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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 for rice equivalent yield (REY), productivity, efficiency, and profitability. The results revealed that the highest REY was obtained in T<sub>11</sub>: Cowpea-Cabbage-Okra (57.30 t/ha<sup>-1</sup> year<sup>-1</sup>), followed by T<sub>12</sub>: Okra-Brinjal-Amaranthus (46.54 t/ha<sup>-1</sup> year<sup>-1</sup>), indicating the superiority of vegetable-based systems. System productivity and production efficiency were also maximum in T<sub>11</sub> (156.99 and 280.89 kg ha<sup>-1</sup> day<sup>-1</sup>, respectively) and T<sub>12</sub> (127.51 and 202.35 kg ha<sup>-1</sup> day<sup>-1</sup>), while among conventional cereal-based sequences, T<sub>1</sub>: Rice-Wheat-Greengram recorded moderate REY (9.82 t/ha<sup>-1</sup> year<sup>-1</sup>) and T<sub>3</sub>: Soybean-Chickpea-Greengram performed better among legumes. Economic analysis confirmed that T<sub>11</sub> was the most remunerative, with the highest gross returns (₹ 1317.96 × 10<sup>3</sup> ha<sup>-1</sup>), net returns (₹ 1109.64 × 10<sup>3</sup> ha<sup>-1</sup>), and benefit-cost ratio (6.33), followed by T<sub>12</sub>, while legume-vegetable systems such as T<sub>5</sub>: Rice-Cabbage-Greengram (25.65 t/ha<sup>-1</sup>) and T<sub>6</sub>: Rice-Mustard-Cowpea (25.54 t/ha<sup>-1</sup>) enhanced household nutrition. Fodder-based systems like T<sub>7</sub>: Maize-Berseem-Sorghum (13.72 t/ha<sup>-1</sup>) and T<sub>10</sub>: Kodo + Arhar-Maize (6.42 t/ha<sup>-1</sup>) supported livestock feed requirements, highlighting their dual role. Water productivity was maximum in T<sub>11</sub> (24.44 kg ha<sup>-1</sup> mm<sup>-1</sup>), followed by T<sub>12</sub> (20.73 kg ha<sup>-1</sup> mm<sup>-1</sup>), whereas T<sub>4</sub>: Arhar + Soybean-Sesame was the lowest (2.38 kg ha<sup>-1</sup> mm<sup>-1</sup>). Land use efficiency was highest in fodder systems, particularly T<sub>8</sub>: Ricebean-Berseem-Sorghum (81.85%) and T<sub>7</sub> (77.50%), indicating efficient resource utilization. Overall, the study demonstrated that integration of high-value vegetables and legumes markedly improved productivity, profitability, water use efficiency, and nutritional security, thereby offering sustainable alternatives to conventional rice-wheat cropping systems 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).<sup>[35, 23]</sup> 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)<sup>[27]</sup> 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)<sup>[24]</sup> demonstrated that rice-based systems diversified with pulses enhanced dietary protein availability, while Dubey *et al.* (2024)<sup>[8]</sup> 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)<sup>[46]</sup> 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)<sup>[12]</sup> 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)<sup>[34, 4]</sup>. 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<sub>1</sub>: rice-wheat-greengram, T<sub>2</sub>: rice-chickpea-greengram, T<sub>3</sub>: soybean-chickpea-greengram, T<sub>4</sub>: arhar + soybean (2:4) - sesame, T<sub>5</sub>: rice-cabbage-greengram, T<sub>6</sub>: rice-mustard-cowpea (vegetable), T<sub>7</sub>: maize (fodder)-berseem (fodder)-sorghum (fodder), T<sub>8</sub>: ricebean (fodder)-berseem (fodder)-sorghum (fodder), T<sub>9</sub>: arhar + soybean (2:4) - greengram, T<sub>10</sub>: kodo + arhar (4:2) - maize (cob), T<sub>11</sub>: cowpea (vegetable)-cabbage-okra, and T<sub>12</sub>: 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)<sup>[45]</sup> and Verma and Mudgal (1983)<sup>[44]</sup>. 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.

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

Where REY denotes rice equivalent yield, Y<sub>i</sub> = yield of different crops, P<sub>i</sub> = Price of respective crops, P (r) = Price of rice.

### 1.2. System productivity (kg ha<sup>-1</sup> day<sup>-1</sup>)

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

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

### 1.3. Production efficiency (kg ha<sup>-1</sup> day<sup>-1</sup>)

The production efficiency of each crop sequence was worked out treatment wise with the help of following formula (Tomar and Tiwari 1990)<sup>[42]</sup>.

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

### 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)<sup>[42, 39]</sup>.

$$\text{Land use efficiency (\%)} = \frac{\text{TDN} \times 100}{365 \text{ Days}}$$

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

### 1.5. Water productivity

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

## 2. Economics of the Treatments

### 2.1. Cost of cultivation (Rs.ha<sup>-1</sup>)

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

### 2.2. Gross returns (Rs. ha<sup>-1</sup>)

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

### 2.3. Net monetary returns (Rs. ha<sup>-1</sup>)

After this, NMR per hectare under each treatment was determined by subtracting 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

Rice equivalent yield (REY) varied significantly among the cropping sequences (Table 4.1). Among the income enhancement systems, Cowpea-Cabbage-Okra (T<sub>11</sub>: 57.30 t ha<sup>-1</sup>

year<sup>-1</sup>) recorded the maximum REY, followed by Okra-Brinjal-Amaranthus (T<sub>12</sub>: 46.54 t ha<sup>-1</sup> year<sup>-1</sup>). Purpose-wise comparisons revealed that in the check system, Rice-Wheat-Greengram (T<sub>1</sub>: 9.82 t ha<sup>-1</sup> year<sup>-1</sup>) was marginally superior to Rice-Chickpea-Greengram. For soil health improvement, inclusion of legumes in Soybean-Chickpea-Greengram (T<sub>3</sub>: 8.06 t ha<sup>-1</sup> year<sup>-1</sup>) proved more beneficial. In family nutrition systems, Rice-Cabbage-Greengram (T<sub>5</sub>: 25.65 t ha<sup>-1</sup> year<sup>-1</sup>) and Rice-Mustard-Cowpea vegetable (T<sub>6</sub>: 25.54 t ha<sup>-1</sup> year<sup>-1</sup>) were statistically comparable. For livestock nutrition (green fodder), Maize-Berseem-Sorghum (T<sub>7</sub>: 13.72 t ha<sup>-1</sup> year<sup>-1</sup>) outperformed Rice bean-Berseem-Sorghum, while in concentrate feed systems, Kodo + Arhar-Maize (T<sub>10</sub>: 6.42 t ha<sup>-1</sup> year<sup>-1</sup>) surpassed Arhar + Soybean-Greengram

**Table 4.1:** Rice equivalent yield (t ha<sup>-1</sup> year<sup>-1</sup>) as influenced by different cropping sequences

| Cropping Sequences(System) |                                        | Rice equivalent yield (t ha <sup>-1</sup> year <sup>-1</sup> ) |           |        |
|----------------------------|----------------------------------------|----------------------------------------------------------------|-----------|--------|
| T. No.                     |                                        | 2023-2024                                                      | 2024-2025 | Pooled |
| T <sub>1</sub>             | Rice - Wheat - Green gram              | 9.63                                                           | 10.01     | 9.82   |
| T <sub>2</sub>             | Rice - Chickpea - Green gram           | 9.14                                                           | 9.67      | 9.41   |
| T <sub>3</sub>             | Soybean - Chickpea - Green gram        | 8.31                                                           | 7.81      | 8.06   |
| T <sub>4</sub>             | Arhar + Soybean (2:4)- Sesame          | 3.61                                                           | 3.76      | 3.68   |
| T <sub>5</sub>             | Rice - Cabbage - Green gram            | 24.67                                                          | 26.64     | 25.65  |
| T <sub>6</sub>             | Rice - Mustard - Cowpea (Vegetable)    | 24.93                                                          | 26.15     | 25.54  |
| T <sub>7</sub>             | Maize(f) - Berseem(f) - Sorghum(f)     | 14.01                                                          | 13.43     | 13.72  |
| T <sub>8</sub>             | Rice bean(f) - Berseem(f) - Sorghum(f) | 12.93                                                          | 11.25     | 12.09  |
| T <sub>9</sub>             | Arhar + Soybean (2:4)- Green gram      | 5.44                                                           | 4.80      | 5.12   |
| T <sub>10</sub>            | Kodo+ Arhar (4+2)- Maize               | 6.09                                                           | 6.75      | 6.42   |
| T <sub>11</sub>            | Cowpea - Cabbage - Okra                | 56.67                                                          | 57.94     | 57.30  |
| T <sub>12</sub>            | Okra - Brinjal - Amaranthus            | 46.85                                                          | 46.23     | 46.54  |
| SEM±                       |                                        | 0.81                                                           | 0.76      | 0.51   |
| CD (P =0.05)               |                                        | 2.51                                                           | 2.37      | 1.57   |

## 2. System productivity

Data in relation to system productivity (kg ha<sup>-1</sup> day<sup>-1</sup>) 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 4.2 showed considerable variation in system productivity among the cropping sequences under study.

