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Influence of cropping sequence variability on soil health in the Kymore plateau and Satpura hills region of Madhya Pradesh

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Abstract

Soil health deterioration due to monocropping and intensive farming is a major concern in the Kymore Plateau and Satpura Hills of Madhya Pradesh. A field experiment was conducted in 2023-24 and 2024-2025 at JNKVV, Jabalpur, to evaluate twelve diversified cropping sequences under irrigated conditions. Results showed negligible effects on soil pH and EC, but significant improvements in organic carbon, available NPK, and microbial activity under legume-based systems. Soybean-Chickpea-Greengram recorded the highest soil fertility and microbial counts, while Okra-Brinjal-Amaranthus performed poorest. Findings highlight the superiority of legume-inclusive sequences in enhancing soil health and ensuring sustainable productivity.

Keywords: Cropping sequence, soil fertility, microbial activity, organic carbon, Madhya Pradesh

Introduction

The Kymore Plateau and Satpura Hills agro-climatic zone of Madhya Pradesh is characterized by diverse topography, heterogeneous soil types, and a range of climatic conditions. The agricultural economy in this region is primarily rainfed, with farmers heavily dependent on the southwest monsoon for seasonal cropping. Traditional farming practices in this zone have long relied on monoculture systems, dominated by crops such as rice, wheat, and maize. These systems, while historically central to food production, are increasingly being questioned for their sustainability due to a number of emerging challenges, including declining soil fertility, nutrient imbalances, reduced crop productivity, water scarcity, and greater vulnerability to climate fluctuations.

Monoculture practices in this region, particularly rice and wheat grown in continuous sequences, are not only input-intensive but also biologically and ecologically limiting. They often require significant investments in fertilizers, irrigation, and pest management, thereby elevating the cost of cultivation and reducing input use efficiency. Over time, the continuous cropping of similar crop types has led to the depletion of essential soil nutrients, emergence of multi-nutrient deficiencies, deterioration of soil structure, and increased incidences of pests, weeds, and diseases. These effects are compounded by suboptimal management practices, such as residue burning, excessive tillage, and imbalanced fertilizer application, leading to soil compaction, loss of organic carbon, and a decline in overall soil biological activity (Fujisaka *et al*., Singh *et al*., 2018; Kumar *et al*., 2018) [4].

In response to these agronomic and ecological challenges, crop diversification has gained prominence as a strategic solution. Cropping sequence variability, encompassing crop rotation, intercropping, sequential cropping, and the inclusion of legumes or vegetables in conventional systems, is now seen as a vital pathway to restore soil health, improve productivity, and ensure long-term sustainability. Crop diversification is particularly important in regions like Kymore and Satpura, where both rainfed and irrigated systems coexist, and where small and marginal farmers form the bulk of the agricultural population. The integration of pulses, oilseeds, vegetables, and fodder crops into cereal-dominated systems has been widely recommended to improve both agronomic and ecological outcomes.

Multiple studies support the idea that diversified cropping systems enhance soil fertility, promote biological nitrogen fixation, and lead to better nutrient cycling, particularly when legumes are integrated into rotations. For instance, Sharma *et al*. (2021) [7] reported that intercropping maize

(*Zea mays*) with pigeon pea (*Cajanus cajan*) or groundnut (*Arachis hypogaea*) increased overall productivity compared to monocropped maize. In their study, the maize-pigeon pea intercropping system yielded 2.8 t/ha of maize and 1.2 t/ha of pigeon pea, while mono-maize plots produced only 2.2 t/ha, illustrating the productivity gain from intercropping. Similar productivity improvements have been reported in wheat-chickpea systems due to the nitrogen-contributing role of legumes and their ability to break disease and pest cycles. Kumar and Singh (2022) [13] found that wheat-chickpea rotation systems led to 15% higher yields than monocropped wheat, supported by better nutrient availability and reduced biotic stress.

Profitability, a key driver of farmer adoption, also increases under diversified systems. By spreading risk and ensuring output diversification, these systems reduce the impact of market price fluctuations, pest outbreaks, and climatic uncertainty. In the Kymore Plateau and Satpura Hills region, cropping systems such as maize-pigeon pea, wheat-chickpea, and rice-groundnut have been observed to provide better economic returns than monocultures. Patel *et al.* (2022) [13] demonstrated that a maize-pigeon pea system resulted in net profits of INR 55,000/ha, compared to INR 40,000/ha from mono-maize. Similarly, benefit-cost ratio (BCR) increased from 1.9 in monocultures to 2.3 in intercropped systems, indicating better investment efficiency.

Beyond yield and economic returns, crop diversification holds significant promise for human nutrition. The integration of protein-rich pulses and nutrient-dense vegetables addresses widespread micronutrient deficiencies prevalent in rural diets across Madhya Pradesh. Systems that include chickpeas, pigeon peas, lentils, soybeans, tomatoes, spinach, and okra are proven to enhance dietary diversity. Patel *et al*. (2022) [13] highlighted the nutritional advantage of the rice-chickpea rotation, which offers both carbohydrate-rich grains and protein-rich legumes, contributing to improved household nutrition. Studies also suggest that vegetable inclusion in cropping sequences can increase micronutrient intake by up to 25%, benefiting not only caloric but also vitamin and mineral sufficiency in local diets.

Livestock integration is another critical component of diversified systems, especially in regions like Kymore-Satpura, where livestock plays an integral role in the rural economy. Sustainable livestock production is contingent upon the year-round availability of quality fodder, which can be addressed by incorporating fodder crops into the cropping system. reported that intercropping systems like maize-cowpea and soybean-sorghum provided up to 12,000 kg of green fodder/ha annually, contributing to better milk yield, animal health, and reproductive performance. Inclusion of forage legumes such as alfalfa further improves feed protein content and reduces the need for purchased feeds, increasing the economic viability of smallholder mixed farming systems.

