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Effect of integrated nutrient management on sustainable productivity in redgram (*Cajanus cajan* L.) + Foxtail millet (*Setaria italica* L.) intercropping system

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ABSTRACT

A field experiment was conducted to study the effect of integrated nutrient management on sustainable productivity in Redgram (*Cajanus cajan* L.) + Foxtail millet (*Setaria italica* L.) intercropping system on clay loam soils at RARS, Lam, Guntur during *kharif*, 2025-2026. The experiment was laid out in randomized block design with ten treatments and replicated thrice. A perusal of the data revealed that different integrated nutrient management treatments significantly influenced the growth, yield attributes, grain yield and economics of the intercropping system. The combined application of inorganic fertilizers with organic manure, biofertilizer and crop residue mulch resulted in superior crop performance compared to the individual application of nutrient sources and with reduced levels of fertilizers (75%). The results revealed that the maximum grain yield was realised with application of 100% RDN + FYM @ 5 t ha^{-1} + VAM @ 12.5 kg ha^{-1} + mulching with crop residue @ 5 t ha^{-1} in redgram (2190 kg ha^{-1}) and foxtail millet (918 kg ha^{-1}). The redgram equivalent yield (2427 kg ha^{-1}), gross returns (Rs.189988) and net returns (Rs. 119770) were also found to be higher with the application of 100% RDN + FYM @ 5 t ha^{-1} + VAM @ 12.5 kg ha^{-1} + mulching with crop residue @ 5 t ha^{-1}.

Key Words: *Integrated nutrient management, Redgram, Foxtail millet, Yield, Yield attributes, Redgram equivalent yield and Economics*

Redgram (*Cajanus cajan* L.) is an important pulse crop cultivated in tropical and subtropical regions, valued for its high protein content, ability to fix atmospheric nitrogen, and contribution to improvement of soil fertility. Although redgram ranks sixth in area and production in comparison to other grain legumes such as beans, peas, and chickpeas, it is used in more diverse ways than others. In India, redgram is cultivated over an area of 43.36 lakh ha with a total production of about 36.24 lakh tonnes and with a productivity of 836 kg ha^{-1}. Andhra Pradesh produces nearly 1.77 lakh tonnes of redgram from an area of 3.72 lakh ha and productivity of 475 kg ha^{-1} (*Indiastat*, 2025-2026). Despite its significance in Indian agriculture, particularly in A.P. its productivity remains low due to cultivation under rainfed conditions, poor soil fertility, and inadequate nutrient management. Intercropping is an effective cropping system that improves resource-use efficiency, enhances productivity, reduces production risks, and ensures greater yield stability under rainfed conditions (Lithourgidis *et al.*, 2011). Among pulse-based intercropping systems, redgram + foxtail millet has gained importance due to the complementary growth habits and efficient utilization of light, water, nutrients, and space by the component crops (Maitra *et al.*, 2020).

Integrated Nutrient Management (INM), involving the combined use of inorganic fertilizers, organic manures, biofertilizers, and crop residue management, has been recognized as a sustainable approach for improving soil fertility, nutrient availability, microbial activity, and crop productivity (Singh *et al.*, 2019). Farmyard manure (FYM), vesicular-arbuscular mycorrhiza (VAM), and crop residue mulching enhance nutrient-use efficiency while improving soil health and moisture conservation (Sharma and Mittra, 1991).

Farmers of Krishna zone mostly cultivated as sole crop and resulted in low net returns. Hence, to improve the income of the farmers, it is proposed to introduce short duration crops like foxtail millet as inter crop for effective utilization of wider space between the rows of redgram as the redgram grows

slowly at initial stage. Foxtail millet (*Setaria italica* L.) a short-duration and drought-tolerant cereal, is well suited for intercropping with redgram because of its efficient utilization of space and resources.

However, the success of such an intercropping system largely depends on efficient nutrient management strategies, as both crops have distinct nutrient uptake patterns and growth requirements. Therefore, understanding the nutrient management strategies in the redgram + foxtail millet intercropping system is very crucial not only enhancing overall land productivity by utilizing the substantial inter-row space but also profitability by providing additional income to the farmers.

