

## Original Research Article

## Integrated Nutrient Management Strategies for Red gram (*Cajanus cajan* L.) Based Intercropping Systems

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### ABSTRACT

The 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 intercropping system includes red gram intercropped with sorghum and black gram in a 1:2 row ratio. Organic fertilizers comprise sole RDF, as well as combinations with vermicompost and FYM applied at varying levels. Seed treatment with PSB was evaluated against a control. The experiments were arranged in a randomized complete block design (RCBD) with 12 treatment combinations and replicated thrice. The results reveal that, the redgram + blackgram (1:2) intercropping system recorded significantly higher plant height (347.6 cm) and more branches (21.2 plant<sup>-1</sup>). This system also resulted in the highest number of pods (295.8 plant<sup>-1</sup>) and seeds pod<sup>-1</sup> (4.3 pod<sup>-1</sup>). The highest grain yield (858 kg ha<sup>-1</sup>), grain equivalent yield (1139 kg ha<sup>-1</sup>), and benefit-cost ratio (2.69) were achieved in this intercropping system. Application of RDF + vermicompost at 2.5 t ha<sup>-1</sup> resulted in the highest plant height (348.8 cm) and the highest number of branches per plant (21.6), which was comparable to RDF + FYM at 5.0 t ha<sup>-1</sup>. Fertilization of RDF + vermicompost at 2.5 t ha<sup>-1</sup> recorded significantly higher numbers of pods (300.6 plant<sup>-1</sup>) and seeds per pod, leading to the highest grain yield (856 kg ha<sup>-1</sup>) and grain equivalent yield (1165 kg ha<sup>-1</sup>). The application of phosphorus solubilizing bacteria (PSB) outperformed the control, resulting in higher grain yields for both the main crop and intercrops. The highest grain equivalent yield (1122 kg ha<sup>-1</sup>) and benefit-cost ratio (2.76) were recorded with PSB application. The findings suggest that a combination of redgram + blackgram (1:2 ratio) intercropping system, application of RDF + vermicompost at 2.5 t ha<sup>-1</sup>, and use of phosphorus solubilizing bacteria is an effective integrated nutrient management practice for pigeonpea-based intercropping systems. These practices can optimize grain yields and profitability.

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**Key words:** 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<sup>-1</sup> (Agricultural statistics at a glance, 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 (Vlahova, 2022). Legume-based intercropping systems, such as redgram (*Cajanus cajan* L.) with cereals and pulses provide complementary advantages, including improved nutrient cycling, and increased productivity (Ofori and Stern ;1987). 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. 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 (Kant *et al.*, 2016).

## 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 arranged in a randomized complete block design (RCBD) with 12 treatment combinations and replicated thrice. 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<sup>-1</sup>. The available phosphorus was estimated by the method of Olsen *et al.* (1954) and expressed in kg ha<sup>-1</sup>. Available potassium was estimated by neutral normal ammonium acetate extraction and flame photometry developed by Stanford and English

(1949) and expressed in kg ha<sup>-1</sup>. The soil pH was estimated as per the method suggested by Jackson (1973). The soil analysis revealed low available nitrogen (175 kg ha<sup>-1</sup>), medium available phosphorus (21.2 kg ha<sup>-1</sup>), and low available potassium (165.8 kg ha<sup>-1</sup>). 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 × 10 cm. 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 as per method suggested by Yadav and Newaj (1990).

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

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 redgram + blackgram intercropping system in a 1:2 ratio (I<sub>2</sub>) significantly increased plant height of 347.6 cm, and the number of branches plant<sup>-1</sup>, averaging 21.2. This system also resulted in the highest number of pods (295.8 plant<sup>-1</sup>) and the more number of seeds (4.3 seeds pod<sup>-1</sup>). However, the intercropping system had no effect on test weight. 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 (Bybee Finley and Ryan, 2018).). 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 (Mousavi & Eskandari ; 2011) and Nishanthi *et al.* (2015). 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<sup>-1</sup> (F<sub>2</sub>) showed superior performance, resulting in the tallest plants (348.8 cm), the highest number of branches (21.6 plant<sup>-1</sup>),