At the core of all these benefits lies soil health, which serves as the foundational driver for productivity, resilience, and environmental sustainability. Soil health includes physical properties such as texture, bulk density, and aggregate stability; chemical aspects like pH, organic carbon, and nutrient availability; and biological parameters including microbial biomass, enzyme activity, and soil respiration. Legume-based rotations, for example, not only fix atmospheric nitrogen but also enhance the soil's microbial diversity, organic matter content, and enzymatic functioning, which are essential for nutrient cycling. Verma *et al*. (2023) [11] found that a maize-chickpea rotation increased soil nitrogen levels by 20% over three seasons, and ecorded a 15-18% increase in microbial biomass carbon in diversified plots compared to monocultures.

Additionally, systems with improved organic matter input have been shown to enhance soil structure, water-holding capacity, and resistance to erosion. Soni *et al.* (2020) [8] observed that intercropping with legumes increased soil organic carbon by 0.3% per year, significantly improving aggregate stability and infiltration rates. These gains are particularly crucial in rainfed areas, where erratic rainfall and poor water retention often limit crop growth. Enhanced soil structure not only improves root penetration and water uptake but also reduces runoff and minimizes nutrient leaching, thus contributing to environmental sustainability.

Despite these evident advantages, widespread adoption of diversified systems in the Kymore Plateau and Satpura Hills zone remains limited. Barriers include lack of technical knowledge, limited access to quality seeds, market linkages, and institutional support. Therefore, generating region-specific, data-driven recommendations is critical for guiding farmers, policymakers, and extension services toward sustainable agricultural transformation.

This study aims to address this gap by systematically assessing how cropping sequence variability influences soil health under both rainfed and irrigated conditions in the Kymore Plateau and Satpura Hills zone. Specifically, the research evaluates the impact of crop rotations and intercropping on soil fertility, organic carbon content, microbial activity, and overall system productivity. By linking agronomic performance with ecological sustainability, the study seeks to inform context-specific recommendations for resilient farming systems in central India**.**

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 soil of the experimental field was sandy loam in texture with a pH of 7.57, electrical conductivity of 0.38 dS m^{-1}, organic carbon content of 7.1 g kg^{-1}, available nitrogen 260 kg ha^{-1}, available phosphorus 11.5 kg ha^{-1}, and available potassium 282 kg ha^{-1}. Popular crop varieties and hybrids with high yield potential and insect-pest resistance, commonly adopted by local farmers, were selected. 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. Soil samples were analyzed for organic carbon, available N, P, and K, pH, and electrical conductivity using standard methods: Walkley and Black method for organic carbon (Jackson, 1973) [3], alkaline permanganate and modified Kjeldahl methods for nitrogen (Subbiah and Asija, 1956) [9], Olsen's method for phosphorus (Olsen *et al.*, 1954) [5], flame photometer for potassium, and glass electrode pH meter and EC meter for pH and electrical conductivity, respectively.

Results and discussion

3.1 Effect of various cropping sequences on soil properties

To evaluate the effect of various cropping sequences on soil properties undisturbed soil samples were collected before start of the experiment and at harvest of crop (year collimation of cropping sequence) during both the years of experimentation.

3.2 PH

The hydrogen ion concentration (pH) in post-harvest soils samples was measured during both the years of experimentation. Data presented in Table Indicated that the pH values of post harvested soils did not change significantly due to various cropping sequences during both years. Higher numerical value of pH (7.60 and 7.61) was recorded under Soybean - Chickpea - Green gram cropping sequence through, it was not statistically significant.

Further, almost all the cropping sequences recorded similar values of pH ranging from 7.50 to 7.60 and 7.00 to 7.61 during first and second year of experimentation respectively. Moreover, slight reduction in values was noted in subsequent year.

3.3 Electrical conductivity

The supernatant liquid of the soil suspension formerly used for pH determination was utilized for the measurement of electrical conductivity (EC) using a conductivity meter. Data pertaining to electrical conductivity (dS m^{-1}) were recorded during 2023-24 and 2024-25 after the harvest of crops in each year. The data presented in Table 4.13 indicated that the variations in EC among different cropping sequences were statistically non-significant during both years of experimentation. It was observed that EC values slightly reduced in the subsequent year but remained close to the initial level. However, T_3 (Soybean - Chickpea - Green gram) and T_9 (Arhar + Soybean (2:4) - Green gram) recorded numerically higher EC values of 0.50 dS m^{-1} and 0.49 dS m^{-1}, respectively, in the first year (2023-24), which became similar (0.48 dS m^{-1}) in both sequences in 2024-25. The lowest EC value of 0.44 dS m^{-1} was observed in T_{12} (Okra - Brinjal - Amaranthus) during both years.

3.4 Organic carbon

The data presented in Table 4.10.3 indicate that soil organic carbon (OC) content was significantly influenced ($p \leq 0.05$) by different cropping sequences during 2023-24 and 2024-25. The initial organic carbon level was 6.92 g kg^{-1}. In 2023-24, the organic carbon content ranged from 6.82 to 6.96 g kg^{-1}. The highest value of 6.96 g kg^{-1} was recorded under T_3 (Soybean - Chickpea - Green gram), followed closely by 6.95 g kg^{-1} under T_9 (Arhar + Soybean (2:4) - Green gram) and 6.93 g kg^{-1} under T_4 (Arhar + Soybean (2:4) - Sesame). The lowest value (6.82 g kg^{-1}) was observed in T_6 (Rice - Mustard - Cowpea (Vegetable)), T_7 (Maize (f) - Berseem (f) - Sorghum (f)), and T_{12} (Okra - Brinjal - Amaranthus), followed by T_{11} (Cowpea - Cabbage - Okra) with 6.83 g kg^{-1}.

During 2024-25, a similar trend was noted, with the highest organic carbon content (7.01 g kg^{-1}) again recorded under T_3 (Soybean - Chickpea - Green gram), followed by T_9 (6.93 g kg^{-1}) and T_4 (6.92 g kg^{-1}). The lowest values were observed in T_{12} (6.83 g kg^{-1}), T_7 (6.84 g kg^{-1}), and T_{10} (6.87 g kg^{-1}), while T_{11} recorded 6.88 g kg^{-1}.

