



RESEARCH ARTICLE

Evaluation of finger millet-toria cropping system under different row proportions with pulses in mid hills of Meghalaya

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Received: 25 December 2025; Accepted: 06 April 2026; Available online: Version 1.0: 19 May 2026

Cite this article: Ranjita B, Singh AK, Saikia R. Evaluation of finger millet-toria cropping system under different row proportions with pulses in mid hills of Meghalaya. Plant Science Today. 2026; 13(sp2): 1-8. <https://doi.org/10.14719/pst.13357>

Abstract

Finger millet-based cropping systems are crucial for ensuring food and livelihood security in the mid-hill regions of the Northeastern Himalayas; however, their productivity and profitability remain constrained due to low soil fertility, limited external inputs and poor system sustainability. In this context, integration of legumes through intercropping and the assessment of their residual effects on succeeding crops offers a promising pathway for sustainable intensification. The present study aimed to evaluate the effect of finger millet-pulse intercropping systems on the performance of finger millet-toria cropping sequence under mid-hill conditions of Meghalaya. A field experiment was conducted for two consecutive years comprising sole finger millet, sole pulses (green gram and black gram) and finger millet intercropped with green gram or black gram in different row proportions (1 : 1, 2 : 1, 2 : 2, 3 : 3 and 4 : 2), followed by toria as a succeeding crop. The results revealed that finger millet intercropped with green gram significantly outperformed sole cropping systems. Finger millet + green gram at 4:2 row proportion recorded the highest system productivity (4.08 t ha⁻¹), sustainable yield index (0.63), system production efficiency (11.18 kg ha⁻¹ d⁻¹) and profitability (₹260.5 ha⁻¹ d⁻¹), along with superior residual effects on yield attributes of toria. The study concludes that finger millet + green gram (4 : 2)-toria cropping sequence is an agronomically efficient, sustainable and economically viable option for smallholder farmers in the mid-hill regions of Meghalaya and similar agro-ecological environments.

Keywords: black gram; green gram; intercropping systems; productivity; profitability; rainfed hill agriculture; sustainable yield index

Introduction

Cereal-based intensive cropping systems constitute a major component of agricultural production across diverse agro-ecological regions of India. Under the present agricultural scenario, reliance on a single cereal crop is inadequate to meet the rising food demand of a rapidly growing population while ensuring farm profitability. Consequently, sustainable intensification through diversified and sequential cropping systems has emerged as a viable strategy to enhance productivity, resource-use efficiency and income stability. Finger millet (*Eleusine coracana* L.), commonly known as ragi, is a highly adaptable and climate-resilient crop that can be effectively integrated into various cropping systems such as intercropping, sequential cropping, mixed cropping and crop rotation (1). It belongs to the family Poaceae, bears a digitate type of inflorescence (finger-like spikes) and produces a caryopsis type of fruit (2). Although its cultivated area is smaller than that of major cereals such as rice and wheat, finger millet plays a strategic role in ensuring food and nutritional security in marginal and rainfed regions due to its high tolerance to drought, ability to grow in poor soils and superior nutritional quality, particularly its high calcium and dietary fiber content. It is a nutritionally rich staple crop supplying substantial amounts of calories, protein, vitamins and minerals, particularly to low-income

populations (3). During 2023–2024, finger millet production in India was about 16.70 lakh tonnes, highlighting its importance in ensuring nutritional security in marginal environments (4). In the state of Meghalaya, finger millet recorded an average productivity of 1108 kg ha⁻¹ during 2023–2024, indicating its continued relevance in traditional hill farming systems (5). In recent decades, research focus has shifted from individual crop productivity to cropping system-based evaluation, as the performance of component crops is strongly influenced by nutrient management practices and residual effects from preceding crops. Inclusion of pulses in cropping sequences has been shown to improve soil fertility, system productivity and sustainability, particularly in upland and rainfed ecosystems. Legume crops fix atmospheric nitrogen through symbiotic association with *Rhizobium*, contributing about 72–350 kg N ha⁻¹ depending on species and environmental conditions, thereby enriching soil fertility and reducing dependence on synthetic fertilisers (6). This additional nitrogen improves soil nutrient availability, enhances microbial activity and supports better growth of the following crop in the sequence. Green gram (*Vigna radiata* L.) and black gram (*Vigna mungo* L.) are grain legumes of the family Fabaceae; both bear racemose inflorescences and produce legume (pod) type fruits, while green gram is relatively erect and black gram exhibits a more spreading growth habit (7). In India, the total production of

green gram and black gram during 2023–2024 was about 31.03 and 23.19 lakh tonnes, respectively, while in Meghalaya the overall pulse productivity was reported to be about 2025 kg ha⁻¹ during the same period (4, 5).

