



## Energy budget, economics and yield performance of millet based crop rotations with Indian mustard in Hisar district of Haryana (India)

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### Abstract

Millets and pulses are the most important dryland crops grown in both *Kharif* and *Rabi* seasons in the semi-arid regions of the country for food, feed and animal fodder. These crops also show considerable resilience to changing climate (drought, heat and nutrient stresses). For diversification of Pearl millet-Chickpea rotation, adoption of small millets (finger millet, foxtail millet, proso millet, little millet, brown top millet, barnyard millet, and kodo millet) in addition to pearl millet may be viable option. A field experiment was carried out at CCS Haryana Agricultural University, Hisar, Haryana, India during 2022-23 in randomized block design in *Kharif* and *Rabi* season, replicated thrice with eight treatments (foxtail millet, little millet, browntop millet, proso millet, kodo millet, barnyard millet, finger millet and pearl millet) in *Kharif* season and eight crop rotations (foxtail millet- Indian mustard, little millet- Indian mustard, browntop millet- Indian mustard, proso millet- Indian mustard, kodo millet- Indian mustard, barnyard millet - Indian mustard, finger millet - Indian mustard and pearl millet - Indian mustard) in *Rabi* season to evaluate yield and economic performance eight millet based crop rotations with Indian mustard. During *Kharif* season among all millets (foxtail millet, little millet, browntop millet, proso millet, kodo millet, barnyard millet, finger millet and pearl millet) tested, Pearl millet was found most suitable, which produced significantly higher grain yield (2462 kg/ha), biological yield (10066 kg/ha), net energy returns (121552 MJ/ha), Energy intensiveness (14.0 MJ/USD), human energy profitability (133.3 MJ/ha) compared to all other millets. In *Rabi* season Indian mustard sown after Pearl millet recorded significantly higher seed yield (3492 kg/ha), biological yield (20666 kg/ha), net returns (Rs. 120471/ha) and B:C (2.97) compared to other crop rotations but Indian mustard sown after foxtail millet recorded higher net energy returns (250664 MJ/ha), energy ratio (25.50), energy profitability (24.50 MJ/ha) and human energy profitability (267.8 MJ/ha).

**Keywords:** Economics, energy budgeting, millets, mustard, yield

### Introduction

Haryana ranks second as a food grains contributor to the nation's food basket with its nearly 70 per cent of the population engaged in agriculture had a rich legacy of sustainable agricultural development witnessing an production of 2.6 MT in 1966-67 to 18.3 MT in 2020-21 food-grain with eleven fold increases in wheat and sixteen fold increase in rice production during this period. The common cropping systems practiced in Haryana are rice-wheat cropping systems (RWCS), cotton-wheat cropping system (CWCS) and pearl millet-mustard cropping system (PMCS). The rice-wheat cropping system (RWCS), with rice occupying 43.8 Mha and wheat occupying 29.3 Mha area, has played a major role in securing and sustaining food security of our country. The crop production pattern in Haryana is dominated by RWCS. But after continuous cropping, this system is facing new challenges like yield stagnation, resources depletion and deterioration, pest pressure, nutrient

mining and burning of crop residue, which put questions on the sustainability of this cropping system (Sammauria *et al.*, 2020). Similarly cotton-wheat cropping system (CWCS) is also becoming less remunerative due to long duration, very high pest damage, increasing cost of inputs and climatic uncertainties in *Kharif* season. From resource conservation and sustainability point of view most successful and highly adopted crop rotation in the dry regions of south Haryana is pearl millet mustard cropping system (PMCS). So, now most of these systems require diversification for greater sustainability, better economics and conservation of natural resources. There is a need for long term planning and development of various strategies for crop diversification in the best national interest (Kumar *et al.*, 2023; Yadav *et al.*, 2017).

The pearl millet mustard cropping system (PMCS) is practiced in the dry regions of Haryana. Pearl millet (*Pennisetum glaucum* L.) is grown in rainfed and in arid

and semi-arid areas of India. Haryana ranks 5<sup>th</sup> in terms of area coverage under this crop. It is one of the most important sources of staple food and fodder for animals (Faiz *et al.*, 2022; Meena *et al.*, 2021). Indian mustard (*Brassica juncea* L.) is the most important oil seed crop of northern India (Kumar *et al.*, 2016). For diversification of PMCS, adoption of small millets (finger millet, foxtail millet, proso millet, little millet, brown top millet, barnyard millet, and kodo millet) in addition to pearl millet may be a viable option (Habiyaremye *et al.*, 2017). There is an immediate need to promote the cultivation of millets to ensure food and nutritional security at national level because small millets are considered climate smart and nature friendly crops because of high nutritive value, tolerance to water and temperature stress, short life, low external inputs requirement (Jeeva *et al.*, 2024; Dhaka *et al.*, 2023). Farmers need to be continuously motivated and encouraged to pursue crop diversification for better sustainability as well as income and employment opportunities.

