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Synergistic agronomic practices in redgram *(Cajanus cajan)* productivity and soil health enhancement under semi-arid tropics

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ABSTRACT

An experiment was conducted during rainy (*kharif*) season of 2020 and 2021 at Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu to study the impact of integrated phosphorus management in redgram (*Cajanus cajan* L.) intercropping systems under irrigated conditions. Redgram variety CO (Rg 7) was chosen as test crop. The experiment was laid out in a split-plot design (SPD) in three replications. The main plot comprised of intercropping systems, viz. sole redgram, redgram intercropped with soybean (*Glycine max* L.), greengram [*Vigna radiata* (L.) R. wilczek] and cowpea [*Vigna unguiculata* (L.) Walp.]. The sub plot consisted 3 forms of P, viz. Single super phosphate (SSP), enriched Mussoorie rock phosphate (MRP) + phosphobacteria and SSP (1/3rd) + enriched MRP (2/3rd) + phosphobacteria and 2 levels of P, viz. 50 and 62.5 kg P_2O_5/ha. The higher redgram grain equivalent yield (1207 kg/ha), net return (₹51,810/ha) and B: C ratio (2.74) were recorded under redgram intercropped with greengram followed by redgram intercropped with soybean, with corresponding values of 1,077 kg/ha, ₹48,141/ha and 2.29, respectively. With regards to various sources of P tried, integrated application of SSP (1/3rd) and enriched MRP (2/3rd) with phosphobacteria registered higher yield (957 kg/ha) of redgram, which was comparable with application of SSP. Regarding levels of P, application of 125% of recommended P (62.5 kg P_2O_5/ha) was recorded higher yield in redgram over 100% of recommended P (50 kg P_2O_5/ha) over the years. Considering the overall monetary returns of different redgram intercropping systems, application of 62.5 kg P_2O_5/ha in combination as SSP (1/3rd) + enriched MRP (2/3rd) along with phosphobacteria to redgram + greengram intercropping registered higher net return and B: C ratio.

Keywords: Economics, Forms of P, Nutrient balance, Production potential, Redgram

Redgram (*Cajanus cajan* L.) is a pulse crop of significant importance in semi-arid tropics areas. Globally it is cultivated in 63.57 lakh ha and has a production of about 54.75 lakh tonnes with a productivity of about 861.25 kg/ha (FAO STAT 2021–22). India ranks first among redgram production and has a yield of about 42.2 lakh tonnes from 49.0 lakh ha and a productivity of about 861 kg/ha (INDIASTAT 2021–22). In Tamil Nadu, redgram is considered as the second vital pulse crop and covers about 0.48 lakh ha and has a total output of 0.45 lakh metric tonnes, but it is considered to be significantly low in productivity considering its potential, because it is cultivated under rainfed situation with wider spacing also widely intercropped only with sorghum, cotton and pulses.

In general, pulse crops, such as redgram, tend to be a major source of phosphorus. The crop growth and yield of all pulses cultivated either as a sole or intercropping shall be greatly increased by the application of phosphorus. Significant response of pigeon pea to phosphate nutrition has been reported by several studies. Effective pulse production would not be possible in the absence of an appropriate P level. In addition, the availability of phosphorus fertiliser is limited and expensive. As a result, rock phosphate has become the primary source of phosphorus for plants. The cost of rock phosphate is 48% lower than phosphatic fertilisers, which makes it essential to conduct research specifically on the location of growing redgram.

Mussoorie Rock Phosphate (MRP) is of good purity as compared to other rock phosphate sources in India. Information available on integrated use of SSP with enriched MRP + biofertilizers in redgram pulse intercropping systems is very meager. For the redgram based intercropping system, an integrated P management approach appears to be more economical and cost effective.

