International Journal of Plant & Soil Science

Volume 36, Issue 10, Page 297-304, 2024; Article no.IJPSS.125123
ISSN: 2320-7035

Effect of Redgram Residue Incorporation on Yields of Redgram and Foxtail Millet in Redgram-Foxtail Millet Intercropping System

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: https://doi.org/10.9734/ijpss/2024/v36i105079

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here:
https://www.sdiarticle5.com/review-history/125123

Original Research Article

Received: 08/08/2024
Accepted: 14/10/2024
Published: 16/10/2024

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Cite as: *K., Sai Manjeera, Sailaja, V., Sammi Reddy, K., Naidu, M.V.S., Padmalatha, Y., and Lakshmipathi, R. 2024. "Effect of Redgram Residue Incorporation on Yields of Redgram and Foxtail Millet in Redgram-Foxtail Millet Intercropping System". International Journal of Plant & Soil Science 36 (10):297-304. https://doi.org/10.9734/ijpss/2024/v36i105079.*

ABSTRACT

The redgram-foxtail millet intercropping system is a sustainable agricultural practice that optimizes resource use, with redgram enriching soil fertility through nitrogen fixation and foxtail millet providing high yields in drought-prone, low-nutrient soils. Foxtail millet is highly valued for its nutritional benefits, including being rich in proteins, fiber, and essential minerals, while also being drought-tolerant and suitable for cultivation in semi-arid regions, making it crucial for food security and climate-resilient farming. Incorporating redgram residue into soil enhances nutrient availability and organic matter content, improving soil structure and fertility. This practice not only supports the growth of subsequent crops but also promotes sustainable agricultural practices by reducing the need for synthetic fertilizers. Hence, a field experiment was conducted at RARS, Lam in *Kharif,* 2021 and 2022 to evaluate the effect of organics (Redgram residue and FYM) and bio-fertilizers (VAM and PSB) on grain yields of Redgram and Foxtail millet in Redgram-Foxtail millet intercropping system. The experiment was laid out in Randomized Block Design comprising eight treatments replicated thrice and the treatment combinations include different organics (FYM @ 10 t ha^{-1}, Redgram residue @ 4 t ha^{-1}), Bio-fertilizers and microbial inoculants (Decomposing inoculum, VAM @ 12.5 kg ha^{-1}, PSB @ 1.25 L ha^{-1}) and Inorganic fertilizers (RDF @ 20-50 kg N-P_2O_5 ha^{-1}). Redgram residue incorporation (RRI) when combined with decomposing inoculum (DI), FYM, VAM and PSB resulted in significantly higher redgram seed yields of 1326 kg ha^{-1} in *Kharif,* 2021 and 1492 kg ha^{-1} in *Kharif,* 2022 respectively. A similar trend was also observed in foxtail millet in both the years with significantly higher grain yield of 1252 kg ha^{-1} in *Kharif,* 2021 and 1492 kg ha^{-1} in *Kharif,* 2022 respectively. Redgram equivalent yields were also found to be significantly higher in the treatment involving Redgram residue incorporation (RRI) when combined with decomposing inoculum (DI), FYM, VAM and PSB being 2414 kg ha^{-1} in *Kharif,* 2021 and 1997 kg ha^{-1} in *Kharif,* 2022 respectively.

Keywords: Farm yard manure; decomposing inoculum; vesicular arbuscular mycorrhizae; phosphate solubilizing bacteria; redgram equivalent yield.

1. INTRODUCTION

Intercropping is an agricultural practice that involves growing two or more crops together on the same piece of land, which can enhance productivity, improve resource utilization, and promote sustainability. The redgram (pigeon pea)–foxtail millet intercropping system is a popular agroecological practice in dryland regions, especially in semi-arid areas. Redgram (*Cajanus cajan*) and foxtail millet (*Setaria italica*) complement each other in terms of growth habits, water, and nutrient requirements, making them an ideal combination for intercropping.