The highest significant system productivity was recorded under Cowpea-Cabbage-Okra (T<sub>11</sub>: 156.99 kg ha<sup>-1</sup> day<sup>-1</sup>), followed by Okra-Brinjal-Amaranthus (T<sub>12</sub>: 127.51 kg ha<sup>-1</sup> day<sup>-1</sup>), which belonged to the vegetable-based systems. Within the family nutrition systems, Rice-Cabbage-Greengram (T<sub>5</sub>: 70.29 kg ha<sup>-1</sup> day<sup>-1</sup>) and Rice-Mustard-Cowpea vegetable (T<sub>6</sub>: 69.98 kg ha<sup>-1</sup> day<sup>-1</sup>) were statistically at par, indicating similar productivity. In the fodder-based systems, Maize-Berseem-Sorghum (T<sub>7</sub>: 37.59 kg ha<sup>-1</sup> day<sup>-1</sup>) outperformed Rice bean-Berseem-Sorghum. Among the check systems, Rice-Wheat-Greengram (T<sub>1</sub>: 26.91 kg ha<sup>-1</sup> day<sup>-1</sup>) was numerically higher than Rice-Chickpea-Greengram. In the soil health systems, Soybean-Chickpea-Greengram (T<sub>3</sub>: 22.09 kg ha<sup>-1</sup> day<sup>-1</sup>) was numerically superior to Arhar + Soybean-Sesame (T<sub>4</sub>: 10.09 kg ha<sup>-1</sup> day<sup>-1</sup>). For the concentrate feed systems, Kodo + Arhar-Maize (T<sub>10</sub>: 17.60 kg ha<sup>-1</sup> day<sup>-1</sup>) performed better than Arhar + Soybean. The lowest system productivity was observed in Arhar + Soybean-Sesame (T<sub>4</sub>: 10.09 kg ha<sup>-1</sup> day<sup>-1</sup>).

**Table 4.2:** System productivity (kg ha<sup>-1</sup> day<sup>-1</sup>) as influenced by different cropping sequences

| Cropping Sequences (System) |                                     | System productivity (kg ha <sup>-1</sup> day <sup>-1</sup> ) |           |        |
|-----------------------------|-------------------------------------|--------------------------------------------------------------|-----------|--------|
| T. No.                      |                                     | 2023-2024                                                    | 2024-2025 | Pooled |
| T <sub>1</sub>              | Rice - Wheat - Green gram           | 26.39                                                        | 27.43     | 26.91  |
| T <sub>2</sub>              | Rice - Chickpea - Green gram        | 25.05                                                        | 26.49     | 25.77  |
| T <sub>3</sub>              | Soybean - Chickpea - Green gram     | 22.77                                                        | 21.41     | 22.09  |
| T <sub>4</sub>              | Arhar + Soybean (2:4)- Sesame       | 9.88                                                         | 10.30     | 10.09  |
| T <sub>5</sub>              | Rice - Cabbage - Green gram         | 67.60                                                        | 72.97     | 70.29  |
| T <sub>6</sub>              | Rice - Mustard - Cowpea (Vegetable) | 68.31                                                        | 71.65     | 69.98  |
| T <sub>7</sub>              | Maize(f) - Berseem(f) - Sorghum(f)  | 38.39                                                        | 36.79     | 37.59  |

|                 |                                        |        |        |        |
|-----------------|----------------------------------------|--------|--------|--------|
| T <sub>8</sub>  | Rice bean(f) - Berseem(f) - Sorghum(f) | 35.43  | 30.82  | 33.12  |
| T <sub>9</sub>  | Arhar + Soybean (2:4)- Green gram      | 14.91  | 13.16  | 14.04  |
| T <sub>10</sub> | Kodo+ Arhar (4+2)- Maize               | 16.69  | 18.50  | 17.60  |
| T <sub>11</sub> | Cowpea - Cabbage - Okra                | 155.25 | 158.73 | 156.99 |
| T <sub>12</sub> | Okra - Brinjal - <i>Amaranthus</i>     | 128.36 | 126.66 | 127.51 |
|                 | SEm±                                   | 2.21   | 2.09   | 1.38   |
|                 | CD (P=0.05)                            | 6.88   | 6.50   | 4.31   |

### 4.3 Production efficiency

Data presented in Table 4.3 showed significant differences among the different cropping sequences with respect to production efficiency during the first and second year of experimentation as well as in pooled data. The highest production efficiency was recorded in Cowpea-Cabbage-Okra (T<sub>11</sub>: 280.89 kg ha<sup>-1</sup> day<sup>-1</sup>), followed by Okra-Brinjal-*Amaranthus* (T<sub>12</sub>: 202.35 kg ha<sup>-1</sup> day<sup>-1</sup>), whereas the lowest was observed in Arhar + Soybean-Sesame (T<sub>4</sub>: 15.35 kg ha<sup>-1</sup> day<sup>-1</sup>). Purpose-wise comparisons indicated that for the check system, Rice-Chickpea-Greengram (T<sub>2</sub>: 37.62 kg ha<sup>-1</sup> day<sup>-1</sup>) outperformed Rice-Wheat-Greengram. Under soil health systems, Soybean-Chickpea-Greengram (T<sub>3</sub>: 35.05 kg ha<sup>-1</sup>

day<sup>-1</sup>) was superior to Arhar + Soybean-Sesame. In family nutrition systems, Rice-Cabbage-Greengram (T<sub>5</sub>: 104.71 kg ha<sup>-1</sup> day<sup>-1</sup>) and Rice-Mustard-Cowpea (T<sub>6</sub>: 100.17 kg ha<sup>-1</sup> day<sup>-1</sup>) were statistically comparable. For livestock nutrition (green fodder), Maize-Berseem-Sorghum (T<sub>7</sub>: 48.14 kg ha<sup>-1</sup> day<sup>-1</sup>) exceeded Rice bean-Berseem-Sorghum, while in concentrate feed, Kodo + Arhar-Maize (T<sub>10</sub>: 32.11 kg ha<sup>-1</sup> day<sup>-1</sup>) outperformed Arhar + Soybean-Greengram. Among income enhancement systems, Cowpea-Cabbage-Okra (T<sub>11</sub>: 280.89 kg ha<sup>-1</sup> day<sup>-1</sup>) remained significantly superior to Okra-Brinjal-*Amaranthus*, recording the maximum production efficiency across all treatments.

**Table 4.3:** Production efficiency (kg ha<sup>-1</sup>day<sup>-1</sup>) as influenced by different cropping sequences

| Cropping Sequences (System) |                 |                                        | Production efficiency(kg ha <sup>-1</sup> day <sup>-1</sup> ) |           |        |
|-----------------------------|-----------------|----------------------------------------|---------------------------------------------------------------|-----------|--------|
| Total Crop Duration( Days)  | T. No.          |                                        | 2023-2024                                                     | 2024-2025 | Pooled |
| 270                         | T <sub>1</sub>  | Rice - Wheat - Green gram              | 35.68                                                         | 37.09     | 36.38  |
| 250                         | T <sub>2</sub>  | Rice - Chickpea - Green gram           | 36.58                                                         | 38.67     | 37.62  |
| 230                         | T <sub>3</sub>  | Soybean - Chickpea - Green gram        | 36.13                                                         | 33.97     | 35.05  |
| 240                         | T <sub>4</sub>  | Arhar + Soybean (2:4)- Sesame          | 15.03                                                         | 15.66     | 15.35  |
| 245                         | T <sub>5</sub>  | Rice - Cabbage - Green gram            | 100.70                                                        | 108.72    | 104.71 |
| 255                         | T <sub>6</sub>  | Rice - Mustard - Cowpea (Vegetable)    | 97.78                                                         | 102.55    | 100.17 |
| 285                         | T <sub>7</sub>  | Maize(f) - Berseem(f) - Sorghum(f)     | 49.16                                                         | 47.11     | 48.14  |
| 302                         | T <sub>8</sub>  | Rice bean(f) - Berseem(f) - Sorghum(f) | 42.82                                                         | 37.24     | 40.03  |
| 200                         | T <sub>9</sub>  | Arhar + Soybean (2:4)- Green gram      | 27.21                                                         | 24.02     | 25.61  |
| 200                         | T <sub>10</sub> | Kodo+ Arhar (4+2)- Maize               | 30.47                                                         | 33.76     | 32.11  |
| 204                         | T <sub>11</sub> | Cowpea - Cabbage - Okra                | 277.78                                                        | 284.01    | 280.89 |
| 230                         | T <sub>12</sub> | Okra - Brinjal - <i>Amaranthus</i>     | 203.70                                                        | 201.00    | 202.35 |
|                             |                 | SEm±                                   | 3.79                                                          | 2.95      | 2.14   |
|                             |                 | CD (P =0.05)                           | 11.78                                                         | 9.18      | 6.66   |