MATERIALS AND METHODS

An experiment was conducted during rainy (*kharif*) season of 2020 and 2021 at Tamil Nadu Agricultural University, Coimbatore (11°N, 77° E and 426.7 m amsl), Tamil Nadu. The soil of the experimental field was sandy clay loam in texture, with low available nitrogen (175 kg/ha), medium available phosphorus (14.3 kg/ha) and high available

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potassium (371 kg/ha). Redgram variety CO (Rg 7) was chosen as test crop for the study which has a duration of 125–130 days. Redgram was intercropped with soybean (CO 2), greengram (VBN 5) and cowpea [CO(CP) 7] and additive series of intercropping in paired row planting was followed. The experiment was laid out in a split plot design (SPD) with three replication. Redgram intercropping systems tested in main plot, viz. Sole redgram (M_1); Redgram + soybean (M_2); Redgram + greengram (M_3) and Redgram + cowpea (M_4). The sub plot consisted 3 forms of P, viz. Single super phosphate (SSP) (F_1); enriched Mussoorie rock phosphate (MRP) + phosphobacteria (F_2) and SSP ($1/3^{rd}$) + enriched MRP ($2/3^{rd}$) + phosphobacteria (F_3) and 2 levels of P, viz. 50 (L_1) and 62.5 (L_2) kg P_2O_5/ha. Ridges and furrows were formed with a spacing of 45 cm and 30 cm for sole cropping and intercropping of redgram. In sole cropping, the seeds were sown with a spacing of 45 cm × 20 cm. For intercropping system, paired row planting method was adopted (redgram intercropped with soybean, greengram and cowpea) in 2:1 ratio with a spacing of 60/30 cm × 20 cm. The recommended dose of fertilisers for redgram (25 kg of N and 25 kg K_2O/ha) was applied on the ridges and furrows. Similarly, phosphorous as SSP and MRP enriched with FYM + phosphobacteria were applied as per treatment schedule. The required quantity of MRP was mixed thoroughly with powdered FYM @750 kg/ha. After moistening, MRP was heaped and covered with mud paste. The heap was opened after 30 days and incorporated into the soil at the time of sowing. On yield attributes redgram equivalent yield (REY) was worked out as follows:

$$\text{REY (kg/ha)} = \frac{\text{Concerned crop economic yield} \times \text{Price of concerned crop/kg}}{\text{Price/kg (Redgram)}}$$

Soil available N, P_2O_5 (kg/ha) and K_2O were analysed by alkaline permanganate method (Subbaiah and Asija 1956), Olsen's method (Olsen *et al.* 1954) and neutral normal ammonium acetate method (Stanford and English 1949) respectively. For plant nutrient analysis, total N, P and K were estimated by Micro Kjeldahl method (Humphries 1956) and Triple acid digestion method (Jackson 1973), respectively. Grain and stover nutrient uptake in/of redgram/soybean/greengram/cowpea crop were calculated in kg/ha in relation to dry matter production/ha:

$$\text{Nutrient uptake (kg/ha)} = \frac{\text{Nutrient content (\%)} \times \text{Grain/stover yield (kg/ha)}}{100}$$

N, P and K balances in various intercropping cropping systems were calculated as follows (Yadav 1981):

$$\text{Nutrient balance} = Y - (X\text{-}a) - N$$

Where Y, Nutrients removal by crop; X, Initial nutrient status of soil; a, Final nutrient status of soil; N, Nutrient added through chemical fertilizers.

In economics, the net income is calculated by deducting cost of cultivation from gross income and B: C ratio has been computed as a result. In line with the methodology proposed by Gomez and Gomez (1984), data were pooled over two years for final statistical analyses.

RESULTS AND DISCUSSION

Growth and yield attributes: According to the data on plant height, intercropping has a significant influence on the height of the redgram. Among the intercropping systems, sole redgram registered higher plant height (124.3 cm) and comparable with intercropping of soybean and greengram. SSP has been shown to be higher in plant height (121.7 cm) with respect to the forms of P and is on par with integrated applications of SSP and enriched MRP + phosphobacteria, however it was superior to enriched MRP. The plant height of the redgram was influenced significantly by P levels. Increased plant height (122.2 cm) was associated with the use of 125% recommended P (62.5 kg P_2O_5/ha). These findings align with the observations of Shanmugam (2008) who reported that higher levels of nutrients attributes better growth in redgram.

