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Performance of Diversified Legume-based High-intensity Cropping Sequence on Productivity and Profitability

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ABSTRACT

Background: Enhancing productivity while conserving soil and resources is a pre-requisite for achieving sustainable intensification of agro-ecosystems. Diversification by integrating legumes with millets for such high-intensity systems not only offers a potential of improving soil fertility by fixing nitrogen and residue addition but overall enhances proper balance in nutrient cycling, ensures efficient use of land enhancing year-round productivity under irrigated conditions.

Methods: Field experiment was conducted at Sher-e-Kashmir University of Agricultural Sciences and Technology of Jammu under irrigated conditions to evaluate high intensity legume-millet-millet cropping sequences. The study consisted of twelve cropping sequences laid down in a randomized block design with three replications, covering a complete annual cycle from *rabi* to *kharif*. Legume crop (Pea) was grown as common *rabi* crop across all treatments, followed by three millets foxtail millet, proso millet and pearl millet in the summer season and four millets finger millet, barnyard millet, little millet and kodo millet during *kharif*.

Result: Productivity of pea remained statistically unaffected during both years. During the summer season, cropping sequences involving pearl millet recorded significantly higher yields followed by foxtail millet. While among the *kharif* crops, finger millet outperformed other millet crops in sequence in terms of productivity. Overall, cropping systems integrating foxtail or pearl millet during summer and finger millet during *kharif* achieved the significantly higher system productivity (14,533.92 and 14,582.74 kg ha^{-1} in the first and second year, respectively) and profitability in terms of benefit : cost ratio of 2.62 and 2.38. Hence, the inclusion of pea-foxtail/pearl millet-finger millet proved to be most productive and economical viable option for irrigated conditions.

Key words: Diversification, High intensity legume-millet-millet crop sequences, Intensification, System productivity, System profitability.

INTRODUCTION

Continuous cultivation of conventional cereal-based systems such as rice-wheat and maize-wheat has long ensured India's food security but has now become ecologically and economically unsustainable. These systems have led to declining productivity, soil degradation, nutrient imbalance, and heavy dependence on chemical fertilizers and water-intensive practices, resulting in reduced resource-use efficiency and environmental imbalance (Bo *et al.*, 2025). To achieve long-term sustainability, a transition is needed from input-intensive monocropping to diversified, legume-based systems that enhance soil health and resource efficiency (Farooq *et al.*, 2025; Sharma *et al.*, 2025). Legume-based cropping systems improve soil fertility, productivity and ecological stability by fixing atmospheric nitrogen, adding organic matter and stimulating microbial activity, which enhances soil structure and nutrient cycling (Kamal *et al.*, 2024). Among legumes, pea (*Pisum sativum* L.) is a short-duration *rabi* crop ideally suited for intensive irrigated systems. Apart from being rich in protein, vitamins and minerals, pea improves soil fertility and system productivity, making it a suitable component for diversified high-intensity cropping systems (Sandhya *et al.*, 2022 and Thesiya *et al.*, 2019). Millets, termed "nutri-cereals" have re-emerged as climate-resilient, low-input and nutrient-dense crops suitable for both rainfed and irrigated conditions (Pawase *et al.*, 2019). Species such as finger millet (*Eleusine coracana*), pearl millet (*Pennisetum glaucum*), little millet (*Panicum sumatrense*) and foxtail

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millet (*Setaria italica*) tolerate drought and poor soils while offering high nutritional value with abundant dietary fibre, iron, zinc and essential amino acids (Goud *et al*., 2022; Dhaka *et al*., 2023; Kothapalli *et al*., 2024; Mukherjee *et al*., 2025).

Empirical evidence confirms the potential of legume-millet integration for improving productivity, profitability and soil health. Dhaka *et al*. (2025) reported significant gains in yield and economic returns from legume-millet systems compared to cereal monocropping. Similarly, Shilpa *et al*. (2025) found that a finger millet + green gram-cow pea sequence achieved the highest system productivity, while Kyuh *et al*. (2022) observed enhanced carbon sequestration and nitrogen cycling in such rotations.