Considering the importance of millets in food and nutritional security, the year 2018 as 'National Year of Millets' at national level and the year 2023 as 'International Year of Millets' was celebrated at global level. Millets are currently grown in 131 countries in over 78 million ha with sorghum and pearl millet accounting for over 90 per cent share at global level (Singh *et al.*, 2023). India is the largest grower (with 19% contribution) and producer (20% production) of millets in the world (Dhaka *et al.*, 2023a). Share of India in Asia stands at 85% in area and 80% in production of millets. Top seven countries in the world for pearl millet cultivation are India, Niger, Sudan, Nigeria, Mali, Burkina Faso and Chad. Thus, among the major millets India ranks first in the world with respect to pearl millet cultivation and third in sorghum cultivation. The most important states for pearl millet cultivation are Rajasthan, Uttar Pradesh and Maharashtra having a total share of 78 per cent (Bhuva and Detroja, 2018). Karnataka alone accounts for more than 2/3rd acreage of finger millet. Chhattisgarh and Madhya Pradesh grow more than 60 per cent of small millets (Bhat *et al.*, 2023).

All efforts made by Government to promote millets have been responded well by farmers and consumers. But very limited research work has been conducted so far on different minor millet based crop rotations with Indian mustard except PMCS. So, considering all these facts mentioned above a field experiment was conducted at CCS Haryana Agricultural University, Hisar, Haryana, India to study the yield and economic performance of

millet based crop rotations with Indian mustard.

## Materials and Methods

A field experiment was carried out at crop physiology field research area of CCS Haryana Agricultural University, Hisar, Haryana, India (29°10'N latitude, 75°46'E longitude and 215.2 M altitude) during 2022-23 in randomized block design in *Kharif* season and split plot design in *Rabi* season, replicated thrice with eight treatments (foxtail millet, little millet, brown top millet, proso millet, kodo millet, barnyard millet, finger millet and pearl millet) in *Kharif* season and eight crop rotations (foxtail millet- Indian mustard, little millet- Indian mustard, brown top millet- Indian mustard, proso millet- Indian mustard, kodo millet- Indian mustard, barnyard millet - Indian mustard, finger millet - Indian mustard and pearl millet - Indian mustard) in *Rabi* season to evaluate yield and economic performance of eight millet based crop rotations with Indian mustard. Soil of the field was sandy loam in texture, slightly alkaline in pH (7.7), low organic carbon, poor in available phosphorus, medium in available nitrogen and rich in available potassium. The maximum and minimum temperature during the crop study period was congenial for the growth and development of crops. Sowing of all millets viz. Foxtail millet (SIA 3156), Little millet (DHLM 36-3), Brown top millet (IIMRAK 2), Proso millet (TNAU 202), Kodo millet (JK 41), Barnyard millet (VC 27), Finger millet (GPU 67) and Pearl millet (HHB 67) in *Kharif* season was done on 27<sup>th</sup> July, 2022 and these were harvested at 78, 92, 73, 69, 91, 78, 116 and 71 days after sowing, respectively.

Agronomical management for each millet was done separately as per the recommendations given by Indian Institute of Millets Research, Hyderabad. During *Rabi* season, all millets were followed by Indian mustard (RH 725). The sowing of Indian mustard was done on 20<sup>th</sup> October, 2022 after Foxtail millet, Brown top millet, Proso millet, Barnyard millet and Pearl millet while after Little millet and Kodo millet it was sown on 27<sup>th</sup> October, 2022 and after Finger millet Indian mustard was sown on 29<sup>th</sup> November, 2022. Indian mustard was harvested at 142 days in case of Foxtail millet, Brown top millet, Proso millet, Barnyard millet and Pearl millet, while after Little millet and Kodo millet Indian mustard was harvested at 149 days after sowing. Minimum days (124) up to harvesting were taken by Indian mustard in case of finger millet. Treatment wise Indian mustard was fertilized with recommended dose of nutrients (80 N + 30 P<sub>2</sub>O<sub>5</sub> + 20 K<sub>2</sub>O kg/ha) and inputs were given as per the recommendations of CCS Haryana Agricultural University, Hisar.