Significantly higher LAI was recorded with sole redgram and this was on par with redgram and greengram intercropping system. These results are further supported by Manjunatha *et al.* (2019) who concluded that sole redgram planting registered higher LAI by effective utilization of available resources. With respect to forms of P, SSP recorded higher LAI (2.71) and it was comparable with integrated application of SSP and enriched MRP + phosphobacteria. The fact that the plant has better initial vigour and growth is clearly advantageous to augmented yield parameters thus improving the production. The sole redgram showed higher yield components such as number of pods/plant (123) and pod weight (37.82 g), intercropping redgram with greengram also showed a comparable result. These results are similar to the findings of Kumar and Kushwaha (2018) who revealed that short duration legumes have beneficial and synergetic effect as in intercropping systems thus increased growth parameters.

Combined use of SSP and enriched MRP with phosphobacteria recorded higher yield parameters and this was comparable with application of SSP alone (Table 1). This is due to the solubility of rock phosphate, which can be enhanced by farmyard manure and phosphorus solubilizing bacteria (PSB), which, in turn, allows phosphorus to be available at the later stages, thus increasing nutrient uptake and improving seed yield. These findings were further supported by Meena and Sharma (2012). In addition, the increase in availability of P from SSP at a much earlier stage and slow and constant availability of P resulting from enhanced MRP has led to greater yield components under combined use. But SSP application fixed in the early stage thus reduced the availability of P in the later stages of the crop which significantly affects the yield components.

With respect to P Levels, application of 62.5 kg P_2O_5/ha registered significantly higher number of pods/plant (122) and pod weight (39.75 g) than P at recommended level of

Table 1 Effect of intercropping and forms and levels of P in growth, yield attributes, yield and economics of redgram (Pooled data for 2 years)

Treatment	Plant height (cm)	LAI	Pods/ plant	Pod weight/ plant (g)	Seed yield (q/ha)	Redgram equivalent yield (q/ha)	Net income (₹/ha)	B: C ratio
Intercropping								
Sole redgram	124.3	2.70	123	39.70	10.22	10.22	46,923	2.27
Redgram + Soybean	118.1	2.50	114	36.45	8.74(4.1)	10.77	48,141	2.29
Redgram + Greengram	118.0	2.63	118	37.85	9.28(3.5)	12.07	51,810	2.74
Redgram + Cowpea	116.0	2.43	113	34.00	8.41(3.0)	10.23	46,381	2.15
CD (*P*=0.05)	7.3	0.22	8	2.18	0.73	0.87	-	-
Forms of phosphorus								
SSP	121.7	2.71	119	37.82	9.37(3.7)	11.10	48,927	2.42
MRP enriched with FYM + Phosphobacteria	114.9	2.40	111	33.68	8.65(3.1)	10.10	46,470	2.19
SSP ($1/3^{rd}$) + MRP ($2/3^{rd}$) enriched with FYM + Phosphobacteria	120.6	2.63	121	39.51	9.57(3.8)	11.27	49,543	2.48
CD (*P* = 0.05)	6.3	0.29	9	2.95	0.59	0.72	-	-
Levels of phosphorus								
50 kg P_2O_5/ha	116.0	2.53	112	34.25	8.95(3.3)	10.21	47,656	2.31
62.5 kg P_2O_5/ha	122.2	2.63	122	39.75	9.44(3.7)	11.12	48,971	2.42
CD (*P*=0.05)	5.4	NS	9	3.00	0.47	0.73	-	-

LAI, Leaf area index.