Several studies have highlighted the advantages of intercropping as a sustainable agricultural practice that enhances biodiversity and optimises resource utilisation (8–10). Intercropping involves the simultaneous cultivation of two or more crops in the same field, sharing growth resources either partially or throughout their growing period (11). Legume–cereal intercropping systems have been reported to reduce weed pressure, insect pests and disease incidence while improving soil nitrogen status through biological nitrogen fixation (12, 13). Additive, replacement and intermediate planting designs are commonly adopted to optimise species compatibility and productivity (9). Despite these advantages, information on suitable legume species, row proportions and their performance in finger millet-based cropping systems followed by oilseed crops under mid-hill conditions of Meghalaya remains limited. In Meghalaya, finger millet is traditionally grown as a mixed crop in shifting cultivation systems; however, systematic integration with pulses followed by an oilseed crop such as toria has not been adequately evaluated. Toria (*Brassica rapa* L. var. *toria*) belongs to the family Brassicaceae and bears racemose inflorescence with silique as the fruit type (14). Rapeseed–toria production in India reached 132.6 lakh tonnes during 2023–2024, while the crop recorded a productivity of 927.9 kg ha⁻¹ in Meghalaya, highlighting its importance in oilseed-based cropping sequences in the region (4, 5). This knowledge gap necessitates a comprehensive assessment of finger millet–pulse intercropping systems for improving land-use efficiency, productivity and profitability in the region.

Therefore, the present study was undertaken to evaluate

the effect of intercropping finger millet with green gram and black gram under different row ratios, followed by toria, on yield attributes, system performance and profitability under mid-hill conditions of Meghalaya. It was hypothesised that intercropping finger millet with legumes at appropriate row ratios, followed by toria, would enhance finger millet grain yield while significantly improving system productivity, production efficiency and profitability compared to sole cropping and other intercropping configurations. Thus, the findings are expected to provide a scientifically validated intercropping strategy with appropriate row proportions for the sustainable intensification of finger millet-based cropping systems in the mid-hill regions of Meghalaya.

Materials and Methods

The field experiment was conducted at the Agricultural Farm of College of Post Graduate Studies in Agricultural Science, Central Agricultural University (Imphal), Kyrdemkulai, Meghalaya, during 2023–2024 and 2024–2025. The experimental site is geographically located at 25°44'4.9" N latitude and 91°49'13.5" E longitude, falling within the sub-tropical hill zone. The experimental soil was sandy loam in texture (sand 76 %, silt 17 %, clay 7 %) with a pH of 4.72 and low fertility status, characterised by low organic carbon content (0.59 %) and deficiency of available nitrogen (265.78 kg ha⁻¹). Available phosphorus (P₂O₅) and potassium (K₂O) were low to medium, measured as 8.45 kg ha⁻¹ and 125.5 kg ha⁻¹, respectively. During 2023–2024, rainfall was mainly concentrated between weeks 29–33 and around week 40, with maximum (≈ 25–35 °C) and minimum (≈ 22–30 °C) temperatures stable and relative humidity moderately high (≈ 60–85 %), indicating favourable conditions (Fig. 1). In 2024–2025, relative humidity remained stable (≈ 60–80 %), rainfall peaked intermittently around week 40 and maximum (28.17°C) and minimum (25.36°C) temperatures were consistent throughout the season (Fig. 2).

