International Journal of Plant & Soil Science

Volume 37, Issue 1, Page 98-105, 2025; Article no.IJPSS.129064
ISSN: 2320-7035

Integrated Nutrient Management Strategies for Red Gram, Sorghum and Blackgram-Based Intercropping Systems

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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/2025/v37i15256

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/129064

Original Research Article

Received: 29/10/2024
Accepted: 31/12/2024
Published: 11/01/2025

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Cite as: *Rajarathinam, P., K. Subrahmaniyan, S. Elamathi, R. Arulananth, R. Nageswari, S. Mathiyazhagan, R. Manimaran, and G. Sivakumar. 2025. "Integrated Nutrient Management Strategies for Red Gram, Sorghum and Blackgram-Based Intercropping Systems". International Journal of Plant & Soil Science 37 (1):98-105. https://doi.org/10.9734/ijpss/2025/v37i15256.*

ABSTRACT

A field experiment was conducted at the National Pulses Research Centre, Vamban, Pudukkottai District, during the *kharif* seasons of 2022 and 2023 to evaluate integrated nutrient management strategies for redgram-based intercropping systems. The study included two intercropping treatments: (I_1) Redgram + Sorghum (1:2) and (I_2) Redgram + Blackgram (1:2), along with three organic fertilizer treatments: (F_1) Recommended Dose of Fertilizer (RDF), (F_2) RDF + Vermicompost @ 2.5 t ha^{-1}, and (F_3) RDF + Farmyard Manure (FYM) @ 5 t ha^{-1}. Two biofertilizer treatments were also evaluated: (B_1) without Phosphorus Solubilizing Bacteria (PSB) and (B_2) with PSB. The experiment was laid out in a Randomized Complete Block Design (RCBD) with three replications. The study utilized the red gram variety VBN 3, intercropped with the sorghum variety K 11 and the black gram variety VBN 6. Results indicated that the redgram + blackgram (1:2) intercropping system produced the highest redgram plant height (347.6 cm), branches per plant (21.2), and number of pods (295.8 per plant). This system also achieved the highest redgram seed yield (858 kg ha^{-1}), redgram grain equivalent yield (1139 kg ha^{-1}), and benefit-cost ratio (2.69). The application of RDF + vermicompost at 2.5 t ha^{-1} produced the tallest redgram plants (348.8 cm) and the highest number of branches (21.6), with significantly higher pod numbers (300.6 per plant) and seed yield (856 kg ha^{-1}). PSB application further enhanced seed yields, with the highest redgram grain equivalent yield (1122 kg ha^{-1}) and benefit-cost ratio (2.76). The study concluded that the combination of redgram + blackgram intercropping, RDF + vermicompost, and PSB application offers an effective integrated nutrient management strategy, optimizing both grain yields and profitability.

Keywords: Redgram; intercropping; organic fertilizer and PSB.

1. INTRODUCTION

Redgram (*Cajanus cajan* L.), commonly known as pigeon pea, is a vital pulse crop in tropical and subtropical regions. It is highly valued for its protein-rich seeds and its adaptability to marginal lands with minimal input requirements. India cultivates redgram over an area of 4.6 million hectares annually, producing approximately 3.8 million tonnes, with an average productivity of 750 kg ha^{-1} (Ministry of Agriculture & Farmers Welfare, Government of India, 2023). Intercropping provides good opportunity to optimize the use of available resources such as light, water, and nutrients, leading to an increase in the combined crop yield (Yadav & Newaj, 1990). Legume-based intercropping systems, such as redgram (*Cajanus cajan* L.) with cereals and pulses provide complementary advantages, including improved nutrient cycling, and increased productivity (Nishanthi et al., 2015). Integrating organic fertilizers with the recommended dose of fertilizers (RDF) is a promising approach to sustain crop productivity while reducing dependence on chemical inputs. The use of organic amendments like vermicompost and farmyard manure (FYM) gather significant attention due to their ability to improve soil fertility, organic matter content, and microbial activity (George et al., 2024; Kant et al., 2016; Patra et al., 2023; Vyas et al., 2012). Vermicompost, a nutrient-rich organic input, enhances soil structure and microbial diversity, whereas FYM contributes to long-term organic matter buildup and provides essential nutrients. Biofertilizers, particularly phosphate-solubilizing bacteria (PSB), play a crucial role in enhancing phosphorus availability in the soil, a nutrient critical for plant growth and development. PSB inoculation has shown potential in promoting root growth, enhancing nutrient uptake, and improving yield in legume-based cropping systems. The PSB, dissolving inter locked phosphates appear to have an important implication in Indian agriculture (Khan et al., 2010).