50 kg P_2O_5/ha (Table 1). Malik *et al.* (2013) also concluded a similar result in their study, reported that the increased levels of phosphorus at 60 kg/ha registered higher yield attributes of redgram. This could be primarily attributed to the plants' early stimulation of root development, energy transformation, and metabolic activities, which in turn led to increased photosynthate translocation towards sink development and an increase in yield.

Redgram seed yield and crop equivalent yield: Data related to seed yield show that intercrops have a significant influence. Redgram grown as sole crop registered higher seed yield (10.22 q/ha) and was comparable with intercropping with greengram. Intercropping greengram with redgram produce highest grain yield over sole redgram (Dudhade *et al.* 2009, Vijayaprabhakar and Jayanthi 2018). Cowpea and soybean intercrops in significantly reduced seed yield (Table 1). The rapid growth of intercrops intensified competition for soil resources, detrimentally impacting redgram growth as evidenced by reduced plant height, LAI, DMP, and other yield parameters, was the primary reason for the considerable drop in seed production of redgram intercropped with soybean and cowpea. Further smothering effect of intercrops also negatively affects the yield of redgram.

When SSP and MRP were applied together, the phosphobacteria performed comparable to SSP applied alone. Applying P as SSP and enriching MRP + phosphobacteria can be versatile since SSP, which is naturally water soluble, first acts as a growth enhancer for crops. Additionally, the enhanced MRP that has been supplied gradually delivers P to the crop throughout its growth. As a result, dry matter production (DMP), the number of pods/plant, pod length and pod weight have all significantly enhanced, which has improved redgram seed output. The increased nutrient availability from combined sources of nutrients helps to supply nutrients up to maturity and leads to better nutrient uptake, growth and yield parameters as well as yield. The delayed release of P from MRP is responsible for lesser yield in use of enriched MRP + phosphobacteria when compared with SSP only and SSP + enriched MRP + phosphobacteria application. The seed yield was significantly influenced by different levels of P, therefore 125% of recommended level of P registered higher yield (9.44 q/ha) and was superior to recommended level of P. These are further in accordance with Sekhon *et al.* (2023) who concluded that increasing levels of nutrients registered higher yield in redgram intercropping system.

A significant variation in redgram seed equivalent yield was observed across intercropping systems, different forms and levels of P (Table 1). Redgram intercropped with greengram gave higher redgram seed equivalent yield (1207 kg/ha) and significantly superior to all other intercropping systems. This was due to the higher redgram and intercrop yield recorded in redgram + greengram intercropping system over others and compared to soybean and cowpea, greengram seed had the highest price among the intercrops. This is yet another important reason for the higher redgram equivalent yield in redgram + greengram intercropping system. This finding is in line with the work of Garud *et al.* (2018) who discovered that intercropping redgram with greengram produced the highest redgram seed eqivalent yield (1832 kg/ha).

Table 2 Seed yield of intercrops in redgram intercropping with P management practices (Pooled data for 2 years)

Treatment	Seed yield (q/ha)		
	Soybean	Greengram	Cowpea
Intercropping			
Redgram + Soybean	406	-	-
Redgram + Greengram	-	348	-
Redgram + Cowpea	-	-	303
Forms of phosphorus			
SSP	415	361	323
MRP enriched with FYM + Phosphobacteria	371	309	298
SSP (1/3rd) + MRP (2/3rd) enriched with FYM + Phosphobacteria	432	375	343
CD (*P*=0.05)	29	22	21
Levels of Phosphorus			
50 kg P_2O_5/ha	391	327	284
62.5 kg P_2O_5/ha	421	369	322
CD (*P*=0.05)	27	19	16

With regard to different forms of P, the higher redgram equivalent yield (1127 kg/ha) was recorded in SSP (1/3rd) and enriched MRP (2/3rd) + phosphobacteria application (Table 1). The observed increase in redgram growth and yield parameters was a direct result of optimized P availability. SSP provided initial P for early growth, while enriched MRP + phosphobacteria sustained P supply throughout the crop cycle, contributing to higher yields. Sharma *et al.* (2012) also stated that, FYM @5 t/ha + 100% RDF + seed inoculation of biofertilizer registered the higher redgram seed equivalent yield. With regards to levels, 125% recommended P (62.5 kg P_2O_5/ha) registered higher redgram equivalent yield (1112 kg/ha).