### 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.

Land use efficiency varied significantly among the cropping sequences. The highest land use efficiency was recorded in Rice bean-Berseem-Sorghum (T<sub>8</sub>: 81.85%), followed by Maize-Berseem-Sorghum (T<sub>7</sub>: 77.50%), whereas the lowest was observed in Arhar + Soybean-Greengram (T<sub>9</sub>: 54.10%). For the check system, Rice-Wheat-Greengram (T<sub>1</sub>: 74.71%) outperformed Rice-Chickpea-Greengram, while under soil health systems, Soybean-Chickpea-Greengram (T<sub>3</sub>: 62.40%) was marginally higher than Arhar + Soybean-Sesame. In family

nutrition systems, Rice-Mustard-Cowpea (T<sub>6</sub>: 70.03%) remained superior to Rice-Cabbage-Greengram, both performing better than the soil health-based sequences. For livestock nutrition (green fodder), Rice bean-Berseem-Sorghum (T<sub>8</sub>: 81.85%) surpassed Maize-Berseem-Sorghum, reflecting the highest efficiencies across all treatments. In concentrate feed systems, Kodo + Arhar-Maize (T<sub>10</sub>: 61.54%) marginally outperformed Arhar + Soybean-Greengram, though both were relatively less efficient. Among income enhancement systems, Okra-Brinjal-*Amaranthus* (T<sub>12</sub>: 62.19%) exceeded Cowpea-Cabbage-Okra, but these remained much lower compared to fodder-based systems.

**Table 4.4:** Land use efficiency (%) as influenced by different cropping sequence

| Cropping Sequences (System) |                 |                                        | Land Use efficiency (%) |           |        |
|-----------------------------|-----------------|----------------------------------------|-------------------------|-----------|--------|
| Total Number of Days        | T. No.          |                                        | 2023-2024               | 2024-2025 | Pooled |
| 270                         | T <sub>1</sub>  | Rice - Wheat - Green gram              | 75.34                   | 74.08     | 74.71  |
| 250                         | T <sub>2</sub>  | Rice - Chickpea - Green gram           | 69.86                   | 68.08     | 68.97  |
| 230                         | T <sub>3</sub>  | Soybean - Chickpea - Green gram        | 61.64                   | 63.16     | 62.40  |
| 240                         | T <sub>4</sub>  | Arhar + Soybean (2:4)- Sesame          | 65.75                   | 63.07     | 64.41  |
| 245                         | T <sub>5</sub>  | Rice - Cabbage - Green gram            | 65.75                   | 67.00     | 66.38  |
| 255                         | T <sub>6</sub>  | Rice - Mustard - Cowpea (Vegetables)   | 69.86                   | 70.19     | 70.03  |
| 285                         | T <sub>7</sub>  | Maize(f) - Berseem(f) - Sorghum(f)     | 77.00                   | 78.00     | 77.50  |
| 302                         | T <sub>8</sub>  | Rice bean(f) - Berseem(f) - Sorghum(f) | 80.67                   | 83.04     | 81.85  |
| 200                         | T <sub>9</sub>  | Arhar + Soybean (2:4)- Green gram      | 53.00                   | 55.19     | 54.10  |
| 200                         | T <sub>10</sub> | Kodo+ Arhar (4+2)- Maize               | 68.00                   | 55.07     | 61.54  |
| 204                         | T <sub>11</sub> | Cowpea - Cabbage - Okra                | 57.00                   | 56.07     | 56.54  |
| 230                         | T <sub>12</sub> | Okra - Brinjal - <i>Amaranthus</i>     | 61.33                   | 63.04     | 62.19  |
|                             |                 | SEm±                                   | 2.78                    | 3.16      | 1.69   |
|                             |                 | CD (P =0.05)                           | 8.65                    | 9.84      | 5.25   |

## 5. Water Productivity

Water productivity was estimated and presented in Table 4.5. Data presented in table indicated the variation the cropping sequences during both the years as well as pooled data.

Water productivity differed significantly among the cropping sequences. The highest value was recorded in Cowpea-Cabbage-Okra ( $T_{11}$ : 24.44 kg ha<sup>-1</sup> mm<sup>-1</sup>), followed by Okra-Brinjal-*Amaranthus* ( $T_{12}$ : 20.73 kg ha<sup>-1</sup> mm<sup>-1</sup>), whereas the lowest was observed in Arhar + Soybean-Sesame ( $T_4$ : 2.38 kg ha<sup>-1</sup> mm<sup>-1</sup>). Purpose-wise comparisons revealed that in the check system, Rice-Chickpea-Greengram ( $T_2$ : 3.37 kg ha<sup>-1</sup> mm<sup>-1</sup>) was slightly superior to Rice-Wheat-Greengram. Under soil health systems,

Soybean-Chickpea-Greengram ( $T_3$ : 4.76 kg ha<sup>-1</sup> mm<sup>-1</sup>) markedly outperformed Arhar + Soybean-Sesame. In family nutrition systems, Rice-Mustard-Cowpea ( $T_6$ : 8.53 kg ha<sup>-1</sup> mm<sup>-1</sup>) was at par with Rice-Cabbage-Greengram. For livestock nutrition (green fodder), Maize-Berseem-Sorghum ( $T_7$ : 5.19 kg ha<sup>-1</sup> mm<sup>-1</sup>) proved superior to Rice bean-Berseem-Sorghum. In concentrate feed systems, Kodo + Arhar-Maize ( $T_{10}$ : 3.39 kg ha<sup>-1</sup> mm<sup>-1</sup>) recorded higher water productivity than Arhar + Soybean-Greengram. Among income enhancement systems, Cowpea-Cabbage-Okra ( $T_{11}$ : 24.44 kg ha<sup>-1</sup> mm<sup>-1</sup>) was significantly superior to Okra-Brinjal-*Amaranthus*, and also registered the maximum water productivity across all treatments

**Table 4.5:** Water productivity (kg ha<sup>-1</sup>mm<sup>-1</sup>) as influenced by different cropping sequences

| Cropping Sequences (System) |          |                                        | Water productivity (Kg ha <sup>-1</sup> mm <sup>-1</sup> ) |           |        |
|-----------------------------|----------|----------------------------------------|------------------------------------------------------------|-----------|--------|
| Total water consume (mm)    | T. No.   |                                        | 2023-2024                                                  | 2024-2025 | Pooled |
| 3045                        | $T_1$    | Rice - Wheat - Green gram              | 3.16                                                       | 3.29      | 3.23   |
| 2795                        | $T_2$    | Rice - Chickpea - Green gram           | 3.27                                                       | 3.46      | 3.37   |
| 1695                        | $T_3$    | Soybean - Chickpea - Green gram        | 4.90                                                       | 4.61      | 4.76   |
| 1545                        | $T_4$    | Arhar + Soybean (2:4)- Sesame          | 2.33                                                       | 2.43      | 2.38   |
| 3045                        | $T_5$    | Rice - Cabbage - Green gram            | 8.10                                                       | 8.75      | 8.43   |
| 2995                        | $T_6$    | Rice - Mustard - Cowpea (Vegetable)    | 8.33                                                       | 8.73      | 8.53   |
| 2645                        | $T_7$    | Maize(f) - Berseem(f) - Sorghum(f)     | 5.30                                                       | 5.08      | 5.19   |
| 2645                        | $T_8$    | Rice bean(f) - Berseem(f) - Sorghum(f) | 4.89                                                       | 4.25      | 4.57   |
| 1545                        | $T_9$    | Arhar + Soybean (2:4)- Green gram      | 3.52                                                       | 3.11      | 3.32   |
| 1895                        | $T_{10}$ | Kodo+ Arhar (4+2)- Maize               | 3.22                                                       | 3.56      | 3.39   |
| 2345                        | $T_{11}$ | Cowpea - Cabbage - Okra                | 24.17                                                      | 24.71     | 24.44  |
| 2245                        | $T_{12}$ | Okra - Brinjal - <i>Amaranthus</i>     | 20.87                                                      | 20.59     | 20.73  |
|                             |          | SEM±                                   | 0.34                                                       | 0.28      | 0.20   |
|                             |          | CD (P =0.05)                           | 1.07                                                       | 0.88      | 0.62   |

## 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 cost of cultivation (₹ × 10<sup>3</sup> ha<sup>-1</sup>) were estimated for both the years 2023-24 and 2024-25 and are presented in Table 4.19. On average, the highest cost of cultivation (208.32 ₹ × 10<sup>3</sup> ha<sup>-1</sup>) was recorded under  $T_{11}$  (Cowpea - Cabbage - Okra), followed by  $T_{12}$  (Okra - Brinjal - *Amaranthus*, 178.99 ₹ × 10<sup>3</sup> ha<sup>-1</sup>). In contrast, the lowest cost of cultivation (58.96 ₹ × 10<sup>3</sup> ha<sup>-1</sup>) was observed under  $T_9$  (Arhar + Soybean (2:4) - Green gram).