and the highest number of pods ( $300.6 \text{ plant}^{-1}$ ). 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 *et al.*, 2022). Moreover, the comparable performance of RDF + FYM at  $5.0 \text{ t ha}^{-1}$  ( $F_3$ ) 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) and Patra *et al.* (2023). 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 ( $20.9 \text{ plant}^{-1}$ ), the highest number of pods ( $290.4 \text{ plant}^{-1}$ ), and more number of seeds ( $4.3 \text{ pod}^{-1}$ ). Test weight remained unaffected by the application of biofertilizers. Notably, the highest grain yield of  $831 \text{ kg ha}^{-1}$  was recorded with the  $B_2$  treatment (Table 1).

### 3.2 Grain yield (Redgram)

The highest redgram seed yield of  $858 \text{ kg ha}^{-1}$  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. Similar results have been reported by Ananthi *et al.* (2017) who 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  $2.5 \text{ t ha}^{-1}$  ( $F_2$ ) resulted in the highest redgram seed yield of  $856 \text{ kg ha}^{-1}$ , followed by RDF + FYM at  $5 \text{ t ha}^{-1}$  ( $F_3$ ). The reason might be due to application of vermicompost enhances soil organic carbon content and nutrient release, fostering better crop growth and yield. The result was in according with Chaudhary *et al.* (2021). The lowest grain yield of  $758 \text{ kg ha}^{-1}$  was recorded with the RDF treatment ( $F_1$ ). Additionally, the highest grain yield of  $831 \text{ kg ha}^{-1}$  was observed with the PSB treatment ( $B_2$ ). RDF + FYM at  $5 \text{ t ha}^{-1}$  ( $F_3$ ) also performed well, shows the benefits of farmyard manure in improving soil organic matter and water-holding capacity, as noted by Kumar *et al.* (2020). The lowest grain yield of  $758 \text{ kg ha}^{-1}$  was recorded with the sole application of RDF ( $F_1$ ) (Table 1). The PSB treatment ( $B_2$ ) recorded a higher grain yield of  $831 \text{ kg ha}^{-1}$ , highlighting the role of phosphorus-solubilizing bacteria in enhancing phosphorus

availability to plants. This aligns with findings by Khan *et al.* (2009) who observed improved nutrient use efficiency and crop yields with biofertilizer applications. 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.

**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 <sup>-1</sup>	No. of pods Plant <sup>-1</sup>	No. of seeds Pod <sup>-1</sup>	Test weight (g)	Grain yield (kg ha <sup>-1</sup> )
<b>Inter cropping system</b>						
I <sub>1</sub>	308.1	18.8	265.1	4.1	8.1	742
I <sub>2</sub>	347.6	21.2	295.8	4.3	8.1	858
<b>S.Em(±)</b>	<b>5.31</b>	<b>0.40</b>	<b>0.54</b>	<b>0.01</b>	<b>0.03</b>	<b>12.01</b>
<b>CD (P=0.05)</b>	<b>16.59</b>	<b>1.27</b>	<b>1.69</b>	<b>0.04</b>	<b>NS</b>	<b>37.5</b>
<b>Organic fertilizer</b>						
F <sub>1</sub>	302.8	18.2	254.0	4.1	8.0	758
F <sub>2</sub>	348.8	21.6	300.6	4.2	8.1	856
F <sub>3</sub>	332.0	20.1	286.7	4.2	8.1	787
<b>S.Em(±)</b>	<b>6.47</b>	<b>0.49</b>	<b>0.65</b>	<b>0.01</b>	<b>0.04</b>	<b>14.71</b>
<b>CD (P=0.05)</b>	<b>20.32</b>	<b>1.56</b>	<b>2.07</b>	<b>0.05</b>	<b>NS</b>	<b>45.9</b>
<b>Bio fertilizer</b>						
B <sub>1</sub>	319.5	19.0	270.5	4.2	8.1	770
B <sub>2</sub>	336.3	20.9	290.4	4.3	8.1	831
<b>S.Em(±)</b>	<b>5.52</b>	<b>0.40</b>	<b>0.54</b>	<b>0.01</b>	<b>0.03</b>	<b>11.98</b>
<b>CD (P=0.05)</b>	<b>16.59</b>	<b>1.27</b>	<b>1.69</b>	<b>0.05</b>	<b>NS</b>	<b>37.5</b>