However, most of these studies have primarily focused on season or location specific rotations, often under rainfed or semi-arid environments, with limited emphasis on year round, high intensity legume-millet systems under irrigated subtropical conditions. In particular empirical information on multi-millet sequences integrating legumes across *rabi*, summer and *kharif* seasons remains scarce. Strategic inclusion of pea during *rabi* followed by short-duration millets in summer and *kharif* seasons can enhance land-use efficiency, sustain soil fertility and ensure continuous ground cover. Therefore, the present study was undertaken with the following specific objectives:

1. To evaluate the performance of diversified legume-based high-intensity cropping systems under irrigated conditions of Jammu.
2. To identify the most productive, profitable and sustainable legume-millet sequence for year-round green cover and ecological balance.

MATERIALS AND METHODS

The field experiment was conducted at Sher-e-Kashmir University of Agricultural Sciences and Technology of Jammu during 2023-24 and 2024-25 under irrigated conditions (Fig 1). The experimental site experiences a subtropical climate with distinct *rabi*, *kharif* and *zaid* seasons. Total annual rainfall was 1487 mm in 2023-24 and 1751.5 mm in 2024-25, predominantly received during the monsoon period (July-September). Mean summer temperatures ranged from 38 to 40°C. The sandy loam soil (pH 7.72) contained 4.21 g kg^{-1} organic carbon and

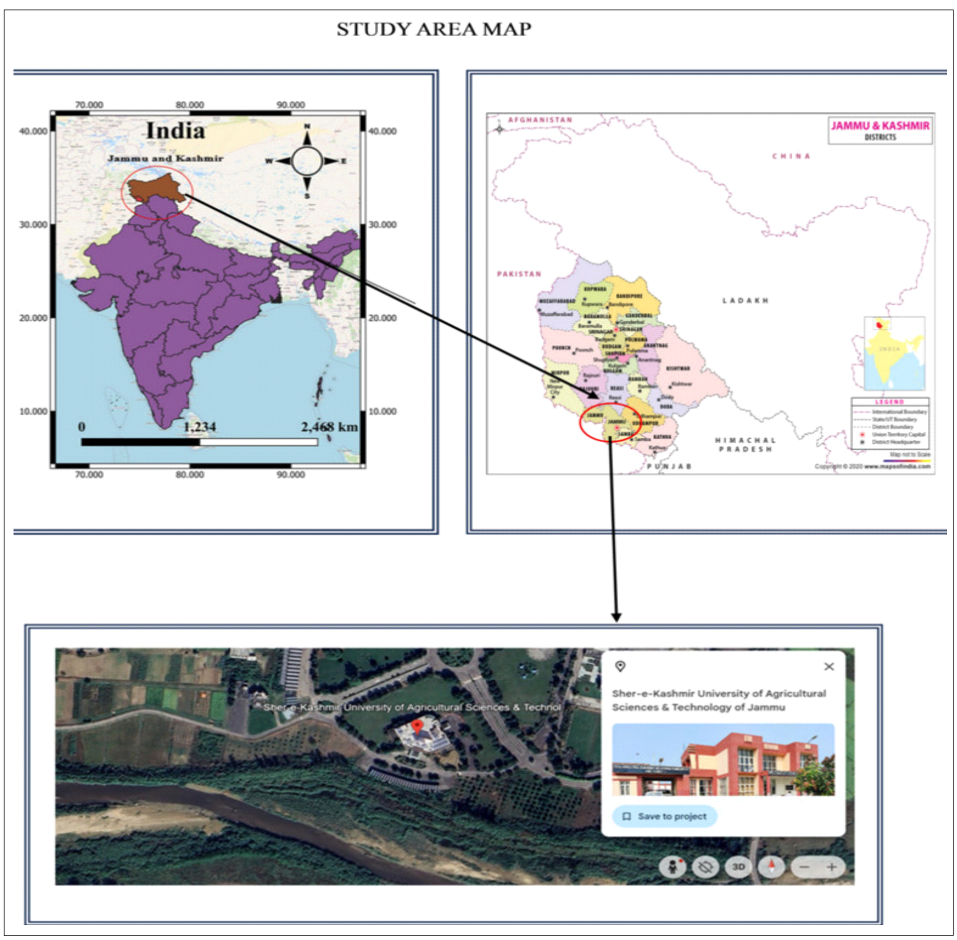

Fig 1: Study area.