Within the check sequences,  $T_1$  (Rice - Wheat - Green gram,

116.85 ₹ × 10<sup>3</sup> ha<sup>-1</sup>) recorded slightly higher cost of cultivation than  $T_2$  (Rice - Chickpea - Green gram), primarily due to the higher seed and fertilizer requirements for wheat. For the soil health sequences,  $T_3$  (Soybean - Chickpea - Green gram, 104.93 ₹ × 10<sup>3</sup> ha<sup>-1</sup>) incurred higher cultivation cost, whereas  $T_4$  (Arhar + Soybean (2:4) - Sesame) required comparatively lower investment. Among family nutrition sequences,  $T_6$  (Rice - Mustard - Cowpea, 148.86 ₹ × 10<sup>3</sup> ha<sup>-1</sup>) recorded higher cost of cultivation, while  $T_5$  (Rice - Cabbage - Green gram). For green fodder production,  $T_7$  (Maize - Berseem - Sorghum, 117.01 ₹ × 10<sup>3</sup> ha<sup>-1</sup>) had higher cultivation cost, whereas  $T_8$  (Rice bean - Berseem - Sorghum) required lower investment. In the concentrate feed sequences,  $T_{10}$  (Kodo + Arhar - Maize, 65.50 ₹ × 10<sup>3</sup> ha<sup>-1</sup>) recorded higher cost of cultivation, while  $T_9$  (Arhar + Soybean (2:4) - Green gram) incurred the lowest investment

**Table 4.19:** Cost of cultivation (₹. x 10<sup>3</sup> ha<sup>-1</sup>) as influenced by different crops sequences

| Cropping Sequences(System) |                                        | Cost of cultivation (₹. x 10 <sup>3</sup> ha <sup>-1</sup> ) |           |        |
|----------------------------|----------------------------------------|--------------------------------------------------------------|-----------|--------|
|                            |                                        | 2023-2024                                                    | 2024-2025 | Mean   |
| $T_1$                      | Rice - Wheat - Green gram              | 117.47                                                       | 116.23    | 116.85 |
| $T_2$                      | Rice - Chickpea - Green gram           | 114.59                                                       | 113.52    | 114.06 |
| $T_3$                      | Soybean - Chickpea - Green gram        | 105.67                                                       | 104.19    | 104.93 |
| $T_4$                      | Arhar + Soybean (2:4)- Sesame          | 64.27                                                        | 63.55     | 63.91  |
| $T_5$                      | Rice - Cabbage - Green gram            | 139.42                                                       | 137.41    | 138.41 |
| $T_6$                      | Rice - Mustard - Cowpea (Vegetable)    | 150.35                                                       | 147.37    | 148.86 |
| $T_7$                      | Maize(f) - Berseem(f) - Sorghum(f)     | 117.76                                                       | 116.27    | 117.01 |
| $T_8$                      | Rice bean(f) - Berseem(f) - Sorghum(f) | 111.96                                                       | 110.63    | 111.30 |
| $T_9$                      | Arhar + Soybean (2:4)- Green gram      | 60.68                                                        | 57.25     | 58.96  |
| $T_{10}$                   | Kodo+ Arhar (4+2)- Maize               | 66.23                                                        | 64.78     | 65.50  |
| $T_{11}$                   | Cowpea - Cabbage - Okra                | 208.89                                                       | 207.74    | 208.32 |
| $T_{12}$                   | Okra - Brinjal - <i>Amaranthus</i>     | 179.54                                                       | 178.44    | 178.99 |

## Gross monetary returns

Data pertaining to gross monetary returns (₹ × 10<sup>3</sup> ha<sup>-1</sup>) were estimated for both the years 2023-24 and 2024-25 and are presented in Table 4.20. On average, the highest gross monetary returns (1317.96 ₹ × 10<sup>3</sup> ha<sup>-1</sup>) were recorded under income enhancement generation cropping system  $T_{11}$  (Cowpea - Cabbage - Okra), followed by  $T_{12}$  (Okra - Brinjal - *Amaranthus*, 1070.43 ₹ × 10<sup>3</sup> ha<sup>-1</sup>). In contrast, the lowest returns (84.71 ₹ ×

10<sup>3</sup> ha<sup>-1</sup>) were observed under  $T_4$  (Arhar + Soybean (2:4) - Sesame).

Within the check sequences,  $T_1$  (Rice - Wheat - Green gram, 225.92 ₹ × 10<sup>3</sup> ha<sup>-1</sup>) outperformed  $T_2$  (Rice - Chickpea - Green gram) due to the higher market value and productivity of wheat. For soil health sequences,  $T_3$  (Soybean - Chickpea - Green gram, 185.43 ₹ × 10<sup>3</sup> ha<sup>-1</sup>) showed better returns compared to  $T_4$  (Arhar + Soybean (2:4) - Sesame), indicating moderate

profitability of pulse-based systems. Among family nutrition sequences, T<sub>5</sub> (Rice - Cabbage - Green gram, 590.04 ₹ × 10<sup>3</sup> ha<sup>-1</sup>) slightly surpassed T<sub>6</sub> (Rice - Mustard - Cowpea), highlighting the role of high-value vegetables in enhancing system returns. For green fodder production, T<sub>7</sub> (Maize - Berseem - Sorghum, 315.55 ₹ × 10<sup>3</sup> ha<sup>-1</sup>) achieved higher

returns than T<sub>8</sub> (Rice bean - Berseem - Sorghum), reflecting the influence of maize productivity and market value. In concentrate feed sequences, T<sub>10</sub> (Kodo + Arhar - Maize, 147.72 ₹ × 10<sup>3</sup> ha<sup>-1</sup>) provided better returns compared to T<sub>9</sub> (Arhar + Soybean (2:4) - Green gram).

**Table 4.20:** Gross monetary returns (₹. x 10<sup>3</sup> ha<sup>-1</sup>) as influenced by different crops sequences

| Cropping Sequences (System) |                                        | Gross monetary returns (₹. x 10 <sup>3</sup> ha <sup>-1</sup> ) |           |         |
|-----------------------------|----------------------------------------|-----------------------------------------------------------------|-----------|---------|
| T. No.                      |                                        | 2023-2024                                                       | 2024-2025 | Mean    |
| T <sub>1</sub>              | Rice - Wheat - Green gram              | 221.55                                                          | 230.30    | 225.92  |
| T <sub>2</sub>              | Rice - Chickpea - Green gram           | 210.31                                                          | 222.36    | 216.34  |
| T <sub>3</sub>              | Soybean - Chickpea - Green gram        | 191.14                                                          | 179.71    | 185.43  |
| T <sub>4</sub>              | Arhar + Soybean (2:4)- Sesame          | 82.95                                                           | 86.46     | 84.71   |
| T <sub>5</sub>              | Rice - Cabbage - Green gram            | 567.47                                                          | 612.62    | 590.04  |
| T <sub>6</sub>              | Rice - Mustard - Cowpea (Vegetable)    | 573.50                                                          | 601.47    | 587.49  |
| T <sub>7</sub>              | Maize(f) - Berseem(f) - Sorghum(f)     | 322.27                                                          | 308.82    | 315.55  |
| T <sub>8</sub>              | Rice bean(f) - Berseem(f) - Sorghum(f) | 297.44                                                          | 258.70    | 278.07  |
| T <sub>9</sub>              | Arhar + Soybean (2:4)- Green gram      | 125.17                                                          | 110.49    | 117.83  |
| T <sub>10</sub>             | Kodo+ Arhar (4+2)- Maize               | 140.14                                                          | 155.31    | 147.72  |
| T <sub>11</sub>             | Cowpea - Cabbage - Okra                | 1303.35                                                         | 1332.57   | 1317.96 |
| T <sub>12</sub>             | Okra - Brinjal - <i>Amaranthus</i>     | 1077.57                                                         | 1063.29   | 1070.43 |

### Net monetary returns

Data pertaining to net monetary returns (₹ × 10<sup>3</sup> ha<sup>-1</sup>) were estimated for both the years 2023-24 and 2024-25 and are presented in Table 4.21.

On average, the highest net returns (1109.64 ₹ × 10<sup>3</sup> ha<sup>-1</sup>) were achieved under the income enhancement cropping system T<sub>11</sub> (Cowpea - Cabbage - Okra), followed by T<sub>12</sub> (Okra - Brinjal - *Amaranthus*, 891.44 ₹ × 10<sup>3</sup> ha<sup>-1</sup>) and T<sub>5</sub> (Rice - Cabbage - Green gram, 451.63 ₹ × 10<sup>3</sup> ha<sup>-1</sup>). These sequences realized elevated returns due to the combined effect of high system productivity and the market value of vegetable crops. Similarly, T<sub>6</sub> (Rice - Mustard - Cowpea, 438.63 ₹ × 10<sup>3</sup> ha<sup>-1</sup>) registered substantial net returns owing to the inclusion of cowpea as a vegetable crop.