### 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<sup>-1</sup>. Among the organic fertilizers, the application of RDF combined with vermicompost (F<sub>2</sub>) resulted in a higher sorghum grain yield of 285 kg ha<sup>-1</sup>, which was comparable to the yield obtained with RDF + FYM at 5 t ha<sup>-1</sup>. Additionally, seed treatment with PSB produced a notable grain yield of 262 kg ha<sup>-1</sup>. Among the organic fertilizers, the combination of RDF with vermicompost (F<sub>2</sub>) resulted in a significant grain yield of 285 kg ha<sup>-1</sup>. 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<sup>-1</sup> 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 (Bharadwaj *et al.*, 2014; Sharma *et al.*, 2017). Seed treatment with PSB further contributed to increased sorghum grain yield, producing 262 kg ha<sup>-1</sup>. 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 (Vyas *et al.*, 2012; Singh *et al.*, 2015). The redgram and blackgram intercropping system in a 1:2 ratio (I<sub>2</sub>) achieving an average grain yield of 309 kg ha<sup>-1</sup>. 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<sub>2</sub>) produced a higher blackgram grain yield of 164 kg ha<sup>-1</sup>. 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 (Kumar *et al.*, 2017; Das *et al.*, 2020). Additionally, RDF combined with FYM at 5 t ha<sup>-1</sup> 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<sup>-1</sup> (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.*, 2013; Singh & Reddy, 2019).

**Table 2. Effect of treatments on grain yield and Grain equivalent yield (mean of two years)**

Treatments	Redgram seed yield (kg ha <sup>-1</sup> )	Sorghum grain yield (kg ha <sup>-1</sup> )	Blackgram seed yield (kg ha <sup>-1</sup> )	Grain equivalent yield (kg ha <sup>-1</sup> )
<b>Inter cropping system</b>				
I <sub>1</sub>	742	511	-	1012
I <sub>2</sub>	858	-	309	1139
<b>S.Em(±)</b>	<b>12.01</b>	<b>3.78</b>	<b>2.42</b>	-
<b>CD (P=0.05)</b>	<b>37.5</b>	<b>11.4</b>	<b>7.3</b>	-
<b>Organic fertilizer</b>				

F <sub>1</sub>	758	216	142	1000
F <sub>2</sub>	856	285	164	1165
F <sub>3</sub>	787	264	157	1067
S.Em(±)	14.7	4.33	2.76	-
CD (P=0.05)	45.9	13.9	8.9	-
<b>Bio fertilizer</b>				
B <sub>1</sub>	770	249	147	1033
B <sub>2</sub>	831	262	162	1122
S.Em(±)	12.03	3.79	2.44	-
CD (P=0.05)	37.5	11.4	7.3	-

### 3.4 Crop equivalent yield

The redgram + blackgram intercropping system (1:2 ratio) (I<sub>2</sub>) achieved the highest redgram equivalent yield (REY) of 1139 kg ha<sup>-1</sup>, due to its superior resource-use efficiency and productivity. The application of RDF combined with vermicompost at 2.5 t ha<sup>-1</sup> (F<sub>2</sub>) resulted in the highest REY of 1165 kg ha<sup>-1</sup>. 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<sub>2</sub>) resulted in a higher REY of 1122 kg ha<sup>-1</sup> (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. Similar findings were reported by Sharma *et al.* (2012), emphasizing the effectiveness of integrated nutrient management practices in enhancing crop yields and system productivity.

### 3.4 Economics

The redgram + blackgram (1:2) intercropping system (I<sub>2</sub>) generated a higher net return of Rs. 44,024 ha<sup>-1</sup> with a benefit-cost ratio of 2.69. Applying the recommended dose of fertilizer (F<sub>1</sub>) fetched a net return of Rs. 41,432 ha<sup>-1</sup> and the highest benefit-cost ratio of 3.30. Furthermore, the use of phosphorus-solubilizing bacteria (B<sub>2</sub>) achieved a net return of Rs. 42,498 ha<sup>-1</sup> 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.