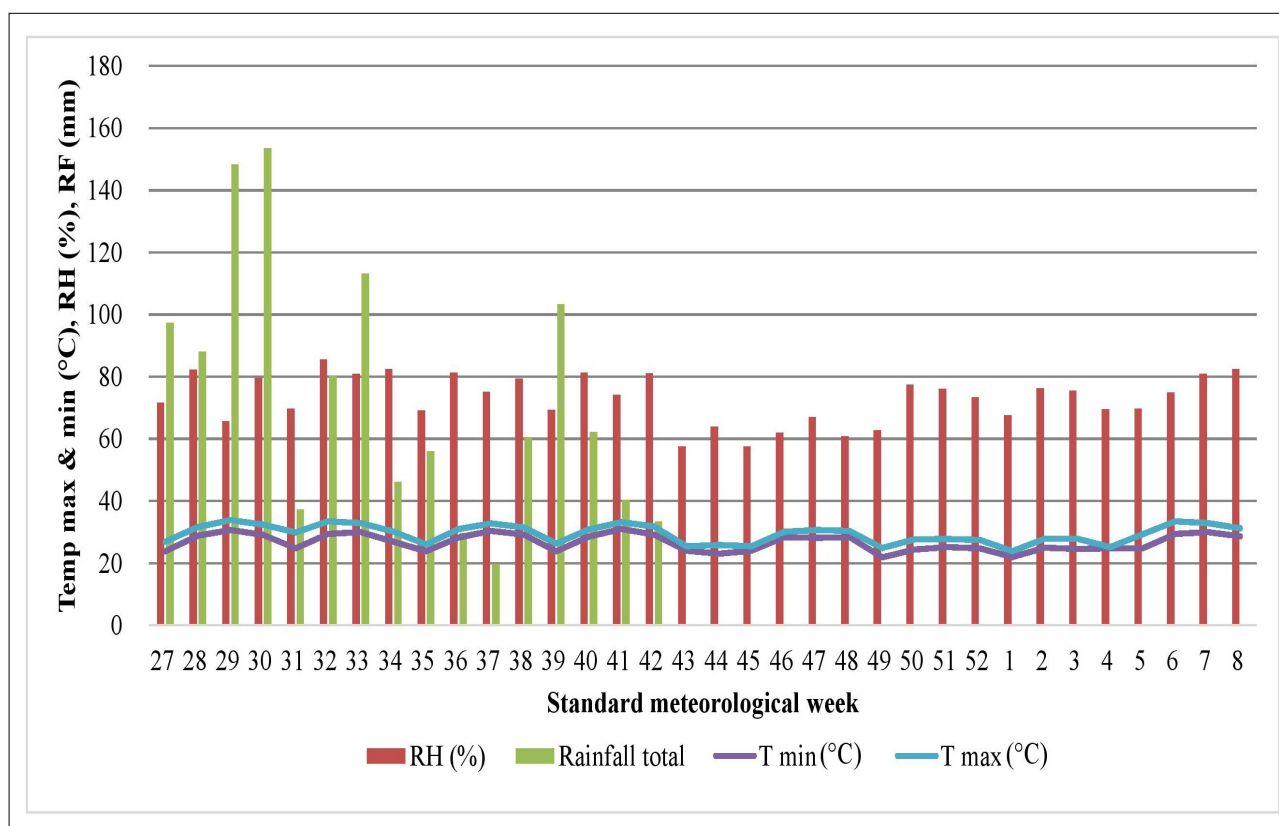


Fig. 1. Weekly weather data during the crop growing season of 2023–2024.

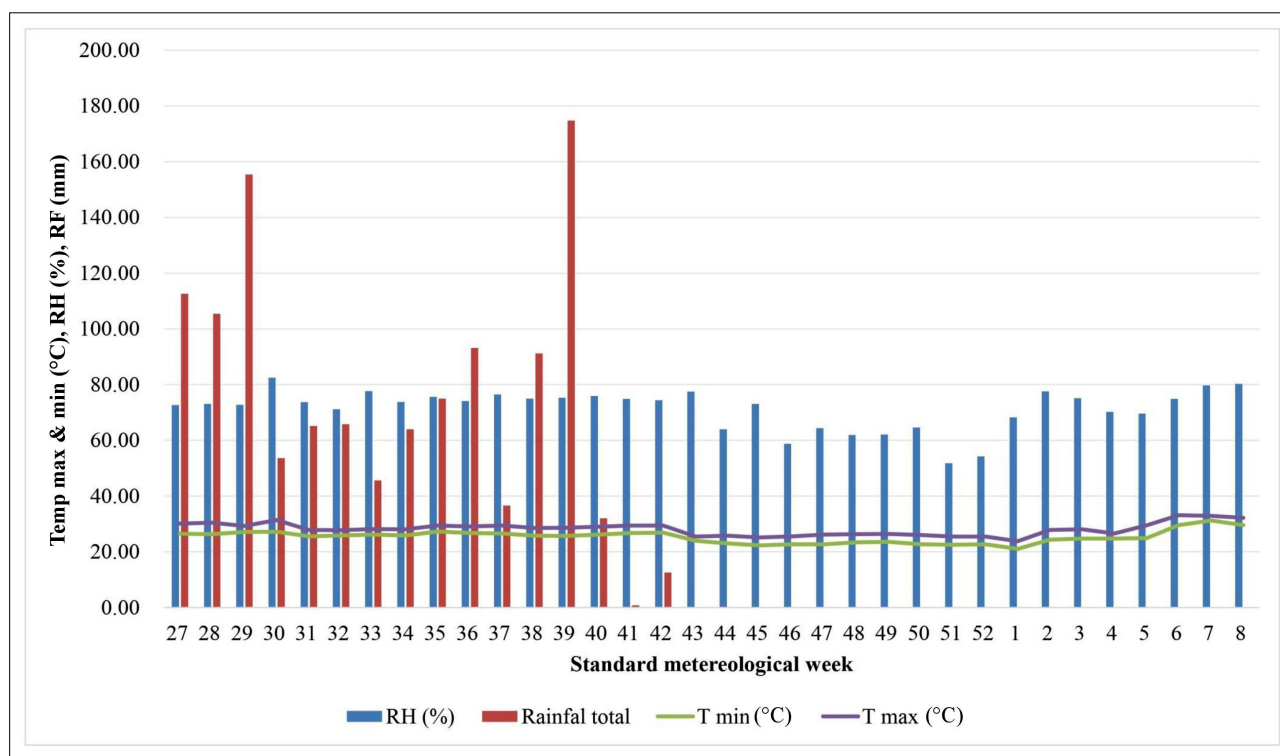


Fig. 2. Weekly weather data during the crop growing season of 2024–2025.