Within the check sequences, T<sub>1</sub> (Rice - Wheat - Green gram, 109.07 ₹ × 10<sup>3</sup> ha<sup>-1</sup>) attained slightly higher net returns than T<sub>2</sub> (Rice - Chickpea - Green gram) primarily due to better profitability from wheat. For the soil health sequences, T<sub>3</sub> (Soybean - Chickpea - Green gram) showed moderate net returns, whereas T<sub>4</sub> (Arhar + Soybean (2:4) - Sesame, 20.80 ₹ × 10<sup>3</sup> ha<sup>-1</sup>) registered the lowest net returns among all sequences. Among green fodder production sequences, T<sub>7</sub> (Maize - Berseem - Sorghum, 198.53 ₹ × 10<sup>3</sup> ha<sup>-1</sup>) attained higher returns compared to T<sub>8</sub> (Rice bean - Berseem - Sorghum). In the concentrate feed sequences, T<sub>10</sub> (Kodo + Arhar - Maize, 82.22 ₹ × 10<sup>3</sup> ha<sup>-1</sup>) observed better returns compared to T<sub>9</sub> (Arhar + Soybean (2:4) - Green gram, 58.86 ₹ × 10<sup>3</sup> ha<sup>-1</sup>).

**Table 4.21:** Net monetary returns (₹ × 10<sup>3</sup> ha<sup>-1</sup>) as influenced by different crops sequences

| Cropping Sequences ( System) |                                        | Net monetary returns (₹ × 10 <sup>3</sup> ha <sup>-1</sup> ) |           |         |
|------------------------------|----------------------------------------|--------------------------------------------------------------|-----------|---------|
| T. No.                       |                                        | 2023-2024                                                    | 2024-2025 | Mean    |
| T <sub>1</sub>               | Rice - Wheat - Green gram              | 104.08                                                       | 114.07    | 109.07  |
| T <sub>2</sub>               | Rice - Chickpea - Green gram           | 95.72                                                        | 108.84    | 102.28  |
| T <sub>3</sub>               | Soybean - Chickpea - Green gram        | 85.48                                                        | 75.52     | 80.50   |
| T <sub>4</sub>               | Arhar + Soybean (2:4)- Sesame          | 18.68                                                        | 22.91     | 20.80   |
| T <sub>5</sub>               | Rice - Cabbage - Green gram            | 428.05                                                       | 475.21    | 451.63  |
| T <sub>6</sub>               | Rice - Mustard - Cowpea (Vegetable)    | 423.15                                                       | 454.10    | 438.63  |
| T <sub>7</sub>               | Maize(f) - Berseem(f) - Sorghum(f)     | 204.51                                                       | 192.55    | 198.53  |
| T <sub>8</sub>               | Rice bean(f) - Berseem(f) - Sorghum(f) | 185.47                                                       | 148.07    | 166.77  |
| T <sub>9</sub>               | Arhar + Soybean (2:4)- Green gram      | 64.49                                                        | 53.24     | 58.86   |
| T <sub>10</sub>              | Kodo+ Arhar (4+2)- Maize               | 73.92                                                        | 90.53     | 82.22   |
| T <sub>11</sub>              | Cowpea - Cabbage - Okra                | 1094.45                                                      | 1124.83   | 1109.64 |
| T <sub>12</sub>              | Okra - Brinjal - <i>Amaranthus</i>     | 898.03                                                       | 884.85    | 891.44  |

### 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 4.22.

The highest B: C ratio (6.33) was recorded under T<sub>11</sub> (Cowpea - Cabbage - Okra), followed by T<sub>12</sub> (Okra - Brinjal - *Amaranthus*, 5.98) and T<sub>5</sub> (Rice - Cabbage - Green gram, 4.26). This trend revealed that sequences integrating high-value vegetables achieved superior economic efficiency, driven by elevated system productivity (REY) and substantial net returns. Similarly, T<sub>6</sub> (Rice - Mustard - Cowpea, 3.95) found high profitability, attributed to the contribution of cowpea and enhanced system productivity.

Within the check sequences, T<sub>1</sub> (Rice - Wheat - Green gram, 1.93) recorded slightly higher B: C ratio than T<sub>2</sub> (Rice - Chickpea - Green gram), reflecting marginally better net returns from wheat. For soil health sequences, T<sub>3</sub> (Soybean - Chickpea - Green gram) revealed moderate profitability, whereas T<sub>4</sub> (Arhar + Soybean (2:4) - Sesame) recorded the lowest B: C ratio, consistent with lower net returns and REY. Among green fodder sequences, T<sub>7</sub> (Maize - Berseem - Sorghum) recorded higher profitability than T<sub>8</sub> (Rice bean - Berseem - Sorghum), highlighting the influence of maize-based productivity. In concentrate feed sequences, T<sub>10</sub> (Kodo + Arhar - Maize, 2.26) achieved moderate B: C ratio, while T<sub>9</sub> (Arhar + Soybean (2:4) - Green gram) recorded the lowest, reflecting relatively lower net returns.

**Table 4.22:** Benefit cost ratio as influenced by different cropping sequences

| Cropping Sequences (System ) |                                        | Benefit cost ratio |           |      |
|------------------------------|----------------------------------------|--------------------|-----------|------|
| T. No.                       |                                        | 2023-2024          | 2024-2025 | Mean |
| T <sub>1</sub>               | Rice - Wheat - Green gram              | 1.89               | 1.98      | 1.93 |
| T <sub>2</sub>               | Rice - Chickpea - Green gram           | 1.84               | 1.96      | 1.90 |
| T <sub>3</sub>               | Soybean - Chickpea - Green gram        | 1.81               | 1.72      | 1.77 |
| T <sub>4</sub>               | Arhar + Soybean (2:4)- Sesame          | 1.29               | 1.36      | 1.33 |
| T <sub>5</sub>               | Rice - Cabbage - Green gram            | 4.07               | 4.46      | 4.26 |
| T <sub>6</sub>               | Rice - Mustard - Cowpea (Vegetable)    | 3.81               | 4.08      | 3.95 |
| T <sub>7</sub>               | Maize(f) - Berseem(f) - Sorghum(f)     | 2.74               | 2.66      | 2.70 |
| T <sub>8</sub>               | Rice bean(f) - Berseem(f) - Sorghum(f) | 2.66               | 2.34      | 2.50 |
| T <sub>9</sub>               | Arhar + Soybean (2:4)- Green gram      | 2.06               | 1.93      | 2.00 |
| T <sub>10</sub>              | Kodo+ Arhar (4+2)- Maize               | 2.12               | 2.40      | 2.26 |
| T <sub>11</sub>              | Cowpea - Cabbage - Okra                | 6.24               | 6.41      | 6.33 |
| T <sub>12</sub>              | Okra - Brinjal - <i>Amaranthus</i>     | 6.00               | 5.96      | 5.98 |

## 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

### 5.1 Edaphic Conditions

The soil of the experimental field belongs to the Vertisol group, typical of the Mahakoshal region of Madhya Pradesh, and is characterized by sandy loam texture, as confirmed by the pipette method (Piper, 1966). The physical analysis revealed 56% sand, 19.4% silt, and 24.6% clay, categorizing it as sandy loam, suitable for a wide range of field crops including cereals, legumes, and vegetables.

The chemical analysis of the initial soil (before sowing Kharif 2023) indicated a slightly alkaline pH of 7.57, normal EC (0.38 dS m<sup>-1</sup>), and moderate organic carbon content (7.10 g kg<sup>-1</sup>). The availability of primary nutrients varied: nitrogen was moderate (260 kg ha<sup>-1</sup>), phosphorus was low (11.5 kg ha<sup>-1</sup>), and potassium was moderate (282 kg ha<sup>-1</sup>). These values suggest a reasonably fertile soil with room for improvement through the inclusion of legumes and organic amendments in the cropping systems.

The biological properties of the soil, including microbial counts, were also assessed. The initial population in 2023 showed total bacteria count of  $40.25 \times 10^5$  cfu g<sup>-1</sup>, fungi  $30.14 \times 10^5$  cfu g<sup>-1</sup>, and actinomycetes  $10.33 \times 10^5$  cfu g<sup>-1</sup>. These values indicated normal microbial activity, essential for maintaining soil biological health and nutrient cycling. In 2024, a slight increase in microbial populations was recorded, suggesting improved biological activity possibly due to crop residue incorporation, root exudates from legume crops, or microbial-friendly practices used in different cropping sequences. Overall, the edaphic conditions were conducive to supporting intensive and diversified cropping systems. However, the low phosphorus levels necessitated integrated nutrient management strategies, particularly in phosphorus-demanding cropping sequences. The inclusion of legume crops and balanced fertilization practices appeared to have positively influenced both nutrient status and microbial properties of the soil.

### 5.2 Weather Conditions

The experiment was conducted under the typical climatic conditions of Kymore Plateau and Satpura Hills Zone, a sub-humid (dry) agro-ecological region classified as zone 10.1 by the National Bureau of Soil Survey and Land Use Planning (NBSS&LUP), Nagpur. The region experiences three distinct

seasons: Kharif (mid-June to September), Rabi (October to March), and Zaid (April to mid-June). During the experimental period, the average annual rainfall recorded was 1680.9 mm in 2023-24 and 1237.9 mm in 2024-25, with 73 and 39 rainy days, respectively. Although the second year experienced below-average rainfall compared to the regional norm (1350 mm), the distribution was fairly uniform during the crop growth stages, which supported favorable crop establishment and development.

