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Assessment of profitability, sustainability, and system productivity of conservation agriculture-based crop diversification in light soils of Prakasam District, Andhra Pradesh

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Abstract
In the light soils of Prakasam district, this investigation assesses the efficacy of conservation agriculture (CA)-based crop diversification systems that incorporate redgram and millets under various residue management practices. Four cropping systems were assessed: sole redgram, solitary bajra, redgram + foxtail millet, cowpea (Rabi season). Each system was subjected to three management practices: conventional ploughing (CP), above-ground biomass incorporation (BI), and incorporation with microbial solution (BIM) for decomposition. Indicators of sustainability, profitability, and productivity were evaluated. Analysis of variance showed the results indicated that intercropping systems under BIM had substantially higher yields, soil organic carbon, and net returns.

Keywords: Conservation agriculture, crop diversification, redgram, millets

Introduction

The livelihoods of millions of subsistence farmers are supported by rainfed agriculture, which accounts for nearly 51% of the net sown area in India (www.agriwelfaregov.in). Nevertheless, these regions are notoriously susceptible to erratic rainfall, terminal moisture stress, and low soil fertility, which frequently lead to unstable crop yields. Conservation agriculture (CA) practices, in conjunction with agricultural diversification, provide a viable approach to improving sustainability, profitability, and productivity in such fragile ecosystems (Pushkar deva *et al*., 2023) [14]. Crop diversification, which involves the integration of crops, particularly cereals and legumes, through intercropping, crop rotation, and integration, not only mitigates production risks but also enhances resource utilisation efficiency and guarantees household food and nutritional security. Diversified systems are more resilient to climatic variability because they exploit various rooting depths, enhance nutrient cycling, and utilise soil moisture over a longer period (Beillouin *et al*., 2021) [6]. Prakasam District is characterised by southern light soils, which are characterised by low fertility and water retention, weak organic matter, and a propensity for crusting. These soils range from sandy loam to sandy clay loam. In Kharif, it has been reported that there is diversification index of approximately 0.8, which is significantly higher than that of other districts. Prakasam has one of the highest levels of crop diversification in Andhra Pradesh. Diversification is positively correlated with an increase in agricultural and horticultural Gross Value Added (GVA), which is facilitated by market access, finance, and phosphorus inputs. Diversified cultivation results in increased farm income, particularly in regions with restricted irrigation and larger farm sizes, according to research published in AP (Venkata Subbaiah *et al*., 2024). However, tenant farmers and small farms encounter additional obstacles to its implementation. In the rain-fed regions of Prakasam, there is a requirement for a novel agronomic practice and an efficient cultivation system that can withstand moisture stress, thereby providing improved yield stability and economic returns during the rabi season (Ram *et al*., 2014) [15]. In addition to diversification, conservation agriculture practices, including the incorporation of above-ground biomass and the implementation of beneficial soil microbial solutions, are essential for the enhancement of soil health, the reduction of erosion, the conservation of scarce precipitation, and the enhancement of soil organic carbon. These practices contribute to the development of soil structure, the regulation of soil temperature, and the enhancement of infiltration, thereby fostering a more conducive environment for crop growth in rainfed environments (Anurag and Aarti, 2025). The combination of crop diversification and conservation agriculture is a comprehensive approach to rainfed cultivation. In addition to contributing to long-term sustainability by restoring soil fertility, enhancing biodiversity, and mitigating the deleterious impacts of climate change, they also stabilise yields and improve farm profitability. (Dubey *et al*., (1991) [7].