2. MATERIALS AND METHODS

The Field trials were conducted at the National Pulses Research Centre, Vamban, Pudukkottai District, during the *kharif* seasons of 2022 and 2023 to assess integrated nutrient management practices in redgram-based intercropping systems. The experiments were conducted using a randomized complete block design (RCBD) with 12 treatment combinations and three replications. The experimental site is situated at 8.30° N latitude and 78.24° E longitude, at an altitude of 122 meters above mean sea level.

The soil is red lateritic, well-drained, and was analyzed for nutrient status using standard methods. The available nitrogen was estimated by alkaline permanganate method of Subbiah and Asija (1956) and expressed in kg ha-1. The available phosphorus was estimated by the method of Olsen *et al*. (1954) and expressed in kg ha-1. Available potassium was estimated by neutral normal ammonium acetate extraction and flame photometry developed by Stanford and English (1949) and expressed in kg ha-1. The soil pH was estimated as per the method suggested by Jackson (1973). The soil analysis revealed low available nitrogen (175 kg ha-1), medium available phosphorus (21.2 kg ha-1), and low available potassium (165.8 kg ha-1). The soil pH was recorded at 5.8, indicating an acidic reaction. The study utilized a sole crop of redgram variety VBN 3 along with intercrops of sorghum variety K 11 and blackgram variety VBN 6. The spacing adopted for redgram was 90 × 30 cm, while for sorghum and blackgram, it was 30 x 10 cm.

2.1 Treatment Details

Inter cropping systems:

I_1 - Redgram + Sorghum (1:2)
I_2 - Redgram + Blackgram (1:2)

Organic fertilizer:

F_1 - RDF (No organic fertilizer)
F_2 - RDF + Vermicompost @ 2.5 t/ha
F_3 - RDF + FYM @ 5 t/ha

Bio fertilizer:

B_1 - No Phosphorus Solubulizing Bacteria (PSB)
B_2 - PSB

The crops were planted using the beds and channels method. The treatments were implemented according to the designated treatment schedule. The crop equivalent yield (CEY) was calculated by using the following formula (Wang et al., 1990).

$$\text{CEY} = \text{Main crop yield} + \frac{Yield\ of\ intercrop\ x\ Price\ of\ intercrop}{Price\ of\ main\ crop}$$

Growth characteristics, yield attributes, and seed yield were recorded at harvest. The experimental data were analyzed using the statistical method outlined Gomez and Gomez (1984).

3. RESULTS AND DISCUSSION

3.1 Growth and Yield Attributes

The effect of intercropping system, organic fertilizers and bio fertilizers on the growth and yield attributes were presented in Table 1. The redgram + blackgram intercropping system in a 1:2 ratio (I2) significantly increased redgram plant height of 347.6 cm, and the number of branches plant-1, averaging 21.2. This system also resulted in the highest number of pods (295.8 / plant) and the more number of seeds (4.3 seeds /pod). However, the intercropping system had no effect on test weight. An increased redgram plant height was also observed in the cassava- redgram intercropping system (George *et al*., 2024). The intercropping system can increase resource use efficiency through better resource partitioning, complementarity, and facilitation among plant species. These mechanisms allow plants to optimize the use of light, water, and nutrients, reducing intra-species competition while boosting growth and yield (Bharadwaj *et al*., 2014). Similarly, Wang *et al*. (2015) and Raza *et al*. (2021) have demonstrated that intercropping systems improve water and nutrient use efficiency, particularly in legumes, which can fix atmospheric nitrogen, enhancing soil fertility. These systems also contribute to improved biomass production and yield stability, as seen in studies on various crop combinations like maize-cowpea and legume- forage intercropping systems (Kumar *et al*., 2020; Mousavi & Eskandari, 2021). Such findings support the idea that well-designed intercropping systems, including the redgram + blackgram system discussed, can lead to significant improvements in plant growth and productivity while ensuring sustainable agricultural practices.