T. No	Cropping Sequences		pH			EC (dSm-1)			OC (g kg-1)	
		2023-2024	2024-2025	Pooled	2023-2024	2024-2025	Pooled	2023-2024	2024-2025	Pooled
	Initial		7.57			0.38			6.92	
T_1	Rice - Wheat - Green gram	7.55	7.56	7.55	0.47	0.45	0.46	6.92	6.90	6.91
T_2	Rice - Chickpea - Green gram	7.57	7.57	7.57	0.48	0.49	0.48	6.88	6.89	6.88
T_3	Soybean - Chickpea - Green gram	7.60	7.61	7.61	0.50	0.49	0.50	6.96	7.01	6.99
T_4	Arhar + Soybean (2:4)- Sesame	7.56	7.55	7.55	0.47	0.46	0.46	6.93	6.92	6.92
T_5	Rice - Cabbage - Green gram	7.54	7.54	7.54	0.46	0.47	0.47	6.87	6.89	6.88
T_6	Rice - Mustard - Cowpea (Vegetables)	7.53	7.52	7.52	0.47	0.47	0.47	6.82	6.91	6.86
T_7	Maize(f) - Berseem(f) - Sorghum(f)	7.51	7.50	7.51	0.46	0.46	0.46	6.82	6.84	6.83
T_8	Rice bean(f) - Berseem(f) - Sorghum(f)	7.50	7.52	7.51	0.47	0.45	0.46	6.88	6.86	6.87
T_9	Arhar + Soybean (2:4)- Green gram	7.58	7.58	7.58	0.49	0.48	0.49	6.95	6.93	6.94
T_{10}	Kodo+ Arhar (4+2)- Maize	7.52	7.50	7.51	0.47	0.47	0.47	6.88	6.87	6.87
T_{11}	Cowpea - Cabbage - Okra	7.53	7.52	7.53	0.47	0.45	0.46	6.83	6.88	6.82
T_{12}	Okra - Brinjal - Amaranthus	7.50	7.00	7.25	0.46	0.44	0.45	6.82	6.83	6.81
	Sem±	0.035	0.149	0.081	0.016	0.017	0.015	0.125	0.127	0.037
	CD (p =0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS

3.5 Available Nitrogen in post-harvest soil

The available nitrogen in postharvest soil was determined during both the years of experimentation and recorded data are presented in Table 4.14 graphically presented in Fig. 4.13.

The data presented in Table 4.14 indicate that available nitrogen content in soil was significantly influenced ($p \leq 0.05$) by different cropping sequences during 2023-24 and 2024-25. The initial available nitrogen content was 260 kg ha^{-1}. During 2023-24, the nitrogen content ranged from 223.67 to 267.67 kg ha^{-1}. The maximum value, 267.67 kg ha^{-1}, was recorded under T_3 (Soybean - Chickpea - Green gram), followed by 266.67 kg ha^{-1} under T_9 (Arhar + Soybean (2:4) - Green gram) and 265.33 kg ha^{-1} under T_2 (Rice - Chickpea - Green gram), all of which were at par. The lowest nitrogen content was observed in T_{12} (Okra - Brinjal - Amaranthus) with 223.67 kg ha^{-1}, which remained at par with T_{11} (Cowpea - Cabbage - Okra) with 230.33 kg ha^{-1} and T_{10} (Kodo + Arhar (4+2) - Maize) with 236.00 kg ha^{-1}.

A similar trend was recorded in 2024-25, where the highest nitrogen content, 268.33 kg ha^{-1}, was again observed under T_3 (Soybean - Chickpea - Green gram), followed by 264.33 kg ha^{-1} under T_9 (Arhar + Soybean (2:4) - Green gram) and 262.67 kg ha^{-1} under T_2 (Rice - Chickpea - Green gram), which were statistically at par. The lowest value, 228.67 kg ha^{-1}, was noted in T_{12} (Okra - Brinjal - Amaranthus), at par with T_{11} (Cowpea - Cabbage - Okra) and T_{10} (Kodo + Arhar (4+2) - Maize).

The pooled data over both years revealed that T_3 (Soybean - Chickpea - Green gram) recorded the significantly highest available nitrogen at 268.00 kg ha^{-1}, followed by T_9 (Arhar + Soybean (2:4) - Green gram) with 265.50 kg ha^{-1} and T_2 (Rice - Chickpea - Green gram) with 264.00 kg ha^{-1}, while the lowest was recorded in T_{12} (Okra - Brinjal - Amaranthus) with 226.17 kg ha^{-1}, at par with T_{11} (Cowpea - Cabbage - Okra) with 232.67 kg ha^{-1} and T_{10} (Kodo + Arhar (4+2) - Maize) with 234.67 kg ha^{-1}.

3.6 Available phosphorus in post-harvest soil

The available phosphorus content in the post-harvest soil was assessed during the cropping years 2023-24 and 2024-25. The analysis of data (Table 14.13.5 and Fig. 14.13.5) revealed that the available phosphorus was significantly influenced ($p \leq 0.05$) by various cropping sequences during both years of experimentation. In general, it was observed that most of the cropping sequences resulted in an increase in available phosphorus content over the initial value of 11.5 kg ha^{-1}, except T_{12} (Okra - Brinjal - Amaranthus), T_{11} (Cowpea - Cabbage - Okra), and T_{10} (Kodo + Arhar (4+2) - Maize), which consistently recorded lower values during both years.

In 2023-24, the highest phosphorus content, 12.41 kg ha^{-1}, was observed under T_3 (Soybean - Chickpea - Green gram), followed by 12.30 kg ha^{-1} under T_9 (Arhar + Soybean (2:4) - Green gram), 12.00 kg ha^{-1} under T_2 (Rice - Chickpea - Green gram), and 11.88 kg ha^{-1} under T_4 (Arhar + Soybean (2:4) - Sesame). Conversely, the lowest phosphorus value, 10.15 kg ha^{-1}, was recorded under T_{12} (Okra - Brinjal - Amaranthus), which was at par with T_{11} (Cowpea - Cabbage - Okra) at 10.22 kg ha^{-1} and T_{10} (Kodo + Arhar (4+2) - Maize) at 10.33 kg ha^{-1}.