Materials and Methods

A field experiment was conducted at the agricultural research station Darsi, Prakasam district of Andhra Pradesh during the kharif and rabi seasons of 2022-23, 2023-24, and 2024-25. The experimental site is situated at an elevation of 110 m above mean sea level, between 15.7701º N latitude and 79.6793º E longitude (www.mapsofindia.com). The region experiences a sweltering and humid monsoon, which is followed by a mild winter. The average annual precipitation is approximately 463.51 mm. During the summer, the maximum temperature can reach 45.0 °C, while the minimum temperature can drop to 24.0 °C in the winter. Sandy loam soil with a medium organic carbon content (32%), low nitrogen (~180 kg ha^{-1}), medium phosphorus (~12 kg ha^{-1}), and medium potassium (~160 kg ha^{-1}) was present at the experimental site. The soil was saline-alkaline (pH range 7.9-8.2) (Vijay Kumar,2009) [17]. Experiment was carried in split plot design with three replications. Treatments (Cropping systems) are sole Redgram, sole Bajra, Redgram + Korra (Intercropping system) and Cowpea (rabi season crop) in place of kharif bajra. Varieties used were Redgram: LRG-52, Bajra: WCC-75, Korra (Little millet): Lepakshi and Cowpea: TPTC 29. Recommended package of practices for each respective crop were followed. Soil organic carbon was estimated by Walkley-Black chromic acid wet oxidation method(www.fao.org)

Data Analysis

The recorded crop yield and economic data were analyzed to assess the comparative performance of different cropping systems. The following indices and formulas were used:

1. Redgram Equivalent Yield (REY)

To compare yields across systems, all yields were converted into Redgram Equivalent Yield (REY) on a price basis: REY = Yi × (Pi / P redgram) Where: Yi = yield of intercrop/crop (kg ha^{-1}) Pi = price of intercrop/crop (Rs. kg^{-1}) P redgram = price of redgram (Rs. kg^{-1}).

2. Relative Economic Efficiency (REE)

The Relative Economic Efficiency compares the economic advantage of a cropping system over sole redgram: REE (%) = [(NRcs - NRsr) / NRsr] × 100. Where: NRcs = Net return from cropping system (Rs. ha^{-1}) NRsr = Net return from sole redgram (Rs. ha^{-1}).

3. Sustainable Yield Index (SYI)

The SYI measures the sustainability of cropping systems across years: SYI = (Ymean - σ) / Ymax. Where: Ymean = mean yield of the system (kg ha^{-1}) σ = standard deviation of yield across years, Ymax = maximum yield observed across treatments and years.

4. Land Use Efficiency (LUE)

The LUE estimates the extent of land utilization in a year: LUE (%) = (ΣDc / 365) × 100 Where: ΣDc = total duration of crops in the system (days).

5. Economic Analysis

Economic performance was evaluated based on Gross Returns, Net Returns, and Benefit: Cost ratio using the following formula: B:C ratio = Gross Return / Cost of Cultivation. The data was analysed statistically using analysis of variance techniques. Agri-Analyze software was used for analysis.

Results and Discussion

The analysis of variance conducted over two consecutive years for *yield* and soil organic carbon (%) revealed that cropping systems (main plot treatments), component crops/management techniques (subplot treatments), and their interactions all had a significant impact on system productivity. The replication effect is significant **(**p = 0.020408, p = 0.0195) (Table-1, Table-2) which reflects field heterogeneity. The main plot factor (different cropping systems**)** had a highly significant effect (P= 0.0004, 0.00041)**.** This indicates that the choice of cropping system strongly influenced system productivity. The subplot factor also shows a highly significant effect (p = 7.1×10^{-11}, $7.01 \times 10^{-11)}$ which means subplot treatments contributed substantially to productivity variations. Indicates strong effects of management practices or intercrops. The interaction effect is highly significant (p = 1.7×10^{-5}, p = 1.69×10^{-5}) (Table-1, Table-2). This shows that the performance of subplot treatments depends on the main plot treatments. For example, a subplot practice (like cowpea in rabi) may perform better under redgram than under bajra. Hence, best treatment recommendations should consider specific crop combinations rather than main/sub-plot effects in isolation. Error component depicts that experiment was done with acceptable precision similar kind of findings was reported by Kumar *et al* (2012) [11]. Analysis of variance for Soil organic carbon (%) results show Replication effects (P= 0.0039) Main plot effects (p = $1.9 \times 10^{-05)}$ and Subplot effects **(**$4.8 \times 10^{-11)}$ were also highly significant ($p < 0.01$) (Table-3, This indicates that both cropping systems and their combinations with component crops strongly influenced productivity, profitability, and sustainability, with interaction showing that the effect of a subplot was highly dependent on the main plot system. Similar kind of findings was reported by Wanjari *et al*,2004 [2] and Jat *et al* 2011 [1] respectively. However, the main plot × subplot interaction was not significant (0.1183**)**, suggesting that in the performance of subplot treatments was relatively stable across cropping systems. the constancy of main plot and subplot relevance across both years clearly shows that cropping system selection and the inclusion of component crops are the primary drivers of yield and system performance under rainfed conditions. The shift in interaction significance over time demonstrates the influence of climatic variability and rainfall distribution on treatment responses, as is common in rainfed ecosystems. Overall, the pooled ANOVA results over years show that cropping systems and component crops have a considerable impact on system productivity, economic efficiency, and sustainability. This highlights the significance of crop diversification techniques in stabilising yields and increasing farm returns under rainfed circumstances. Similar reports were communicated by Prasad *et al*., (2013) [13]