The experiment was laid out in a randomised block design (RBD) with 15 treatments and 3 replications. Finger millet was intercropped with pulses, viz., green gram (*V. radiata*) and black gram (*V. mungo*) in kharif season and toria as follow up crop in rabi season. The treatments were T₁- sole finger millet, T₂- sole green gram, T₃- sole black gram, T₄- finger millet + green gram (1 : 1), T₅- finger millet + green gram (2 : 1), T₆- finger millet + green gram (2 : 2), T₇- finger millet + green gram (3 : 3), T₈- finger millet + green gram (4 : 2), T₉- finger millet + green gram (2 : 2 paired row), T₁₀- finger millet + black gram (1 : 1), T₁₁- finger millet + black gram (2 : 1), T₁₂- finger millet + black gram (2 : 2), T₁₃- finger millet + black gram (3 : 3), T₁₄- finger millet + black gram (4 : 2), T₁₅- finger millet + black gram (2 : 2 paired row).

The experimental field was prepared by ploughing twice using a power tiller, followed by harrowing to achieve a fine tilth. Farmyard manure was applied at the rate of 5 t ha⁻¹ and recommended doses of fertilisers (RDF) were applied as 40 : 20 : 20 kg N : P₂O₅ : K₂O ha⁻¹ for finger millet, while the pulse crops received RDF at 20 : 40 : 20 kg N : P₂O₅ : K₂O ha⁻¹, adjusted according to plant population in each treatment. The succeeding toria crop received only half of the RDF (60 : 40 : 40 kg N : P₂O₅ : K₂O ha⁻¹) across all the treatments. To enhance nutrient availability and microbial activity under acidic soil conditions, seeds were inoculated with suitable biofertilisers prior to sowing. Finger millet seeds were treated with *Azospirillum* and phosphate-solubilising bacteria (PSB), green gram and blackgram seeds with *Rhizobium* and PSB, while toria seeds were inoculated with *Azotobacter* and PSB using standard seed treatment procedures. Finger millet-pulse intercropping was implemented using a replacement series, where the population of finger millet was adjusted to accommodate intercrop legumes at different row ratios, except in the paired-row treatments. For sole crops and replacement series, row spacing of 25 × 10 cm for finger millet and 30 × 10 cm for pulses was maintained. In the paired-row configuration, two rows of finger millet were planted at 15 cm spacing, leaving a 45 cm gap between pairs, into which two rows of the intercrop pulses were sown, maintaining the full plant

population of finger millet. Finger millet, green gram and black gram were sown on 20th June 2023 and 24th June 2024. The succeeding crop toria was sown on 25th October 2023 and 29th October 2024 by maintaining a row spacing of 30 × 10 cm. Green gram and black gram were harvested at 65 days after sowing, finger millet at 120 days after sowing and toria at 95 days after sowing. The varieties used for the experiment were VL 376 for finger millet, SGC 16 for green gram, SBC 40 for blackgram and TS 38 for toria, which were consistent across all treatments.

Five randomly selected plants were tagged for recording observation on yield attributes of different crops in each plot. Plot wise yield data of different crops were measured by following the standard agronomic procedures (15). Grain yield of pulses and toria were converted into finger millet equivalent yield (FMEY) by using the formula suggested by previous researchers (16). The system productivity (t ha⁻¹) was calculated by adding finger millet equivalent yield of toria with the total finger millet equivalent yield of intercropping system for each treatment. Further, the sustainable yield index (SYI) was computed using the following equation as per previous studies (17).

$$\text{Sustainable yield index} = \frac{Y - \sigma}{Y_{\max}} \quad (\text{Eqn. 1})$$

Where, Y = average yield obtained in a particular system, σ = standard deviation and Y_{max} = Maximum yield obtained in a particular system.

