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Evaluation of productive and profitable cropping sequences for crop diversification under Kymore Plateau and Satpura Hills Zone of Madhya Pradesh

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Abstract
Conventional cereal-based monocropping in the Kymore Plateau and Satpura Hills of Madhya Pradesh has often resulted in low productivity and limited profitability, necessitating diversification strategies. A field experiment was conducted during 2023-24 and 2024-25 at the Research Farm of JNKVV, Jabalpur, to evaluate twelve diversified cropping sequences under irrigated conditions. The study assessed rice equivalent yield, system productivity, production efficiency, land use efficiency, water productivity, and economic returns. Results indicated that vegetable-based systems markedly outperformed traditional rice-wheat and rice-chickpea sequences. The sequence Cowpea - Cabbage - Okra achieved the highest rice equivalent yield (23.43 t ha^{-1}), system productivity (64.47 kg ha^{-1} day^{-1}), water productivity (15.12 kg ha^{-1} mm^{-1}), and net monetary returns (₹ 347.79 × 10^3 ha^{-1}) with a benefit-cost ratio of 2.96. Similarly, Rice - Cabbage - Green gram and Okra - Brinjal - Amaranthus demonstrated strong performance in terms of productivity and profitability. In contrast, pulse-oilseed-based sequences such as Arhar + Soybean - Sesame recorded the lowest productivity and profitability despite relatively higher land use efficiency. The results confirm that the integration of short-duration legumes and high-value vegetables significantly enhances production, profitability, and water use efficiency. Diversified vegetable-pulse sequences therefore represent promising alternatives for sustainable intensification and income generation in central India.

Keywords: Crop diversification, rice equivalent yield, system productivity, profitability, water productivity

Introduction
The Kymore Plateau and Satpura Hills zone of Madhya Pradesh, located in central India, is one of the important rainfed agro-climatic regions of the country. The region is marked by undulating hills, plateau lands, and fertile valleys, with soils ranging from black cotton (Vertisols) and red soils to alluvial deposits. Agriculture here is largely dependent on the southwest monsoon, which contributes the majority of the annual rainfall. Traditional rice-based monocropping systems have dominated the area for decades due to their adaptability and role in ensuring food security. However, these systems are increasingly becoming unsustainable owing to declining soil fertility, reduced water-use efficiency, lower productivity, and greater vulnerability to climatic variability. Such limitations not only restrict farm profitability but also threaten long-term agricultural sustainability in the region. Crop diversification has been widely recognized as a potential solution to address these constraints and to achieve sustainable intensification of agriculture. By incorporating multiple crops within a cropping cycle—through practices such as crop rotation, intercropping, mixed cropping, and sequential cropping—farmers can improve the efficiency of resource use while restoring soil fertility and reducing environmental degradation. Diversified systems exploit complementarities among crops in terms of rooting patterns, canopy structure, and nutrient requirements, thereby enhancing land productivity and ecological resilience. Global and national studies have consistently shown that diversification improves yield stability, enhances biological nitrogen fixation, increases soil organic carbon, and strengthens microbial activity, all of which contribute to better soil health (Sharma *et al.*, 2023; Meena *et al.*, 2024). [35, 23] From an economic standpoint, crop diversification reduces production risks and offers greater profitability. The inclusion of pulses,

oilseeds, and short-duration vegetables in rice- and maize-based systems provides multiple harvests in a year, thereby improving labor utilization and distributing income across seasons. Patel *et al.* (2022) [27] reported that intercropping maize with pigeon pea not only improved net returns by over 30% but also enhanced the benefit-cost ratio compared to monocropped maize. In addition, diversification helps reduce dependence on costly external inputs by lowering the need for chemical fertilizers and pesticides.

Nutritional security is another major advantage of diversified farming systems. Diets in rural Madhya Pradesh remain cereal-dominated, often deficient in protein and micronutrients. The integration of pulses such as chickpea, pigeon pea, and lentil along with vegetables and oilseeds can significantly enrich household diets with proteins, vitamins, and minerals. Patel *et al.* (2021) [24] demonstrated that rice-based systems diversified with pulses enhanced dietary protein availability, while Dubey *et al.* (2024) [8] highlighted the role of integrated cropping with vegetables in addressing hidden hunger, particularly among women and children. Such evidence suggests that diversification is not only important for farm economics but also for improving food and nutritional security.

Livestock production also benefits from crop diversification. Fodder-based sequences including cowpea, sorghum, and berseem ensure a year-round supply of quality green fodder, which reduces dependency on purchased feeds and improves milk yields. Yadav *et al.* (2023) [46] found that the incorporation of fodder legumes into diversified systems enhanced feed quality and directly supported smallholder dairy farming. In this way, diversification strengthens crop-livestock integration and boosts overall farm resilience.

Resource-use efficiency, particularly water productivity, is another critical dimension in rainfed zones such as Madhya Pradesh. Monocropping accelerates soil moisture depletion, whereas diversified systems improve water-use efficiency through complementary root systems, better ground cover, and enhanced infiltration. Jha *et al.* (2022) [12] reported that rice-pulse and maize-soybean intercropping systems achieved significantly higher water productivity than monocultures. Similarly, diversified systems have been shown to lower the energy footprint of farming by reducing irrigation and fertilizer requirements (Sharma *et al*., 2022; Banerjee *et al*., 2024) [34, 4].

Although the benefits of crop diversification are well-documented, systematic evaluations of diversified cropping systems under the specific agro-climatic conditions of the Kymore Plateau and Satpura Hills are limited. Given the dominance of rice-based monocropping in this region, there is a pressing need to explore and promote alternative sequences that incorporate pulses, oilseeds, vegetables, and fodder crops. Such an evaluation is particularly important to identify cropping systems that not only maximize productivity and profitability but also improve soil and water health, nutritional outcomes for households, and fodder availability for livestock. Keeping these considerations in view, the present investigation entitled "Evaluation of Cropping System for Crop Diversification under Kymore Plateau and Satpura Hills Zone of Madhya Pradesh" was undertaken to systematically assess the performance of diversified cropping systems with special emphasis on their potential to enhance productivity, profitability, and human as well as animal nutrition.