Among the treatments, RDF combined with vermicompost at 2.5 t ha^{-1} (F_2) showed superior performance, resulting in the tallest plants (348.8 cm), the highest number of branches (21.6 /plant), and the highest number of pods (300.6 /plant). These findings are consistent with recent studies of vermicompost in enhancing soil nutrient availability, improving soil structure, and stimulating plant growth through the production of plant growth-promoting substances (Singh & Reddy, 2019). Moreover, the comparable performance of RDF + FYM at 5.0 t ha^{-1} (F_3) underscores the versatility of organic amendments like FYM in boosting plant productivity. FYM contributes to the slow and sustained release of nutrients while improving microbial activity and organic matter content in the soil (Khan *et al*., 2010). The application of phosphorus-solubilizing bacteria significantly outperformed the control, resulting in higher grain yields for both the main crop and intercrops. The treatment with phosphorus-solubilizing bacteria (B_2) achieved the highest plant height (336.3 cm), higher number of branches (20.9 plant^{-1}), the highest number of pods (290.4 /plant), and more number of seeds (4.3 /pod). Test weight remained unaffected by the application of biofertilizers. Notably, the highest grain yield of 831 kg ha^{-1} was recorded with the B_2 treatment (Table 1).

3.2 Grain Yield (Redgram)

The highest redgram seed yield of 858 kg ha^{-1} was achieved with the redgram + blackgram (1:2) intercropping system (I_2), followed by the redgram + sorghum (1:2) intercropping system (I_2). This result can be attributed to the complementary interactions between the two crops, which likely enhanced resource use efficiency, such as water, light, and nutrients (Olsen et al., 1954) and found that legume-based intercropping systems improve soil fertility and productivity through nitrogen fixation and reduced competition. Among the organic fertilizers, the application of RDF + vermicompost at 2.5 t ha^{-1} (F_2) resulted in the highest redgram seed yield of 856 kg ha^{-1}, followed by RDF + FYM at 5 t ha^{-1} (F_3). The reason might be due to application of vermicompost enhances soil organic carbon content and nutrient release, fostering better crop growth and yield (Bybee-Finley & Ryan, 2018). The lowest grain yield of 758 kg ha^{-1} was recorded with the RDF treatment (F_1). Additionally, the highest grain yield of 831 kg ha^{-1} was observed with the PSB treatment (B_2). RDF + FYM at 5 t ha^{-1} (F_3) also performed well, shows the benefits of farmyard manure in improving soil organic matter and water-holding capacity (Kumar et al., 2017). The lowest grain yield of 758 kg ha^{-1} was recorded with the sole application of RDF (F_1) (Table 1). The PSB treatment (B_2) recorded a higher grain yield of 831 kg ha^{-1}, highlighting the role of phosphorus-solubilizing bacteria in enhancing phosphorus availability to plants improved nutrient use efficiency and crop yields with biofertilizer applications (Ofori & Stern, 1987). Overall, these results emphasize the significance of adopting integrated nutrient management practices that combine intercropping, organic fertilizers, and biofertilizers to achieve sustainable agricultural productivity while maintaining soil health.

3.3 Grain Yield (Intercrop)

In the redgram and sorghum intercropping system (1:2 ratio), the average sorghum grain yield recorded was 511 kg ha^{-1}. Among the organic fertilizers, the application of RDF combined with vermicompost (F_2) resulted in a higher sorghum grain yield of 285 kg ha^{-1}, which

Table 1. Effect of treatments on growth, yield attributes and yield of redgram (mean of two years)