available N, P and K of 237.21, 15.86 and 160.21 kg ha^{-1}, respectively. Twelve legume-based high-intensity cropping systems were evaluated, each comprising pea in *rabi* followed by millets in summer and *kharif*. The experiment was laid out in a randomized block design (RBD) with three replications and 36 plots (5.4 m × 3.0 m each). Treatments included combinations of pea with foxtail, proso and pearl millet in summer and finger, barnyard, little and kodo millet in *kharif*. Fertilization was carried out as per the locally recommended dose of fertilizers (RDF). The RDF applied was 40:60:50 kg N:P_2O_5: K_2O ha^{-1} for pea, 100:60:25 kg N:P_2O_5: K_2O ha^{-1} for pearl millet and 40:20:0 kg N: P_2O_5: K_2O ha^{-1} for the other millets included in the experiment. Weed control involved pre-emergence application of pendimethalin (1.0 kg a.i. ha^{-1}) followed by hand weeding at 30 DAS. Irrigation was applied at critical stages; proso millet received an extra irrigation, while *kharif* millets were rainfed. In pea, pod weight and green pod yield were recorded, while in millets, yield attributes and grain yields were measured. System productivity was expressed as pea equivalent yield (PEY) following Yadav *et al*. (2018) and total system productivity was the sum of *rabi*, summer and *kharif* PEY. Economic analysis was performed using prevailing prices of inputs and outputs. Prices of finger millet and pearl millet were considered as per the Minimum Support Price (MSP) notified for the respective years, while prices of vegetable pea and other millets were based on the auction prices recorded at SKUAST-Jammu during the corresponding cropping seasons (2023-24 and 2024-25). Input costs were calculated based on actual field expenditure. Soil samples (0-15 cm) were analyzed for pH (Jackson, 1973), organic carbon (Walkley and Black, 1934) and available N (Subbiah and Asija, 1956), P (Olsen *et al*., 1954) and K (Jackson, 1973) using standard methods. Data were analysed year-wise using analysis of variance (ANOVA) under a randomized block design (RBD) with IBM SPSS (v29.0) and treatment means were compared at $p \le 0.05$.

RESULTS AND DISCUSSION

Effect of legume-based cropping sequence on productivity of pea crop

Table 1 shows that pod weight per plant and green pod yield of pea were statistically at par across diversified legume-based cropping sequences during both years. However, both parameters improved slightly in the second year, reflecting a cumulative positive effect. Treatment T_3 (Pea-Foxtail millet-Little millet) and T_8 (Pea-Proso millet-Kodo millet) recorded highest pod weight and pod yield during first and second year, respectively. Overall, all sequences were statistically at par with only slight enhancement in pea productivity in the second year. The improvement may be due to residual legume effects enhancing soil nitrogen and organic matter. Proso and kodo millets, being less nutrient-exhaustive, possibly left higher fertility for the succeeding pea. Early sowing also promoted better pod development. Similar outcomes were noted by Franke *et al*. (2018); Zhao *et al*. (2022); Olson (2023) and Saskatchewan Pulse Growers (2023).

Effect of legume-based cropping sequence on productivity of millets grown in summer season

Significant variations were recorded in yield attributes and yields of summer millets (Table 2). Among millets sown in summer season Proso millet-based systems (T_5 to T_9) recorded highest number of effective tillers, followed by foxtail and pearl millet. While, Foxtail millet (T_1 to T_4) produced significantly higher grains per panicle, while pearl millet (T_9 to T_{12}) showed maximum 1000-grain weight and harvest index. Pearl millet recorded the highest grain and straw yields, followed by foxtail millet. Overall, pearl millet-based systems exhibited superior yield performance followed by foxtail millet. Yield improvement was attributed to enhanced availability of nutrients in soil which lead to increase in overall growth and development of crop. Moreover, Pearl millet's deep roots and efficient nutrient

Table 1: Effect of legume-based cropping sequence on yield attributes and yield of pea crop.