Foxtail millet is an ancient and highly nutritious grain that has been cultivated for thousands of years, especially in Asia and Africa. It stands out for its remarkable resilience to harsh environmental conditions, particularly drought, and thrives in semi-arid regions where other crops often struggle. Nutritionally, foxtail millet is a powerhouse, rich in proteins, dietary fiber, vitamins, and essential minerals such as iron, calcium, and magnesium. It is also gluten-free, making it an excellent alternative for those with celiac disease or gluten intolerance. Its low glycemic index ensures a slow and steady release of glucose into the bloodstream, which is beneficial for managing diabetes and promoting overall metabolic health. One of the most significant advantages of foxtail millet is its adaptability to poor soils and minimal input requirements, making it a sustainable crop for resource-constrained farmers. It grows well without the need for heavy use of fertilizers or pesticides, contributing to lower production costs while also enhancing soil health by improving soil structure and reducing erosion. Historically, foxtail millet has been a staple in the diets of rural communities, and it continues to hold cultural significance in many traditional farming systems. Its cultivation supports agricultural biodiversity by offering an alternative to the dominant monocultures of wheat, rice, and maize. Furthermore, the growing awareness of the health benefits associated with foxtail millet, particularly its high antioxidant content and positive effects on digestion, has increased its popularity in health-conscious markets around the world. For smallholder farmers, this presents an economic opportunity to tap into a rising demand for nutritious, climate-resilient grains.

Redgram is a deep-rooted legume that enriches the soil by fixing atmospheric nitrogen, improving soil fertility, and supporting the growth of companion crops. Foxtail millet, a drought-resistant cereal, matures quickly and thrives in low-fertility soils, utilizing the available moisture effectively. The contrasting root structures of these crops reduce competition for nutrients and water, allowing them to grow harmoniously.

This intercropping system offers multiple benefits, such as higher total productivity, better risk management under erratic rainfall conditions, improved soil health, and enhanced biodiversity. Additionally, it contributes to a diversified diet by providing both protein-rich pulses and energy-dense cereals, making it a sustainable and climate-resilient farming practice. The integration of organics and bio-fertilizers plays a crucial role in improving soil fertility, nutrient availability, and crop yields.

Redgram residue incorporation is a sustainable agricultural practice that involves returning the remnants of redgram plants—such as leaves, stems, and pods—back into the soil after harvest. This practice plays a vital role in enhancing soil fertility and structure, primarily due to the leguminous nature of redgram, which is known for its ability to fix atmospheric nitrogen. By enriching the soil with organic matter, redgram residue helps improve nutrient availability for subsequent crops, promoting healthier plant growth and higher yields.

Incorporating plant residues also contributes to better soil moisture retention and reduced erosion, especially in semi-arid and drought-prone regions where soil degradation is a significant concern. The organic matter from redgram residue fosters a favorable environment for beneficial soil microorganisms, enhancing overall soil health and biodiversity. Furthermore, this practice supports the principles of sustainable agriculture by reducing reliance on synthetic fertilizers and improving soil carbon sequestration. As farmers increasingly seek environmentally friendly and economically viable farming practices, redgram residue incorporation emerges as a valuable strategy for maintaining soil productivity and promoting long-term agricultural sustainability.

The integration of VAM, PSB, FYM, and decomposing inoculum with redgram residue creates a synergistic effect that significantly boosts soil fertility and crop productivity. This holistic approach not only enhances the growth and yield of redgram and its intercrop, foxtail millet, but also fosters sustainable agricultural practices by promoting soil health and reducing dependence on synthetic fertilizers. Together, these inputs contribute to a more resilient farming system capable of withstanding environmental challenges while ensuring food security.

In the present study, a field experiment was conducted during *Kharif* 2021 and 2022 at the Regional Agricultural Research Station (RARS), Lam, to assess the effect of organics (Redgram residue and FYM) and bio -fertilizers (VAM and PSB) on the grain yields of redgram and foxtail millet in an intercropping system. The findings from this experiment provide insights into optimizing nutrient management practices for enhanced productivity in redgram-foxtail millet intercropping systems.