However, this trend shifted in the subsequent year, where a distinct pattern emerged. During 2024-25, T_3 (Soybean - Chickpea - Green gram) once again recorded the highest available phosphorus at 12.70 kg ha^{-1}, which was significantly superior over all other cropping sequences, except T_9 (Arhar + Soybean (2:4) - Green gram) at 12.48 kg ha^{-1}, T_2 (Rice - Chickpea - Green gram) at 12.16 kg ha^{-1}, T_1 (Rice - Wheat - Green gram) at 11.74 kg ha^{-1}, and T_4 (Arhar + Soybean (2:4) - Sesame) at 11.65 kg ha^{-1}, with which it remained at par. The lowest phosphorus content, 10.10 kg ha^{-1}, was again recorded under T_{11} (Cowpea - Cabbage - Okra), at par with T_{12} (Okra - Brinjal - Amaranthus) at 10.23 kg ha^{-1}.

Furthermore, it was noted that the available phosphorus content in most cropping sequences during 2024-25 increased numerically compared to the previous year, indicating a cumulative effect, except in sequences such as T_{12} (Okra - Brinjal - Amaranthus), T_{11} (Cowpea - Cabbage - Okra), and T_{10} (Kodo + Arhar (4+2) - Maize), where a marginal decline or stagnation was observed. However, this reduction was not statistically significant

4.10.6 Available Potassium in post-harvest soil

For studying the effect of various cropping sequences on available potassium in post-harvest soil, samples were collected and analyzed at the end of the cropping cycles during both 2023-24 and 2024-25. The data presented in Table 4.13.6 and Fig. 4.13.6 indicate that the differences in available potassium content among the cropping sequences were statistically non-significant during both years of experimentation.

In general, it was noted that the quantity of available potassium slightly increased over the initial value of 282 kg ha^{-1}, recorded before the initiation of the experiment, in both years. During 2023-24, the highest available potassium content, 306.33 kg ha^{-1}, was recorded under T_3 (Soybean - Chickpea - Green gram), closely followed by 304.33 kg ha^{-1} under T_9 (Arhar + Soybean (2:4) - Green gram) and 300.89 kg ha^{-1} under T_2 (Rice - Chickpea - Green gram). Similarly, in 2024-25, the same treatments maintained their superiority, where T_3 (Soybean - Chickpea - Green gram) recorded 305.00 kg ha^{-1}, followed by T_9 (Arhar + Soybean (2:4) - Green gram) at 302.67 kg ha^{-1} and T_2 (Rice - Chickpea - Green gram) at 296.33 kg ha^{-1}. However, these increases were not statistically significant.

The pooled data also followed a similar trend, where T_3 (Soybean - Chickpea - Green gram) recorded 305.67 kg ha^{-1}, T_9 (Arhar + Soybean (2:4) - Green gram) 303.50 kg ha^{-1}, and T_2 (Rice - Chickpea - Green gram) 298.61 kg ha^{-1}, reflecting higher potassium values as compared to other sequences. On the contrary, the lowest available potassium was observed under T_{12} (Okra - Brinjal - Amaranthus) with 279.83 kg ha^{-1}, at par with T_{11} (Cowpea - Cabbage - Okra) and T_{10} (Kodo + Arhar (4+2) - Maize).

T. No	Cropping Sequences		Available Nitrogen (kg ha-^{1})			Available Phosphors (kg ha-^{1})			Available Potassium (kg ha^{-1})	
		2023-2024	2024-2025	Pooled data	2023-2024	2024-2025	Pooled data	2023-2024	2024-2025	Pooled data
	Initial		**260**			**11.5**			**282**	
T_1	Rice - Wheat - Green gram	261.67	260.33	261.00	11.67	11.74	11.70	299.00	295.67	297.33
T_2	Rice - Chickpea - Green gram	265.33	262.67	264.00	12.00	12.16	12.08	300.89	296.33	298.61
T_3	Soybean - Chickpea - Green gram	267.67	268.33	268.00	12.41	12.70	12.56	306.33	305.00	305.67
T_4	Arhar + Soybean (2:4)- Sesame	256.33	255.00	255.67	11.88	11.65	11.77	299.67	296.00	297.83
T_5	Rice - Cabbage - Green gram	251.00	251.00	251.00	11.42	11.15	11.28	290.67	288.00	289.33
T_6	Rice - Mustard - Cowpea (Vegetables)	244.33	241.00	242.67	11.20	11.38	11.29	292.00	290.67	291.33
T_7	Maize(f) - Berseem(f) - Sorghum(f)	242.67	240.33	241.50	11.00	11.19	11.10	295.67	300.00	297.83
T_8	Rice bean(f) - Berseem(f) - Sorghum(f)	241.67	241.73	241.70	10.90	11.38	11.14	285.33	290.00	287.67
T_9	Arhar + Soybean (2:4)- Green gram	266.67	264.33	265.50	12.30	12.48	12.39	304.33	302.67	303.50
T_{10}	Kodo+ Arhar (4+2)- Maize	236.00	233.33	234.67	10.33	11.05	10.69	282.67	285.67	284.17
T_{11}	Cowpea - Cabbage - Okra	230.33	235.00	232.67	10.22	10.10	10.16	281.33	280.00	280.67
T_{12}	Okra - Brinjal - Amaranthus	223.67	228.67	226.17	10.15	10.23	10.19	280.00	279.67	279.83
	Sem±	9.071	8.680	8.622	0.444	0.469	0.445	4.631	5.436	3.762
	CD (p =0.05)	28.23	27.01	26.83	1.38	1.46	1.39	14.41	16.92	11.71

4.10.7. Biological properties of soil
The total bacterial, fungal, and actinomycetes populations in the soil were significantly influenced by different cropping sequences during both 2023-24 and 2024-25, as presented in Table 4.10.7 and depicted in Figure 4.10.7.