Treatments	Plant height (cm)	No. of branches Plant^{-1}	No. of pods Plant^{-1}	No. of seeds Pod^{-1}	Test weight (g)	Seed yield (kg ha^{-1})
Inter cropping system						
I_1	308.1	18.8	265.1	4.1	8.1	742
I_2	347.6	21.2	295.8	4.3	8.1	858
S.Em(±)	**5.31**	**0.40**	**0.54**	**0.01**	**0.03**	**12.01**
CD (P=0.05)	**16.59**	**1.27**	**1.69**	**0.04**	**NS**	**37.5**
Organic fertilizer						
F_1	302.8	18.2	254.0	4.1	8.0	758
F_2	348.8	21.6	300.6	4.2	8.1	856
F_3	332.0	20.1	286.7	4.2	8.1	787
S.Em(±)	**6.47**	**0.49**	**0.65**	**0.01**	**0.04**	**14.71**
CD (P=0.05)	**20.32**	**1.56**	**2.07**	**0.05**	**NS**	**45.9**
Bio fertilizer						
B_1	319.5	19.0	270.5	4.2	8.1	770
B_2	336.3	20.9	290.4	4.3	8.1	831
S.Em(±)	**5.52**	**0.40**	**0.54**	**0.01**	**0.03**	**11.98**
CD (P=0.05)	**16.59**	**1.27**	**1.69**	**0.05**	**NS**	**37.5**

was comparable to the yield obtained with RDF + FYM at 5 t ha^{-1}. Additionally, seed treatment with PSB produced a notable grain yield of 262 kg ha^{-1}. Among the organic fertilizers, the combination of RDF with vermicompost (F_2) resulted in a significant grain yield of 285 kg ha^{-1}. Vermicompost enhances soil structure, microbial activity, and nutrient availability, which can explain its superior performance. The comparable yield achieved with RDF + FYM at 5 t ha^{-1} highlights that FYM also plays a crucial role in supplying organic matter and nutrients to the soil. These findings align with previous studies demonstrating the benefits of integrating organic fertilizers with inorganic nutrients for improved crop performance and sustainability (Ananthi et al., 2017 & Sharma et al., 2013). Seed treatment with PSB further contributed to increased sorghum grain yield, producing 262 kg ha^{-1}. PSB enhances phosphorus availability in the soil by converting insoluble phosphorus into soluble forms, facilitating its uptake by plants. This result was supported by earlier research (Vlahova, 2022 & Sharma et al., 2017).

The redgram and blackgram intercropping system in a 1:2 ratio (I_2) achieving an average seed yield of 309 kg ha^{-1}. Intercropping systems are widely recognized for their ability to improve resource utilization and enhance overall productivity compared to monocropping. In this system, redgram acts as a complementary crop, likely improving the microenvironment and nutrient availability for blackgram growth. The application of RDF combined with vermicompost (F_2) produced a higher blackgram grain yield of 164 kg ha^{-1}. Vermicompost improves soil fertility by supplying essential nutrients, enhancing microbial activity, and improving soil structure, making nutrients more accessible to plants. This result is consistent with findings from earlier studies indicating that vermicompost contributes significantly to improving legume yields (Khan et al., 2009; Chaudhary & Panjla, 2021). Additionally, RDF combined with FYM at 5 t ha^{-1} yielded similar results, emphasizing the importance of integrating organic matter for sustainable productivity. Seed treatment with PSB resulted in a grain yield of 162 kg ha^{-1} (Table 2), underscoring the role of beneficial microbes in nutrient mobilization, particularly phosphorus. PSB converts insoluble phosphate into forms readily available for plant uptake, which is particularly beneficial for legumes due to their high phosphorus demand during flowering and pod formation stages (Sharma et al., 2012 & Singh et al., 2015).

3.4 Crop Equivalent Yield

The redgram + blackgram intercropping system (1:2 ratio) (I_2) achieved the highest redgram equivalent yield (REY) of 1139 kg ha^{-1}, due to its superior resource-use efficiency and productivity. The application of RDF combined with

Table 2. Effect of treatments on seed yield and redgram equivalent yield (mean of two years)