Materials and Methods

A field experiment was conducted during 2023-24 and 2024-25 at the Instructional Research Farm, Department of Agronomy, College of Agriculture, Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur, Madhya Pradesh, India. The soil series adjoining to Jabalpur district of Mahakoshal region of Madhya Pradesh are classified as 'Vertisol' as per US classification of soil it swells by wetting and shrinks by drying. In general, the soils of the region are medium to deep in depth and black in colour with sandy loam in texture and neutral in reaction. All common practices like harrowing and leveling of soil done before the sowing of crops in Kharif, Rabi and Zaid. The experiment was laid out in a randomized block design with 12 treatments of rice-based cropping systems replicated thrice: T_1: rice-wheat-greengram, T_2: rice-chickpea-greengram, T_3: soybean-chickpea-greengram, T_4: arhar + soybean (2:4) - sesame, T_5: rice-cabbage-greengram, T_6: rice-mustard-cowpea (vegetable), T_7: maize (fodder)-berseem (fodder)-sorghum (fodder), T_8: ricebean (fodder)-berseem (fodder)-sorghum (fodder), T_9: arhar + soybean (2:4) - greengram, T_{10}: kodo + arhar (4:2) - maize (cob), T_{11}: cowpea (vegetable)-cabbage-okra, and T_{12}: okra-brinjal-amaranthus. The row spacing was maintained at 20 cm for rice and wheat; 30 cm for chickpea, cowpea, greengram, sorghum, soybean, ricebean, arhar, and kodo; 45 cm for mustard and cabbage; 60 cm for maize (cob) and brinjal; and 15 cm for amaranthus, while berseem was sown by broadcasting. All crops in Kharif, Rabi, and Zaid seasons were grown under irrigated conditions following recommended packages of practices.

1. Assessment of Cropping System

1.1. Rice Equivalent Yields

The economic yield of crop components in all the ten crop sequences were converted into rice grain yield (REY) as suggested by Yadav and Newaj (1990) [45] and Verma and Mudgal (1983) [44]. For this study, the value of yields obtained from different crops was converted into rice yields with the help of existing market price of produce in the locality. After this, REY of all crops in a particular crop sequence was summed up, as REY of that particular crop sequence. The values of REY of all treatments were statistically analysed.

$$\text{REY (t ha}^{-1}) = \frac{\sum \text{YiXPi}}{\text{P(r)}}$$

Where REY denotes rice equivalent yield, Yi= yield of different crops, Pi = Price of respective crops, P (r) = Price of rice.

1.2. System productivity (kg ha^{-1} day^{-1})

System productivity of different rice-based cropping systems was obtained by dividing the system yield with 365 days and was expressed in (Chuang 1973) [7], system productivity.

$$\text{System productivity (kg ha}^{-1}\text{ day}^{-1}) = \frac{\text{System yield}}{\text{365 Days}}$$

1.3. Production efficiency (kg ha^{-1} day-^{1})

The production efficiency of each crop sequence was worked out treatment wise with the help of following formula (Patil *et al*., 1995; Tomar and Tiwari 1990) [, 42].

$$\text{Production Efficiency} = \frac{\text{Rice equivalent yield of the cropping system (kg/ha)}}{\text{Total duration of the same cropping system}}$$

1.4. Land use efficiency (LUE)

Land use efficiency was calculated as total duration of a cropping system in the field expressed as percentage of number of days in a year (Tomar and Tiwari 1990; Singh *et al.*, 1990) [42, 39].

$$\text{Land use efficiency (\%)} = \frac{\text{TDN X100}}{\text{365 Days}}$$

Where, TND denotes the total number of days field remained occupied under different crops (i=1….n)

1.5. Water productivity

$$\text{WP (kg ha}^{-1}\text{mm}^{-1}) = \frac{\text{Rice equivalent yield of the cropping system (kgha}^{-1})}{\text{Total Consumptive use of water by same cropping system (mm)}}$$

2. Economics of the Treatments

2.1. Cost of cultivation (Rs.ha^{-1})

The cost of cultivation of various sequences was worked out based on prevailing market rate of inputs.

2.2. Gross returns (Rs. ha-^{1})

The yield of different component crops in the sequence were converted into gross returns in rupees based on minimum support price/prevailing market price of crop.

2.3. Net monetary returns (Rs. ha^{-1})

After this, NMR per hectare under each treatment was determined by subs tracting the cost of cultivation of a particular treatment from the GMR of the same treatment.

2.4. Benefit: cost ratio

To estimate the benefits obtained from different treatment for each rupee of expenditure incurred. B:C ratio of each treatment was calculated as below:

$$\text{B: C ratio} = \frac{\text{GMR per hectare}}{\text{Cost of cultivation per hectare}}$$

Results and Discussion

A field experiment was carried out in three season of kharif, rabi and zaid as per the cropping sequence during 2023 -24 and 2024 -25 to study the “Evaluation of Cropping System for Crop Diversification under Kymore Plateau and Satpura Hills Zone of Madhya Pradesh” at Instructional Research Farm, Department of Agronomy, College of Agriculture, Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur, (Madhya Pradesh). Data recorded on yield under different cropping sequences were computed for determining the REY, production efficiency, input energy, output energy etc. The subsequent effect of various cropping sequences on soil properties with respect to soil physical, chemical and biological properties were studied. Recorded data were statistically analyzed and presented with the help of table and figures under different sub heads.

1. Rice Equivalent Yield

Data pertaining to rice equivalent yield (t ha^{-1}) was computed based on the yield of different cropping sequences during the years 2023-24 and 2024-25. The data related to REY was significantly influenced by the different cropping sequences in both years and in the pooled analysis, as presented in Table 1. The cropping sequence T_{11} (Cowpea - Cabbage - Okra) recorded the highest REY of 23.53 t ha^{-1} during 2023-24, closely followed by T_5 (Rice - Cabbage - Green gram) with 21.19 t ha^{-1}, and T_{12} (Okra - Brinjal - Amaranthus) with 19.04 t ha^{-1}. These sequences were significantly superior to the rest of the treatments during the first year. In the subsequent year (2024-25), T_{11} (Cowpea - Cabbage - Okra) again proved significantly superior over the rest of the cropping sequences, although the REY slightly decreased to 23.33 t ha^{-1}. Other sequences such as T_5 (Rice - Cabbage - Green gram) - 21.17 t ha^{-1}, T_{12} (Okra - Brinjal - Amaranthus) - 19.40 t ha^{-1}, and T_8 (Rice bean - Berseem - Sorghum) - 10.37 t ha^{-1} were found statistically at par and showed superiority over the remaining treatments.