2. MATERIALS AND METHODS

The field experiment was conducted during *kharif,* 2021 and *kharif,* 2022 at the Regional Agricultural Research Station (RARS), Lam, Guntur, which is situated in Krishna Zone of Andhra Pradesh (15^0 55' N latitude and 80^0 30' E longitude) at an altitude of 31.5 m above mean sea level. Experimental soil was silty clay loam in texture, moderately alkaline in reaction, non-saline, low in organic carbon, low in available nitrogen, high in available phosphorus, high potassium and deficient in available sulphur and Zinc; while sufficient in available iron, manganese and copper (Fe, Mn and Cu). The (gross) plot size used was 3.6 m × 7.5 m = 27.0 m^2. Redgram (LRG52) and Foxtail millet (SIA3156) were sown in 1:5 ratio. The experiment was laid out in a randomized block design with eight treatments replicated thrice and the treatmental combinations were **T_1:** Inorganic farming; **T_2:** RDF + FYM @ 10 t ha^{-1}; **T_3:** FYM @ 10 t ha^{-1}; **T_4:** Red gram Residue Incorporation by Shredding @ 4 t ha^{-1} + Decomposing inoculum + FYM @ 10 t ha^{-1} + VAM @ 12.5 kg ha^{-1} + PSB @ 1.25 L ha^{-1} (soil application); **T_5:** Red gram Residue Incorporation + RDF; **T_6:** Red gram

Residue Incorporation + FYM @ 10 t ha^{-1}; **T_7:** Red gram Residue Incorporation + Decomposing inoculum + FYM @ 10 t ha^{-1}**; T_8:** Red gram Residue Incorporation + Decomposing inoculum + FYM @ 10 t ha^{-1} + VAM @ 12.5 kg ha^{-1}. **Note:** a) For organic farming (T_3, T_4, T_6, T_7, T_8) seed inoculation with *Rhizobium;* Pest management in organic farming will be through seed treatment with *Pseudomonas* @ 5g kg^{-1}, basal application of *Trichoderma viridae* @ 2.5 kg ha^{-1} and need based application neem oil @ 5ml L^{-1} and NSKE @ 50 ml L^{-1}.b) For (T_1, T_2 & T_5) inorganic farming (IF) with (20-50-0 kg N-P_2O_5-K_2O ha^{-1}) through chemical fertilizers and pest management was through chemical means. Grain yield from each net plot was sun dried for 4 to 6 days and then the weight of grains per net plot area was recorded and expressed in kg ha^{-1}. The data were analysed statistically using Fisher's method of analysis of variance as suggested by Panse and Sukhatme [1] for the randomized block design adopted in this study. Statistical significance was tested by applying F-test at 0.05 level of probability. Critical differences at 0.05 levels were worked out for the effects, which were significant.

3. RESULTS AND DISCUSSION

3.1 Grain Yield

Grain yield of redgram and foxtail millet were recorded during 2021 & 2022 and redgram equivalent yield was calculated using standard formulae and were presented in Table 1. Along with pooled yield.

3.1.1 Kharif, 2021

Redgram seed yields were significantly lower (704 kg ha^{1}) with the application of FYM @ 10 t ha^{-1} alone which was on par with the yield obtained when FYM was integrated with redgram residue incorporation (735 kg ha^{-1}) and RDF alone (860 kg ha^{-1}). Redgram residue incorporation (RRI) when combined with decomposing inoculum (DI), FYM, VAM either with or without PSB were found to be significantly higher resulting in redgram seed yields of 1326 and 1290 kg ha^{-1} respectively.

Similarly, the intercrop, foxtail millet showed significantly lower grain yield of 673 kg ha^{-1} with FYM alone which was on par with the yield realized when it was applied in conjunction with redgram residue incorporation. Application of RRI + FYM + DI + VAM + PSB resulted in a significantly higher grain yield of 1252 kg ha^{-1}.

Redgram Equivalent Yields were significantly lower with FYM i.e., 1289 kg ha^{-1} which increased significantly to 2414 kg ha^{-1} when RRI + FYM + DI + VAM + PSB were imposed; however, without PSB also comparable Redgram Equivalent Yields were realized (2243 kg ha^{-1}).

3.1.2 Kharif, 2022

During 2022, redgram seed yield was significantly higher when RRI + FYM+ DI + VAM were combinedly applied either with PSB (1092 kg ha^{-1}) or without PSB (1057 kg ha^{-1}) and were at a par. Significantly lower seed yield of 655 kg ha^{-1} was recorded with RDF.

Grain yield of foxtail millet also was significantly influenced by the residue incorporation along with FYM and microbial consortia. Grain yield was significantly higher when RRI + FYM+ DI + VAM were combinedly applied either with PSB (1492 kg ha^{-1}) or without PSB (1306 kg ha^{-1}) and were at a par.