Table 1: ANOVA for Yield during 2023-24

Source of Var.	DF	Sum of Sq.	Mean Sq.	F value	P value	Result
Replications	2	74450.0000	37225.0000	12.361	. 020408	*
Main Plot	2	1858786.9651	929393.4825	308.640	0.0004	**
Error a	4	12045.0000	3011.25			
SubPlot	3	1458872.1122	486290.7041	86.2812	7.1 x 10^-11	**
Main Plot X Sub Plot	6	410748.1733	68458.0289	12.1463	1.7 x 10^-05	**
Error b	18	101450.0000	5636.1111			
Total:	35	3916352.2506				

*, ** Significant at 5% and 1% level of significance

Table 2: ANOVA for Yield during 2024-25

	DF	Sum of Sq.	Mean Sq.	F value	P value	Result
Replications	2	73480.0000	36740.0000	12.303	0.0195	*
Main Plot	2	1854784.9651	927392.4825	310.554	0.00004	**
Error a	4	11945.0000	2986.25			
SubPlot	3	1438872.779	479624.2596	86.0312	7.01 x 10^-11	**
Main Plot X Sub Plot	6	411748.225	68624.7041	12.309	1.69 x 10^-05	**
Error b	18	100350.071	5575.003			
Total:	35	3891181.0401				

*, ** Significant at 5% and 1% level of significance

Table 3: ANOVA for Soil organic carbon (%)

Source of Var.	DF	Sum of Sq.	Mean Sq.	F value	P value / Result
Replication	2	77.5939	38.7969	30.0105	0.0039 **
Main Plot	2	1181.9939	590.9969	457.1528	1.9 x 10^-05 **
Error a	4	5.1711	1.2928		
SubPlot	3	198.2778	66.0926	90.3888	4.8 x 10^-11 **
MainPlotxSubPlot	6	8.7906	1.4651	2.0037	0.1183 NS
Error b	18	13.1617	0.7312		
Total	35	1484.9889			

Tukey HSD test for Yield and SOC (%)

The Tukey HSD test for yield across main plots, subplots, and their interactions revealed significant differences in productivity. Main Plots (Yield): M3 (1189.39 kg ha^{-1}) was significantly superior (group ‘a’). M2 (892.10 kg ha^{-1}) was intermediate (group ‘b’). M1 (633.24 kg ha^{-1}) recorded the lowest yield (group ‘c’). Ranking: M3 > M2 > M1. Subplots (Yield): S3 (Redgram + Korra: 1145.08 kg ha^{-1}) was the best performer (group ‘a’). S1 (Redgram) and S4 (Cowpea rabi) were statistically similar (group ‘b’). S2 (Bajra: 590.58 kg ha^{-1}) was significantly lowest (group ‘c’). Ranking: S3 > S1 ≈ S4 > S2. Main Plot × Subplot (Yield): M3 × S3 (Redgram + Korra: 1642.97 kg ha^{-1}) was the highest yielding combination (group ‘a’). M3 × S1 (1278.33 kg ha^{-1}) and M3 × S4 (1134.93 kg ha^{-1}) followed (groups ‘b-bc’). M1 × S2 (Bajra: 482.06 kg ha^{-1}) was the lowest (group ‘f’). Ranking: M3×S3 > M3×S1 and lowest is M1×S2. Kumar *et al*., (2021) [12] suggested similar kind of reports (Table-4, 5, 6)

Soil Organic Carbon (%)