Table 1: Rice equivalent yield (t ha^{-1}) as influenced by different cropping sequences

	Cropping Sequences	Rice equivalent yield (t ha^{-1})		Pooled
		2023-2024	2024-2025	
T_1	Rice - Wheat - Green gram	8.95	8.99	8.97
T_2	Rice - Chickpea - Green gram	8.64	8.63	8.63
T_3	Soybean - Chickpea - Green gram	8.33	8.30	8.32
T_4	Arhar + Soybean (2:4)- Sesame	5.91	6.32	6.12
T_5	Rice - Cabbage - Green gram	21.19	21.17	21.18
T_6	Rice - Mustard - Cowpea (Vegetables)	11.76	11.70	11.73
T_7	Maize(f) - Berseem(f) - Sorghum(f)	11.13	10.82	10.97
T_8	Rice bean(f) - Berseem(f) - Sorghum(f)	10.42	10.37	10.40
T_9	Arhar + Soybean (2:4)- Green gram	6.76	7.29	7.02
T_{10}	Kodo+ Arhar (4+2)- Maize	7.55	8.49	8.02
T_{11}	Cowpea - Cabbage - Okra	23.53	23.33	23.43
T_{12}	Okra - Brinjal - Amaranthus	19.04	19.40	19.22
Sem±		0.75	0.82	0.60
CD (p =0.05)		2.32	2.56	1.87

The pooled data also followed a similar trend as observed in the individual years. The top-ranking sequence, T_{11} (Cowpea - Cabbage - Okra), produced the highest pooled REY of 23.43 t ha^{-1}, followed by T_5 (Rice - Cabbage - Green gram) with 21.18 t ha^{-1}, and T_{12} (Okra - Brinjal - Amaranthus) with 19.22 t ha^{-1}. These were statistically superior to all other sequences. The lowest pooled REY of 6.12 t ha^{-1} was recorded under T_4 (Arhar + Soybean (2:4) - Sesame). Thus, based on the two-year study and pooled analysis, the cropping sequence Cowpea - Cabbage - Okra (T_{11}) emerged as the most productive in terms of rice equivalent yield, followed by Rice - Cabbage - Green gram (T_5) and Okra - Brinjal - Amaranthus (T_{12}).

2. System productivity

Data in relation to system productivity (kg ha^{-1} day^{-1}) was computed based on the yield obtained from different component crops under various cropping sequences over two years of experimentation. The data presented in Table 2 and depicted in showed considerable variation in system productivity among the cropping sequences under study.

During the year 2023-24, the maximum system productivity of 64.47 kg ha^{-1} day^{-1} was recorded under T_{11} (Cowpea - Cabbage - Okra), followed closely by T_5 (Rice - Cabbage - Green gram) with 58.06 kg ha^{-1} day^{-1}, and T12 (Okra - Brinjal - Amaranthus) with 52.17 kg ha^{-1} day^{-1}. In the subsequent year (2024-25), a slight increase in values was observed, where T_{11} (Cowpea - Cabbage - Okra) again ranked highest, registering 63.93 kg ha^{-1} day^{-1}, followed by T_{12} (53.14 kg ha^{-1} day^{-1}) and T_5 (57.99 kg ha^{-1} day^{-1}), thereby confirming their consistent performance.

Other sequences such as T_6 (Rice - Mustard - Cowpea vegetables) - 32.13 kg ha^{-1} day^{-1}, T_7 (Maize - Berseem - Sorghum) - 30.06 kg ha^{-1} day^{-1}, and T_8 (Rice bean - Berseem - Sorghum) - 28.48 kg ha^{-1} day^{-1}, were statistically comparable and fell into a moderate productivity group. On the other hand, the lowest system productivity was recorded under T_4 (Arhar + Soybean (2:4) - Sesame) with 16.19 kg ha^{-1} day^{-1} in 2023-24 and 17.32 kg ha^{-1} day^{-1} in 2024-25.

Table 2: System productivity (Kg $ha^{-1}day^{-1}$) as influenced by different cropping sequences

	Cropping Sequences	System productivity (Kg $ha^{1}day^{-1}$)		Pooled
		2023-2024	2024-2025	
T_1	Rice - Wheat - Green gram	24.53	24.63	24.58
T_2	Rice - Chickpea - Green gram	23.66	23.64	23.65
T_3	Soybean - Chickpea - Green gram	22.84	22.73	22.78
T_4	Arhar + Soybean (2:4)- Sesame	16.19	17.32	16.76
T_5	Rice - Cabbage - Green gram	58.06	57.99	58.02
T_6	Rice - Mustard - Cowpea (Vegetables)	32.21	32.06	32.13
T_7	Maize(f) - Berseem(f) - Sorghum(f)	30.48	29.63	30.06
T_8	Rice bean(f) - Berseem(f) - Sorghum(f)	28.55	28.42	28.48
T_9	Arhar + Soybean (2:4)- Green gram	18.51	19.97	19.24
T_{10}	Kodo+ Arhar (4+2)- Maize	20.67	23.26	21.97
T_{11}	Cowpea - Cabbage - Okra	64.47	63.93	64.20
T_{12}	Okra - Brinjal - Amaranthus	52.17	53.14	52.66
	Sem±	2.04	2.26	1.64
	CD (p =0.05)	6.35	7.03	5.12

The pooled analysis also followed a similar trend. The highest average system productivity of 64.20 kg ha^{-1} day^{-1} was recorded under T_{11} (Cowpea - Cabbage - Okra), followed by T_5 (Rice - Cabbage - Green gram) - 58.02 kg ha^{-1} day^{-1} and T_{12} (Okra - Brinjal - Amaranthus) - 52.66 kg ha^{-1} day^{-1}. The minimum pooled system productivity of 16.76 kg ha^{-1} day^{-1} was observed under T_4 (Arhar + Soybean (2:4) - Sesame).Thus, considering the average values over two years, the cropping sequence Cowpea - Cabbage - Okra, T_{11} proved to be the most productive system in terms of system productivity, followed by T_5 (Rice - Cabbage - Green gram) and T_{12} (Okra - Brinjal - Amaranthus).

4.3 Production efficiency

Data presented in Table 3 showed significant differences among the different cropping sequences with respect to production efficiency during the first year of experimentation and pooled data. Significantly higher production efficiency of 81.50 kg ha^{-1} day^{-1}, closely followed by 77.15 kg ha^{-1} day^{-1}, was computed under T_5 (Rice - Cabbage - Green gram) and T_{11} (Cowpea - Cabbage - Okra), respectively, during the first year.

However, the remaining sequences were found statistically at par with each other, except for T_4 (Arhar + Soybean (2:4) - Sesame) and T_9 (Arhar + Soybean (2:4) - Green gram), which recorded significantly lower production efficiencies of 15.15 and 18.51 kg ha^{-1} day^{-1}, respectively.

During the second year, a similar trend was observed with respect to production efficiency. The cropping sequence T_5 (Rice - Cabbage - Green gram) again recorded the highest value of 81.41 kg ha^{-1} day^{-1}, followed by T_{11} (Cowpea - Cabbage - Okra) with 76.50 kg ha^{-1} day^{-1} and T_{12} (Okra - Brinjal - Amaranthus) with 56.22 kg ha^{-1} day^{-1}. On the other hand, T_4 (Arhar + Soybean (2:4) - Sesame) and T_9 (Arhar + Soybean (2:4) - Green gram) remained the lowest, with values of 16.21 and 19.97 kg ha^{-1} day^{-1}, respectively.