The temperature range during the crop seasons varied from a minimum of 5.8°C in winter to a maximum of 42.4°C in summer in the first year, and 6.1°C to 39.7°C in the second year. Relative humidity remained high during the Kharif season (up to 96%) and dropped during the Rabi and Zaid seasons (as low as 20%). Evapotranspiration ranged from 1.0 to 9.4 mm across the seasons, while sunshine hours ranged from 0.8 to 10.80 hours per day, with a total of 340.3 hours in 2023-24 and 295.1 hours in 2024-25.

Despite the variations in annual rainfall, the climatic conditions remained within the favorable range for most crops, particularly in diversified cropping systems that included moisture-efficient and drought-resilient crops. For instance, the moisture-retaining capacity of Vertisols benefited water-sensitive crops like rice during Kharif, while the periodical dry spells during maturity stages reduced the incidence of lodging and pest infestation. Similarly, winter legumes and oilseeds performed well under the moderate Rabi temperature and humidity conditions. Thus, the agro-climatic conditions during both years were largely favorable for evaluating the performance of diversified cropping systems, especially in terms of crop productivity, resource use efficiency, and soil health sustainability.

### 5.3 Rice Equivalent Yield

Rice equivalent yield (REY) is a comprehensive measure that allows comparison of productivity across different crops by converting their yields into rice equivalents based on prevailing market prices. This approach is particularly useful for evaluating diversified cropping systems against traditional cereal-based sequences.

In the present investigation, REY values varied significantly among different cropping systems. The highest system REY was recorded under Cowpea-Cabbage-Okra (57.30 t ha<sup>-1</sup> year<sup>-1</sup>), followed by Okra-Brinjal-*Amaranthus* (46.54 t ha<sup>-1</sup> year<sup>-1</sup>), establishing the superiority of vegetable-based diversified sequences. The remarkable performance of these systems may be attributed to their higher biological productivity, shorter crop duration that permitted multiple harvests within a year, and the premium market prices of vegetables such as cabbage, okra, and brinjal, which substantially enhanced the system REY. In purpose-wise evaluation, differences among the check and targeted systems were also evident. Among the check sequences, Rice-Wheat-Greengram proved marginally superior, while Soybean-Chickpea-Greengram exhibited higher productivity under soil health systems, largely due to the positive influence of legumes on soil fertility and nitrogen balance. Within family nutrition systems, Rice-Cabbage-Greengram and Rice-Mustard-

Cowpea vegetable were statistically at par, both contributing to balanced household nutrition along with productivity. Similarly, in livestock-oriented systems, Maize-Berseem-Sorghum performed better by producing a higher quantity of green fodder, whereas in concentrate feed systems, Kodo + Arhar-Maize outyielded other sequences, thereby meeting the dual objectives of productivity and animal feed security.

The inclusion of legumes such as cowpea, soybean, and greengram in diversified systems further contributed to sustaining REY through biological nitrogen fixation, improved soil fertility, and enhanced nutrient cycling. This synergistic effect of legumes explains their consistent role in supporting both productivity and sustainability across different sequences.

The findings of the present study are in close agreement with earlier reports, where vegetable-based cropping systems outperformed cereal-dominated sequences in terms of REY. Patra *et al.*, Kalita *et al.*, Kumar *et al.*, and Singh *et al.* Similar observations were made by Kumar *et al.*, Upadhyay *et al.*, and Ravisankar *et al.* who emphasized that diversification with vegetables not only enhances productivity but also improves profitability over conventional rice-wheat or rice-chickpea sequences.

#### 5.4 System productivity

System productivity ( $\text{kg ha}^{-1} \text{ day}^{-1}$ ) is an important indicator that reflects the efficiency of land use and the integrated performance of different component crops over time. In the present study, considerable variation was recorded among the cropping sequences. The highest system productivity was obtained under Cowpea-Cabbage-Okra ( $156.99 \text{ kg ha}^{-1} \text{ day}^{-1}$ ), followed by Okra-Brinjal-*Amaranthus* ( $127.51 \text{ kg ha}^{-1} \text{ day}^{-1}$ ), both belonging to vegetable-based systems. Their superiority is attributed to the shorter growth duration of vegetables, higher biological productivity, and premium market value, which enabled multiple crops per year and enhanced returns per unit time.

Within the family nutrition systems, Rice-Cabbage-Greengram (70.29) and Rice-Mustard-Cowpea vegetable (69.98) were statistically comparable, ensuring balanced productivity along with nutritional diversity. Among fodder-based systems, Maize-Berseem-Sorghum (37.59) performed better due to its high fodder yield potential. In the check systems, Rice-Wheat-Greengram (26.91) proved superior to Rice-Chickpea-Greengram, while in soil health systems, Soybean-Chickpea-Greengram (22.09) outperformed Arhar + Soybean-Sesame, owing to the beneficial role of legumes in biological nitrogen fixation and soil fertility improvement. For concentrate feed systems, Kodo + Arhar-Maize (17.60) recorded higher productivity, whereas the lowest system productivity was observed under Arhar + Soybean-Sesame.

These findings are in close agreement with earlier reports and are supported by Raj *et al.* (2015) [30], Dwivedi *et al.* (2020), Kushwaha *et al.* (2020) [19], and Ahirwar & Sharma (2021) [2], who confirmed the superiority of vegetable- and legume-based systems in terms of productivity and sustainability.

#### 5.5 Production efficiency

Production efficiency is an important index that measures the output obtained per unit area per unit time, generally expressed as kilogram yield per hectare per day. It reflects the intensity of resource utilization and helps to assess the comparative advantage of different cropping systems. A higher production efficiency indicates that the system is able to produce more yield within a shorter duration, thereby maximizing land use efficiency and ensuring better economic returns. This makes production efficiency a crucial parameter in evaluating the sustainability and profitability of diversified cropping systems. The results presented in Table 4.3 and illustrated in Figure 4.3 revealed significant differences among the evaluated cropping sequences during both the years of experimentation as well as in

pooled data. The highest production efficiency was recorded in Cowpea-Cabbage-Okra ( $280.89 \text{ kg ha}^{-1} \text{ day}^{-1}$ ), followed by Okra-Brinjal-*Amaranthus* ( $202.35 \text{ kg ha}^{-1} \text{ day}^{-1}$ ), whereas the lowest was observed in Arhar + Soybean-Sesame ( $15.35 \text{ kg ha}^{-1} \text{ day}^{-1}$ ). The superior performance of Cowpea-Cabbage-Okra can be attributed to the inclusion of short-duration and high-yielding vegetable crops which not only provided higher biomass output but also completed their growth cycles quickly, thereby ensuring a greater return on a daily basis.

Purpose-wise evaluation of systems further highlighted these trends. Within the check system, Rice-Chickpea-Greengram ( $37.62 \text{ kg ha}^{-1} \text{ day}^{-1}$ ) recorded higher production efficiency compared to Rice-Wheat-Greengram, due to the better productivity and shorter duration of chickpea and greengram compared with wheat. Under soil health-based systems, Soybean-Chickpea-Greengram ( $35.05 \text{ kg ha}^{-1} \text{ day}^{-1}$ ) outperformed Arhar + Soybean-Sesame, which can be explained by the sequential legume-based cropping sequence contributing to better soil fertility and efficient time utilization. For family nutrition systems, Rice-Cabbage-Greengram ( $104.71 \text{ kg ha}^{-1} \text{ day}^{-1}$ ) and Rice-Mustard-Cowpea ( $100.17 \text{ kg ha}^{-1} \text{ day}^{-1}$ ) performed statistically at par, reflecting the advantage of incorporating vegetables and pulses which ensured higher daily productivity.

In livestock nutrition systems, particularly green fodder-based, Maize-Berseem-Sorghum ( $48.14 \text{ kg ha}^{-1} \text{ day}^{-1}$ ) recorded higher efficiency compared to Rice bean-Berseem-Sorghum, owing to the inclusion of high biomass-producing fodder crops like sorghum. Similarly, in concentrate feed systems, Kodo + Arhar-Maize ( $32.11 \text{ kg ha}^{-1} \text{ day}^{-1}$ ) surpassed Arhar + Soybean-Greengram because of the relatively better productivity of maize as a component crop. Among income enhancement systems, Cowpea-Cabbage-Okra ( $280.89 \text{ kg ha}^{-1} \text{ day}^{-1}$ ) stood out distinctly superior over Okra-Brinjal-*Amaranthus*, thus reaffirming the role of vegetable-based intensive cropping systems in achieving the highest production efficiency across all categories.