Intercrops seed yield: The application of SSP (1/3rd) + enriched MRP (2/3rd) + phosphobacteria significantly increased seed yields in soybean, greengram, and cowpea intercrops. Moreover, seed yield exhibited a positive trend with increasing levels of P application (Table 2).

Economics: Redgram intercropped with greengram gave higher net income (₹ 51,810/ha) and B: C ratio (2.74) among the various intercropping systems studied. This is because of high growth and yield attributes of redgram and high price of greengram. According to Kumar *et al.* (2012), increased fertility levels significantly enhanced the economic returns of redgram + greengram intercropping systems. Further with regard to P combination, SSP (1/3rd) and enriched MRP (2/3rd) + phosphobacteria recorded higher net income (₹49,543/ha) and B: C ratio (2.48). Application of P at 62.5 kg P_2O_5/ha recorded maximum net income (₹48,971/ha) and B: C ratio (2.42) when compared with application of P at 50 kg P_2O_5/ha (Table 1). These results are in line with the findings of Bhardwaj *et al.* (2023), concludes that application 125% RDF registered higher net income and B: C ratio. The highest net income of ₹51,452 (B:C ratio - 2.68) were recorded in redgram + greengram intercropping under the combined application of SSP + enriched MRP + phosphobacteria at 62.5 kg P_2O_5/ha.

Balance sheet of nutrients

Nitrogen (N) balance: During *kharif* 2020, with regarded to N fertility status, 175 kg/ha was recorded initial soil N. The ($M_3F_3L_2$), redgram + greengram intercropping with application of SSP (1/3rd) and enriched MRP (2/3rd) with phosphobacteria at 62.5 kg P_2O_5/ha removed maximum amount of N (180.14 kg/ha) (Fig. 1). The pigeonpea + greengram intercropping system with different fertility levels and phosphate stabilizing bacteria (PSB) also showed similar results. $M_1F_1L_2$ recorded higher positive N status in the soil followed by $M_1F_3L_2$. $M_4F_2L_1$ showed higher negative status followed by $M_2F_2L_1$.

During *kharif* 2021, initial soil N status of 190 kg/ha was recorded in soil. The maximum N removed by sole redgram under the application of SSP (1/3rd) and enriched MRP (2/3rd) with phosphobacteria at 62.5 kg P_2O_5/ha (148.36 kg/ha) followed by $M_3F_3L_2$ (148.22 kg/ha). Positive N status was observed with $M_1F_3L_2$ followed by $M_1F_1L_2$. Similar to *kharif* 2020, $M_4F_2L_1$ has higher negative N status (-39.18 kg/ha). Both *kharif* seasons, irrespective of treatments, redgram + cowpea intercropping noticed higher negative N status followed by redgram + soybean intercropping. All the intercropping systems showed positive balance and indicates that the nitrogen removal by all intercropping systems was sustainable, as it did not exceed the total nitrogen status of the soil. Overall, net gain was higher in redgram + greengram intercropping (131 and 126 kg/ha) during *kharif* season of 2020 and 2021 than redgram + soybean or cowpea and sole redgram.

Phosphorus (P) balance: The P status initially was 15 and 16 kg/ha during *kharif* 2020 and 2021. The sole crop of redgram under application of SSP(1/3rd) and enriched MRP (2/3rd) in combination with phosphobacteria at 62.5 kg P_2O_5/ha showed higher positive P status. Similar findings was reported by Girijesh *et al.* (2017) revealed that, sole redgram registered higher soil available phosphorus. This is because of the phosphorus build up due to P addition to the soil as a result of population basis, litter fall and added fertilizers. Native P mineralization in soil because of root exudates and organic acids from decomposing organic matter in legume cropping systems might also be a reason. Irrespective of P in all seasons, redgram + cowpea intercropping registered less positive P status followed by redgram + soybean intercropping. As a whole, P buildup was predominant in sole redgram and redgram with greengram.