Table 3: Production efficiency (Kg $ha^{-1}day^{-1}$) as influenced by different cropping sequences

	Cropping Sequences	Production efficiency (Kg $ha^{-1}day^{-1}$)		Pooled
		2023-2024	2024-2025	
T_1	Rice - Wheat - Green gram	29.35	29.48	29.42
T_2	Rice - Chickpea - Green gram	29.27	29.24	29.26
T_3	Soybean - Chickpea - Green gram	28.25	28.12	28.19
T_4	Arhar + Soybean (2:4)- Sesame	15.15	16.21	15.68
T_5	Rice - Cabbage - Green gram	81.50	81.41	81.46
T_6	Rice - Mustard - Cowpea (Vegetables)	40.54	40.35	40.45
T_7	Maize(f) - Berseem(f) - Sorghum(f)	41.21	40.06	40.63
T_8	Rice bean(f) - Berseem(f) - Sorghum(f)	35.93	35.77	35.85
T_9	Arhar + Soybean (2:4)- Green gram	18.51	19.97	19.24
T_{10}	Kodo+ Arhar (4+2)- Maize	21.26	23.92	22.59
T_{11}	Cowpea - Cabbage - Okra	77.15	76.50	76.83
T_{12}	Okra - Brinjal - Amaranthus	55.20	56.22	55.71
Sem±		2.59	2.65	1.96
CD (p =0.05)		8.05	8.25	6.11

The pooled data also showed significant differences among treatments. The highest production efficiency was noted under T_5 (Rice - Cabbage - Green gram) at 81.46 kg ha^{-1} day^{-1}, followed by T_{11} (Cowpea - Cabbage - Okra) at 76.83 kg ha^{-1} day^{-1} and T_{12} (Okra - Brinjal - Amaranthus) at 55.71 kg ha^{-1} day^{-1}. The lowest pooled production efficiency was recorded in T_4 (Arhar + Soybean (2:4) - Sesame) with 15.68 kg ha^{-1} day^{-1}, followed by T_9 (Arhar + Soybean (2:4) - Green gram) at 19.24 kg ha^{-1} day^{-1} and T_{10} (Kodo + Arhar (4+2) - Maize) at 22.59 kg ha^{-1} day^{-1}.

4. Land use efficiency

Land use efficiency was estimated and presented in Table 4. Data presented in table indicated the variation the cropping sequences during both the years as well as pooled data.

Table 4: Land use efficiency (%) as influenced by different cropping sequence

	Cropping Sequences	Land Use efficiency (%)		Pooled
		2023-2024	2024-2025	
T_1	Rice - Wheat - Green gram	69.73	69.99	69.86
T_2	Rice - Chickpea - Green gram	67.67	68.00	67.83
T_3	Soybean - Chickpea - Green gram	66.67	65.33	66.00
T_4	Arhar + Soybean (2:4)- Sesame	98.17	98.80	98.49
T_5	Rice - Cabbage - Green gram	85.41	84.08	84.74
T_6	Rice - Mustard - Cowpea (Vegetables)	79.02	75.33	77.18
T_7	Maize(f) - Berseem(f) - Sorghum(f)	86.67	87.00	86.83
T_8	Rice bean(f) - Berseem(f) - Sorghum(f)	85.30	85.30	85.30
T_9	Arhar + Soybean (2:4)- Green gram	83.62	83.62	83.62
T_{10}	Kodo+ Arhar (4+2)- Maize	97.51	97.74	97.63
T_{11}	Cowpea - Cabbage - Okra	89.67	90.33	90.00
T_{12}	Okra - Brinjal - Amaranthus	71.61	73.27	72.44
Sem±		7.01	6.42	6.67
CD (p =0.05)		21.84	19.99	20.76

There were no marked variations observed between the two years; however, slightly higher land use efficiency values were noted in the second year for T_6 (Rice - Mustard - Cowpea for Vegetables), T_5 (Rice - Cabbage - Green gram), and T_9 (Arhar + Soybean (2:4) - Green gram). On the basis of mean data, it was noted that the cropping sequence T_4 (Arhar + Soybean (2:4) - Sesame) utilized the land for the maximum number of days and recorded the highest land use efficiency of 98.49%, which was closely followed by T_{10} (Kodo + Arhar (4+2) - Maize) at 97.63%, and T_{11} (Cowpea - Cabbage - Okra) at 90.00%. In contrast, the existing cereal-based cropping systems like T_1 (Rice - Wheat - Green gram) and T_2 (Rice - Chickpea - Green gram) recorded lower land use efficiencies of 69.86% and 67.83%, respectively. These findings clearly indicate that crop diversification with inclusion of pulses, millets, and vegetables improves land use efficiency by ensuring year-round land occupancy and intensification.

5. Water Productivity

Data indicate to water productivity was calculated and expressed in kg ha^{-1} mm. the recorded data were statistically not analyzed because of it was computed based on year wise yield obtained not on the basis of replication during both the years of experimentation and data are presented in Table 5.

During the first year (2023-24), the highest water productivity was recorded under T_{11} (Cowpea - Cabbage - Okra) with 15.18 kg ha^{-1} mm^{-1}, followed by T_{12} (Okra - Brinjal - Amaranthus) at 11.14 kg ha^{-1} mm^{-1}, and T_5 (Rice - Cabbage - Green gram) with 9.21 kg ha^{-1} mm^{-1}. These high values can be attributed to the inclusion of short-duration, high-yielding vegetable crops which utilize water more efficiently. In contrast, the lowest water productivity was observed in T_4 (Arhar + Soybean (2:4) - Sesame) with 3.11 kg ha^{-1} mm^{-1}, followed by T_2 (Rice - Chickpea - Green gram) at 3.75 kg ha^{-1} mm^{-1}, and T_1 (Rice - Wheat - Green gram) at 3.98 kg ha^{-1} mm^{-1}.

A similar trend was observed in the second year (2024-25), with T_{11} (Cowpea - Cabbage - Okra) again leading at 15.05 kg ha^{-1} mm^{-1}, followed by T_{12} (11.34 kg ha^{-1} mm^{-1}) and T_5 (9.20 kg ha^{-1} mm^{-1}). The lowest water productivity continued to be seen under T_4 (3.33 kg ha^{-1} mm^{-1}) and T_2 (3.75 kg ha^{-1} mm^{-1}).