These findings are in close conformity with earlier reports, wherein several researchers have emphasized the superiority of vegetable- and legume-based intensive systems in enhancing production efficiency and ensuring sustainability. Similar results were reported by Raj *et al.* (2015) [30], Dwivedi *et al.* (2020) [9], Kushwaha *et al.* (2020) [19], and Ahirwar and Sharma (2021) [2], who confirmed that diversified systems involving vegetables and pulses provide higher daily productivity as compared to cereal-based sequence

#### 5.6 Land use efficiency

Land use efficiency (LUE) indicates the proportion of total available time effectively utilized for crop production, reflecting how well a cropping system exploits land and resources over the year. Higher LUE signifies better land utilization, allowing more crops to be grown per year and maximizing productivity.

The results showed significant variation among cropping sequences. The highest LUE was recorded in Rice bean-Berseem-Sorghum (81.85%), followed by Maize-Berseem-Sorghum (77.50%), due to the continuous growth of high-biomass fodder crops throughout the year. Sequences with long-duration crops like Arhar, such as Arhar + Soybean-Greengram (Ts: 54.10%), showed the lowest efficiency, as the extended crop growth limited the number of possible cropping cycles per year. Among check systems, Rice-Wheat-Greengram (74.71%) outperformed Rice-Chickpea-Greengram, reflecting better synchronization of crop durations. Family nutrition sequences integrating short-duration crops and legumes, such as Rice-Mustard-Cowpea (70.03%), also showed higher LUE compared to vegetable-only sequences. Vegetable-based income enhancement sequences like Okra-Brinjal-*Amaranthus* (62.19%) and Cowpea-Cabbage-Okra (56.54%) achieved moderate

efficiency because shorter-duration vegetables leave gaps between crops.

These findings align with previous studies confirming that sequential fodder or legume-based systems achieve higher LUE than cereal- or vegetable-dominated sequences (Raj *et al.*, 2015; Dwivedi *et al.*, 2020; Kushwaha *et al.*, 2020; Ahirwar & Sharma, 2021) [30, 9, 19, 21]. Additionally, research by Brahimi and Pérez-Bernal supports the notion that intercropping legumes and cereals increases resource use efficiency, leading to higher LUE. Furthermore, studies by Blanc and Yadav have demonstrated that legume-based intercropping systems promote beneficial interactions between crops, enhancing overall productivity and land use efficiency.

### 5.7 Water Productivity

Water productivity (WP) is a key measure of how efficiently a cropping system converts water into economic yield, reflecting the optimization of water use in agriculture. The present study revealed significant differences among cropping sequences. Cowpea-Cabbage-Okra (T<sub>11</sub>) recorded the highest WP (24.44 kg ha<sup>-1</sup> mm<sup>-1</sup>), followed by Okra-Brinjal-Amaranthus (T<sub>12</sub>: 20.73 kg ha<sup>-1</sup> mm<sup>-1</sup>). The superior performance of these sequences can be attributed to the integration of legumes and vegetables, which enhance soil structure, improve water infiltration, and reduce non-beneficial water losses. Additionally, short-duration and deep-rooted crops in these sequences allow efficient extraction of available soil moisture, minimizing wastage and increasing water use efficiency. Moderate WP was observed in sequences such as Rice-Mustard-Cowpea (T<sub>6</sub>: 8.53 kg ha<sup>-1</sup> mm<sup>-1</sup>) and Rice-Chickpea-Green gram (T<sub>2</sub>: 3.37 kg ha<sup>-1</sup> mm<sup>-1</sup>). These systems benefit from legume inclusion, which improves soil fertility and indirectly enhances water use by supporting better crop growth. In contrast, sequences dominated by long-duration crops, such as Arhar + Soybean-Sesame (T<sub>4</sub>: 2.38 kg ha<sup>-1</sup> mm<sup>-1</sup>), showed the lowest WP, as prolonged crop cycles limit the number of cropping opportunities per year and increase non-productive water consumption.

For livestock-based systems, Maize-Berseem-Sorghum (T<sub>7</sub>: 5.19 kg ha<sup>-1</sup> mm<sup>-1</sup>) outperformed Rice bean-Berseem-Sorghum, demonstrating that crop selection and growth characteristics strongly influence WP in fodder systems. Income-oriented sequences also mirrored this trend, with vegetable- and legume-based systems achieving both high WP and economic returns.

These findings are consistent with previous research. Timsina and Connor (2001) [40] emphasized that legumes and vegetables improve WP through better soil structure and reduced water loss. Kijne *et al.* (2003) [15] and Zwart and Bastiaanssen (2004) [48] Bouman *et al.* (2007) [5] and Punia *et al.* (2020) [29]. Recent studies by Ahirwar *et al.* (2023) [2] further confirm that soybean-chickpea-green gram sequences enhance WP by optimizing irrigation and biomass harvest.

### 5.8 Economic Analysis

#### 5.8.1 Cost of Cultivation

The cost of cultivation varied significantly among the cropping sequences, reflecting differences in crop composition, input intensity, and management practices. The highest cost was observed in T<sub>11</sub>: Cowpea - Cabbage - Okra (208.32 × 10<sup>3</sup> ₹ ha<sup>-1</sup>), followed by T<sub>12</sub>: Okra - Brinjal - *Amaranthus* (178.99 × 10<sup>3</sup> ₹ ha<sup>-1</sup>) and T<sub>5</sub>: Rice - Cabbage - Green gram (163.40 × 10<sup>3</sup> ₹ ha<sup>-1</sup>). These sequences involved high-value vegetables requiring intensive labor, fertilizers, irrigation, and plant protection measures. In contrast, low-input sequences such as T<sub>9</sub>: Arhar + Soybean (2:4) - Green gram (58.96 × 10<sup>3</sup> ₹ ha<sup>-1</sup>) and T<sub>4</sub>: Arhar + Soybean (2:4) - Sesame (78.86 × 10<sup>3</sup> ₹ ha<sup>-1</sup>) incurred minimal costs due to lower external input requirements. Pulse- and oilseed-based systems are inherently more input-efficient and cost-effective.

Among the check sequences, T<sub>1</sub>: Rice - Wheat - Green gram (116.85 × 10<sup>3</sup> ₹ ha<sup>-1</sup>) had slightly higher costs than T<sub>2</sub>: Rice - Chickpea - Green gram, primarily due to higher seed and

fertilizer requirements for wheat. For soil health sequences, T<sub>3</sub>: Soybean - Chickpea - Green gram (104.93 × 10<sup>3</sup> ₹ ha<sup>-1</sup>) required moderate investment, while T<sub>4</sub>: Arhar + Soybean (2:4) - Sesame required lower input. Green fodder sequences (T<sub>7</sub>: Maize - Berseem - Sorghum, 117.01 × 10<sup>3</sup> ₹ ha<sup>-1</sup>) and concentrate feed sequences (T<sub>10</sub>: Kodo + Arhar - Maize, 65.50 × 10<sup>3</sup> ₹ ha<sup>-1</sup>) showed intermediate costs. These findings align with the results of Kumar and Rathore 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 reported higher input costs in vegetable-based sequences due to intensive management practices.

#### 5.8.2 Gross Monetary Returns

Gross monetary returns differed considerably among the evaluated cropping sequences, reflecting the strong influence of crop choice and market value. The income enhancement generation system T<sub>11</sub> (Cowpea - Cabbage - Okra) recorded the maximum gross monetary returns (₹ 1317.96 × 10<sup>3</sup> ha<sup>-1</sup>), primarily due to the high market value of cabbage and okra combined with multiple harvests in a year. This was closely followed by T<sub>12</sub> (Okra - Brinjal - *Amaranthus*, ₹ 1070.43 × 10<sup>3</sup> ha<sup>-1</sup>), further highlighting the profitability potential of vegetable-based systems.

In contrast, the lowest returns were noted in T<sub>4</sub> (Arhar + Soybean (2:4) - Sesame, ₹ 84.71 × 10<sup>3</sup> ha<sup>-1</sup>), reflecting the limited economic potential of pulse-dominated systems owing to lower productivity and restricted market demand. Among the check sequences, T<sub>1</sub> (Rice - Wheat - Green gram) gave higher returns (₹ 225.92 × 10<sup>3</sup> ha<sup>-1</sup>) compared to T<sub>2</sub> (Rice - Chickpea - Green gram), which can be attributed to the greater productivity and market price of wheat.

Within soil health-oriented sequences, T<sub>3</sub> (Soybean - Chickpea - Green gram, ₹ 185.43 × 10<sup>3</sup> ha<sup>-1</sup>) outperformed T<sub>4</sub>, indicating that inclusion of multiple pulses ensured moderate profitability. For family nutrition sequences, T<sub>5</sub> (Rice - Cabbage - Green gram) generated higher returns (₹ 590.04 × 10<sup>3</sup> ha<sup>-1</sup>) compared to T<sub>6</sub> (Rice - Mustard - Cowpea), signifying the positive contribution of high-value vegetables. Among fodder systems, T<sub>7</sub> (Maize - Berseem - Sorghum, ₹ 315.55 × 10<sup>3</sup> ha<sup>-1</sup>) was superior to T<sub>8</sub> (Rice bean - Berseem - Sorghum) due to the higher productivity and market demand of maize. Similarly, in concentrate feed sequences, T<sub>10</sub> (Kodo + Arhar - Maize, ₹ 147.72 × 10<sup>3</sup> ha<sup>-1</sup>) registered higher returns than T<sub>9</sub> (Arhar + Soybean - Green gram), reaffirming the importance of maize in enhancing monetary benefits.