The Tukey HSD test for SOC also revealed clear differences among treatments, closely reflecting yield performance. Main Plots (SOC): M3 (45.86%) recorded the highest SOC (group ‘a’). M2 (40.29%) was intermediate (group ‘b’). M1 (31.92%) maintained the lowest SOC (group ‘c’). Ranking: M3 > M2 > M1. Subplots (SOC): S3 (Redgram + Korra: 42.50%) was highest (group ‘a’). S1 (Redgram: 40.07%) was next (group ‘b’). S4 (Cowpea rabi: 38.88%) was moderate (group ‘c’). S2 (Bajra: 35.98%) recorded the lowest SOC (group ‘d’). Ranking: S3 > S1 > S4 > S2. Main Plot × Subplot (SOC): M3 × S3 (Redgram + Korra: 49.13%) was the highest (group ‘a’). M3 × S1 (46.97%) and M3 × S4 (45.80%) followed (groups ‘b-bc’). M1 × S2 (29.20%) and M1 × S4 (30.87%) recorded the lowest SOC (group ‘f’). Ranking: M3×S3 > M3×S1 and least is M1×S2. Billore *et al* 2014 [5] and tetawar *et al*., reported similar kind of findings. (Table-7,8,9)

The combined analysis of yield and SOC demonstrates that M3 consistently outperformed M2 and M1 in both productivity and soil fertility. Redgram + Korra (S3) was the most beneficial subplot for yield and SOC. The interaction M3 × S3 emerged as the most productive and sustainable option.

Conventional ploughing with sole Bajra (M1 × S2) was the poorest performer. Thus, legume-based intercropping under improved management (M3 × S3) is the most promising strategy for enhancing productivity, profitability, and soil health in rainfed conditions.

Table 4: Tukey's HSD Test - Main Plot (Redgram Equivalent Yield)

MainPlot	Yield (kg/Ha)	Standard Error	Standard Dev	Group
M3	1189.389	105.5691	365.7021	a
M2	892.099	60.9075	210.9898	b
M1	633.237	30.7258	106.4374	c

Table 5: Tukey's HSD Test - SubPlot (Redgram Equivalent Yield)

SubPlot	Yield (kg/Ha)	Standard Error	Standard Dev	Group
S3 (Redgram+Korra)	1145.078	142.4613	427.3839	a
S1 (Redgram)	979.812	89.5372	268.6116	b
S4 (Cowpea Rabi)	904.167	70.3554	211.0661	b
S2 (Bajra)	590.577	35.4476	106.3428	c

Table 6: Tukey's HSD Test - MainPlot x SubPlot (Redgram Equivalent Yield)

MainPlot x SubPlot	Yield (kg/Ha)	Standard Error	Standard Dev	Group
M3xS3 (Redgram+Korra)	1642.967	120.185	208.1666	a
M3xS1 (Redgram)	1278.333	33.3333	57.735	b
M3xS4 (Cowpea Rabi)	1134.933	33.3333	57.735	bc
M2xS3 (Redgram+Korra)	1080.133	88.1917	152.7525	bc
M2xS1 (Redgram)	983.45	57.735	100.0	c
M2xS4 (Cowpea Rabi)	916.467	33.3333	57.735	cd
M1xS3 (Redgram+Korra)	712.133	39.2994	68.0686	de
M3xS2 (Bajra)	701.323	33.3333	57.735	def
M1xS1 (Redgram)	677.653	39.2994	68.0686	ef
M1xS4 (Cowpea Rabi)	661.1	30.5505	52.915	ef
M2xS2 (Bajra)	588.347	33.3333	57.735	ef
M1xS2 (Bajra)	482.06	28.8675	50.0	f

Table 7: Tukey's HSD Test - Main Plot (SOC%)

Main Plot	SOC (%)	Standard Error	Standard Dev	Group
M3	45.858	0.977	3.3843	a
M2	40.292	0.8451	2.9274	b
M1 (Conventional Ploughing)	31.917	0.7917	2.7425	c

Table 8: Tukey's HSD Test - SubPlot (SOC%)

SubPlot	SOC (%)	Standard Error	Standard Dev	Group
S3 (Redgram+Korra)	42.5	2.0233	6.0698	a
S1 (Redgram)	40.067	2.2087	6.6261	b
S4 (Cowpea Rabi)	38.878	2.2273	6.6818	c
S2 (Bajra)	35.978	1.9845	5.9535	d