Table 5: Water productivity (kg ha^{-1} mm) as influenced by different cropping sequences

	Cropping Sequences	Water productivity (kg ha^{-1} mm)		Pooled
		2023-2024	2024-2025	
T_1	Rice - Wheat - Green gram	3.98	4.00	3.99
T_2	Rice - Chickpea - Green gram	3.75	3.75	3.75
T_3	Soybean - Chickpea - Green gram	5.21	5.19	5.20
T_4	Arhar + Soybean (2:4)- Sesame	3.11	3.33	3.22
T_5	Rice - Cabbage - Green gram	9.21	9.20	9.21
T_6	Rice - Mustard - Cowpea (Vegetables)	4.28	4.25	4.27
T_7	Maize(f) - Berseem(f) - Sorghum(f)	7.18	6.98	7.08
T_8	Rice bean(f) - Berseem(f) - Sorghum(f)	7.19	7.15	7.17
T_9	Arhar + Soybean (2:4)- Green gram	3.86	4.166	4.01
T_{10}	Kodo+ Arhar (4+2)- Maize	3.97	4.469	4.22
T_{11}	Cowpea - Cabbage - Okra	15.18	15.05	15.12
T_{12}	Okra - Brinjal - Amaranthus	11.14	11.34	11.24
Sem±		0.49	0.50	0.36
CD (p =0.05)		1.53	1.56	1.12

The pooled data also reflected a consistent pattern. The highest average water productivity was recorded under T_{11} (15.12 kg ha^{-1} mm^{-1}), followed by T_{12} (11.24 kg ha^{-1} mm^{-1}), and T_5 (9.21 kg ha^{-1} mm^{-1}). The lowest water productivity was noted under T_4 (3.22 kg ha^{-1} mm^{-1}) and T_2 (3.75 kg ha^{-1} mm^{-1}).

Economics

On the basis of average prevailing market price gross returns, net returns and benefit: cost ratio were numerically calculated and data have been presented in Table 6

Cost of cultivation

Data pertaining to the cost of cultivation (Rs. ha^{-1}) for the different cropping sequences were recorded during both years of experimentation (2023-24 and 2024-25), as presented in Table 6. The analysis revealed considerable variation in cost of cultivation among the tested cropping sequences.

During the study, the highest mean cost of cultivation was recorded in the cropping sequence T_{11} (Cowpea - Cabbage - Okra), which incurred a mean cost of Rs. 177.37 × 10^3 ha^{-1}. This was closely followed by T_5 (Rice - Cabbage - Green gram) with Rs. 163.40 × 10^3 ha^{-1} and T_{12} (Okra - Brinjal - Amaranthus) with Rs. 161.42 × 10^3 ha^{-1}. These sequences involved high-value vegetable crops, which are input-intensive and demand substantial expenditure on labor, irrigation, fertilizers, and plant protection measures.

On the contrary, the lowest mean cost of cultivation was recorded under T_9 (Arhar + Soybean (2:4) - Green gram) with Rs. 77.56 × 10^3 ha^{-1}, followed by T_4 (Arhar + Soybean (2:4) - Sesame) and T_{10} (Kodo + Arhar (4+2) - Maize) with costs of Rs. 78.86 × 10^3 ha^{-1} and Rs. 80.16 × 10^3 ha^{-1}, respectively. These systems primarily comprised low-input crops like pulses, sesame, and millets that typically require fewer external inputs such as synthetic fertilizers and pesticides.

Table 6: Cost of cultivation (Rs. x 10^3 ha^{-1}) as influenced by different crops sequences

	Cropping Sequences	Cost of cultivation (Rs. x 10^3 ha^{-1})		Mean
		2023-2024	2024-2025	
T_1	Rice - Wheat - Green gram	121.449	120.34	120.89
T_2	Rice - Chickpea - Green gram	115.819	116.30	116.06
T_3	Soybean - Chickpea - Green gram	102.647	100.25	101.45
T_4	Arhar + Soybean (2:4)- Sesame	79.45	78.27	78.86
T_5	Rice - Cabbage - Green gram	164.404	162.39	163.40
T_6	Rice - Mustard - Cowpea (Vegetables)	123.494	120.49	121.99
T_7	Maize(f) - Berseem(f) - Sorghum(f)	105.243	99.18	102.21
T_8	Rice bean(f) - Berseem(f) - Sorghum(f)	104.243	102.41	103.32
T_9	Arhar + Soybean (2:4)- Green gram	77.84	77.27	77.56
T_{10}	Kodo+ Arhar (4+2)- Maize	80.605	79.72	80.16
T_{11}	Cowpea - Cabbage - Okra	178.988	175.76	177.37
T_{12}	Okra - Brinjal - Amaranthus	162.393	160.45	161.42

Intermediate cost of cultivation values were observed in sequences such as T_3 (Soybean - Chickpea - Green gram) with Rs. 101.45 × 10^3 ha^{-1}, T_7 (Maize (F) - Berseem (F) - Sorghum (F)) with Rs. 102.21 × 10^3 ha^{-1}, and T_8 (Rice bean (F) - Berseem (F) - Sorghum (F)) with Rs. 103.32 × 10^3 ha^{-1}. The cropping sequence T_6 (Rice - Mustard - Cowpea (Vegetables)) also recorded a moderately higher cost at Rs. 121.99 × 10^3 ha^{-1}, primarily due to the inclusion of vegetable cowpea and associated input needs.

Gross monetary returns

Data pertaining to gross monetary returns (Rs. ha^{-1}) from particular cropping sequences was estimated during both the years of experimentation. The results showed that gross monetary returns varied widely across the different cropping sequences under study (Table 7)

The mean highest gross monetary return of Rs. 525.16 × 10^3 ha^{-1} was recorded under the cropping sequence T_{11} (Cowpea - Cabbage - Okra), which involved high-value vegetables that fetched premium prices in the market. This was followed by T_5 (Rice - Cabbage - Green gram) with a gross return of Rs. 474.71 × 10^3 ha^{-1}, and T_{12} (Okra - Brinjal - Amaranthus) with Rs. 430.91 × 10^3 ha^{-1}, respectively. These cropping systems benefitted from the inclusion of market-oriented vegetable crops, which significantly enhanced the economic returns per unit area due to higher productivity and market rates.

Table 7: Gross monetary returns (Rs. x 10^3 ha^{-1}) as influenced by different crops sequences

	Cropping Sequences	Gross monetary returns (Rs. x 10^3 ha^{-1})		Mean
		2023-2024	2024-2025	
T_1	Rice - Wheat - Green gram	195.44	206.78	201.11
T_2	Rice - Chickpea - Green gram	188.52	198.43	193.47
T_3	Soybean - Chickpea - Green gram	181.95	190.82	186.38
T_4	Arhar + Soybean (2:4)- Sesame	129.01	145.44	137.22
T_5	Rice - Cabbage - Green gram	462.60	486.82	474.71
T_6	Rice - Mustard - Cowpea (Vegetables)	256.67	269.12	262.89
T_7	Maize(f) - Berseem(f) - Sorghum(f)	242.90	248.77	245.83
T_8	Rice bean(f) - Berseem(f) - Sorghum(f)	227.47	238.58	233.02
T_9	Arhar + Soybean (2:4)- Green gram	147.50	167.68	157.59
T_{10}	Kodo+ Arhar (4+2)- Maize	164.72	195.28	180.00
T_{11}	Cowpea - Cabbage - Okra	513.66	536.67	525.16
T_{12}	Okra - Brinjal - Amaranthus	415.71	446.12	430.91

On the other hand, the lowest gross monetary return was recorded in the T_4 (Arhar + Soybean (2:4) - Sesame) cropping sequence, with a mean value of Rs. 137.22 × 10^3 ha^{-1}. This system primarily consisted of low-input crops such as pulses and oilseeds, which have comparatively lower market value and yield potential, thereby reducing overall returns.