Additionally, system production efficiency value was calculated by using the following formula suggested by previous researchers (18):

$$\text{System production efficiency (kg ha}^{-1}\text{d}^{-1}) = \frac{\text{System productivity (kg ha}^{-1})}{365} \quad (\text{Eqn. 2})$$

The profitability of the system was calculated by using the following formula (19):

System profitability ($\text{₹ ha}^{-1}\text{d}^{-1}$) =

$$\frac{\text{Net return (₹ ha}^{-1}\text{)}}{365} \quad (\text{Eqn. 3})$$

The data obtained from the two-year experiment were pooled and subjected to statistical analysis following the procedure outlined previously (20). Analysis of variance (ANOVA) was performed to evaluate the significance of differences among treatments for all measured parameters. Treatment means were compared using the least significant difference (LSD) test at a 5 % probability level.

Results

Yield attributes of finger millet

The pooled mean of two years of experimental data pertaining to yield attributes are presented in Table 1. The different yield attributes of finger millet were influenced by different row proportion of green gram and blackgram. Sole finger millet (T_1) produced the highest number of earheads per plant (2.7), which was statistically at par with finger millet + green gram in 4 : 2 row proportion (T_8 ; 2.6) and finger millet + black gram in 4 : 2 row proportion (T_{14} ; 2.5). In contrast, finger millet + black gram (3 : 3) (T_{13}) recorded the lowest earheads per plant (2.0). Number of fingers per earhead were significantly higher under finger millet + green gram (4 : 2) (T_8 ; 7.54), followed by sole finger millet (T_1 ; 7.44) and finger millet + green gram (2:1) (T_5 ; 7.13). Compared with sole finger millet, T_8 showed a marginal increase (1.3 %), whereas finger millet + green gram (3 : 3) (T_7) and finger millet + black gram (2 : 2) (T_{12}), significantly reduced number of fingers per earhead by 20–26 %.

Number of grains per earhead differed significantly among treatments and ranged from 666 to 923. Sole finger millet (T_1) recorded the maximum number of grains per earhead (923), followed by finger millet + green gram (4 : 2) (T_8 ; 832) and finger millet + green gram (2 : 1) (T_5 ; 828). A similar trend was observed for grain weight, wherein sole finger millet produced the highest grain weight per plant (7.7 g), followed by finger millet + green gram (4 : 2) (T_8 ; 7.3 g) and finger millet + green gram (2 : 1) (T_5 ; 6.6 g). Test weight varied narrowly from 2.5 to 3.0 g and was not significantly influenced by intercropping, although finger millet + green gram (4 : 2) (T_8) recorded the highest value.

Yield attributes of toria

The residual effect of preceding finger millet-pulse intercropping systems significantly influenced siliqua production and seed setting in toria (Fig. 3). The highest number of siliquae per plant were recorded under sole green gram (T_2 ; 69.6), which was statistically at par with sole black gram (T_3 ; 66.4), finger millet + green gram (3 : 3) (T_7 ; 66.7) and finger millet + black gram (3 : 3) (T_{13} ; 64.7). In contrast, sole finger millet (T_1 ; 47.8) and finger millet + black gram (2 : 2 paired row) (T_{15} ; 48.7) recorded the lowest siliqua numbers. The number of seeds per siliqua were also significantly higher under sole green gram (T_2 ; 19.5), followed by sole black gram (T_3 ; 19.3) and finger millet + green gram (3 : 3) (T_7 ; 19.1), whereas sole finger millet (T_1 ; 11.4) recorded the lowest value.

Sole green gram (T_2) produced the maximum number of grains per plant (1361), followed by finger millet + green gram (3 : 3) (T_7 ; 1284), sole black gram (T_3 ; 1271) and finger millet + black gram (3 : 3) (T_{13} ; 1194), all of which were significantly superior to sole finger millet (T_1 ; 544). Compared with sole finger millet, these treatments registered an increase of more than 120–150 % in number of grains per plant, reflecting substantial residual nitrogen contribution from legumes. Test weight ranged from 2.3–2.85 g and did not differ significantly among treatments; however, finger millet + green gram (3 : 3) (T_7) recorded the highest numerical value (2.85 g).

System productivity, sustainable yield index, production efficiency and profitability of finger millet-based cropping system

The intercropping systems significantly influenced system productivity and system production efficiency compared with sole cropping (Table 2). The highest system productivity was recorded under finger millet + green gram (4 : 2) (T_8 ; 4.08 t ha⁻¹), which was followed by finger millet + green gram (3 : 3) (T_7 ; 3.74 t ha⁻¹) and finger millet + green gram (2 : 1) (T_5 ; 3.62 t ha⁻¹). Compared with sole finger millet (T_1 ; 3.34 t ha⁻¹), T_8 registered a 22.2 % increase in system productivity. The lowest system productivity was recorded under sole black gram (T_3 ; 2.56 t ha⁻¹). Furthermore, the highest SYI was recorded under finger millet + green gram (4 : 2) (T_8 ; 0.63), which was followed by finger millet + green gram (3 : 3) (T_7 ; 0.56) and finger millet + green gram (2 : 2 paired row) (T_9 ; 0.55), all of which maintained significantly higher SYI compared to sole cropping systems. Sole finger millet