Treatments	Pod weight per plant (g)		Green pod yield (q ha^{-1})	
	2023-2024	2024-2025	2023-2024	2024-2025
T_1	35.86	35.88	92.06	92.29
T_2	35.61	35.90	90.34	92.59
T_3	36.16	35.77	92.82	92.48
T_4	35.60	36.04	89.78	92.76
T_5	35.75	36.59	91.73	93.77
T_6	35.71	36.91	91.18	94.04
T_7	35.86	36.99	92.05	94.67
T_8	35.81	37.21	91.08	95.57
T_9	34.98	35.72	89.72	92.24
T_{10}	35.89	35.90	92.14	92.69
T_{11}	35.68	36.16	90.00	93.04
T_{12}	35.91	36.37	92.17	93.62
SEm (±)	0.87	0.89	1.76	1.91
CD (5%)	NS	NS	NS	NS

Table 2: Effect of legume-based cropping sequence on yield attributes and yield of millets grown in summer season.

Treatments	No. of effective tillers per m^2		No. of grains per panicle		1000-grain weight (g)		Grain yield (q ha^{-1})		Straw yield (q ha^{-1})		Harvest index (%)	
	2024	2025	2024	2025	2024	2025	2024	2025	2024	2025	2024	2025
T_1	51.14	51.17	1142.14	1148.24	3.46	3.47	15.87	15.89	30.65	30.69	34.12	34.13
T_2	51.23	51.25	1146.94	1151.29	3.47	3.47	15.93	15.98	30.71	30.81	34.16	34.18
T_3	51.89	51.28	1150.23	1153.61	3.49	3.49	16.05	16.10	30.91	31.09	34.18	34.18
T_4	49.71	51.93	1137.61	1158.11	3.43	3.50	15.72	16.22	30.37	31.23	34.11	34.15
T_5	84.32	83.01	411.98	411.89	2.67	2.63	7.72	7.59	18.65	18.36	29.27	29.25
T_6	84.1	83.21	413.21	412.21	2.64	2.65	7.66	7.61	18.53	18.41	29.25	29.24
T_7	80.71	83.98	410.91	418.98	2.66	2.67	7.59	7.63	18.40	18.50	29.21	29.21
T_8	83.19	84.21	362.21	421.23	2.68	2.68	7.63	7.86	18.45	19.00	29.26	29.27
T_9	24.11	24.27	1425.51	1426.25	7.46	7.49	23.21	23.24	44.68	44.74	34.18	34.19
T_{10}	24.31	24.65	1431.32	1431.16	7.48	7.52	22.98	23.04	44.24	44.35	34.19	34.20
T_{11}	24.4	24.98	1433.11	1438.98	7.49	7.53	23.46	23.49	45.12	45.18	34.21	34.21
T_{12}	25.03	25.17	1435.2	1440.19	7.52	7.55	23.49	23.57	45.16	45.31	34.22	34.24
SEm (±)	1.87	1.83	33.33	35.18	0.16	0.17	0.50	0.54	0.68	0.71	0.98	0.93
CD (5%)	5.45	5.34	97.76	103.19	0.49	0.53	1.47	1.59	2.00	2.09	2.88	2.73

Table 3: Effect of legume-based cropping sequence on yield attributes and yield of millets grown in *kharif* season.

Treatments	No. of effective tillers per m^2		No. of grains per panicle		1000-grain weight (g)		Grain yield (q ha^{-1})		Straw yield (q ha^{-1})		Harvest index (%)	
	2024	2025	2024	2025	2024	2025	2024	2025	2024	2025	2024	2025
T_1	52.76	50.16	1725.32	1631.24	2.91	2.87	21.72	19.21	45.86	40.58	32.14	32.13
T_2	70.25	66.21	852.17	777.23	3.22	3.05	15.81	13.65	36.64	31.64	30.14	30.14
T_3	188.97	185.17	532.36	502.67	2.12	2.10	11.87	10.90	25.03	23.00	32.17	32.15
T_4	161.15	160.24	164.21	161.28	6.35	6.31	13.54	12.90	31.33	29.84	30.18	30.18
T_5	54.13	52.19	1868.91	1679.9	2.95	2.93	22.85	19.99	48.20	42.17	32.16	32.16
T_6	72.04	68.17	855.58	792.18	3.29	3.09	16.63	14.22	38.49	32.92	30.17	30.16
T_7	191.12	186.25	535.12	532.18	2.16	2.13	12.56	10.98	26.48	23.15	32.18	32.17
T_8	164.36	162.18	167.18	163.26	6.38	6.36	14.23	13.61	32.91	31.48	30.19	30.19
T_9	53.02	51.18	1791.01	1645.17	2.92	2.87	21.96	19.77	46.38	41.72	32.13	32.15
T_{10}	71.45	67.24	853.36	785.26	3.24	3.07	16.20	14.04	37.57	32.54	30.13	30.14
T_{11}	189.97	185.2	533.93	521.87	2.13	2.11	12.04	10.91	25.38	23.02	32.17	32.16
T_{12}	162.15	162.01	166.21	161.97	6.36	6.33	13.90	13.04	32.15	30.17	30.18	30.18
SEm (±)	1.81	1.98	26.11	27.98	0.17	0.18	0.53	0.51	0.71	0.69	0.38	0.39
CD (5%)	5.32	5.82	76.58	82.26	0.49	0.53	1.55	1.51	2.05	1.99	1.17	1.47