Redgram Equivalent Yield (RGEY) also followed similar trend. RDF and FYM were at a par in realizing significantly lower RGEY with corresponding yields of 1352 and 1365 kg ha^{-1}.

3.1.3 Pooled

In pooled data, FYM was found to result in significantly lower redgram, foxtail millet and RGE yields of 718, 858 and 1327 kg ha^{-1} respectively. RRI + FYM +DI+VAM+PSB was found to be significantly superior with a yield of 1209, 1372 and 2206 kg ha^{-1} respectively of redgram, foxtail millet and RGEY.

Incorporation of redgram residue along with decomposing inoculum might have resulted in the release of plant nutrients for crop absorption. Coupled with this FYM acts both as a source of nutrients and also as substrate for VAM and PSB for proliferation and brought about better crop nutrition and yields.

These results were in corroboration with studies of Kumar et al. [2], Yaseen et al. [3], Nalatwadmath et al. [4], Aparna et al. [5], Kalaiyarasi et al. [6], Garg et al. [7], Nissi and Debbarma [8], Aechra et al. [9] Kumar et al. [10].

Table 1. Grain Yields of Redgram, Foxtail millet crops and redgram equivalent yield of foxtail millet in *kharif,* 2021 and *kharif*, 2022 as influenced by redgram residue incorporation

Grain yield	2021			2022			Pooled		
	Red gram	Foxtail millet	RGEY	Red gram	Foxtail millet	RGEY	Red gram	Foxtail millet	RGEY
T1: RDF	860	869	1616	655	1148	1352	758	1009	1484
T2: RDF + FYM	954	985	1810	766	1231	1514	860	1108	1662
T3: FYM	704	673	1289	731	1043	1365	718	858	1327
T4: RRI + FYM + DI + VAM + PSB	1326	1251	2414	1092	1492	1997	1209	1372	2206
T5: RRI + RDF	938	833	1663	723	1296	1510	831	1065	1587
T6: RRI + FYM	735	717	1358	825	1114	1501	780	916	1430
T7: RRI + FYM + DI	1080	991	1942	893	1287	1674	987	1139	1808
T8: RRI + FYM + DI + VAM	1290	1096	2243	1057	1306	1849	1174	1201	2046
SEm (±)	**68**	**44**	**66**	**58**	**63**	**60**	**102**	**87**	**158**
SEd	**96**	**62**	**93**	**82**	**89**	**86**	**144**	**123**	**223**
CD (p=0.05)	**205**	**132**	**199**	**176**	**192**	**183**	**293**	**249**	**453**
CV (%)	**12**	**8**	**6**	**12**	**9**	**7**	**27**	**20**	**23**
	*****	*****	*****	*****	*****	*****	*****	*****	*****

**RDF: 20-50-0 kg N-P_2O_5-K_2O ha^{-1} through urea and DAP; RRI: Red gram Residue Incorporation by Shredding @ 4 t ha^{-1}; DI: Decomposing inoculum; FYM: Farm Yard Manure @ 10 t ha^{-1}; VAM: Vesicular Arbuscular Mycorrhizae @ 12.5 kg ha^{-1}; PSB: Phosphate Solubilizing Bacteria @ 1.25 L ha^{-1} (soil application)*