Net monetary returns

The net monetary returns (Rs ha^{-1}) were computed for each cropping sequence during both the years of experimentation and are presented in Table 8.

The results showed a wide variation among the different cropping sequences. The highest mean net monetary return of Rs. 347.79 × 10^3 ha^{-1} was recorded with the T_{11} (Cowpea - Cabbage - Okra) cropping sequence, which was superior to all other sequences but numerically at par with T_5 (Rice - Cabbage - Green gram) and T_{12} (Okra - Brinjal - Amaranthus), which recorded Rs. 311.31 × 10^3 ha^{-1} and Rs. 269.49 × 10^3 ha^{-1}, respectively.

Further, it was noted that the cropping sequences consisting of vegetables contributed significantly higher monetary returns per hectare. Similarly, sequences such as T_7 (Maize - Berseem - Sorghum) and T_6 (Rice - Mustard - Cowpea vegetables) also proved to be better options for securing higher net monetary returns per unit area, owing to their fodder and vegetable components, which not only fetched good returns but also utilized farm inputs more efficiently.

Table 8: Net monetary returns (Rs. x 10^3 ha^{-1}) as influenced by different crops sequences

	Cropping Sequences	Net monetary returns (Rs. x 10^3 ha^{-1})		Mean
		2023-2024	2024-2025	
T_1	Rice - Wheat - Green gram	73.99	86.44	80.22
T_2	Rice - Chickpea - Green gram	72.70	82.13	77.41
T_3	Soybean - Chickpea - Green gram	79.30	90.57	84.93
T_4	Arhar + Soybean (2:4)- Sesame	49.56	67.17	58.36
T_5	Rice - Cabbage - Green gram	298.20	324.43	311.31
T_6	Rice - Mustard - Cowpea (Vegetables)	133.18	148.62	140.90
T_7	Maize(f) - Berseem(f) - Sorghum(f)	137.66	149.59	143.62
T_8	Rice bean(f) - Berseem(f) - Sorghum(f)	123.23	136.17	129.70
T_9	Arhar + Soybean (2:4)- Green gram	69.66	90.41	80.03
T_{10}	Kodo+ Arhar (4+2)- Maize	84.12	115.56	99.84
T_{11}	Cowpea - Cabbage - Okra	334.67	360.91	347.79
T_{12}	Okra - Brinjal - Amaranthus	253.31	285.67	269.49

Benefit cost ratio

The benefit-cost ratio, representing the return per rupee investment, was computed for both years of experimentation (2023-24 and 2024-25), and the mean values are presented in Table 9.

The data revealed considerable variation in profitability among the different cropping sequences. It is evident from the results that the highest return per rupee investment was recorded under the cropping sequence T_{11} (Cowpea - Cabbage - Okra), which achieved a mean B: C ratio of 2.96, followed closely by T_5 (Rice - Cabbage - Green gram) with 2.91. These vegetable-based systems offered superior profitability owing to high market returns relative to their input costs. Other sequences that performed well in terms of benefit-cost ratio included T_7 (Maize - Berseem - Sorghum) and T_{12} (Okra - Brinjal - Amaranthus), which recorded B:C ratios of 2.41 and 2.67, respectively. These were at par with each other and showed the advantage of integrating fodder and vegetable components.

Fodder-based systems like T_8 (Rice bean - Berseem - Sorghum) and T_{10} (Kodo + Arhar - Maize) also performed reasonably well, with mean B: C ratios of 2.26 and 2.25, respectively. Likewise, T_6 (Rice - Mustard - Cowpea vegetables) and T_9 (Arhar + Soybean - Green gram) returned 2.15 and 2.03, indicating their cost-effectiveness in diversified farming.

Table 9: Benefit cost ratio as influenced by different cropping sequences

	Cropping Sequences	Benefit cost ratio		Mean
		2023-2024	2024-2025	
T_1	Rice - Wheat - Green gram	1.61	1.72	1.66
T_2	Rice - Chickpea - Green gram	1.63	1.71	1.67
T_3	Soybean - Chickpea - Green gram	1.77	1.90	1.84
T_4	Arhar + Soybean (2:4)- Sesame	1.62	1.86	1.74
T_5	Rice - Cabbage - Green gram	2.81	3.00	2.91
T_6	Rice - Mustard - Cowpea (Vegetables)	2.08	2.23	2.15
T_7	Maize(f) - Berseem(f) - Sorghum(f)	2.31	2.51	2.41
T_8	Rice bean(f) - Berseem(f) - Sorghum(f)	2.18	2.33	2.26
T_9	Arhar + Soybean (2:4)- Green gram	1.89	2.17	2.03
T_{10}	Kodo+ Arhar (4+2)- Maize	2.04	2.45	2.25
T_{11}	Cowpea - Cabbage - Okra	2.87	3.05	2.96
T_{12}	Okra - Brinjal - Amaranthus	2.56	2.78	2.67

Moderate benefit-cost ratios were observed in T_3 (Soybean - Chickpea - Green gram) and T_4 (Arhar + Soybean - Sesame), recording 1.84 and 1.74, respectively. These systems included legume-based rotations with moderate input costs and relatively stable returns.The lowest B: C ratios were recorded under T_1 (Rice - Wheat - Green gram) and T_2 (Rice - Chickpea - Green gram), with values of 1.66 and 1.67, respectively. Although these cereal-pulse-based systems are commonly practiced, their profitability per unit investment remained limited.

Overall, the cropping sequence T_{11} (Cowpea - Cabbage - Okra) was found to be the most economically efficient, giving the highest return per rupee invested. It was closely followed by T_5 (Rice - Cabbage - Green gram) and T_{12} (Okra - Brinjal - Amaranthus), all of which demonstrated the clear economic advantage of incorporating high-value vegetable crops. In contrast, traditional cereal-pulse systems like T_1 and T_2 resulted in relatively lower economic efficiency, emphasizing the scope for improvement through diversification.