Table 1. Effect of intercropping on yield attributes of finger millet (Pooled mean of two years)

Treatments	Ear heads (nos. per plant)	Fingers (nos. per earhead)	Grains (nos. per earhead)	Grain weight (g per earhead)	Grain weight (g per plant)	Test weight (g)
T_1	2.7	7.44	923	2.8	7.7	2.9
T_2	-	-	-	-	-	-
T_3	-	-	-	-	-	-
T_4	2.2	5.86	691	2.0	4.4	2.7
T_5	2.4	7.13	828	2.7	6.6	2.9
T_6	2.1	5.61	760	2.1	4.4	2.7
T_7	2.1	5.50	768	1.8	3.9	2.6
T_8	2.6	7.54	832	2.7	7.3	3.0
T_9	2.2	6.52	762	2.2	4.8	2.8
T_{10}	2.2	5.64	666	1.8	4.0	2.6
T_{11}	2.3	6.76	767	1.9	4.3	2.5
T_{12}	2.1	5.92	743	1.8	3.8	2.5
T_{13}	2.0	6.01	770	1.9	3.9	2.5
T_{14}	2.5	7.00	788	2.0	5.2	2.9
T_{15}	2.2	6.08	748	1.9	4.1	2.6
SEm±	0.1	0.47	45	0.2	0.4	0.2
LSD ($p = 0.05$)	0.4	1.36	132	0.5	1.1	NS

NS: no significant difference observed at 0.05 % level of significance.

Table 2. Effect of intercropping system productivity, sustainable yield index, system production efficiency and profitability in finger millet-based cropping system (Pooled mean of two years)

Treatments	System productivity (t ha ⁻¹)	Sustainable yield index	System production efficiency (kg ha ⁻¹ d ⁻¹)	System profitability (₹ ha ⁻¹ d ⁻¹)
T ₁	3.34	0.51	9.14	200.30
T ₂	2.84	0.41	7.78	160.30
T ₃	2.56	0.38	7.02	122.20
T ₄	3.03	0.43	8.29	101.20
T ₅	3.62	0.52	9.92	212.50
T ₆	2.90	0.45	7.94	230.60
T ₇	3.74	0.56	10.24	231.60
T ₈	4.08	0.63	11.18	260.50
T ₉	3.51	0.55	9.62	167.40
T ₁₀	2.79	0.41	7.63	90.70
T ₁₁	3.28	0.51	8.99	185.70
T ₁₂	2.93	0.43	8.03	177.60
T ₁₃	2.90	0.40	7.95	194.40
T ₁₄	3.57	0.53	9.79	211.30
T ₁₅	2.95	0.46	8.08	133.20
SEm±	0.23	0.06	0.46	15.30
LSD (<i>p</i> = 0.05)	0.67	0.16	1.33	44.35