Table 9: Means of Main Plot x SubPlot Interaction (SOC%)

Main Plot x SubPlot	SOC (%)	Standard Error	Standard Dev	Group
M3xS3 (Redgram +Korra)	49.1333	0.6667	1.1547	a
M3xS1 (Redgram)	46.9667	0.8819	1.5275	b
M3xS4 (Cowpea Rabi)	45.8	1.1547	2.0	bc
M2xS3 (Redgram+Korra)	42.8667	1.3333	2.3094	bc
M3xS2 (Bajra)	41.5333	1.7638	3.0551	c
M2xS1 (Redgram)	41.1333	0.809	1.4012	cd
M2xS4 (Cowpea Rabi)	39.9667	0.8819	1.5275	de
M2xS2 (Bajra)	37.2	2.0	3.4641	de
M1xS3 (Redgram+Korra)	35.5	0.5774	1.0	ef
M1xS1 (Redgram)	32.1	1.0	1.7321	ef
M1xS4 (Cowpea Rabi)	30.8667	0.8819	1.5275	f
M1xS2 (Bajra)	29.2	1.0	1.7321	f

Table 10: Economics of different cropping systems

Cropping System	Practice	Redgram equivalent Yield (kg/ha)	Price (₹/kg)	Gross Return (₹)	Net Return (₹)	B:C Ratio	Relative economic efficiency	Sustainable yield index	Land Use efficiency	Profitability (Rs/day/Ha
Bajra (Sole)	BIM	1150	75	86,250	68,750	4.93	121	0.45	32.14	57.5
Redgram (Sole)	BIM	1450	75	1,08,750	89,650	5.69	345	0.72	54.36	241.35
Redgram+korra	BIM	1720	75	1,29,000	1,09,900	6.76	546	0.97	63.12	400.56
Cowpea (Rabi)	BIM	1660	75	1,24,500	1,05,400	6.52	308	0.65	48.77	220.12

The evaluation of different cropping systems under Best Improved Management (BIM) revealed substantial variations in productivity, profitability, sustainability, and resource-use efficiency. System Productivity (Redgram Equivalent Yield) Among the systems, Redgram + Korra intercropping (1720 kg ha^{-1}) recorded the highest Redgram Equivalent Yield (REY), clearly demonstrating the advantage of diversified systems in efficiently utilizing soil moisture and nutrients. This was closely followed by Cowpea grown in rabi (1660 kg ha^{-1}) and sole Redgram (1450 kg ha^{-1}). In contrast, sole Bajra (1150 kg ha^{-1}) was the least productive, reflecting the limitations of monocropping in rainfed conditions. (Table-10)

Economic Returns (Gross Return, Net Return, B:C Ratio): Gross and net returns followed a similar trend. The highest gross return (₹1,29,000 ha^{-1}) and net return (₹1,09,900 ha^{-1}) were achieved in Redgram + Korra, followed by Cowpea in rabi (₹1,05,400 ha^{-1}) and sole Redgram (₹89,650 ha^{-1}). Sole Bajra (₹68,750 ha^{-1}) was again the lowest. The Benefit: Cost (B:C) ratio also confirmed this trend, with Redgram + Korra (6.76) giving the best economic advantage, while sole Bajra (4.93) gave the least. These results highlight the economic superiority of legume-based and intercropping systems over monocropping. Similar findings were suggested by Baishya *et al.*, (2021) [4], respectively.

Relative Economic Efficiency (REE): Relative economic efficiency was highest in Redgram + Korra (546%), showing more than five times the advantage compared to the base system (sole Redgram). Cowpea (308%) and sole Bajra (121%) showed moderate efficiency, but none matched the Redgram + Korra system. This indicates that diversification substantially improves the economic efficiency of land use under rainfed conditions. (Table-10)

Sustainable Yield Index (SYI): The SYI values revealed clear differences in yield stability across systems. Redgram + Korra (0.97) maintained the most stable yields across seasons, followed by sole Redgram (0.72) and Cowpea in rabi (0.65). Sole Bajra (0.45) showed the lowest sustainability, highlighting its vulnerability to rainfall variability. The results confirm that systems with legumes (Redgram, Cowpea) enhance resilience in rainfed farming. Similar findings were reported by Islam *et al*., 2020 [9] respectively.