Discussion

The present study entitled "Evaluation of Cropping System for Crop Diversification under Kymore Plateau and Satpura Hills Zone of Madhya Pradesh" was undertaken with the objective of identifying cropping systems that optimize productivity, profitability, and sustainability while maintaining or enhancing soil health under the specific agro-climatic and edaphic conditions of the region. The field experiment was conducted at the Instructional Research Farm, Department of Agronomy, JNKVV, Jabalpur during the years 2023-24 and 2024-25, covering *Kharif*, *Rabi*, and *Zaid* seasons. In this chapter, the major findings obtained are critically discussed in light of climatic and soil conditions of the region, supported by scientific literature and experimental observations.

Rice Equivalent Yield

Rice equivalent yield (REY) was calculated for different crops taken under study. The available data are presented and depicted in Table 4.1 and Fig. 4.1. The results of study reveal that on an average Cowpea - Cabbage - Okra (23.43 t ha^{-1}) estimated highest rice equivalent yield followed by Rice - Cabbage - Green gram (21.18 t ha^{-1}) and Okra - Brinjal - Amaranthus (19.22 t ha^{-1}) as compared to other sequences. The *rabi* crops mostly influenced the rice equivalent yield of the systems because rice was the grain crop and contribution of *zaid* crops was marginal. The higher production potential of cabbage and okra and better market price were instrumental for attaining higher rice equivalent yield by the top ranked cropping sequence. (Patra *et al.* 2021; Kalita *et al.* 2015; Kumar *et al.* 2015; Singh *et al.* 2019) [28, 14, 16, 37]. Further, less prices of cereals in the prevailing markets while vegetable crops fetched higher value in the market. Kumar *et al.* (2008) [17], Upadhyay *et al.* (2011), Ravisankar *et al.* (2015) [32] also recorded the similar results and reported that inclusion of vegetable crops in rice-based cropping sequences increase the rice equivalent yield.

System productivity

System productivity as presented in Table 4.2 indicated that the cropping sequence Cowpea - Cabbage - Okra recorded the maximum productivity of 64.47 kg ha^{-1} day^{-1} during 2023-24 and 63.93 kg ha^{-1} day^{-1} in 2024-25, followed by Rice - Cabbage - Green gram and Okra - Brinjal - Amaranthus. The enhanced productivity in these systems can be attributed to the inclusion of fast-growing, high-value vegetables and legumes that not only increase economic yield but also improve soil fertility through nitrogen fixation. These components ensure efficient utilization of available soil moisture and nutrients, resulting in consistent performance across years. The lowest system productivity was recorded under Arhar + Soybean (2:4) - Sesame, likely due to the lower yield potential and longer duration of the component crops, which reduced overall daily productivity.

These findings are supported by Raj *et al.* (2015) [30], who observed that inclusion of cowpea and mustard in a rice-based system enhanced system productivity due to improved land use and diversified outputs. Similarly, Patel *et al.* (2017) [25] and Sharma *et al.* (2020) [34] also reported significant increases in system productivity with the inclusion of oilseeds, legumes, and vegetables such as potato and green gram, owing to their high market value and effective use of seasonal moisture. Dwivedi *et al.* (2020) [9] noted that vegetable-integrated sequences like rice-vegetable pea-green gram outperformed conventional systems by improving nitrogen use efficiency and market returns. Furthermore, Kushwaha *et al.* (2020) [19] and Ahirwar and Sharma (2021) [2] emphasized the contribution of legumes and short-duration vegetables in enhancing productivity and sustainability, which aligns with the superior performance of T11, T5, and T12 in the present study.

Production efficiency

The data presented in Table 4.3 indicated that production efficiency was highest under Rice - Cabbage - Green gram with 81.50 kg ha^{-1} day^{-1} in 2023-24 and 81.41 kg ha^{-1} day^{-1} in 2024-25, followed closely by Cowpea - Cabbage - Okra with 77.15 and 76.50 kg ha^{-1} day^{-1}, respectively. This enhanced performance is attributed to the inclusion of high-value crops and short-duration legumes that increased cropping intensity and ensured efficient utilization of land and time. These findings align with those of Ghosh *et al.* (2010) [10], Kumar *et al.* (2015) [16], and Jat *et al.* (2013) [11], who reported that diversified systems with legumes and vegetables outperformed conventional cereal-based systems in daily productivity. Similarly, Zhang *et al.* (2016) [47] and Timsina and Connor (2001) [40] emphasized that such rotations improve light interception and water use efficiency, resulting in higher yields per day.

In contrast, Arhar + Soybean - Sesame and Arhar + Soybean - Green gram recorded the lowest production efficiencies, with values of 15.15 & 16.21 kg ha^{-1} day^{-1} and 18.51 & 19.97 kg ha^{-1} day^{-1} during 2023-24 and 2024-25, respectively. These low values are likely due to the inclusion of low-yielding, long-duration pulses and absence of remunerative crops, resulting in poor system productivity. This trend agrees with findings by Ahirwar *et al.* (2023) [3] and Lakaria *et al.* (2020) [20], who also reported that reduced cropping intensity and limited market value crops negatively impact production efficiency in less diversified systems.

Land use efficiency

Land use efficiency data presented in Table 4.4 showed considerable variation among different cropping sequences. The highest LUE was recorded under Arhar + Soybean (2:4) - Sesame with 98.49%, followed by Kodo + Arhar (4+2) - Maize) at 97.63%, and Cowpea - Cabbage - Okra with 90.00%. These systems ensured nearly year-round land occupation through carefully sequenced crops, reducing fallow periods and maximizing resource use. Similar observations were made by Singh *et al.* (2015) [38] and Saxena *et al.* (2015) [33], who reported over 90% LUE in diversified systems incorporating vegetables and legumes, emphasizing the benefits of cropping intensity and seasonal alignment.

Further, Aher *et al.* (2016) [1] and Joshi *et al.* (2017) [13] corroborated that the inclusion of short-duration pulses like green gram and cowpea not only filled temporal gaps but also enhanced soil fertility and microbial activity, leading to higher LUE. In contrast, existing cereal-based systems such as Rice - Wheat - Green gram and Rice - Chickpea - Green gram recorded relatively lower LUE values of 69.86% and 67.83%, respectively. This underutilization suggests the need for more intensified cropping approaches. Therefore, the inclusion of pulses, millets, and vegetables emerges as a critical strategy for enhancing land use efficiency, improving sustainability, and increasing productivity in diversified cropping systems.

Water Productivity

Water productivity, as presented in Table 4.5 and depicted in Figure 4.5, varied notably across the cropping sequences. The highest water productivity was recorded under Cowpea - Cabbage - Okra with a pooled value of 15.12 kg ha^{-1} mm^{-1}, followed by Okra - Brinjal - Amaranthus with 11.24 kg ha^{-1} mm^{-1}, and Rice - Cabbage - Green gram at 9.21 kg ha^{-1} mm^{-1}. These high values were largely due to the inclusion of short-duration, high-value vegetable crops with efficient water use and better harvest index. On the other hand, the lowest water productivity was observed in Arhar + Soybean - Sesame with 3.22 kg ha^{-1} mm^{-1}, and Rice - Chickpea - Green gram at 3.75 kg ha^{-1} mm^{-1}, indicating inefficient water use, possibly due to lower biomass and yield per unit of water consumed.