Potassium (K) balance: The soil K status was initially at 392 and 401 kg/ha during *kharif* 2020 and 2021. During *kharif* 2020, the treatment combination $M_2F_3L_2$ removed higher K (196.48 kg/ha) followed by $M_3F_3L_2$ (Fig. 2). The available K status was higher in $M_3F_3L_2$. This finding

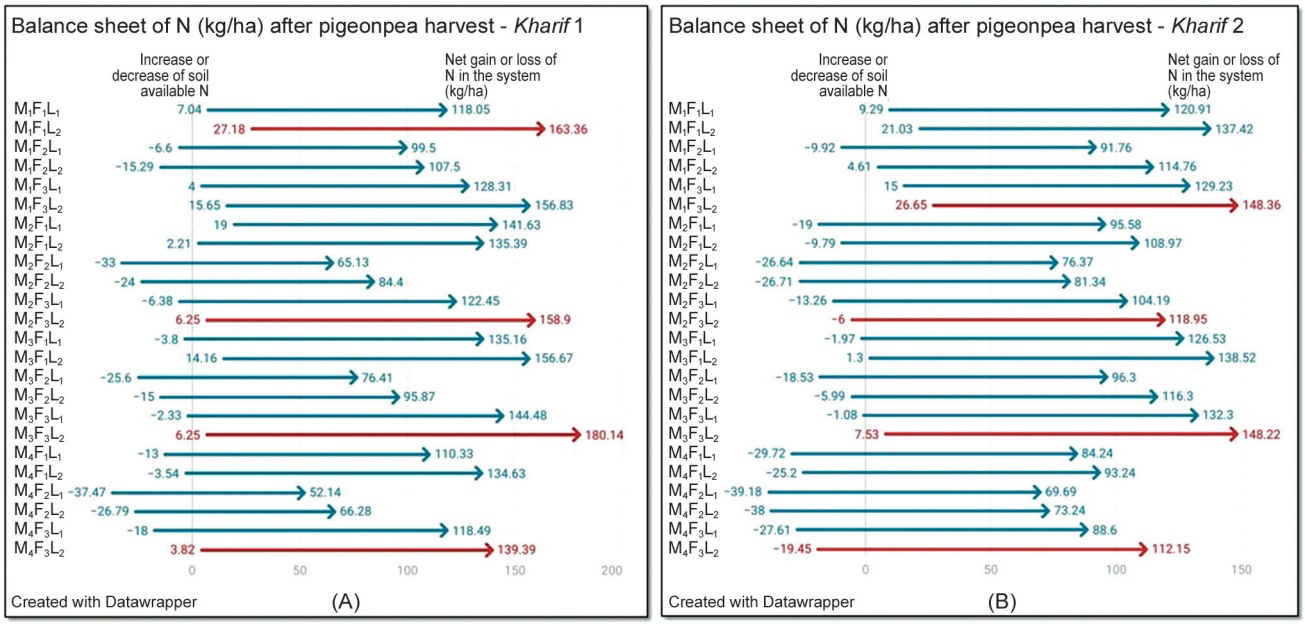

Fig. 1 Balance sheet of N (kg/ha) after redgram harvest. (A) *Kharif*-2020; (B) *Kharif* -2021.