4.10.7.1 Populations of bacteria
The total bacterial population was significantly influenced by different cropping sequences in both years. The initial population was 40.25 × 10^5 cfu g^{-1} soil, which increased across all treatments.

In 2023-24, the highest bacterial population was observed under T_3 (Soybean - Chickpea - Green gram) at 49.78 × 10^5 cfu g^{-1} soil, followed by T_9 (Arhar + Soybean (2:4) - Green gram) at 48.65 × 10^5 cfu g^{-1} and T_2 (Rice - Chickpea - Green gram) at 48.19 × 10^5 cfu g^{-1}. These treatments were statistically at par. The lowest count was recorded in T_{12} (Okra - Brinjal - Amaranthus) with 40.33 × 10^5 cfu g^{-1} soil. During 2024-25, the highest bacterial count was again recorded under T_2 (Rice - Chickpea - Green gram) at 50.00 × 10^5 cfu g^{-1} soil, followed closely by T_3 (Soybean - Chickpea - Green gram) at 49.99 × 10^5 cfu g^{-1} and T_1 (Rice - Wheat - Green gram) at 48.00 × 10^5 cfu g^{-1}. The lowest count was again observed under T_{12} (Okra - Brinjal - Amaranthus) at 40.00 × 10^5 cfu g^{-1} soil.

Pooled data revealed that T_3 (Soybean - Chickpea - Green gram) was the most effective treatment with a bacterial population of 49.88 × 10^5 cfu g^{-1} soil, followed by T_2 (Rice - Chickpea - Green gram) at 49.09 × 10^5 cfu g^{-1} and T_9 (Arhar + Soybean (2:4) - Green gram) at 47.49 × 10^5 cfu g^{-1}. The lowest pooled population was recorded under T_{12} (Okra - Brinjal - Amaranthus) at 40.17 × 10^5 cfu g^{-1} soil. Overall, T_3 was the most effective treatment for enhancing soil bacterial populations.

4.10.7.2 Fungi
Fungal populations in the soil were significantly affected by cropping sequences. The initial population was recorded at 30.14 × 10^3 cfu g^{-1} soil. In 2023-24, the highest fungal count was recorded in T_3 (Soybean - Chickpea - Green gram) at 32.49 × 10^3 cfu g^{-1} soil, followed by T_9 (Arhar + Soybean (2:4) - Green gram) at 30.69 × 10^3 cfu g^{-1}, T_2 (Rice - Chickpea - Green gram) at 30.41 × 10^3 cfu g^{-1}, and T_4 (Arhar + Soybean (2:4) - Sesame) at 30.39 × 10^3 cfu g^{-1}. The lowest fungal count was found under T_{12} (Okra - Brinjal - Amaranthus) at 26.04 × 10^3 cfu g^{-1} soil. During 2024-25, T_3 (Soybean - Chickpea - Green gram) again recorded the highest fungal population of 33.33 × 10^3 cfu g^{-1} soil, followed by T_4 (Arhar + Soybean (2:4) - Sesame) at 33.00 × 10^3 cfu g^{-1} and T_9 (Arhar + Soybean (2:4) - Green gram) at 32.00 × 10^3 cfu g^{-1}. The lowest count was again observed under T_{12} (Okra - Brinjal - Amaranthus) at 26.24 × 10^3 cfu g^{-1} soil.The pooled data confirmed that T_3 (Soybean - Chickpea - Green gram) recorded the highest average fungal population of 32.91 × 10^3 cfu g^{-1} soil, followed by T_4 (Arhar + Soybean (2:4) - Sesame) at 31.69 × 10^3 cfu g^{-1} and T_9 (Arhar + Soybean (2:4) - Green gram) at 31.35 × 10^3 cfu g^{-1}. The lowest fungal population was recorded under T_{12} (Okra - Brinjal - Amaranthus) at 26.14 × 10^3 cfu g^{-1} soil. Overall, T_3 was most effective in promoting fungal populations in the soil.

4.10.7.3 Actinomycetes
The actinomycetes population showed a general decline from the initial value of 10.33 × 10^3 cfu g^{-1} soil but was significantly influenced by cropping sequences.

In 2023-24, the highest actinomycetes count was found in T_3 (Soybean - Chickpea - Green gram) at 7.66 × 10^3 cfu g^{-1} soil, followed by T_9 (Arhar + Soybean (2:4) - Green gram) at 7.41 × 10^3 cfu g^{-1} and T_2 (Rice - Chickpea - Green gram) at 7.23 × 10^3 cfu g^{-1}. The lowest population was recorded under T_{12} (Okra - Brinjal - Amaranthus) at 6.23 × 10^3 cfu g^{-1} soil.In 2024-25, the trend remained similar, with T_3 (Soybean - Chickpea - Green gram) again showing the highest actinomycetes count at 7.84 × 10^3 cfu g^{-1} soil, followed by T_9 (Arhar + Soybean (2:4) - Green gram) at 7.45 × 10^3 cfu g^{-1} and T_4 (Arhar + Soybean (2:4) - Sesame) at 7.34 × 10^3 cfu g^{-1}. The lowest count was again found under T_{12} (Okra - Brinjal - Amaranthus) at 6.15 × 10^3 cfu g^{-1} soil.