utilization contributed to its superior performance (Dhaka *et al*., 2025; Rao and Kumar, 2023).

Effect of legume-based cropping sequence on productivity of millets grown in *kharif* season

Table 3 revealed significant differences in *kharif* millet productivity, with a slight decline during second year of experiment. Kodo millet (T_4, T_8 and T_{12}) recorded highest effective tillers, followed by little millet (T_3, T_7 and T_{11}), while finger millet (T_1, T_5 and T_9) recorded highest grain and straw yield. Overall, finger millet showed superior performance among millets sown in *kharif* season. Slight decline in yield during second year may be attributed to floods during September month coinciding with late vegetative to reproductive stage of crops sown in *kharif* season. Finger millet's superior nutrient efficiency and enhanced soil fertility from the preceding pea crop contributed to its performance (Patil and Raundal, 2018; Arora *et al*., 2023; Dhaka *et al*., 2025).

Effect of legume-based cropping sequences on pea equivalent yield and system productivity.

Significant differences in pea equivalent yield and system productivity were observed during both years (Table 4). Among millets sown in summer season treatment T_3 (Pea-Foxtail millet-Little millet) recorded highest pea equivalent yield, followed by T_2 and T_1. However, among *kharif* sown millets, T_5 (Pea-Proso millet-Finger millet) and T_9 (Pea-Pearl millet-Finger millet) were observed with higher equivalent yield. Treatment T_1 and T_9 recorded highest system productivity. Overall, sequences integrating finger millet as *kharif* crop were more efficient in terms of system productivity. Differences reflected combined effects of yield potential and market value (Dhaka *et al*., 2025; Singh *et al*., 2022; Singh and Yadav, 2021). However, slight decline in system productivity in 2025 were due to flooding.

Table 4: Effect of legume-based cropping sequence on pea equivalent yield of *kharif* and summer millets and system productivity.

Treatments	PMEY of summer millets (kg ha^{-1})		PMEY of *kharif* millets (kg ha^{-1})		System productivity (kg ha^{-1})	
	2024	2025	2024	2025	2023-2024	2024-2025
T_1	2222.11	2224.92	3106.11	3129.06	14533.92	14582.74
T_2	2230.38	2237.44	2371.01	2047.67	13635.4	13544.07
T_3	2246.97	2254.11	1899.71	1743.44	13428.73	13245.54
T_4	2201.00	2270.77	1354.25	1289.96	12533.25	12836.84
T_5	1209.26	1189.48	3267.75	3255.64	13650.43	13822.1
T_6	1199.93	1192.59	2494.22	2132.75	12811.95	12729.52
T_7	1189.52	1195.74	2010.37	1756.66	12405.06	12419.61
T_8	1195.76	1231.37	1423.36	1361.21	11726.86	12149.76
T_9	2033.61	2111.14	3139.92	3219.56	14145.54	14554.41
T_{10}	2011.03	2092.90	2429.88	2106.14	13654.58	13467.94
T_{11}	2053.06	2133.87	1925.93	1745.81	12978.66	13183.82
T_{12}	2055.56	2141.08	1389.70	1304.28	12662.69	12807.23
SEm (±)	87.27	79.57	94.65	95.08	516.00	505.25
CD (5%)	255.71	233.50	275.43	272.98	1513.36	1481.67

Table 5: Effect of legume-based cropping sequence on profitability of pea crop.