MATERIAL AND METHODS

The present field experiment was carried out at the Regional Agricultural Research Station (RARS), ANGRAU, Lam, Guntur, Andhra Pradesh, India. The experimental site is located at 25°18' N latitude and 83°36' E longitude, with an altitude of 128.93 m above mean sea level (MSL) and comes under the Krishna agro-climatic zone of Andhra Pradesh. The soil of the experimental field was clay loam with neutral in soil reaction (pH 8.3), low in organic carbon (0.48 %), low in available nitrogen (175 kg ha^{-1}), medium in available phosphorus (48 kg ha^{-1}) and high in available potassium (795 kg ha^{-1}). A total of 891.9 mm rainfall with 37 rainy days received during crop growth period. The experiment was laid out in randomized block design (RBD) and the treatments were replicated thrice. The treatments consisted of ten nutrient management treatments *viz*., T_1:100% RDN + FYM @ 5 t ha^{-1}, T_2: 100% RDN + VAM @ 12.5 kg ha^{-1}, T_3:100% RDN + mulching with crop residue @ 5 t ha^{-1}, T_4: 100% RDN + VAM @ 12.5 kg ha^{-1} + mulching with crop residue @ 5 t ha^{-1}, T_5: 100% RDN + FYM @ 5 t ha^{-1} + VAM @ 12.5 kg ha^{-1} + mulching with crop residue @ 5 t ha^{-1}, T_6: 75% RDN + FYM @ 5 t ha^{-1}, T_7: 75% RDN + VAM @ 12.5 kg ha^{-1}, T_8: 75% RDN + mulching with crop residue @ 5 t ha^{-1}, T_9: 75% RDN + VAM @ 12.5 kg ha^{-1} + mulching with crop residue @ 5 t ha^{-1}, T_{10}: 75% RDN + FYM @ 5 t ha^{-1} + VAM @ 12.5 kg ha^{-1} + mulching with crop residue @ 5 t ha^{-1}. Prior to sowing, bold healthy seeds were initially treated with imidacloprid 500 FS @ 5 ml kg^{-1} seed.

The redgram and foxtail millet crops were sown on 1st August, 2025 with a seed drill at a depth of 4 -5 cm, maintaining the recommended spacing of 150 cm x 20 cm and 30 cm x 10 cm, respectively in 1:4 ratio. The recommended seed rates of 5 kg ha^{-1} were adopted for both crops of redgram and foxtail millet and treated seeds were used for sowing. Fertilizers were applied according to the treatment schedule. The recommended dose of fertilizers, comprising nitrogen through urea (46% N) and phosphorus through single super phosphate (16% P, O…), was applied at the rate of 20:50:0 kg NPK ha^{-1}. The entire quantity of phosphorus and nitrogen were applied as a basal at the time of sowing as per the respective treatments. Five plants from each plot were randomly selected and observations on plant height, drymatter production, number of branches $plant^{-1}$, number of pods $plant^{-1}$ and pod length in redgram and plant height, drymatter production, number of panicles m^{-2}, number of grains $panicle^{-1}$ and panicle length in foxtail millet were recorded. The collected samples were shade-dried for 24 hours and subsequently oven-dried at 60 $\pm$ 5°C until a constant weight was attained. The dry weights were then recorded and expressed in kg ha^{-1}. Test weight and grain yield were measured after harvest. The yields of the intercrop (foxtail millet) was appropriated to the redgram equivalent yield (REY) by using formula,

$$\text{Redgram equivalent yield} = \frac{\text{Seed yield of intercrop} \times \text{Price of intercrop} + \text{Seed yield of redgram}}{\text{Price of redgram}}$$

The experimental data were analyzed using analysis of variance (ANOVA) for a Randomized Block Design (RBD) as described by Panse and Sukhatme (1978). Treatment means were compared using the F-test at the 5% level of significance, and the Critical Difference (CD) was calculated for significant effects.

RESULTS AND DISCUSSION

GROWTH

The productivity of the redgram + foxtail millet intercropping system is largely governed by nutrient management practices, which influence crop growth, yield attributes, yield and nutrient availability.