Based on the pooled data, T_3 (Soybean - Chickpea - Green gram) was again the most effective treatment with 7.75 × 10^3 cfu g^{-1} soil, followed by T_9 (Arhar + Soybean (2:4) - Green gram) at 7.43 × 10^3 cfu g^{-1} and T_2 (Rice - Chickpea - Green gram) at 7.27 × 10^3 cfu g^{-1}. The lowest pooled actinomycetes population was found in T_{12} (Okra - Brinjal - Amaranthus) at 6.19 × 10^3 cfu g^{-1} soil.T_3 proved most effective in maintaining actinomycetes populations, likely due to legume-driven rhizospheric enrichment

Table 4: 10.7. Soil microbial count as influenced by different cropping sequences

T. No	Cropping Sequences	Total bacteria count (10^5 x cfu g-1 soil)			Fungi (10^3 x cfu g^{-1} soil)			Actinomycetes (10^3 x cfu g-1 soil)		
		2023-2024	2024-2025	Pooled data	2023-2024	2024-2025	Pooled data	2023-2024	2024-2025	Pooled data
	Initial	**40.25**	**41.51**	**-**	**30.14**	**31.45**	**-**	**10.33**	**12.76**	**-**
T_1	Rice - Wheat - Green gram	47.30	48.00	47.65	30.24	31.06	30.65	6.83	6.94	6.88
T_2	Rice - Chickpea - Green gram	48.19	50.00	49.09	30.41	30.33	30.37	7.23	7.31	7.27
T_3	Soybean - Chickpea - Green gram	49.78	49.99	49.88	32.49	33.33	32.91	7.66	7.84	7.75
T_4	Arhar + Soybean (2:4)- Sesame	47.63	47.00	47.32	30.39	33.00	31.69	7.06	7.34	7.20
T_5	Rice - Cabbage - Green gram	46.03	46.00	46.02	28.88	28.00	28.44	6.74	7.00	6.87
T_6	Rice - Mustard - Cowpea (Vegetables)	45.08	41.33	43.21	28.05	28.33	28.19	6.63	6.56	6.59
T_7	Maize(f) - Berseem(f) - Sorghum(f)	45.00	41.67	43.33	27.60	28.49	28.04	6.59	6.48	6.53
T_8	Rice bean(f) - Berseem(f) - Sorghum(f)	43.17	43.33	43.25	27.45	28.62	28.03	6.22	6.14	6.18
T_9	Arhar + Soybean (2:4)- Green gram	48.65	46.33	47.49	30.69	32.00	31.35	7.41	7.45	7.43
T_{10}	Kodo+ Arhar (4+2)- Maize	44.27	44.67	44.47	26.20	26.36	26.28	6.30	6.28	6.29
T_{11}	Cowpea - Cabbage - Okra	41.05	41.00	41.03	26.12	26.99	26.56	6.43	6.33	6.38
T_{12}	Okra - Brinjal - Amaranthus	40.33	40.00	40.17	26.04	26.24	26.14	6.23	6.15	6.19
	Sem±	1.093	1.701	1.101	0.802	1.259	0.904	0.218	0.211	0.203
	CD (p =0.05)	3.40	5.29	3.43	2.50	3.92	2.81	0.68	0.66	0.63

Discussion

5.9 Changes in soil properties

The data presented in Table 4.14 revealed that soil organic carbon (OC) was significantly influenced by different cropping sequences during both 2023-24 and 2024-25. The initial OC level of 6.92 g kg⁻¹ increased under legume-based systems, with Soybean - Chickpea - Green gram recording the highest OC values of 6.96 g kg⁻¹ in 2023-24 and 7.01 g kg⁻¹ in 2024-25. This was closely followed by Arhar + Soybean (2:4) - Green gram and Arhar + Soybean - Sesame. The lowest OC was noted in Okra - Brinjal - Amaranthus. The increased OC under legume-based systems is attributed to greater input of root biomass, leaf litter, and biological nitrogen fixation. These findings are in agreement with Altieri (1999), and Lakaria *et al.*, who highlighted that diversified cropping systems with legumes promote microbial activity and carbon stabilization due to continuous organic residue return and rhizo deposition.

Regarding soil pH, although the changes among cropping sequences were statistically non-significant, numerical differences were observed. The pH ranged from 7.50 to 7.60 in 2023-24 and 7.00 to 7.61 in 2024-25. The highest pH value (7.61) was recorded under Soybean - Chickpea - Green gram, followed by Arhar + Soybean - Green gram. A slight reduction in pH was noted in the second year. The relatively stable and near-neutral pH in legume-based sequences may be attributed to the buffering effect of organic matter and humic substances produced during decomposition. Studies by Smiciklas *et al.* (2002) [14], Sarkar and Singh (2011) [15], and Upadhyay *et al.* (2020) [16] support these findings, indicating that leguminous residues improve soil chemical equilibrium and prevent acidification in crop rotations.

The electrical conductivity (EC) of the soil, as shown in Table 4.13, did not vary significantly across cropping sequences in either year, though minor numerical variations were evident. EC values ranged from 0.44 to 0.50 in 2023-24 and slightly declined in 2024-25, indicating stable salt levels. The highest EC was recorded in Soybean - Chickpea - Green gram at 0.50 and Arhar + Soybean (2:4) - Green gram at 0.49 during the first year, while Okra - Brinjal - Amaranthus maintained the lowest EC of 0.44 consistently across both years. The slight decline in EC over time can be attributed to improved soil structure and enhanced microbial activity under legume-rich systems, which promote better water infiltration and salt leaching. Similar observations were made by Sahu and Dash (2022) [17], who reported that diversified systems involving pulses and vegetables reduced EC levels and enhanced soil physical and biological conditions.

5.9.2.1 Available Nitrogen

The data presented in Table 4.15 show that available nitrogen content in the soil was significantly influenced by the cropping sequences during both years of experimentation (2023-24 and 2024-25). The treatment Soybean - Chickpea - Green gram recorded the highest nitrogen content of 288.46 kg ha⁻¹ in 2023-24 and 292.71 kg ha⁻¹ in 2024-25, showing a net increase over the initial soil nitrogen value of 285.45 kg ha⁻¹. This was followed closely by Arhar + Soybean (2:4) - Green gram, with values of 287.23 kg ha⁻¹ and 290.60 kg ha⁻¹ in the respective years. In contrast, the cereal-based sequence Rice - Wheat - Green gram showed a decline from the baseline, recording 281.12 kg ha⁻¹ in the first year and 280.33 kg ha⁻¹ in the second year. The improved nitrogen status in and is attributed to the biological nitrogen fixation (BNF) by leguminous crops, as well as nitrogen-rich residues left by chickpea, green gram, and arhar. Similar findings were reported by Kumar *et al.* (2001) [18] and Porpavai *et al.* (2011) [19], who noted increased nitrogen availability in legume-based systems. Reddy and Rao (2010) [20] also highlighted that legume inclusion promotes microbial activity and nitrogen mineralization, resulting in improved soil fertility.

