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Performance of little millet *(Panicum flexuosum)* based cropping system for rainfed agro ecosystems: A path to sustainable crop diversification

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ABSTRACT

An experiment was conducted during 2019, 2020 and 2021 at Centre of Excellence in Millets, (Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu), Athiyandal, Tiruvanamalai, Tamil Nadu. to study the performance of little millet (*Panicum flexuosum* Retz.) based cropping system for rainfed agro ecosystems for north-eastern part of Tamil Nadu. The experiment was laid out in randomized block design (RBD) comprised of 9 treatments, viz. T_1, Little millet + Redgram [*Cajanus cajan* (L.) Millsp.] (4:1)-Moth bean [*Vigna aconitifolia* (Jacq.) Marechal]; T_2, Little millet + Redgram (4:1)-Blackgram [*Vigna mungo* (L.) Hepper]; T_3, Little millet + Redgram (4:1)-Horsegram [*Macrotyloma uniflorum* (Lam.) Verdc.]; T_4, Little millet + Redgram (6:2)-Moth bean; T_5, Little millet + Redgram (6:2)-Blackgram; T_6, Little millet + Redgram (6:2)-Horsegram; T_7, Little millet + Redgram (8:2)- Mothbean; T_8, Little millet + Redgram (8:2)-Blackgram; T_9, Little millet + Redgram (8:2)- Horsegram, with three replications. The good quality seeds of little millet (CO 4), redgram (Paiyur 2), horsegram (Paiyur 2), blackgram (VBN 3) and mothbean [TMV (Mb) 1] were used. The result shows that the higher yield for little millet and intercropped redgram was recorded in T_9 (985 and 362 kg/ha) followed by T_7 (853 and 356 kg/ha) and T_8 (834 and 337 kg/ha). The 8:2 row ratio exhibited the highest little millet equivalent yield when compared to 6:2 and 4:1 row ratio. The highest economic return and benefit cost (B:C) ratio was observed in T_9 with gross return of ₹60,962/ha, net returns of ₹35,362/ha and B:C ratio (2.38). This was followed by T_7 which had gross returns of ₹51,314/ha, net returns of ₹25,989/ha and B:C ratio (2.10).

Keywords: Crop diversification, Economic return, Inter cropping, Little millet, Nutritional security, Pulses

Rainfed agriculture plays an important role in global agricultural systems especially in regions where irrigation facilities are limited or where water resources are scarce. However, farmers face several problems related to weather uncertainties (Malarkodi *et al.* 2023) in rainfed area poses significant challenges to improve crop yields (Sharma *et al.* 2022), farmers' income, livelihoods and ensure food security. To overcome these challenges, it is essential to diversify cropping systems with climate resistant and nutritious crops (Balaji *et al.* 2023). One such crop is millet which act as a climate resilient crop (Singh *et al.* 2023) that are well adapted to a broad spectrum of natural environmental conditions. They have minimum water requirement, enhanced growth and productivity even in nutrient deprived soil, thereby decrease reliance on inorganic fertilizers and reduce susceptibility to environmental and ecological stresses (Kole *et al.* 2015) and higher carbon sequestration. This resilient crop has been a staple in the diet of numerous communities for centuries and recently referred as nutri-cereals owing to the high nutritive qualities (Saini *et al.* 2021) of the grains and they are good source of essential micronutrients, especially Ca, Fe and Zn. Moreover, they contain abundant vitamins, dietary fibers, amino acids, storage proteins and various bioactive agents (Amadou *et al.* 2013).

Global millet production reached a total of 30.1 million tonnes in the year 2021 (Kheya *et al.* 2023). India contributed 41% of the overall output within the cultivated area of 7.0 lakh ha approximately with the productivity of 633 kg/ha (Anbukkani *et al.* 2017) as a rainfed crop. In Tamil Nadu, little millets are sown as sole crop in the month of June-July and sometime the sowing observed from September

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to October (Maitra and Shankar 2019). The major millets growing areas are Vellore, Dharmapuri, Krishnagiri and Tiruvanamalai district. Following the cultivation of little millets, farmers often follow pulses sowing (Sivagamy *et al.* 2020). With the primary objective to maximize the production of the main crop, intercropping serves as a strategic approach to enhance the overall productivity of cropping system by efficiently utilizing the available resources (Manasa *et al*. 2018) and suppress weeds (Sivagamy and Chinnusamy 2014). Therefore, an experiment was planned to evolve a suitable inter and sequential cropping system for little millet (*Panicum flexuosum* Retz.) under rainfed conditions