**Table 3. Effect of treatments on economics (mean of two years)**

Treatments	Cost of Cultivation (Rs. ha <sup>-1</sup> )	Gross Return (Rs. ha <sup>-1</sup> )	Net Return (Rs. ha <sup>-1</sup> )	BC Ratio
<b>Inter cropping system</b>				
I <sub>1</sub>	22189	57828	35639	2.61
I <sub>2</sub>	26077	70102	44024	2.69
<b>Organic fertilizer</b>				
F <sub>1</sub>	18050	59482	41432	3.30
F <sub>2</sub>	33050	69092	36042	2.09
F <sub>3</sub>	21300	63320	42020	2.97
<b>Bio fertilizer</b>				
B <sub>1</sub>	24124	61289	37165	2.54
B <sub>2</sub>	24142	66640	42498	2.76

#### 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<sup>-1</sup> due to efficient resource use. RDF combined with vermicompost at 2.5 t ha<sup>-1</sup> (F<sub>2</sub>) further enhanced REY (1165 kg ha<sup>-1</sup>) and seed yield (856 kg ha<sup>-1</sup>). Similarly, phosphorus-solubilizing bacteria (B<sub>2</sub>) improved grain yield (831 kg ha<sup>-1</sup>) and REY (1122 kg ha<sup>-1</sup>), indicating its effectiveness in enhancing phosphorus uptake. The intercropping system delivered the highest net return (Rs. 44,024 ha<sup>-1</sup>) and a benefit-cost ratio of 2.69, while RDF alone (F<sub>1</sub>) 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.

#### REFERENCES

Agricultural Statistics at Glance. (2023). Ministry of Agriculture & Farmers Welfare, Government of India.

- Ananthi, T., Amanullah, M.M & Al-Tawaha, A. R. M. S. (2017). A review on maize-legume intercropping for enhancing the productivity and soil fertility for sustainable agriculture in India. *Advances in environmental biology*. 11(5), 49-64.
- Bharadwaj, D., Sinha, R., & Bala, A. (2014). Integrated nutrient management: An approach for sustainable crop production and soil health. *Journal of Soil Science and Plant Nutrition*, 14(3), 1–19.
- Bybee-Finley, K.A. and Ryan, M.R. (2018). Advancing intercropping research and practices in industrialized agricultural landscapes. *Agriculture*. 8(6):80.
- Chaudhary, S., & Panjla, R. (2021). Role of vermicompost on crop yield: A Review, *Pharmacy and pharmaceutical sciences*. 10(11), 136-144.
- Das, P., Sahoo, R., & Behera, B. (2020). Comparative effects of vermicompost and farmyard manure on soil quality and legume productivity. *Indian Journal of Agronomy*, 65(1), 87–92.
- Gomez, K.A. and Gomez, A.A. (1984). *Statistical procedure for Agricultural Research* John Wiley and Sons, New York.
- Jackson, M.L. (1973). *Soil Chemical Analysis*, Constable and Co Ltd., London. p.327.
- Khan, N.I., Malik, A.U., Umer, F. & Bodla, M.I. (2010). Effect of tillage and farm yard manure on physical properties of soil. *International Research Journal of Plant Science*. 1(4), 75-82.
- Kant, S., Kumar, A., Kumar, S., Kumar, V., Pal, Y., Shukla, A.K. (2016). Effect of rhizobium, PSB and p-levels on growth, yield attributes and yield of Urdbean (*Vigna Mungo* L.). *J Pure Applied Microbiology*. 10(4):3093-8.
- Khan, M.S., Zaidi, A., & Wani, P.A. (2009). Role of phosphate solubilizing microorganisms in sustainable agriculture-a review. *Sustainable agriculture*. 2009; 551-570.
- Kumar, V., Singh, M., & Yadav, A. (2020). Influence of farmyard manure and chemical fertilizers on soil health and yield of crops under different cropping systems. *International Journal of Chemical Studies*. 8(2), 152-157.
- Kumar, A., Sharma, M., & Singh, R. (2017). Impact of vermicompost on soil health and legume crop productivity. *Journal of Agricultural Research*, 45(4), 254–263.
- Mousavi, S.R., & Eskandari, H. (2011). A general overview on intercropping and its advantages in sustainable agriculture. *Journal of Applied Environmental and Biological Sciences*. 1(11), 482-486.
- Nishanthi, S., Damayanthi, M.M., & Ratnayake, W. M. P. (2015). Performance of maize (*Zea mays* L.) and cowpea (*Vigna unguiculata* L.) under different intercropping systems. *Tropical Agricultural Research and Extension*. 18(2), 68-73.  
<https://doi.org/10.4038/tare.v18i2.5321>
- Patra, A., Sharma, V.K., Nath, D.J., Dutta, A., Purakayastha, T. J., Kumar S., & Kumawat, C. (2023). Long-term impact of integrated nutrient management on sustainable yield index of rice and soil quality under acidic inceptisol. *Archives of Agronomy and Soil Science*. 69(7), 1111-1128.
- Olsen, S.R., Cole, C.V, Watanabae F.S., and Dean, L.A. (1954). Estimation of available phosphorus in soils by extraction with sodium bicarbonate. *US Department of Agriculture*. 939.
- Ofori F, Stern, W.R. (1987). Cereal-legume intercropping systems. *Advances in Agronomy*. 1; 41:41-90.
- Raza, M. A., Feng, L. Y., Van der Werf, W., Iqbal, N., Khan, I., Noor, M. A., & Yang, W. (2021). Optimum planting density and nitrogen application mitigate lodging risk and enhance nitrogen use