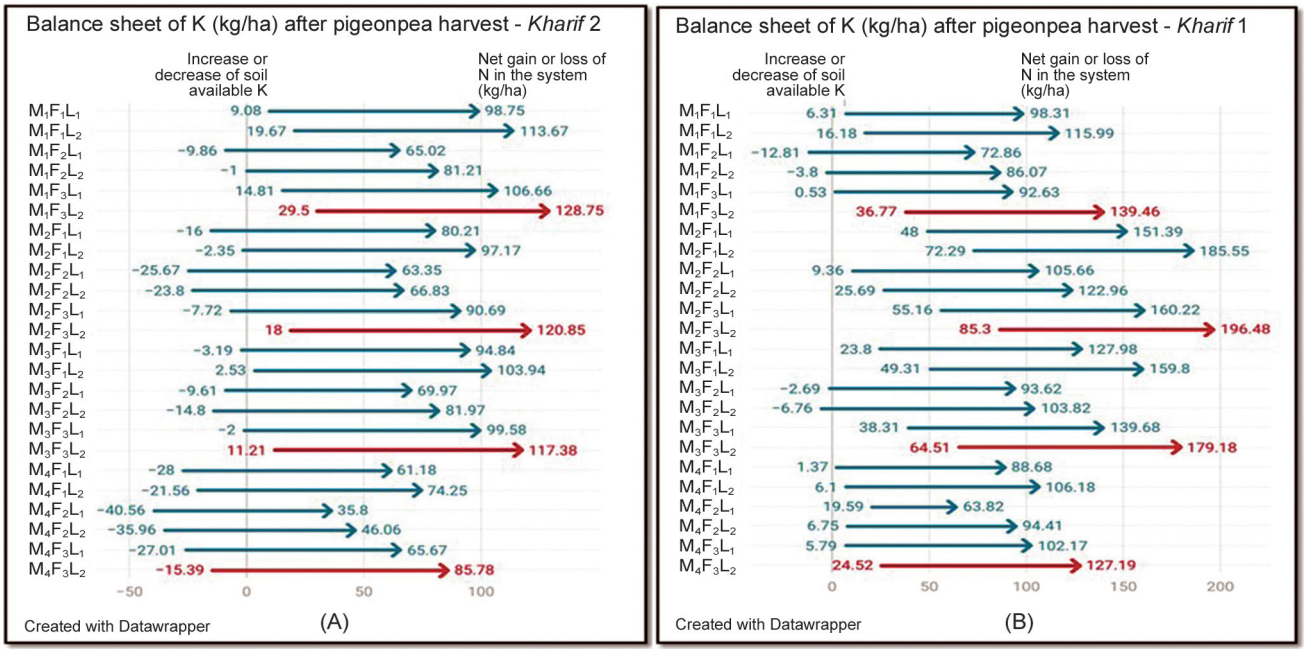

Fig. 2 Balance sheet of K (kg/ha) after redgram harvest. (A) *Kharif*-2020; (B) *Kharif* 2021.
Treatment details are given under Materials and Methods.

was supported by Ahamad *et al.* (2018) stated that, the integrated use of RDF, PSB, Rhizobium, FYM (3 t/ha), and 'Haritvardan' (5 kg/ha) resulted in significantly higher N, P and K uptake. This was primarily due to enhanced biological activity and improved root system development (Varatharajan *et al.* 2019). Considerably less positive K status was with redgram intercropped with cowpea followed by sole redgram. On comparison with *kharif* 2020, *kharif* 2021 has very less positive balance of K. Among all the treatments, redgram with cowpea has higher negative K status compared. High depletion of K was in redgram with cowpea. Therefore, all the intercropping system has negative K balance.

The redgram intercropped with greengram in paired row planting with 60/30 cm × 20 cm is highly remunerative and applying of P_2O_5 @ 62.5 kg/ha as SSP(1/3rd) and enriched MRP (2/3rd) in combination with phosphobacteria may be recommended for sandy clay loam soils with medium P status for increased productivity and profitability. To minimize production cost and maximize the returns, redgram + greengram intercropping system grown with application of P_2O_5 @ 62.5 kg/ha in combination of SSP (1/3rd) and enriched MRP (2/3rd) with phosphobacteria is both economically beneficial and environmentally sound,

while also being practical for farmers of semi-arid conditions of India.

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