Treatments	**Redgram seed yield (kg ha^{-1})**	**Sorghum grain yield(kg ha^{-1})**	**Blackgram seed yield (kg ha^{-1})**	**Redgram equivalent yield (kg ha^{-1})**
Inter cropping system				
I_1	742	511	-	1012
I_2	858	-	309	1139
S.Em(±)	**12.01**	**3.78**	**2.42**	**-**
CD (P=0.05)	**37.5**	**11.4**	**7.3**	**-**
Organic fertilizer				
F_1	758	216	142	1000
F_2	856	285	164	1165
F_3	787	264	157	1067
S.Em(±)	**14.7**	**4.33**	**2.76**	**-**
CD (P=0.05)	**45.9**	**13.9**	**8.9**	**-**
Bio fertilizer				
B_1	770	249	147	1033
B_2	831	262	162	1122
S.Em(±)	**12.03**	**3.79**	**2.44**	**-**
CD (P=0.05)	**37.5**	**11.4**	**7.3**	**-**

Table 3. Effect of Inter cropping system, organic fertilizer and Bio fertilizer on economics (mean of two years)

Treatments	Cost of Cultivation (Rs. ha^{-1})	Gross Return (Rs. ha^{-1})	Net Return (Rs. ha^{-1})	BC Ratio
Inter cropping system				
I_1	22189	57828	35639	2.61
I_2	26077	70102	44024	2.69
Organic fertilizer				
F_1	18050	59482	41432	3.30
F_2	33050	69092	36042	2.09
F_3	21300	63320	42020	2.97
Bio fertilizer				
B_1	24124	61289	37165	2.54
B_2	24142	66640	42498	2.76

vermicompost at 2.5 t ha^{-1} (F_2) resulted in the highest REY of 1165 kg ha^{-1}. This outcome highlights the effectiveness of vermicompost in enhancing soil fertility and nutrient availability. Vermicompost, with its faster nutrient availability and higher microbial activity, appears to be a more effective supplement than FYM for maximizing REY. The application of phosphorus-solubilizing bacteria (B_2) resulted in a higher REY of 1122 kg ha^{-1} (Table 2). This was due to effectiveness of biological inputs in enhancing crop productivity. The higher yields achieved across these treatments can be attributed to improved grain yield and the market value of both component crops (Raza et al., 2021) emphasizing the effectiveness of integrated nutrient management practices in enhancing crop yields and system productivity.

3.5 Economics

The redgram + blackgram (1:2) intercropping system (I_2) generated a higher net return of Rs. 44,024 ha^{-1} with a benefit-cost ratio of 2.69. Applying the recommended dose of fertilizer (F_1) fetched a net return of Rs. 41,432 ha^{-1} and the highest benefit-cost ratio of 3.30. Furthermore, the use of phosphorus-solubilizing bacteria (B_2) achieved a net return of Rs. 42,498 ha^{-1} with a benefit-cost ratio of 2.76. (Table 3). These findings suggest that integrating intercropping, organic fertilizers, and biofertilizers can lead to higher economic returns while promoting sustainability. Future studies should focus on assessing these practices in diverse cropping systems and under different agro-climatic conditions to validate their broader applicability. Additionally, cost-benefit analyses over multiple seasons could provide insights into long-term profitability and economic resilience.

4. CONCLUSION

The redgram + blackgram intercropping system (1:2 ratio) shows excellent performance by maximizing growth, yield attributes, and redgram equivalent yield (REY), achieving 1139 kg ha^{-1} due to efficient resource use. RDF combined with vermicompost at 2.5 t ha^{-1} (F_2) further enhanced REY (1165 kg ha^{-1}) and seed yield (856 kg ha^{-1}). Similarly, phosphorus-solubilizing bacteria (B_2) improved seed yield (831 kg ha^{-1}) and REY (1122 kg ha^{-1}), indicating its effectiveness in enhancing phosphorus uptake. The intercropping system delivered the highest net return (Rs. 44,024 ha^{-1}) and a benefit-cost ratio of 2.69, while RDF alone (F_1) provided the highest benefit-cost ratio (3.30). This study highlights the importance of combining organic fertilizers, biofertilizers, and intercropping systems to achieve sustainable and economically viable agriculture.

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 writing or editing of this manuscript.

ACKNOWLEDGEMENT

The technical guidance and financial support provided by the ICAR - AICRP on MULLaRP Scheme, Indian Institute of Pulses Research, Kanpur, India for conducting the rice fallow trials at Tamil Nadu Rice Research Institute, Aduthurai is gratefully acknowledged.

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/129064