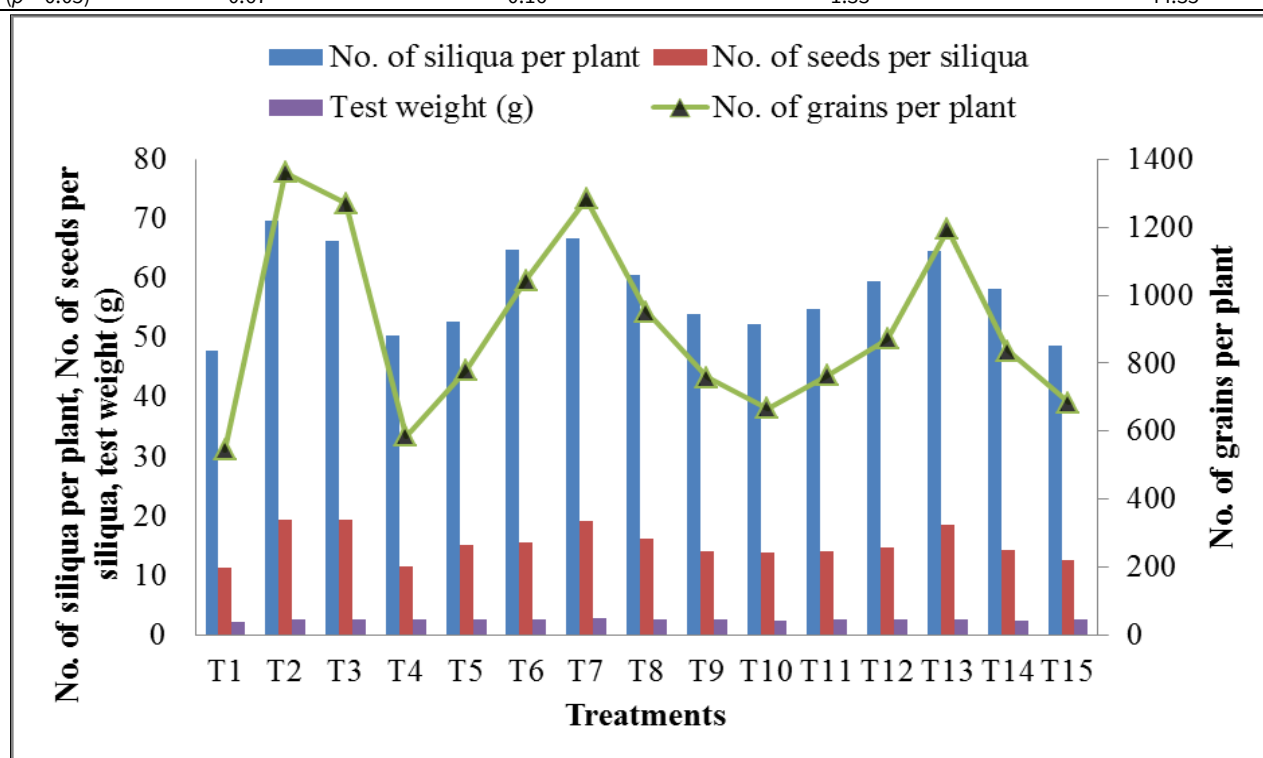


Fig. 3. Residual effect of intercropping finger millet with pulses on yield attributes of toria (Pooled mean of two years).

(T₁) recorded a SYI of 0.51, which was at par with finger millet + green gram (2 : 1) (T₅; 0.52) and finger millet + black gram (2 : 1) (T₁₁; 0.51). In contrast, sole black gram (T₃; 0.38) recorded the lowest SYI values, indicating relatively poor sustainability and higher yield variability.

A similar trend was observed for system production efficiency, which varied from 7.02 to 11.18 kg ha⁻¹ d⁻¹. Finger millet + green gram (4 : 2) (T₈) recorded the highest production efficiency (11.18 kg ha⁻¹ d⁻¹), followed by finger millet + green gram (3 : 3) (T₇; 10.24 kg ha⁻¹ d⁻¹), reflecting efficient conversion of growing period into biomass and yield. The maximum system profitability was obtained with finger millet + green gram (4 : 2) (T₈; ₹260.50 ha⁻¹ d⁻¹), followed by finger millet + green gram (3 : 3) (T₇; ₹231.60 ha⁻¹ d⁻¹) and finger millet + green gram (2 : 2) (T₆; ₹230.60 ha⁻¹ d⁻¹). These treatments recorded 30.1–53.0 % higher profitability over sole finger millet (T₁; ₹200.30 ha⁻¹ d⁻¹). In contrast, finger millet + black gram (1 : 1) (T₁₀; ₹90.70 ha⁻¹ d⁻¹) resulted in the lowest system profitability.

Discussion

Yield attributes of finger millet

The variation in yield attributes of finger millet under different intercropping systems was primarily governed by differences in crop growth, resource utilisation and interspecific interactions associated with row proportions. Higher number of earheads per plant under sole finger millet and finger millet intercropped with green gram or black gram in 4 : 2 row proportions can be attributed to reduced competition and better spatial complementarity, allowing efficient use of light, nutrients and moisture. Similar improvements in yield-attributing characters with wider row ratios in finger millet–legume intercropping have been reported in earlier studies (21).

The superiority of finger millet + green gram (4 : 2) is attributed to a more favourable source–sink relationship, resulting from improved canopy structure and enhanced assimilate translocation. Green gram exhibits rapid early growth, relatively erect growth habit and shorter crop duration, which

reduces temporal and spatial competition with finger millet for light and nutrients (22). In contrast, black gram tends to develop a comparatively spreading canopy and longer vegetative phase, which may intensify interspecific competition under replacement series planting (23). Progressive increase in finger millet rows from narrower to wider proportions enhanced yield attributes by minimising competition while retaining the beneficial effects of legumes, which agrees with the findings of previous researchers (24). The non-significant variation in test weight across treatments suggests that grain size is largely a genetically controlled trait and is least influenced by cropping systems or environmental variation, as also observed in previous studies (25).