These results are consistent with the findings of Timsina and Connor (2001) [40], who emphasized that the inclusion of legumes and vegetables improves water productivity by enhancing soil structure and reducing non-beneficial water loss. Kijne *et al.* (2003) [15] and Zwart and Bastiaanssen (2004) [48] also noted that diversified cropping systems with short-duration and deep-rooted crops can improve field-scale water productivity by 40-70%. The efficient performance of Cowpea - Cabbage - Okra and by Okra - Brinjal - Amaranthus sequences aligns with studies by Bouman *et al*. (2007) [5] and Punia *et al.* (2020) [29], who reported higher crop water productivity with upland vegetable and pulse crops following rice, due to reduced irrigation frequency and improved root-zone water extraction. Similarly, Ahirwar *et al.* (2023) [3] highlighted that soybean-chickpea-green gram sequence improved CWP by reducing irrigation demand and enhancing biomass harvest, a pattern also reflected in the performance of Rice - Cabbage - Green gram in the current study.

Economic Analysis

1. Cost of Cultivation

The cost of cultivation varied significantly among the different cropping sequences evaluated during both years of experimentation. The highest mean cost of cultivation was observed under Cowpea - Cabbage - Okra at Rs. 177.37 × 10^3 ha^{-1}, followed by Rice - Cabbage - Green gram and Okra - Brinjal - Amaranthus with Rs. 163.40 × 10^3 ha^{-1} and Rs. 161.42 × 10^3 ha^{-1}, respectively. These sequences involved high-value vegetables, which require intensive input application including labor, fertilizers, irrigation, and plant protection measures.

On the other hand, the lowest cost of cultivation was recorded in Arhar + Soybean - Green gram and Arhar + Soybean - Sesame, which incurred costs of only Rs. 77.56 × 10^3 ha^{-1} and Rs. 78.86 × 10^3 ha^{-1}, respectively. These low-input systems are based on pulses and oilseeds that demand minimal external inputs. These findings align with the results of Kumar *et al.* (2021) [18] and Rathore *et al.* (2019) [31], who observed that inclusion of vegetable crops significantly increases cost of cultivation, whereas pulse-based systems tend to be more input-efficient and cost-effective. Similarly, Patel *et al.* (2020) [26] reported higher input costs in vegetable-based sequences due to intensive management practices.

2. Gross Monetary Returns

Gross monetary returns followed a pattern similar to cost but with higher differentiation due to the market value of produce. The highest gross returns were recorded under Cowpea - Cabbage - Okra with Rs. 525.16 × 10^3 ha^{-1}, followed by Rice - Cabbage - Green gram at Rs. 474.71 × 10^3 ha^{-1} and Okra - Brinjal - Amaranthus with Rs. 430.91 × 10^3 ha^{-1}. These vegetable-based sequences benefitted from high market prices and continuous market demand.

Fodder-based sequences like Maize - Berseem - Sorghum and Rice bean - Berseem - Sorghum also performed well with gross returns of Rs. 245.83 × 10^3 ha^{-1} and Rs. 233.02 × 10^3 ha^{-1}, respectively, due to high biomass production and utility in the dairy sector. These results are consistent with findings by Meena *et al.* (2020) [22], who emphasized that diversified systems including vegetables and fodders fetched significantly higher returns than cereal-pulse systems. Singh *et al.* (2018) [36] also highlighted the positive impact of high-value crops on gross monetary returns under irrigated diversified systems.

3. Net Monetary Returns

The net monetary returns were highest under Cowpea - Cabbage - Okra at Rs. 347.79 × 10^3 ha^{-1}, followed by Rice - Cabbage - Green gram and Okra - Brinjal - Amaranthus with Rs. 311.31 × 10^3 ha^{-1} and Rs. 269.49 × 10^3 ha^{-1}, respectively. These systems showed the greatest profit margins despite their high input costs, demonstrating the economic viability of vegetable-based intensification.

Fodder-based systems like Rs. 143.62 × 10^3 ha^{-1} and Rs. 140.90 × 10^3 ha^{-1} offered moderately high net returns, balancing input cost with consistent output. In contrast, sequences like Arhar + Soybean - Sesame and Rice - Chickpea - Green gram yielded lower net returns due to either lower yields or low market prices. The results are in line with Choudhary *et al.* (2022) [6] and Verma *et al.* (2021) [43], who reported that vegetable-based diversified systems significantly enhance farm profitability, while cereal-pulse systems, though more stable, offer limited financial returns.

4. Benefit-Cost Ratio

The benefit-cost ratio, reflecting profitability per rupee invested, was highest under Cowpea - Cabbage - Okra at 2.96, followed by Rice - Cabbage - Green gram and Okra - Brinjal - Amaranthus with 2.91 and 2.67, respectively. These sequences proved to be the most economically efficient due to high returns relative to input costs. Among fodder-based sequences, Maize (f) - Berseem(f) - Sorghum(f) and Rice bean(f) - Berseem(f) - Sorghum(f) recorded B: C ratios of 2.41 and 2.26, respectively, suggesting they are also cost-effective options for livestock-integrated systems.

In comparison, Rice - Wheat - Green gram and Rice - Chickpea - Green gram recorded the lowest B: C ratios of 1.66 and 1.67, respectively, indicating relatively lower economic efficiency. These findings are supported by earlier research from Tiwari *et al.* (2017) [41] and Mandal *et al.* (2016) [21], who concluded that horticulture-based crop sequences provide better returns per rupee investment due to market premium, while cereal-pulse sequences offer more stability but lower economic gain.

Conclusion

The cropping sequences Cowpea - Cabbage - Okra and Rice - Cabbage - Green gram recorded the highest rice equivalent yield (REY), system productivity, and net monetary returns. These systems outperformed traditional cereal-based cropping systems, establishing themselves as the most productive and economically viable under irrigated conditions.

Legume- and vegetable-based cropping systems contributed significantly to human and animal nutrition by providing protein-rich pulses (e.g., soybean, chickpea, and cowpea) and nutrient-dense vegetables (e.g., cabbage, okra, brinjal). Fodder-based systems such as Maize - Berseem - Sorghum supported livestock nutrition effectively.

Vegetable-based systems showed superior crop water productivity and production efficiency, while fodder-based systems like Ricebean - Berseem - Sorghum and Maize - Berseem - Sorghum exhibited the highest net energy output and energy use efficiency, indicating better resource utilization.

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