Land Use Efficiency (LUE): The time-wise use of land was highest in Redgram + Korra (63.12%), indicating prolonged and efficient utilization of land resources. Sole Redgram (54.36%) and Cowpea (48.77%) were moderately efficient, while sole Bajra (32.14%) had the poorest land utilization, leaving land fallow for longer durations.

Profitability (Rs/day/ha): Profitability expressed as daily net return per hectare further supported these findings. Redgram + Korra (₹400.56 ha^{-1} day^{-1}) was the most profitable system, followed by sole Redgram (₹241.35 ha^{-1} day^{-1}) and Cowpea in rabi (₹220.12 ha^{-1} day^{-1}). Sole Bajra (₹57.50 ha^{-1} day^{-1}) was the least profitable system. Similar kind of reports have been made by Kaushik *et al*., (2018) [10] (Table-10).

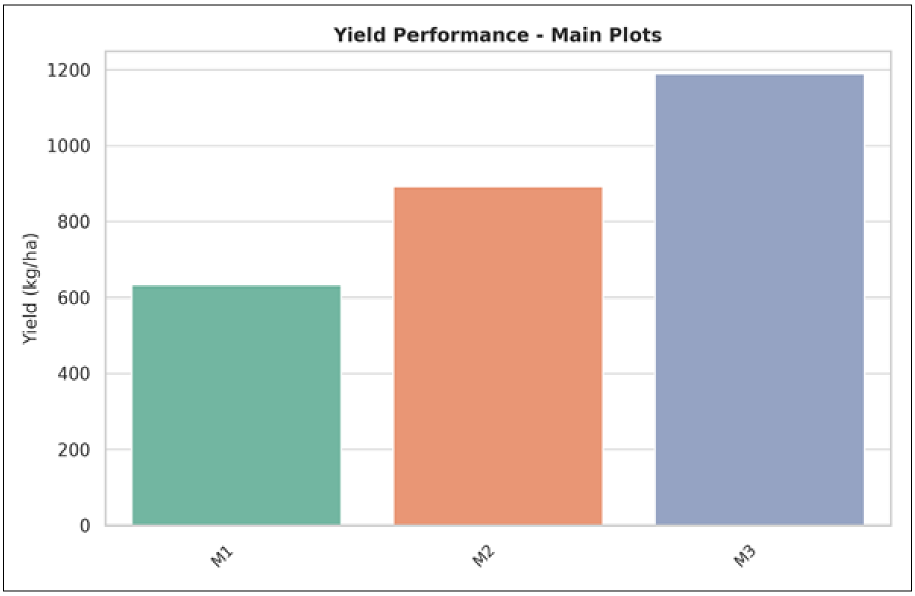


Fig 1: Yield performance

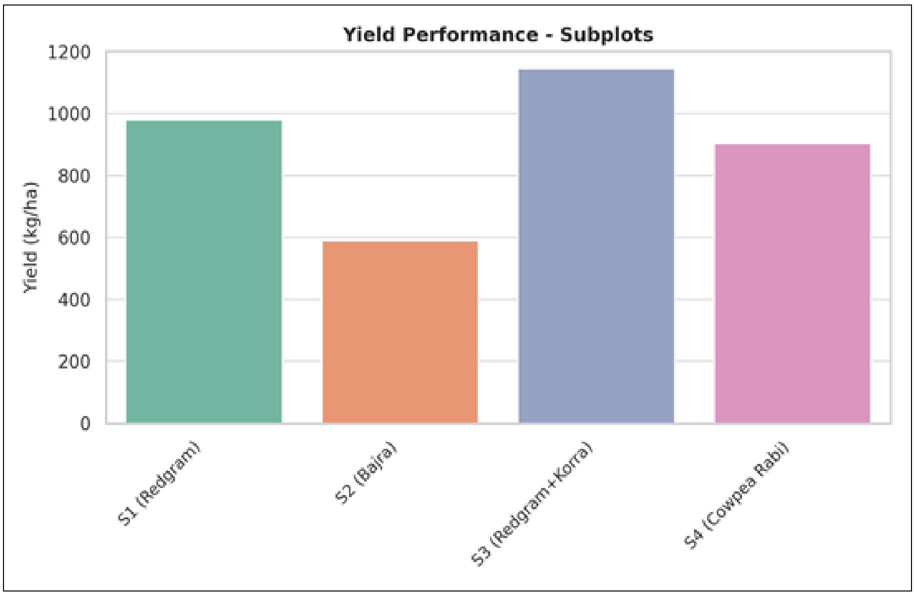


Fig 2: Yield performance subplots

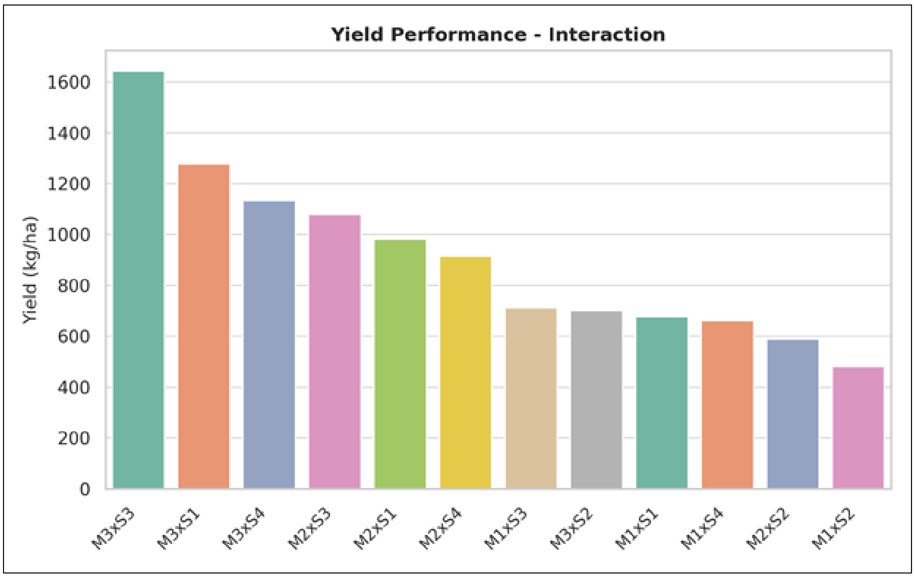


Fig 3: Yield performance-interaction

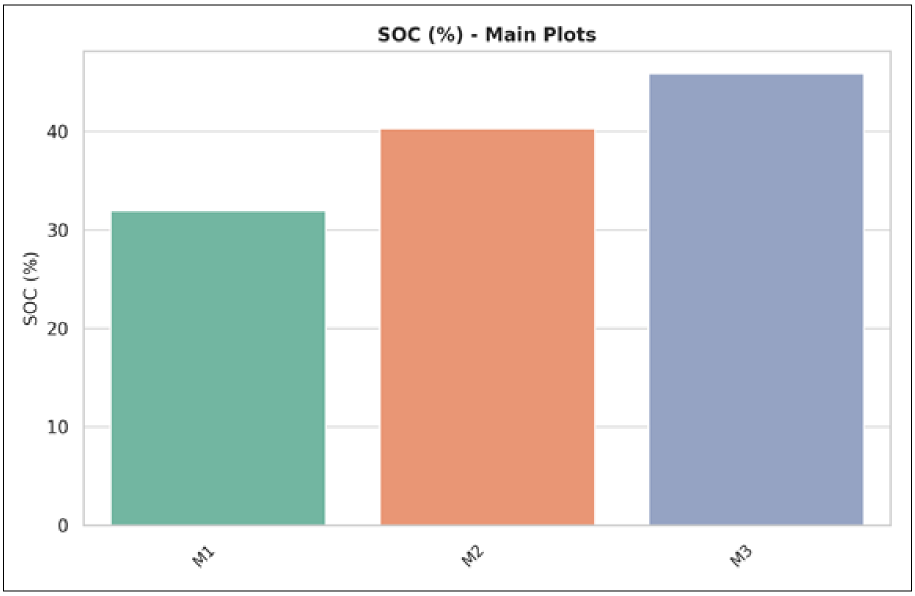


Fig 4: SOC (%) (main plots)