Yield attributes of toria

The yield attributes of toria were significantly influenced by the residual effects of preceding finger millet–pulse intercropping systems, mainly due to enhanced soil nitrogen availability from legumes. Green gram exhibits relatively higher nodulation efficiency and biological nitrogen fixation under rainfed upland conditions, contributing greater residual soil N (~ 20–25 kg ha⁻¹) to succeeding crops through leaf fall and root residues (26, 27). This residual nitrogen advantage was reflected in higher siliqua number, seeds per siliqua and grains per plant in toria grown after green gram and black gram-based systems compared with sole finger millet. Higher siliqua production and seed set under sole green gram, sole black gram and finger millet intercropped with pulses at 3 : 3 row proportions indicate a stronger residual fertility effect due to greater legume biomass and population. Among the intercropping treatments, finger millet + green gram (3 : 3) proved most effective, suggesting that increased legume proportion enhanced nitrogen carryover to the succeeding toria crop. Similar benefits of legumes on succeeding crops have been reported earlier, with increased yields of cereals and oilseeds following green gram and black gram (28, 29). The marked increase in grains per plant over sole finger millet further confirms the role of residual nitrogen in improving sink development and reproductive efficiency. These findings are consistent with earlier reports (30).

System productivity, sustainable yield index, production efficiency and profitability of finger millet-based cropping system

The superiority of legume-based intercropping systems in enhancing system productivity and sustainability of the finger millet-based cropping system can be attributed to improved resource use and strong residual fertility effects (31). Finger millet intercropped with green gram, particularly at 4 : 2 and 3 : 3 row proportions, recorded higher system productivity and SYI due to better complementarity between component crops and enhanced performance of the succeeding toria. The relatively shallow but profusely branched root system of green gram enables efficient exploitation of surface soil moisture and nutrients with minimal competition with the deeper-rooted finger millet, thereby improving niche differentiation and overall resource-use efficiency (32). The inclusion of green gram improved soil nitrogen availability and nutrient cycling, which supported higher and more stable yields across seasons.

Furthermore, despite the strongly acidic soil conditions, finger millet's tolerance to low pH and the ability of green gram to improve nitrogen availability and rhizosphere nutrient

mobilisation through biological nitrogen fixation and root exudates likely contributed to better crop performance. Similar improvements in productivity of cereal–legume intercropping systems due to optimised row proportions and complementary resource use have been reported earlier (22, 33). The SYI incorporates both mean yield and variability across seasons, thereby reflecting the stability and risk associated with a cropping system. Higher SYI values observed under these treatments indicate relatively stable system performance with lower yield variability across years. In contrast, sole black gram and some black gram-based intercropping systems exhibited lower productivity and SYI, reflecting weaker residual effects and greater yield variability. These results were consistent with the findings of previous studies (34, 35).

System production efficiency and profitability closely followed trends in system productivity. The highest production efficiency under finger millet + green gram (4 : 2) resulted from greater total system output over time, as this parameter is directly related to cumulative productivity of the cropping sequence. Enhanced profitability under the same treatments was primarily driven by higher system net returns associated with improved yields of both finger millet and toria, along with reduced reliance on external nitrogen inputs due to legume inclusion. These findings corroborate earlier reports that legume-based intercropping and sequential systems improve efficiency and economic viability through better temporal and spatial use of resources (2, 36), underscoring the agronomic advantage of optimised finger millet–green gram intercropping for sustainable intensification.

Conclusion

The present study addressed the need for identifying a productive, sustainable and profitable finger millet-based cropping system suitable for the mid-hill conditions of Meghalaya, where low soil fertility and rainfed conditions constrain crop productivity. The results clearly demonstrated that intercropping finger millet with pulses, particularly green gram, followed by toria as a succeeding crop, significantly improved yield attributes of finger millet, enhanced residual benefits for toria and increased overall system productivity, sustainability and profitability compared to sole cropping systems. Among the evaluated treatments, finger millet + green gram at a 4 : 2 row proportion consistently recorded superior performance in terms of system productivity, sustainable yield index, production efficiency and profitability. The study clearly demonstrates that optimised legume integration improves immediate crop performance, stabilises system productivity and enhances economic returns at the system level. These findings underscore the agronomic and ecological advantages of finger millet–green gram–toria cropping sequence as a viable strategy for sustainable intensification and income security for smallholder farmers in the mid-hill regions of Meghalaya and similar agro-ecological environments. However, the present findings are based on two years of field experimentation; therefore, longer term studies across multiple years and locations are required to further validate the long-term sustainability and risk buffering capacity of the identified cropping system.

Acknowledgements

The authors extend their sincere gratitude to the authorities of the College of Post Graduate Studies in Agricultural Sciences, Central Agricultural University (Imphal), Umiam, Meghalaya, for providing field and laboratory facilities for conducting the experiment.

Authors' contributions

RB carried out the study, data collection, tabulation and statistical analysis; and also drafted the manuscript. AKS contributed to data analysis, review and editing of the manuscript. RS was involved in data collection, tabulation, manuscript editing and reference collection. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interest to declare.

Ethical issues: None

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