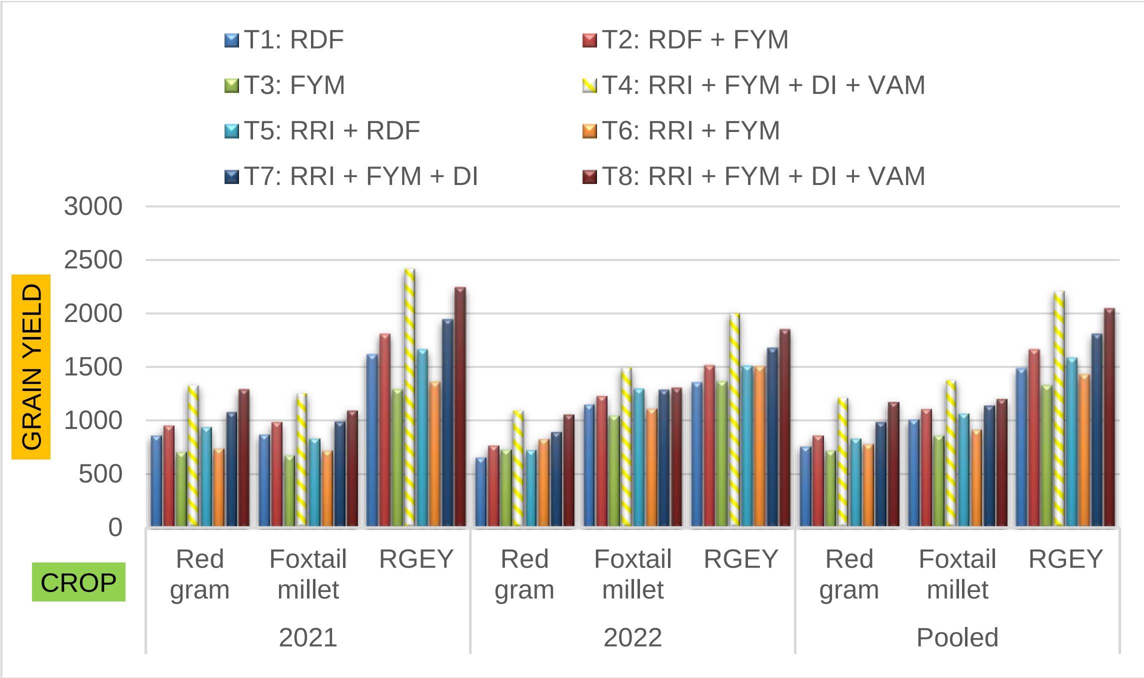

Fig. 1. Effect of Redgram residue incorporation on grain Yields of Redgram, Foxtail millet crops and redgram equivalent yield of foxtail millet in *kharif,* 2021 and *kharif*, 2022

4. CONCLUSION

The field experiment conducted over two consecutive *kharif* seasons (2021 and 2022) demonstrated the positive effects of integrating organics, bio-fertilizers, and microbial inoculants in a Redgram-Foxtail millet intercropping system. The following conclusions can be drawn from the study:

1. **Superior Yield Performance**: The treatment involving Redgram residue incorporation (RRI) combined with FYM, decomposing inoculum (DI), VAM, and PSB (T_4) consistently produced the highest grain yields of both redgram and foxtail millet in 2021 and 2022. This treatment also resulted in the highest Redgram Equivalent Yields (RGEY) in both individual years and pooled results.
2. **Organic and Bio-fertilizers Boost Productivity**: The combination of redgram residue, farmyard manure, and bio-fertilizers (VAM and PSB) significantly enhanced the yields compared to treatments with only inorganic fertilizers or organics applied alone. This highlights the importance of integrating organic and biological inputs for sustainable yield improvement.
3. **Sustainability in Intercropping Systems**: The use of organics, especially redgram residue, and microbial inoculants not only increased crop productivity but also potentially improved soil health and nutrient cycling, making the system more sustainable in the long term.
4. **Economic Viability**: The highest redgram equivalent yields (RGEY) observed in the treatment with RRI + FYM + DI + VAM + PSB suggest that this combination offers a more economically viable option for farmers, enhancing overall productivity in intercropping systems.

In conclusion, the integration of organics and bio-fertilizers in intercropping systems holds great potential for improving crop yields and sustainability. Among the tested treatments, T_4 (RRI + FYM + DI + VAM + PSB) proved to be the most effective in maximizing yield and ensuring long-term soil fertility.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

ACKNOWLEDGEMENTS

I would like to express my heartfelt gratitude to Dr. V. Sailaja from the Department of Soil Science & Agricultural Chemistry, RARS, Lam, ANGRAU, Guntur, for her guidance and support throughout this research. Special thanks to Dr. K. Sammi Reddy, Director, ICAR-NIASM, Baramati, Pune, for his valuable insights, and to Dr. M.V.S. Naidu from S.V. Agricultural College, Tirupati, for his constant encouragement. I am also deeply thankful to Dr. Y. Padmalatha from the Professor, Department of Agronomy, Lam, Guntur, and the Dr. R. Lakshmipathi, Department of Agricultural Microbiology, APCARL Campus, Pulivendula, for their collaborative efforts. I am very thankful to our university ANGRAU, for funding my research.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Peer-review history:
The peer review history for this paper can be accessed here:
https://www.sdiarticle5.com/review-history/125123