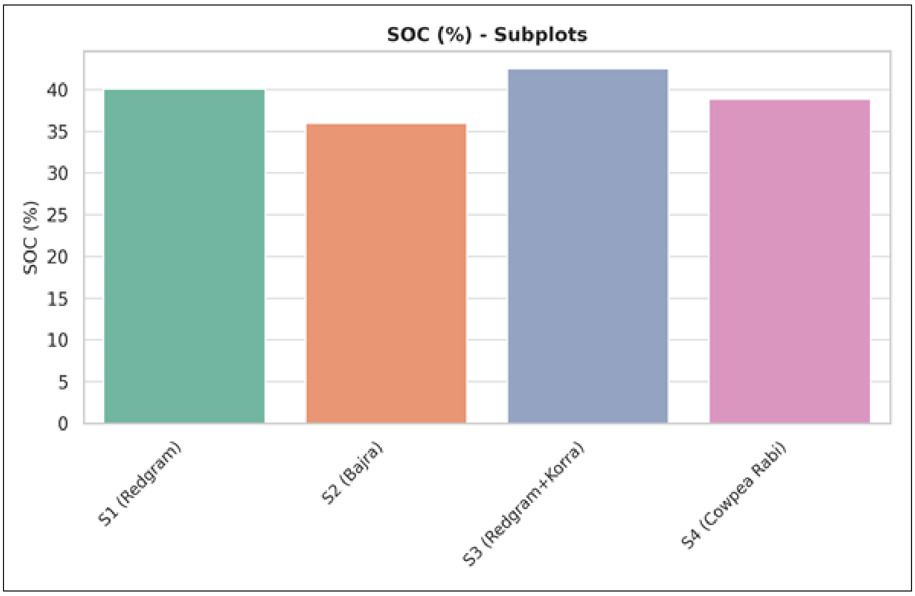
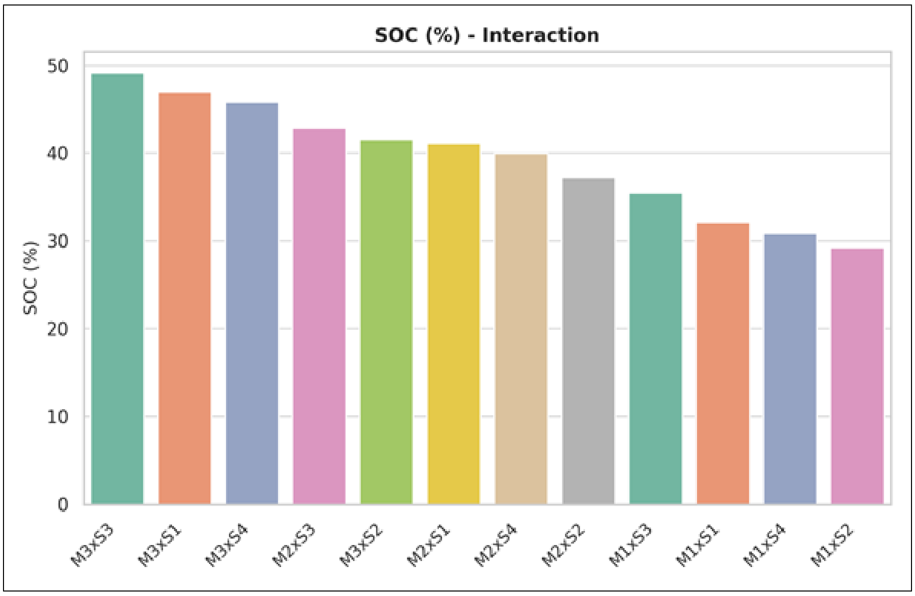


Fig 5: SOC (%) (Subplots)



Conclusion

The results clearly indicate that Redgram + Korra intercropping under BIM is the most productive, profitable, and sustainable cropping system in rainfed conditions. It not only ensured higher system productivity and economic returns but also maintained yield stability and improved resource-use efficiency. Sole Bajra, on the other hand, was the least efficient and least sustainable option. Thus, legume-based diversification, particularly Redgram + Korra intercropping, offers a superior alternative to monocropping systems, ensuring both short-term profitability and long-term sustainability in rainfed farming systems.

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