through FYM (C_2N_6).

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