MATERIALS AND METHODS

Present study was carried out during rainy (*kharif*) season of 2019, 2020 and 2021 at Centre of Excellence in Millets, (Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu), Athiyandal, Tiruvanamalai, Tamil Nadu. Intercropping pattern is a common agricultural practice in the rainfed region characterized by the sequential cultivation of millet crops to maximize agricultural productivity and crop diversity. The major challenges faced during the study period was rainfall and the variability in rainfall patterns between years could significantly impact crop performance and results. It was addressed by analyzed long term rainfall patterns.

The experiment was laid out in randomized block design (RBD) comprised of 9 treatments, viz. T_1, Little millet + Redgram [*Cajanus cajan* (L.) Millsp.] (4:1)-Moth bean [*Vigna aconitifolia* (Jacq.) Marechal]; T_2, Little millet + Redgram (4:1)-Blackgram [*Vigna mungo* (L.) Hepper]; T_3, Little millet + Redgram (4:1)-Horsegram [*Macrotyloma uniflorum* (Lam.) Verdc.]; T_4, Little millet + Redgram (6:2)-Moth bean; T_5, Little millet + Redgram (6:2)-Blackgram; T_6, Little millet + Redgram (6:2)-Horsegram; T_7, Little millet + Redgram (8:2)-Mothbean; T_8, Little millet + Redgram (8:2)-Blackgram; T_9, Little millet + Redgram (8:2)- Horsegram, with three replications. The grain and straw yield of all treatments were recorded. Good quality seeds of little millet (CO 4), redgram (Paiyur 2), horsegram (Paiyur 2), blackgram (VBN 3) and mothbean [TMV (Mb) 1] were used and the seed material was obtained from Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu. The soil type of experimental field was sandy clay loam. The experimental field was ploughed using a tractor drawn disc plough followed by harrowing, leveling and manual formation of field bunds around these plots are ensued. The basal application of farmyard manure at a rate of 12.5 t/ha was uniformly spread across the entire experimental field during the last ploughing. The high-quality little millet seeds along with intercrop seeds were promptly sown immediately after field preparation under rainfed conditions. A basal application of 44:22:0 kg NPK/ha for the base crop of little millet was uniformly carried out for all plots at the time of sowing. Germination of little millet seeds was observed from the third day after sowing. In the case of intercrops, both gap filling and thinning activities were undertaken on the 10^{th} day after sowing. These ensured the establishment of a well-prepared and carefully managed experimental area conducive to optimal crop growth and development.

In the trial field, 5 randomly plants from each plot were selected and tagged for the measurement of growth traits. Plant height was calculated by measuring the distance from the ground level to the tip of the main shoot at the 30, 60 days after sowing (DAS) and at harvest stage expressed in cm. In each plot, measurements were taken for the total number of leaves as well as the length and width of the third leaf from the top of the tagged plants to calculate the leaf area index using the formula recommended by Hughes *et al*. (1981).

Chlorophyll content was measured using a SPAD meter for non-destructive measurement on the fully expanded third leaf from the top. These measurements were taken during a clear sunny day between 09:00 h and 11:30 h. Data was collected at various growth stages, including seedling, vegetative, flowering and maturity and the average values across these stages were presented. The plants were harvested at ground level when they reach physiological maturity. The productive tillers from the tagged plants were individually collected to determine the grain yield and expressed in grams per plant after they were manually threshed, cleaned and dried to a moisture content of 12–14%. The remaining plant sample was dried at 65±5°C to record dry matter production expressed in kg/ha. Additionally, the weight of 1000 grains randomly selected from five plants was recorded and expressed in grams (g). The crop growth rate (CGR) was estimated at 30, 60 DAS and at harvest stage by using the formula as suggested by Watson (1958) and expressed in g/m^2/day. The intercropping system was evaluated using economic indicators such as the gross returns (₹/ha), net returns (₹/ha) and B:C ratio. The statistical significance of yield parameters and overall yield was assessed by ANOVA.