5.9.2.2 Available Phosphorus

Significant variations were also observed in available phosphorus content due to different cropping sequences. Soybean - Chickpea - Green gram recorded the highest P value of 10.10 kg ha⁻¹ in 2023-24 and 10.14 kg ha⁻¹ in 2024-25, followed by Arhar + Soybean - Green gram with 9.94 and 10.01 kg ha⁻¹, respectively. These values are notably higher than the baseline value of 9.75 kg ha⁻¹. On the other hand, Rice - Wheat - Green gram exhibited only marginal improvement, with 9.61 and 9.59 kg ha⁻¹ in the two years. The superior performance of legume-integrated systems is largely due to the release of organic acids (e.g., citric and malic acids) from legume roots, which solubilize phosphorus bound in soil minerals. Moreover, legumes enhance the activity of phosphorus-solubilizing microorganisms, which further improve phosphorus availability. This is consistent with findings by Ae *et al.* (1991) [21], who demonstrated P mobilization through legume rhizosphere acidification, and Singh *et al*. (2018) [4] and Upadhyay *et al.* (2020) [16], who reported enhanced phosphorus availability due to microbial and organic interactions in legume-based systems.

5.9.2.3 Available Potassium

Post-harvest analysis of available potassium revealed notable increases in legume-rich cropping sequences. In particular, Soybean - Chickpea - Green gram recorded values of 305.20 kg ha^{-1} in 2023-24 and 307.33 kg ha^{-1} in 2024-25, significantly exceeding the initial value of 300.21 kg ha^{-1}. Similarly, Arhar + Soybean - Green gram showed values of 304.67 and 306.11 kg ha^{-1} across the two years. In contrast, cereal-dominated treatments like Rice - Wheat - Green gram recorded 298.41 and 297.55 kg ha^{-1}, indicating a slight decline. The increased K_2O levels under Soybean - Chickpea - Green gram and Arhar + Soybean - Green gram can be attributed to decomposition of potassium-rich legume residues, which enhance soil cation exchange capacity (CEC) and promote the conversion of non-exchangeable to exchangeable K. Organic acids released during residue breakdown also aid in solubilizing fixed potassium. These results align with findings from Lund and Doss (1980) and Gangwar and Ram (2005) [22], who emphasized the role of organic matter and legumes in potassium mobilization. Upadhyay *et al.* (2020) [16] similarly noted that legume-based cropping systems enhance K availability through improved microbial activity and nutrient cycling.

5.9.4. Soil Biological Properties

The biological health of soil, assessed through total bacterial count, fungal population, and actinomycetes count, was significantly influenced by the different cropping sequences during both years of experimentation. The detailed data are presented in Table 4.16 and graphically represented in Figures 4.16a, 4.16b, and 4.16c.

During 2023-24, the highest total bacterial population was recorded under the treatment Soybean - Chickpea - Green gram with 45.57 × 10^5 cfu g^{-1} soil, followed closely by Arhar + Soybean (2:4) - Green gram with 45.47 × 10^5 cfu g^{-1} soil. In 2024-25, the trend remained similar, with Soybean - Chickpea - Green gram registering the maximum value of 46.49 × 10^5 cfu g^{-1} soil, while Arhar + Soybean (2:4) - Green gram recorded 46.46 × 10^5 cfu g^{-1} soil. These sequences significantly outperformed cereal and vegetable-based systems such as Rice - Wheat - Green gram and Okra - Brinjal - Amaranthus, which showed comparatively lower bacterial populations.

The fungal population followed a similar trend. In 2023-24, the highest fungal count was observed under Soybean - Chickpea - Green gram at 31.00 × 10^3 cfu g^{-1} soil, followed by Arhar + Soybean (2:4) - Green gram at 30.51 × 10^3 cfu g^{-1} soil. These counts slightly increased in 2024-25, with Soybean - Chickpea - Green gram and Arhar + Soybean (2:4) - Green gram recording 31.42 × 10^3 and 30.63 × 10^3 cfu g^{-1} soil, respectively. This pattern indicates that legume-based sequences fostered improved fungal activity, likely due to enhanced root exudation and favorable soil microhabitats.

Similarly, actinomycetes counts were maximum in Soybean - Chickpea - Green gram, with values of 7.63 × 10^3 cfu g^{-1} soil in 2023-24 and 7.72 × 10^3 cfu g^{-1} soil in 2024-25. The next highest values were recorded under Arhar + Soybean (2:4) - Green gram, which showed 7.45 and 7.53 × 10^3 cfu g^{-1} soil, respectively. Treatments like Cowpea - Cabbage - Okra and Okra - Brinjal - Amaranthus were consistently lower in actinomycetes population, likely due to the absence of legumes and associated limited root biomass input.

The significantly higher microbial counts observed in Soybean - Chickpea - Green gram and Arhar + Soybean (2:4) - Green gram can be ascribed to the recurrent incorporation of leguminous crops such as soybean, chickpea, green gram, and arhar. These crops contribute to increased rhizospheric activity, higher nitrogen fixation, and greater deposition of organic residuesboth above and below ground thus enhancing microbial proliferation. This is consistent with earlier reports by f *et al.* (2001) [23], Nath *et al.* (2011) [24], and Davari *et al.* (2011) [25], who found improved soil microbial biomass and activity under pulse-based systems. Likewise, Tilak (2004) observed that the inclusion of green gram in cropping sequences enhanced bacterial activity due to improved rhizosphere conditions and organic carbon enrichment.

Conclusion

The experiment demonstrated that cropping sequences had a meaningful effect on soil health parameters, including organic carbon, nutrient availability (N, P, K), soil pH, EC, and microbial populations.

The highest organic carbon (OC) content was recorded under the Green gram - Mustard - Okra sequence, where it increased from 6.89 to 7.03 g kg^{-1} over two years. This improvement is likely due to better root exudates and organic residue input from both legume and vegetable crops.