The growth parameters of redgram, *viz.,* plant height, drymatter production and number of branches $plant^{-1}$ were significantly influenced by nutrient management practices (Table 1). Across all the

treatments, application of 100% RDN + FYM @ 5 t ha^{-1} + VAM @ 12.5 kg ha^{-1} + crop residue mulching @ 5 t ha^{-1} (T…) recorded highest plant height (183.5 cm), drymatter production (5945 kg ha^{-1}) and number of branches plant^{-1} (19.1) at harvest than that of other treatments. Similarly, the growth parameters of foxtail millet were significantly influenced by different nutrient management treatments (Table 1). Application of recommended dose of nitrogen along with integration of organic (FYM and crop residue) and biological fertilizer (VAM) produced higher plant height (115.0 cm) and drymatter production (2834 kg ha^{-1}) than rest of the treatments. The higher growth in redgram and foxtail millet could be attributed to the balanced and continuous supply of nutrients throughout the crop growth period. These favourable conditions promoted vigorous vegetative growth through enhanced cell division, photosynthetic activity and increased drymatter accumulation. Similar findings were reported by Pandey *et al*. (2013), Rao *et al*. (2019), Mathimaran *et al.* (2020), Rao *et al.* (2021) and Kokani *et al*. (2025), who observed enhanced growth of pigeonpea under integrated nutrient management practices, Priya and Sathyamoorthi (2019), Ramesh *et al.* (2019) and Raviraja *et al.* (2020) in foxtail millet.

YIELD ATTRIBUTES

The yield attributes of redgram and foxtail millet were also significantly affected by integrated nutrient management (Table 1). The highest number of pods plant^{-1} (420) and pod length (6.9 cm) in redgram, productive panicles (36.7 m^{-2}), grains panicle^{-1} (1124) and panicle length (20.8 cm) in foxtail millet recorded under the treatment that received 100% RDN + FYM @ 5 t ha^{-1} + VAM @ 12.5 kg ha^{-1} + mulching with crop residue @ 5 t ha^{-1} (T_5) which was significantly superior than that of other seven treatments but it was remained on par with T_4 and T_{10}. However, test weight of both the crops were not significantly affected. The improvement in these yield attributes could be attributed to an adequate supply of nutrients, which enhanced photosynthetic activity and increased the production of assimilates for translocation to the developing pods and panicles in both crops of redgram and foxtail millet. These findings corroborate the reports of Rao *et al.* (2019), Tripathi *et al.* (2019), Rao *et al.* (2021), Bhardwaj *et al*. (2022) Kokani *et al.* (2025) and Rajarathinam *et al.* (2025), who reported significant improvement in yield attributes of pigeonpea under integrated nutrient management and Priya and Sathyamoorthi (2019), Ramesh *et al.* (2019) and Raviraja *et al.* (2020) in foxtail millet.

YIELD

The yield of redgram and foxtail millet were significantly influenced by different nutrient management treatments (Table 1) and depicted in Fig 1. Application of recommended dose of nitrogen along with integration of organics and biological fertilizer resulted in higher seed yield of 2190 kg ha^{-1} in redgram and 918 kg ha^{-1} in foxtail millet which was statistically on par with treatment T_4 and treatment T_{10}. The seed yield advantage in redgram to line of 29.4% was realised with T_5 over T_1 and it was closely followed by T_4 (13.5%) and T_{10} (13.1%). Whereas, the lowest seed yield (1423 kg ha^{-1}) was recorded with the application of 75% RDN + mulching with crop residue @ 5 t ha^{-1} (T_8), which was statistically not comparable with these four treatments T_3, T_6, T_7 and T_9. With respect to grain yield in foxtail millet, the yield advantage recorded with these six treatments *viz*., T_5, T_4, T_{10}, T_2, T_9 and T_7 was in descending order 29.1%, 24.2%, 24.1%, 16.6%, 13.6% and 11.4% compared to T_1 (711 kg ha^{-1}). The lowest grain yield (608 kg ha^{-1}) was realised with the application of lower N (75%) + crop residue mulching @ 5 t ha^{-1} (T_8), which was statistically on par with T_3 (654 kg ha^{-1}), T_6 (704 kg ha^{-1}) and T_1 (711 kg ha^{-1}). Under 100% RDN, T_5 recorded the highest seed yield (2190 kg ha^{-1} in redgram and 910 kg ha^{-1} in foxtail millet) and was statistically comparable with T_4, whereas T_3 recorded the lowest seed yield (1597 kg ha^{-1} in redgram and 654 kg ha^{-1} in foxtail millet). Under lower levels of N (75%), T_{10} recorded the highest seed yield (1915 kg ha^{-1} in redgram and 882 kg ha^{-1} in foxtail millet) and was on par with T_7 and T_9, while T_8 recorded the lowest seed yield (1423 kg ha^{-1} in redgram and 608 kg ha^{-1} in foxtail millet). Across all nutrient management practices, irrespective of manures or bioinoculants or mulching with crop residue, treatments receiving 100% RDN recorded higher seed yield than their corresponding reduced level of nitrogen treatments (75% RDN).