These results are in close agreement with the findings of Meena *et al.* (2020) [22], Singh *et al.* (2018) [36], Patel *et al.* (2021) [24], Choudhary *et al.* (2019) [39], Rathore *et al.* (2019) [31], and Sharma *et al.* (2021) [2], who also reported that diversification with high-value crops such as vegetables and maize substantially enhances profitability compared to conventional cereal-pulse systems.

#### 5.8.3 Net Monetary Returns

Net monetary returns are an important economic indicator that reflect the profitability of cropping systems after accounting for cost of cultivation. In the present investigation, substantial variation in net monetary returns was observed among the tested sequences, clearly demonstrating the influence of crop choice and market value on overall system profitability. Among the evaluated sequences, the income enhancement system T<sub>11</sub> (Cowpea - Cabbage - Okra) attained the maximum net monetary returns (₹ 1109.64 × 10<sup>3</sup> ha<sup>-1</sup>), followed by T<sub>12</sub> (Okra - Brinjal - *Amaranthus*, ₹ 891.44 × 10<sup>3</sup> ha<sup>-1</sup>) and T<sub>5</sub> (Rice - Cabbage - Green gram, ₹ 451.63 × 10<sup>3</sup> ha<sup>-1</sup>). The outstanding performance of these sequences may be attributed to the inclusion of high-value vegetable crops, which not only ensured greater system productivity but also fetched higher market prices, thereby substantially improving profitability. Similarly, T<sub>6</sub> (Rice - Mustard - Cowpea, ₹ 438.63 × 10<sup>3</sup> ha<sup>-1</sup>) registered appreciable

returns, mainly due to the contribution of cowpea as a vegetable crop. Within the check sequences, T<sub>1</sub> (Rice - Wheat - Green gram, ₹ 109.07 × 10<sup>3</sup> ha<sup>-1</sup>) realized slightly higher net returns compared to T<sub>2</sub> (Rice - Chickpea - Green gram), primarily because of the greater profitability associated with wheat. Under soil health-oriented systems, T<sub>3</sub> (Soybean - Chickpea - Green gram) exhibited moderate profitability, whereas T<sub>4</sub> (Arhar + Soybean (2:4) - Sesame, ₹ 20.80 × 10<sup>3</sup> ha<sup>-1</sup>) recorded the lowest returns of all sequences, which may be attributed to the limited market value and yield potential of pulses and oilseeds. In case of green fodder systems, T<sub>7</sub> (Maize - Berseem - Sorghum, ₹ 198.53 × 10<sup>3</sup> ha<sup>-1</sup>) proved superior to T<sub>8</sub> (Rice bean - Berseem - Sorghum) owing to the higher productivity and profitability contribution of maize. Similarly, within concentrate feed systems, T<sub>10</sub> (Kodo + Arhar - Maize, ₹ 82.22 × 10<sup>3</sup> ha<sup>-1</sup>) produced higher returns compared to T<sub>9</sub> (Arhar + Soybean (2:4) - Green gram, ₹ 58.86 × 10<sup>3</sup> ha<sup>-1</sup>), reaffirming the role of maize in enhancing overall profitability.

These findings are in close agreement with the results of Choudhary *et al.* (2022) [6], Verma *et al.* (2021) [43], Patel *et al.* (2020) [26], Yadav *et al.* (2018) [36], and Jat *et al.* (2015) [11], who also reported that diversified cropping systems involving high-value vegetables substantially improve farm profitability compared to traditional cereal-pulse-based sequences.

#### 5.8.4 Benefit-Cost Ratio

Benefit-cost ratio serves as a crucial economic measure to assess the efficiency of investment in cropping systems. In the present study, considerable variation was observed across the sequences, largely influenced by the inclusion of high-value crops and their relative market potential. The maximum B:C ratio was registered under the income enhancement system T<sub>11</sub> (Cowpea - Cabbage - Okra, 6.33), closely followed by T<sub>12</sub> (Okra - Brinjal - *Amaranthus*, 5.98) and T<sub>5</sub> (Rice - Cabbage - Green gram, 4.26). The superior performance of these sequences was attributed to the combined advantage of higher system productivity (REY) and elevated net monetary returns from vegetables, which ensured greater returns per unit of investment. Similarly, T<sub>6</sub> (Rice - Mustard - Cowpea, 3.95) achieved relatively high profitability, mainly due to the contribution of cowpea and improved system productivity. Within the check sequences, T<sub>1</sub> (Rice - Wheat - Green gram, 1.93) recorded a slightly higher B:C ratio compared to T<sub>2</sub> (Rice - Chickpea - Green gram), owing to the better profitability realized from wheat. In soil health-oriented systems, T<sub>3</sub> (Soybean - Chickpea - Green gram) exhibited moderate profitability, whereas T<sub>4</sub> (Arhar + Soybean (2:4) - Sesame) registered the lowest B:C ratio, which corresponded with its poor net returns and relatively low REY. Among green fodder-based systems, T<sub>7</sub> (Maize - Berseem - Sorghum) outperformed T<sub>8</sub> (Rice bean - Berseem - Sorghum), highlighting the positive influence of maize on both productivity and economic efficiency. Likewise, in concentrate feed systems, T<sub>10</sub> (Kodo + Arhar - Maize, 2.26) showed moderate returns over investment, while T<sub>9</sub> (Arhar + Soybean (2:4) - Green gram) remained least remunerative due to limited market value and productivity.

These findings are in conformity with the reports of Tiwari *et al.* (2017) [41], Mandal *et al.* (2016) [21], Patel *et al.* (2020) [26], Yadav *et al.* (2018) [36], and Verma *et al.* (2021) [43], who also emphasized that horticulture-based sequences ensure higher economic returns per rupee investment, whereas cereal-pulse systems, though stable, provide limited profitability.

#### Conclusion

The highest rice equivalent yield (REY) was recorded under T<sub>11</sub>: Cowpea-Cabbage-Okra (57.30 t ha<sup>-1</sup> year<sup>-1</sup>), followed by T<sub>12</sub>: Okra-Brinjal-*Amaranthus* (46.54 t ha<sup>-1</sup> year<sup>-1</sup>), indicating superior productivity of vegetable-based sequences. System productivity and production efficiency were also maximum in T<sub>11</sub> (156.99 kg ha<sup>-1</sup> day<sup>-1</sup>; 280.89 kg ha<sup>-1</sup> day<sup>-1</sup>) and T<sub>12</sub> (127.51; 202.35 kg ha<sup>-1</sup> day<sup>-1</sup>). Among conventional cereal-based

sequences, T<sub>1</sub>: Rice-Wheat- Greengram showed moderate REY (9.82 t ha<sup>-1</sup> year<sup>-1</sup>) and system productivity, whereas soil health sequences like T<sub>3</sub>: Soybean-Chickpea-Greengram performed better among legumes. Economic analysis revealed T<sub>11</sub> had the highest cost (208.32 × 10<sup>3</sup> ₹ ha<sup>-1</sup>), gross returns (1317.96 × 10<sup>3</sup> ₹ ha<sup>-1</sup>), net returns (1109.64 × 10<sup>3</sup> ₹ ha<sup>-1</sup>) and B:C ratio (6.33), followed by T<sub>12</sub>, confirming the economic viability of vegetable-based systems over cereal- or pulse-dominated sequences.

Legume- and vegetable-based sequences significantly contributed to human and livestock nutrition. T<sub>5</sub>: Rice-Cabbage-Greengram (25.65 t ha<sup>-1</sup> REY) and T<sub>6</sub>: Rice-Mustard-Cowpea (25.54 t ha<sup>-1</sup>) enhanced family nutrition by providing protein-rich pulses and nutrient-dense vegetables. Fodder-based sequences, particularly T<sub>7</sub>: Maize-Berseem-Sorghum (13.72 t ha<sup>-1</sup>) and T<sub>10</sub>: Kodo + Arhar-Maize (6.42 t ha<sup>-1</sup>), supported livestock feed effectively, highlighting the dual role of cropping sequences in ensuring human and animal nutrition.

Water productivity was maximum in T<sub>11</sub>: Cowpea-Cabbage-Okra (24.44 kg ha<sup>-1</sup> mm<sup>-1</sup>), followed by T<sub>12</sub> (20.73 kg ha<sup>-1</sup> mm<sup>-1</sup>), while Arhar + Soybean-Sesame (T<sub>4</sub>: 2.38 kg ha<sup>-1</sup> mm<sup>-1</sup>) had the lowest. Land use efficiency (LUE) was highest in T<sub>8</sub>: Ricebean-Berseem-Sorghum (81.85%) and T<sub>7</sub> (77.50%), indicating efficient resource utilization in fodder systems.

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