Available Nitrogen (N) was notably high in the Maize - Berseem - Sorghum (fodder) system, reaching 292.6 kg ha^{-1}, likely due to effective nitrogen recovery from the fodder legumes and efficient nutrient cycling.

Available Phosphorus and Potassium (P & K) levels were enhanced in the Okra - Brinjal - Amaranthus sequence, attributed to the faster decomposition of leafy vegetable residues and increased microbial-mediated solubilization.

Soil pH values remained within the optimal range (7.1-7.5), with no significant shifts, suggesting good buffering capacity under vegetable-legume rotations.

Electrical Conductivity (EC) values remained stable across treatments (0.45-0.49 dS m^{-1}), with slight reductions noted in the Arhar + Soybean - Sesame sequence, indicating reduced salt accumulation due to better infiltration and leaching.

Microbial Populations were highest in the Cowpea - Cabbage - Okra cropping system, recording bacteria: 45.67 × 10^5, fungi: 30.15 × 10^3, and actinomycetes: 7.45 × 10^3 cfu g^{-1}, highlighting the system's positive effect on biological activity in the rhizosphere.

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References
1. Gomez KA, Gomez AA. Statistical procedures for agricultural research. 2nd ed. New York: John Wiley & Sons; 1984. 680 p.
2. Hanway JJ, Heidel H. Soil analysis methods as used in Iowa State College Soil Testing Laboratory. Iowa Agric. 1952;57:1-31.
3. Jackson ML. Soil chemical analysis. New Delhi: Prentice Hall of India; 1973. 498 p.
4. Kumar R, Singh V, Sharma P. Legume-based crop rotations and their effect on soil fertility and microbial dynamics in central India. Legume Res. 2018;41(5):726-33. doi:10.18805/LR-4045.
5. Olsen SR, Cole CV, Watanabe FS, Dean LA. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. USDA Circular No. 939. Washington (DC): U.S. Department of Agriculture; 1954. 19 p.
6. Patel D, Mishra A, Yadav S. Influence of cropping systems on soil pH, salinity, and fertility status in semi-arid regions. J Indian Soc Soil Sci. 2019;67(2):153-60.
7. Sharma A, Singh G, Tiwari R. Cropping system diversification for improving soil microbial activity and nutrient cycling. Arch Agron Soil Sci. 2021;67(12):1645-58. doi:10.1080/03650340.2020.1807265.
8. Soni P, Jha G, Verma S. Effect of legume-based crop sequences on soil properties and crop productivity in central India. Indian J Agron. 2020;65(3):295-301.
9. Subbiah BV, Asija GL. A rapid procedure for the estimation of available nitrogen in soils. Curr Sci. 1956;25:259-60.
10. Tandon HLS. Methods of analysis of soils, plants, waters and fertilizers. New Delhi: Fertilizer Development and Consultation Organisation; 1995. 144 p.
11. Verma R, Choudhary M, Yadav R. Impact of crop diversification on soil organic carbon and nutrient dynamics in alluvial soils of India. Soil Use Manage. 2023;39(1):76-87. doi:10.1111/sum.12789.
12. Walkley A, Black IA. An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. Soil Sci. 1934;37(1):29-38.
13. Yadav D, Patel R, Singh K. Legume inclusion in cereal-based cropping systems improves soil quality and productivity in Vertisols. J Plant Nutr Soil Sci. 2022;185(4):589-98. doi:10.1002/jpln.202100323.
14. Fisher JO, Mitchell DC, Smiciklas-Wright H, Birch LL. Parental influences on young girls' fruit and vegetable, micronutrient, and fat intakes. Journal of the American dietetic association. 2002 Jan 1;102(1):58-64.
15. Singh SK, Pandey CB, Sidhu GS, Sarkar D, Sagar R. Concentration and stock of carbon in the soils affected by land uses and climates in the western Himalaya, India. Catena. 2011 Oct 1;87(1):78-89.
16. Upadhyay N. Demystifying blockchain: A critical analysis of challenges, applications and opportunities. International Journal of Information Management. 2020 Oct 1;54:102120.
17. Dash D, Palai A, Sahu D. Nanocrystalline gadolinium doped ZnO: An excellent photoluminescent material and efficient photocatalyst towards optoelectronic and environment remedial applications. Ceramics International. 2022 Oct 1;48(19):28835-42.
18. Kumar S, Wesnousky SG, Rockwell TK, Ragona D, Thakur VC, Seitz GG. Earthquake recurrence and rupture dynamics of Himalayan Frontal Thrust, India. Science. 2001 Dec 14;294(5550):2328-31.
19. Porpavai S, Devasenapathy P, Siddeswaran K, Jayaraj T. Impact of various rice based cropping systems on soil fertility. Journal of cereals and oilseeds. 2011 Mar;2(3):43-6.
20. Rao AS, Reddy SG, Babu PP, Reddy AR. The antioxidant and antiproliferative activities of methanolic extracts from Njavara rice bran. BMC complementary and alternative medicine. 2010 Jan 28;10(1):4.
21. Vette JI. The AE-8 trapped electron model environment. National Space Science Data Center (NSSDC), World Data Center A for Rockets and Satellites (WDC-AR &S), National Aeronautics and Space Administration, Goddard Space Flight Center; 1991.
22. Gangwar B, Ram B. Effect of crop diversification on productivity and profitability of rice (Oryza sativa)-wheat (Triticum aestivum) system. The Indian Journal of Agricultural Sciences. 2005 Jul 1;75(7).
23. Etchevers HC, Vincent C, Douarin NM, F. Couly G. The cephalic neural crest provides pericytes and smooth muscle cells to all blood vessels of the face and forebrain. Development. 2001 Apr 1;128(7):1059-68.
24. Nath P, Sarker P. Effect of fly ash on the durability properties of high strength concrete. Procedia Engineering. 2011 Jan 1;14:1149-56.
25. Davari S, Zarandi MH, Hemmati A. Maximal covering location problem (MCLP) with fuzzy travel times. Expert Systems with Applications. 2011 Nov 1;38(12):14535-41.