- efficiency of maize in maize-soybean intercropping. *Field Crops Research*. 270, 108217. <https://doi.org/10.1016/j.fcr.2021.108217>
- Sharma, A., Rathore, P., & Singh, B. (2013). Role of phosphate-solubilizing bacteria in improving nutrient availability and legume yields. *Agricultural Science Digest*, 33(2), 109–114.
- Singh, S., & Reddy, K. (2019). Enhancing legume yield with microbial inoculants: A review on PSB and rhizobia. *Advances in Microbial Ecology*, 8(3), 78–95.
- Singh, V.K., Malhi, G.S., Kaur, M., Singh, G., & Jatav, H.S. (2022). Use of organic soil amendments for improving soil ecosystem health and crop productivity. *Ecosystem Services*.
- Stanford, S and English, L. (1949). Use of the flame photometer in rapid soil tests for K and Ca. *Agronomy Journal*. 41: 446-447.
- Subbiah, B.V. Asija, G.L. (1956). A rapid procedure for the estimation of available nitrogen in soils. *Current Science*, 25: 259-60.
- Wang, Z., Gong, Y., Lu, Q., Liu, C., Guo, Y., & Li, C. (2015). Intercropping enhances productivity and water-use efficiency but reduces radiation-use efficiency of maize and soybean under reduced nitrogen inputs. *Plant and Soil*. 391(1-2), 53–63. <https://doi.org/10.1007/s11104-015-2402-5>
- Yadav D. S & Newaj R. (1990). Studies on increasing the utilization of natural resources through intensive cropping systems. *Indian J of Agronomy*. 1990; 35(1,2): 50-55.
- Singh, M., Yadav, B., & Kumar, R. (2015). Role of PSB in crop production and soil fertility improvement. *Agricultural Science Digest*, 35(4), 258–264.
- Sharma, A., Singh, S., & Singh, R. (2017). Effect of organic and inorganic fertilizers on crop yield and soil health. *International Journal of Agriculture and Biology*, 19(4), 601–608.
- Sharma, A., Rathod, P.S., Dharmaraj, P.S., & Chavan, M. (2012). Response of pigeonpea to biofertilizers in pigeonpea based intercropping systems under rainfed conditions, Karnataka J. Agric. Science, 2012; 25(3), 322-325.
- Vlahova, V. (2022). Intercropping-an opportunity for sustainable farming systems. A Review. *Scientific Papers, Series A. Agronomy*. 65(1).
- Vyas, P., Gulati, A., & Gupta, R. (2012). Phosphate-solubilizing bacteria as bio-fertilizers and their role in enhancing soil fertility and crop productivity. *Advances in Agricultural Research*, 5(2), 113–124.