The higher seed yield obtained in both crops with the application of recommended fertilizer N along with FYM @ 5 t ha^{-1}, VAM @ 12.5 kg ha^{-1} and

Table 1. Effect of integrated nutrient management on performance of redgram + foxtail millet intercropping system

Treatments		Redgram							Foxtail millet						
		Plant height (cm)	Drymatter production (kg ha^{-1})	No. of branches plant^{-1}	No. of pods plant^{-1}	Pod length (cm)	100 seed weight (g)	Seed yield (kg ha^{-1})	Plant height (cm)	Dry matter production (kg ha^{-1})	No. of panicles m^{-2}	No. of grains panicle^{-1}	Panicle length (cm)	1000 seed weight	Grain yield (kg ha^{-1})
T_1:	100% RDN + FYM @ 5 t ha^{-1}	164.5	4535	13.5	302	6.4	3.9	1693	109.6	2086	33.6	824	17.7	2.23	711
T_2:	100% RDN + VAM @ 12.5 kg ha^{-1}	168.4	4872	16.1	343	6.7	4	1824	112	2394	35	953	19.2	2.3	829
T_3:	100% RDN + mulching with crop residue @ 5 t ha^{-1}	159.1	4084	12.8	300	6.4	3.9	1597	101.7	1984	29.8	756	16.9	2.17	654
T_4:	100% RDN + VAM @ 12.5 kg ha^{-1} + mulching with crop residue @ 5 t ha^{-1}	186.3	5192	18.3	390	6.9	4.1	1922	112.9	2588	37	1099	20.3	2.34	883
T_5:	100% RDN + FYM @ 5 t ha^{-1} + VAM @ 12.5 kg ha^{-1} + mulching with crop residue @ 5 t ha^{-1}	186.6	5945	19.1	420	6.9	4.1	2190	115	2834	36.7	1124	20.8	2.34	918
T_6:	75% RDN + FYM @ 5 t ha^{-1}	160.2	4226	13.6	295	6.4	3.9	1613	107.2	2031	31	799	17.3	2.2	704
T_7:	75% RDN + VAM @ 12.5 kg ha^{-1}	166.7	4329	13.9	303	6.6	3.9	1709	110.3	2174	33.8	886	18.6	2.23	792
T_8:	75% RDN + mulching with crop residue @ 5 t ha^{-1}	158.6	3842	12.8	265	6.3	3.8	1423	99.7	1726	27.3	703	16.5	2.16	608
T_9:	75% RDN + VAM @ 12.5 kg ha^{-1} + mulching with crop residue @ 5 t ha^{-1}	167.2	4623	14.7	329	6.6	4	1714	111.5	2337	34.7	924	18.9	2.27	808
T_{10}:	75% RDN + FYM @ 5 t ha^{-1} + VAM @ 12.5 kg ha^{-1} + mulching with crop residue @ 5 t ha^{-1}	183.5	5082	16.3	364	6.9	4	1915	112.5	2427	36.2	989	19.6	2.33	882
SEm±		8.59	241.2	0.66	24.29	0.15	0.14	97.3	4.33	124.38	1.92	42.4	1.07	0.06	42.1
CD (p=0.05)		27.5	772	2.1	78	0.5	NS	311	13.8	397.9	6.1	135.6	3.4	NS	135
CV (%)		8.8	8.9	7.7	12.7	3.9	6.1	9.6	6.9	9.5	9.9	8.1	9.9	4.9	9.4

crop residue mulching @ 5 t ha^{-1} might be due to the fact that the synergistic effect of these nutrient sources might have enhanced nutrient availability, improved soil health, stimulated microbial activity and promoted better root growth, thereby ensuring efficient absorption and utilization of nutrients. Further, these favourable conditions might have facilitated effective translocation of photosynthates towards reproductive organs, enhanced source-sink relationship and resulting higher seed yield. The present findings are in accordance with the investigations of Pandey *et al.* (2017), Zadode *et al.* (2017), Ahamad *et al.* (2018), Rao *et al.* (2019), Jadav *et al.* (2020), Mathimaran *et al.* (2020), Rao *et al.* (2021), Manjeera *et al.* (2024), Kokani *et al.* (2025), Rajarathinam *et al.* (2025) in redgram and Rao *et al.* (2025) in blackgram and greengram.