Little millet grain equivalent yield (LMGEY): The conversion of yields from different intercrops into a single unit. The calculation is done on a market price basis which helps to identify the economically more viable combinations.

$$\textit{LMGEY (kg/ha)} = \frac{\text{Yield of intercrop (kg/ha)} \times \text{Price of little millet (₹/ha)}}{\text{Price of intercrop}}$$

RESULTS AND DISCUSSION

The impact of intercrop on growth and yield attributes of little millet: The influence of intercropping of little millet alongside redgram with three various row proportions (4:1, 6:2 and 8:2 respectively) on growth and yield of little millet and the results of the pooled data are given below. The highest plant height (96.6 cm) was observed in the 8:2 row proportions (Table 1), where little millet was intercropped with red gram followed by horse gram as succeeding crop. This finding suggests that a higher row proportion of T_9 can promote taller growth, possibly due to vigorous root development induces plant growth (Bitew and Asargew 2014) and wider space minimizes competition between

Table 1 Crop growth attributes of different little millet based intercropping system under rainfed condition

Treatment	Little millet plant height (cm)	Red gram plant height (cm)	Leaf area index of little millet	SPAD value of little millet	Crop growth rate (g/m^2/day) of little millet	Productive tillers/hill (No.) of little millet	Panicle length (cm) of little millet	Panicle weight (g) of little millet	No. of pods/plant in red gram (kg/ha)
T_1	91.2	125.1	1.48	36.4	20.7	6.8	25.3	6.3	114.1
T_2	92.6	120	1.63	39.8	21.4	6.5	25	5.8	119.0
T_3	92.3	122.8	1.64	44.1	22.1	6.9	24.3	5.4	113.0
T_4	92.7	127	1.68	41.3	21.0	8.2	24.3	6.2	122.4
T_5	95.9	126.1	1.65	43.2	22.4	8.0	25	6.6	119.9
T_6	93.3	130.6	1.53	36.1	20.3	7.5	24.9	6	117.1
T_7	94.2	131.5	1.54	42.9	22.8	8.0	24.8	6.5	125.7
T_8	90.2	137.1	1.51	40.5	21.0	8.0	24.6	6.1	121.9
T_9	96.6	130.5	1.61	44.1	25.4	8.2	25	6.5	127.4
SEm ±	3.2	2.8	0.2	1.3	1.9	0.6	0.5	0.3	3.8
CD (P=0.05)	9.7	8.5	0.6	3.9	5.8	1.7	1.4	1.1	11.5

Treatment details are given under Materials and Methods.

plants to utilize sunlight and providing sufficient space for the expansion of the canopy which promotes optimal growth and better utilization of available resources and reduced competition for water, light and nutrients (Fig. 1). The highest plant height of redgram (137.1 cm) was recorded in T_8 which may lead to more shading effect in adjoining little millet rows (plant height, 90.2 cm). The taller redgram plant reduces light availability and impact chlorophyll content which may exhibit photosynthetic activity (Li *et al.* 2014) which resulted in reduced crop growth rate of little millet in T_8. The SPAD value was found to be higher in T_9 followed by T_7 and T_8, similar SPAD values range are found in Pavithra *et al.* (2020). The highest leaf area index recorded in T_9 could be attributed to its ability to produce the tallest plants in little millet (Tsado *et al.* 2016).

The growth attributes such as plant height, leaf area index, SPAD and crop growth rate was found to be significantly influenced by intercropping row combinations of 4:1, 6:2 and 8:2 respectively. The crop yield is the reflection of yield attributing characters. In the case of little millet, the key yield attributing characters include the number of productive tillers per plant, number of grains per panicle and 1000-grain weight. The yield attributes were significantly influenced by the different row ratios of little millet with redgram intercrop systems. The little millet yield attributes such as the panicle length (25.0 cm), panicle weight (6.5 g) and number of productive tillers per hill (8.2) are found to be higher in treatment (T_9) (Table 1) followed by T_7 and T_8.

The observed increase in grain yield aligns with the higher number of productive tillers indicated higher grain productions and the length of panicle has more space available for the development of more grains. This could be the result of increased metabolic activity, effective use of nutrients, water and solar radiation which leads to more vegetative growth (Michaelraj and Shahmugam 2013).