Treatments	Net returns (₹ ha^{-1})		B:C ratio (₹ ha^{-1})		Per day returns (₹ ha^{-1})	
	2023-24	2024-25	2023-24	2024-25	2023-24	2024-25
T_1	229523	228011	4.92	4.67	2031	1781
T_2	224372	228917	4.81	4.69	1986	1788
T_3	231814	228588	4.97	4.68	2051	1786
T_4	223692	229432	4.80	4.70	1980	1792
T_5	228555	232458	4.90	4.76	2023	1816
T_6	226886	233274	4.86	4.78	2008	1822
T_7	229507	235165	4.92	4.81	2031	1837
T_8	226585	237864	4.86	4.87	2005	1858
T_9	222512	227860	4.77	4.66	1969	1780
T_{10}	229762	229216	4.93	4.69	2033	1791
T_{11}	223342	230273	4.79	4.71	1976	1799
T_{12}	229876	232004	4.93	4.75	2034	1813

Effect of legume-based cropping sequence on system profitability

Economic analysis (Table 5-8) showed marked variations among systems. For pea, T_3 (Pea-Foxtail millet-Little millet) recorded the highest net returns and B:C ratio, followed by T_1 and T_7. Maximum per-day returns occurred in T_7 (Pea-Proso millet-Little millet) and T_8 (Pea-Proso millet-Kodo millet). Among summer sown millets, foxtail millet-based

Table 6: Effect of legume-based cropping sequence on profitability of millets grown in summer season.

Treatments	Net returns (₹ ha^{-1})		B:C ratio (₹ ha^{-1})		Per day returns (₹ ha^{-1})	
	2024	2025	2024	2025	2024	2025
T_1	37058	35473	0.96	0.876	374	358
T_2	37324	35884	0.96	0.886	377	362
T_3	37882	36445	0.98	0.900	383	368
T_4	36341	37014	0.94	0.914	367	374
T_5	4066	144	0.11	0.004	44	2
T_6	3748	252	0.10	0.006	40	3
T_7	3398	372	0.09	0.009	37	4
T_8	3601	1592	0.10	0.039	39	17
T_9	35621	34045	0.82	0.759	409	391
T_{10}	34847	33363	0.81	0.744	401	383
T_{11}	36461	34878	0.84	0.777	419	401
T_{12}	36550	35140	0.85	0.783	420	404

Table 7: Effect of legume-based cropping sequence on millets grown in *kharif* season.

Treatments	Net returns (₹ ha^{-1})		B:C ratio (₹ ha^{-1})		Per day returns (₹ ha^{-1})	
	2024	2025	2024	2025	2024	2025
T_1	62367	48869	1.56	1.17	562	440
T_2	37716	25586	0.97	0.63	356	241
T_3	25027	18048	0.63	0.44	236	170
T_4	10702	6647	0.27	0.16	99	62
T_5	67685	52520	1.69	1.26	589	457
T_6	41690	28331	1.07	0.70	379	258
T_7	28781	18490	0.73	0.45	262	168
T_8	13251	9275	0.34	0.23	118	83
T_9	63485	51480	1.59	1.24	557	452
T_{10}	39621	27476	1.02	0.68	374	259
T_{11}	25918	18125	0.66	0.44	245	171
T_{12}	12011	7176	0.31	0.18	113	68

Table 8: System profitability as effected by legume based cropping sequences.

Treatments	System net returns (₹ ha^{-1})		System B:C ratio (₹ ha^{-1})		System per day returns (₹ ha^{-1})	
	2023-2024	2024-2025	2023-2024	2024-2025	2023-2024	2024-2025
T_1	328948	312354	2.62	2.38	1018	924
T_2	299412	290388	2.41	2.24	942	872
T_3	294723	283081	2.36	2.17	927	850
T_4	270735	273093	2.17	2.10	846	815
T_5	300305	285122	2.41	2.17	936	849
T_6	272324	261857	2.21	2.01	862	791
T_7	261687	254026	2.11	1.94	828	767
T_8	243436	248730	1.97	1.90	766	747
T_9	321618	313385	2.48	2.31	1024	953
T_{10}	304230	290055	2.36	2.16	994	904
T_{11}	285721	283276	2.21	2.10	934	882
T_{12}	278437	274320	2.16	2.04	910	855