The productivity of Redgram + Foxtail millet intercropping system, expressed as redgram equivalent yield (REY), varied significantly among the treatments (Table 2) depicted in Fig 1. The highest REY (2427 kg ha $^{-1}$) was obtained with integrated application of inorganic fertilizers, organic and bioinoculant followed by crop residue mulching than other nine treatments. The higher equivalent yield mainly due to the increased grain yields of both redgram and foxtail millet resulting from efficient utilization of available resources such as nutrients, moisture, light and space. The complementary effect of integrated nutrient management improved the productivity of both component crops, thereby enhancing the overall biological efficiency of the intercropping system. Similar observations were reported by Tripathi *et al.* (2019), Vinay *et al*. (2021), Manjeera *et al.* (2024) and Panda *et al.* (2025) in pigeonpea-based intercropping systems.

ECONOMICS

Economic analysis further indicated that profitability of the redgram + foxtail millet intercropping system influenced by adoption of integrated nutrient management practices Table 2. The highest gross returns (¹ 189,988 ha^{-1}) and net returns (¹ 119,770 ha^{-1}) were realized with the application of 100% RDN + FYM @ 5 t ha^{-1} + VAM @ 12.5 kg ha^{-1} + mulching with crop residue @ 5 t ha^{-1} owing to its superior grain and straw yields of both component crops. Although the highest benefit-cost ratio (2.75), realised

Table 2. Effect of INM on redgram equivalent yield and economics in redgram+foxtail millet intercropping system

Treatments		Redgram Equivalent Yield (kg ha-1)	Gross returns (₹ ha^{-1})	Net returns (₹ ha^{-1})	B:C ratio
T_1:	100% RDN + FYM @ 5 t ha^{-1}	1877	145833	80917	2.25
T_2:	100% RDN + VAM @ 12.5 kg ha^{-1}	2039	158463	100893	2.75
T_3:	100% RDN + mulching with crop residue @ 5 t ha^{-1}	1767	136953	77037	2.29
T_4:	100% RDN + VAM @ 12.5 kg ha^{-1} + mulching with crop residue @ 5 t ha^{-1}	2150	167664	106528	2.74
T_5:	100% RDN + FYM @ 5t ha^{-1} + VAM @ 12.5 kg ha^{-1} + mulching with crop residue @ 5 t ha^{-1}	2427	189988	119770	2.71
T_6:	75% RDN + FYM @ 5 t ha^{-1}	1795	139272	74421	2.15
T_7:	75% RDN + VAM @ 12.5 kg ha^{-1}	1914	148778	91273	2.59
T_8:	75% RDN + mulching with crop residue @ 5 t ha^{-1}	1581	122089	62238	2.04
T_9:	75% RDN + VAM @ 12.5 kg ha^{-1} + mulching with crop residue @ 5 t ha^{-1}	1923	149453	91948	2.6
T_{10}:	75% RDN + FYM @ 5 t ha^{-1} + VAM @ 12.5 kg ha^{-1} + mulching with crop residue @ 5 t ha^{-1}	2143	167088	96935	2.38
SEm±		103.2	-	-	-
CD (5%)		330	-	-	-
CV (%)		9.1	-	-	-

MSP of Redgram: Rs. 80 kg^{-1} , MSP of Foxtail millet: Rs. 20.7 kg^{-1}, Source: CCEA 2026