The impact of intercrops on yield of little millet: The increased grain yield observed in the 8:2 planting ratio with red gram can be attributed to a combination of factors that optimize resource utilization and create a more favourable environment for the crop growth. This planting arrangement, in comparison to the 6:2 and 4:1 row ratio, exhibits enhanced yield attributes, higher plant population and reduced competition among crops. One key factor contributing to the higher grain yield is the optimal balance achieved in the 8:2 row ratio. This row ratio effectively balance the planting density and spacing for optimal growth development. When crops are managed in such a way that maximizes their resource utilization to sunlight, water and nutrients which can result in improved

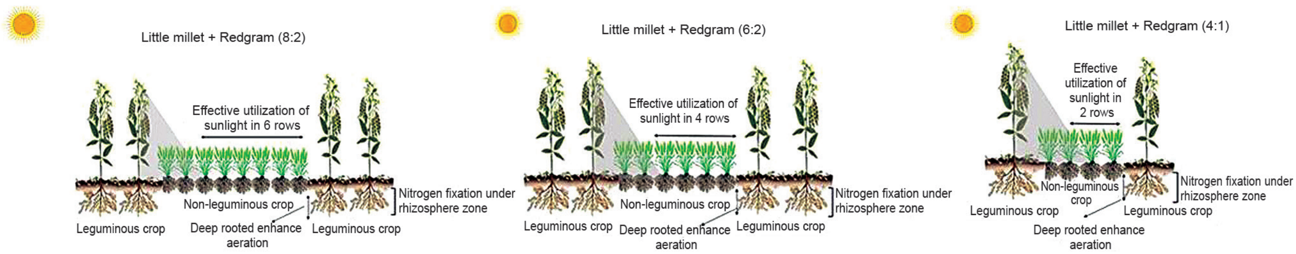

Fig. 1 Influence of solar radiation and rhizosphere interaction in little millet + redgram based intercropping system.

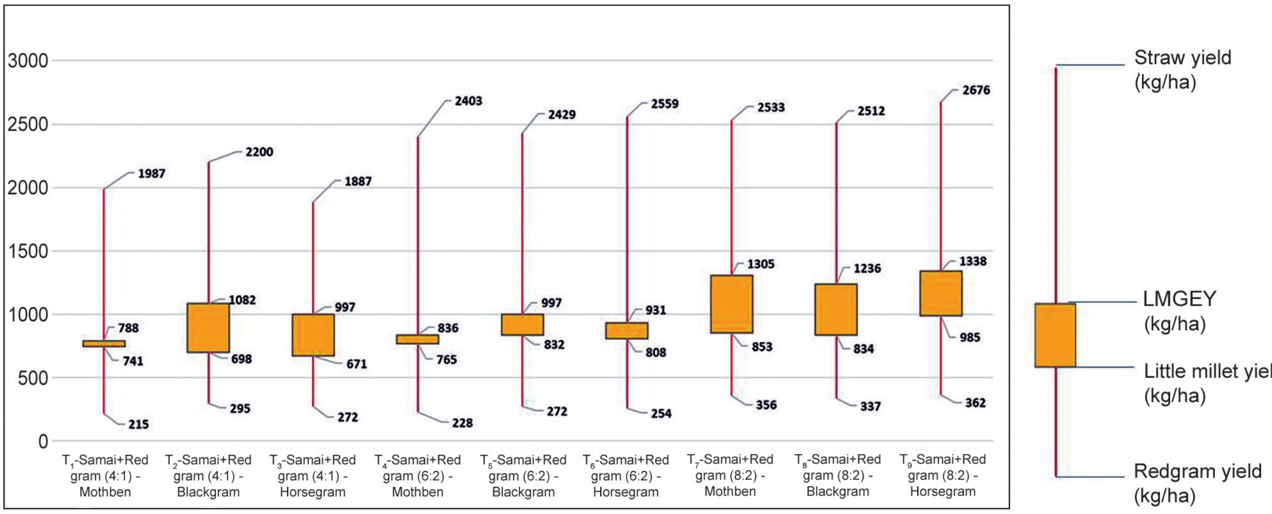

Fig. 2 Yield of little millet based intercropping system under rainfed system.

crop growth and higher yield. The recorded higher yield for the combination of little millet and intercropped red gram in the 8:2 row ratio further supports the effectiveness of this planting arrangement. Specifically, in the crop sequence of little millet and intercropped red gram with horsegram T_9 showed the highest yield at 985 kg/ha for little millet and 362 kg/ha for red gram. This was followed by T_7 (853 and 356 kg/ha) and T_8 (834 and 337 kg/ha). The findings align with similar patterns observed by Sharmili and Manoharan (2018), highlighted the consistency and reliability of the results. The little millet + redgram with crop sequence of horsegram (T_9) and moth bean (T_7) yield were significantly higher in 8:2 planting ratio (Fig. 2).