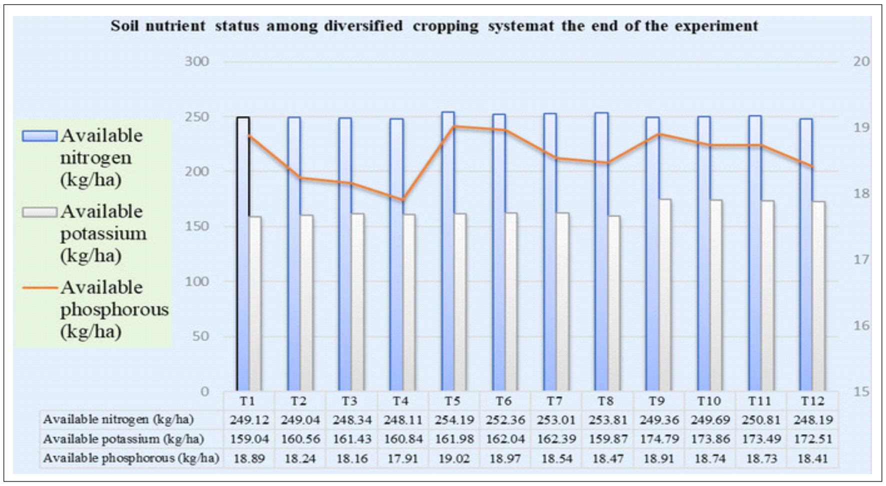

Fig 2: Effect of diversified cropping systems on soil fertility.

systems (T_1-T_4) were most profitable, while proso millet-based systems (T_5-T_8) were least profitable due to poor adaptability and low prices. While, among *kharif* sown millets, T_9 (Pea-Proso millet-Finger millet) fetched highest net returns and B:C ratio, followed by T_9 and T_1. Overall, T_1 (Pea-Foxtail millet-Finger millet) yielded maximum system returns (₹ 3,28,948 and ₹ 3,12,354 ha^{-1}) and B:C ratios (2.62 and 2.38), confirming its superior profitability. These findings are in line with those of Patil (2021); Meena *et al*. (2023) and Dhaka *et al*. (2025).

Effect of legume-based cropping systems on soil fertility

Fig 2 depicts soil fertility after two years. Available nitrogen and phosphorus showed non-significant variation, indicating balanced nutrient management. However, available potassium differed significantly-highest under T_9 (Pea-Pearl millet-Finger millet) (174.79 kg ha^{-1}), followed by T_{10} and T_{11}. Foxtail and proso millet-based systems (T_1-T_8) had lower K (159.04-162.39 kg ha^{-1}). Higher K in pearl millet systems was due to RDF containing K_2O, unlike others with minimal K inputs. Continuous non-K-supplemented cropping depleted soil K, aligning with Majumdar *et al*. (2019); Kumar *et al*. (2022) and Pathak *et al*. (2021), highlighting the need for balanced nutrient replenishment for soil sustainability.

CONCLUSION

The two-year study demonstrated that integrating legumes with millets in sequence offers a sustainable intensification strategy for enhancing productivity, profitability and soil fertility under subtropical conditions. Systems involving foxtail or pearl millet in summer, followed by finger or barnyard millet in *kharif*, performed best. Among all, pea-foxtail millet-finger millet and pea-pearl millet-finger millet proved most profitable, showing higher net returns, benefit-cost ratio and per-day returns. The inclusion of pea as a preceding legume improved soil fertility and boosted subsequent millet yields. However, these findings are primarily applicable to irrigated conditions, as the feasibility and performance of such high-intensity legume-millet sequences under rainfed environments may be constrained by moisture availability**.** Overall, legume-millet sequences, particularly those involving foxtail, pearl and finger millet, enhance resilience, resource-use efficiency and long-term sustainability of high-intensity cropping systems.

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Disclaimers

The views and conclusions expressed in this article are solely those of the authors and do not necessarily represent the views of their affiliated institutions. The authors are responsible for the accuracy and completeness of the information provided, but do not accept any liability for any direct or indirect losses resulting from the use of this content.

Conflict of interest

The authors declare that there are no conflicts of interest associated with this study.

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