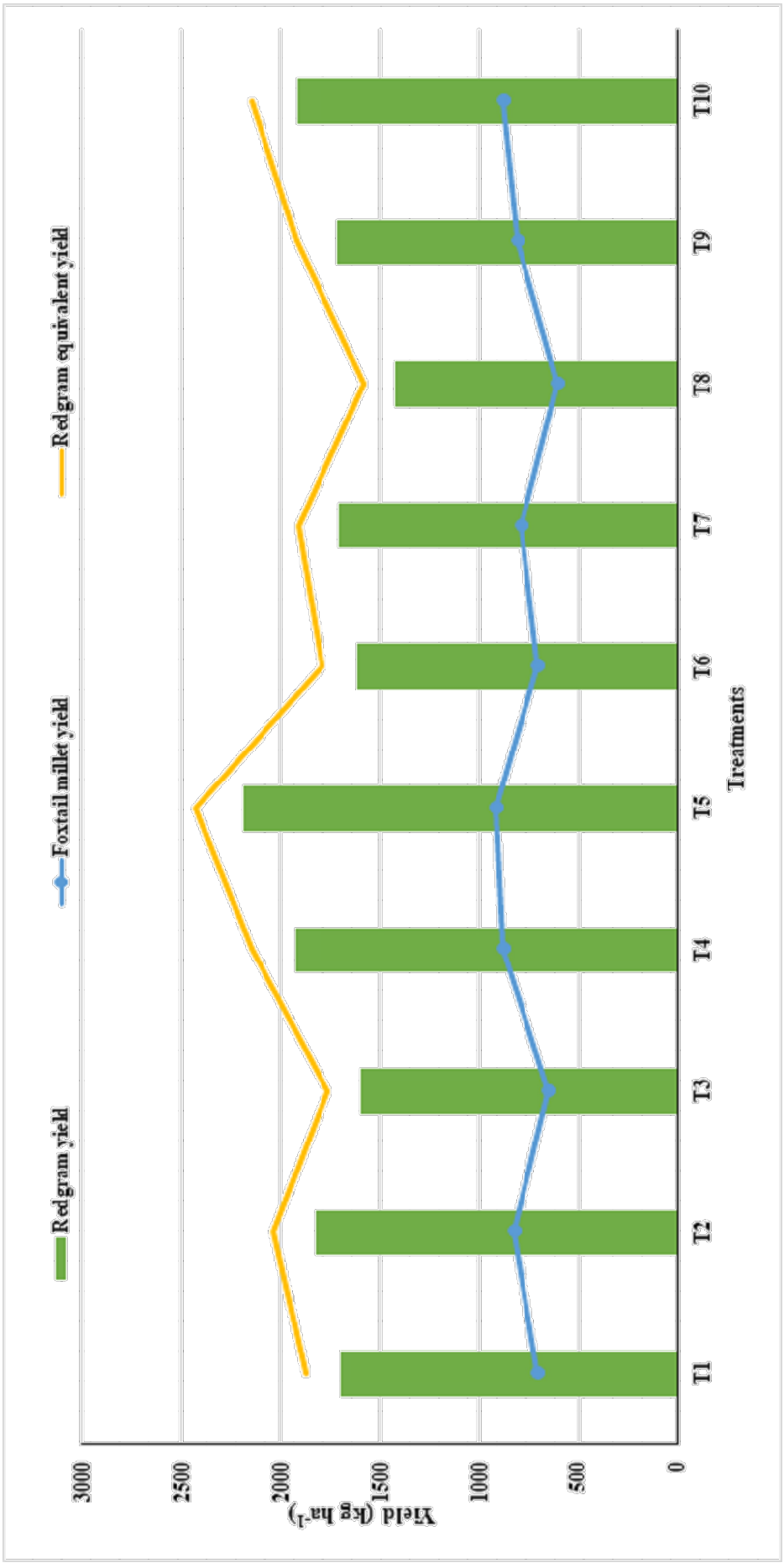


Fig 1. Redgram yield (kg ha^{-1}), Foxtail millet (kg ha^{-1}) and Redgram equivalent yield (kg ha^{-1}) as influenced by different INM practices in redgram + foxtail millet intercropping system

with T_2 and it was closely followed by T… (2.71) despite higher cultivation costs associated with the application of FYM and crop residue mulch. The lower benefit-cost ratio under fifth treatment than second treatment was mainly due to the additional expenditure incurred on procurement of organic inputs rather than reduced productivity. Similar economic advantages of integrated nutrient management in pigeonpea-based intercropping systems have also been reported by Ahamad *et al.* (2018), Ramesh *et al.* (2019), Bharadwaj *et al.* (2022), Iraiyanban *et al.* (2023), Sanjay *et al.* (2024) and Rajarathinam *et al.* (2025).

CONCLUSION

In conclusion, the integrated application of 100% RDN + FYM @ 5 t ha^{-1} + VAM @ 12.5 kg ha^{-1} + crop residue mulching @ 5 t ha^{-1} resulted higher productivity, efficient nutrient utilization with more profitability of the redgram + foxtail millet intercropping system and proved to be a sustainable and economically viable nutrient management practice under the rainfed conditions of the Krishna Agro-climatic Zone of Andhra Pradesh.

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