The impact of various intercropping treatments on little millet grain equivalent yield (LMGEY): The LMGEY was computed to compare various intercropping combinations. Among different intercropping systems, the highest grain equivalent yield was observed in the case of little millet grown alongside red gram at an 8:2 ratio with a subsequent crop of horse gram recorded a yield of 1338 kg/ha (T_9). This was followed by little millet intercropped with redgram at an 8:2 ratio with the succeeding crop of mothbean (T_7, 1305 kg/ha) and little millet alongside red gram at 8:2 ratios with succeeding crop of blackgram (T_8, 1236 kg/ha). This finding suggested that wider spacing is one of the factors to increase yield in 8:2 planting ratio compare to 6:2 and 4:1 which was supported by (Sharmili *et al.* 2023). Intercropped red gram, as a leguminous crop have the capacity to fix atmospheric nitrogen through a symbiotic relationship with nitrogen-fixing bacteria located in its root nodules (Mishra *et al.* 2013) and extensive root system helps to access nutrient and moisture from deeper layer of soil (Schneider *et al.* 2021) which makes a non-legume plants such as little millet to extend the benefits of rhizobia to a wider range of crops and this practice has the potential to enhance the crop growth and yields, as also highlighted by Dent and Cocking (2017). A study of Basavarajappa *et al.* (2010) revealed that the foxtail millet and pigeonpea intercropping system yielded a higher equivalent yield of foxtail millet. According to Kumar *et al.* (2008) the higher LMGEY in 6:2 row ratio with a horsegram sequence was attributed to the higher yield of little millet and redgram, along with effective use of natural resources by the component crop in the intercropping system.

The economic aspects of intercropping: The higher gross return (₹60,962/ha), net returns of (₹35,362/ha) and benefit cost ratio (2.38) were observed in little millet grown alongside with redgram at 8:2 row ratio (T_9) followed by little millet grown alongside with redgram at 8:2 ratio (T_7) with gross returns (₹51,314/ha), net returns of (₹25,989/ha) and benefit cost ratio (2.10) and little millet grown alongside with redgram at 8:2 row ratio (T_8) with gross returns (₹49,700/ha), net returns of (₹25,856/ha) and benefit cost ratio (2.02). The lowest gross return was occurred in T_3 with gross income of 45,040/ha, net income of 21,190/ha and benefit gross ratio (1:89). The main reason for these high returns can be attributed to the higher market prices of pulses prevailing during the study period. The increased demand and higher market value for pulses significantly contributed to the higher gross and net returns, as well as the impressive benefit-cost ratios. This economic situation highlights the sensitivity of agricultural profitability to market dynamics and underscores the potential for strategic crop selection to capitalize on favourable market conditions. From the results it is evident that little millet intercropped with redgram followed by succeeding crop of horsegram was the best combination due to its higher economic returns.

Seran and Brintha (2009) found that intercropping systems yield greater cash returns for small-holding farmers compared to monoculture farming. The significance of selecting appropriate intercropping ratios such as the 8:2 row ratio in the case of little millet and redgram, becomes evident in achieving optimal economic benefits. Overall, the treatment T_9 provides valuable insights into sustainable and economically suitable cropping systems for small-holding farmers. These findings not only contribute to the understanding of optimal cropping practices but also offer practical guidance for farmers seeking to maximize their economic returns in a dynamic agricultural market.

Based on the 3-years study it can be concluded that intercropping little millet with redgram, particularly at an 8:2 row proportion strategy will promote sustainable agriculture with rainfed agro ecosystems. This approach not only enhances growth attributes but also leads to improved economic returns to small holder farmers in rainfed agro ecosystems, underlining its suitability for environmentally conscious and economically viable farming practices.

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