The energy equivalents of all inputs in the form of labour, seeds, fertilizers, hoeing, implements and pesticides and the energy output as produce was converted into energy(MJ) to calculated input and output energy of both crop seasons as well as crop rotation as per conversion factors as given by Kumar *et al.*, (2022) and Dhaka *et al.*, (2017) and Net energy return was calculated as difference between the total output energy and total input energy. Energy ratio was determined as energy output divided by input energy. Human energy Profitability was calculated by dividing output energy with Labour Energy. Energy Productivity was calculated by dividing the seed yield of crop by their respective input energy requirement. Energy intensiveness was expressed as total input energy divided by cost of cultivation. Energy profitability was computed by dividing the Net energy return with total input energy. Specific energy was calculated by Input energy divided by grain yield in kg/ha. To compute the relative economics of all crop rotations, the data provided by Department Agriculture Economics, CCS Haryana Agricultural university, Hisar was considered for both season crop’s inputs and outputs. The price considered for grains of Foxtail millet, Little millet/ Brown top millet/ Proso millet, Kodo millet, Barnyard millet, Finger millet and Pearl millet was Rs 2909, 2300, 2599, 2800, 3578 and 2350 per quintal, respectively, while straw rate was Rs1500/ acre. The prices used for Indian mustard seed and straw were Rs 5050/q and Rs 2100/acre. The total and variable cost, Gross and net returns, B:C and per day returns for all eight crop rotations were calculated.

**Results and Discussion**  
**Kharif season**

Table 1 cleared that yield attributes and yield was significantly affected by millets. Among millets Pearl millet and Kodo millet recorded significantly higher (190.5cm) and lower (89.1 cm) plant height, respectively. Foxtail millet, Little millet, Browntop millet and Barnyard millet recorded plant height within range of 156.1- 167.3 cm with nonsignificant variation among themselves. Little millet followed by Proso millet and Kodo millet followed by Finger millet recorded significantly higher (29.6 - 28.6 cm) and lower (5.6-7.1 cm) earhead length, respectively. Brown top millet (17.5 cm) and Barnyard millet (18.6 cm), Foxtail millet (20.3 cm) and Pearl millet (20.0 cm) recorded statistically similar ear head length. Significantly higher total tillers (86.5), ear heads (77.3) and lower total tillers (9.3), ear heads (8.3) per plants were recorded with Proso millet and Finger millet, respectively. Foxtail millet, Kodo millet and Barnyard millet had shown non-significant variation regarding total tillers and ear heads per plant. Pearl millet followed by Barnyard millet and Little millet followed by Brown top

Table 1: Comparative yield performance of millets in Hisar district of Haryana

Millets	Yield attributes per plant					Yield per hectare area					
	Plant height (cm)	Ear head length (cm)	Tillers (no.)	Ear heads (ns.)	Ear heads weight (g)	Seed weight (g)	Seed yield (kg/ha)	Biological yield (kg/ha)	Straw yield (kg/ha)	HI (%)	Test weight (g)
Foxtail millet	156.1	20.3	16.5	15.5	40.8	31.2	1,347	4,424	3,076	30.2	2.58
Little millet	166.3	29.6	27.8	18.0	13.5	9.5	761	4,280	3,518	17.9	1.94
Browntop millet	167.3	17.5	25.6	20.1	15.2	10.9	1,571	5,985	4,414	26.2	3.37
Proso millet	120.3	28.6	86.5	77.3	25.8	9.2	930	4,190	3,260	22.4	4.40
Kodo millet	89.1	5.6	19.5	16.1	20.2	14.3	816	4,117	3,301	20.6	4.87
Barnyard millet	159.5	18.6	18.6	14.0	56.3	37.2	1,618	7,805	6,186	20.7	3.29
Finger millet	112.1	7.1	9.3	8.3	30.9	24.3	1,971	9,479	7,507	20.8	3.29
Pearl millet	190.5	20.0	14.0	10.8	81.8	52.7	2,462	10,066	7,604	24.4	6.73
SEM±	5.1	0.6	1.6	1.8	1.6	1.4	125	224	234	2.3	0.10
CD (p=0.05)	15.8	1.9	5.0	5.5	5.0	4.3	383	687	717	7.0	0.32

Table 2: Comparative economics of different millets in Hisar district of Haryana

Treatments	Total duration (days)	Variable cost (Rs/ha)	Total Cost (Rs/ha)	Gross returns (Rs/ha)	Net returns (Rs/ha)	B:C ratio	Per day return (Rs/day/ha)
Foxtail millet	78	22958	50675	42,953	-7,721	0.84	-98.9
Little millet	92	23298	51083	21,273	-29,808	0.41	-324.0
Browntop millet	73	25885	54188	39,892	-14,294	0.73	-195.8
Proso millet	69	24780	52863	25,147	-27,714	0.47	-401.6
Kodo millet	91	23168	50928	24,895	-26,032	0.48	-286.0
Barnyard millet	78	24473	52495	49,072	-3,422	0.93	-43.8
Finger millet	116	32523	62153	74,128	11,975	1.19	103.2
Pearl millet	71	28463	57280	61,607	4,327	1.07	60.9
SEm $\pm$	2.1	-	-	3,274	3,274	0.06	42.4
CD (p=.005)	6.7	-	-	10,029	10,029	0.19	130.0

Table 3: Energy budgeting of different millets in Hisar district of Haryana

Treatments	Input energy (MJ/ha)	Output energy (MJ/ha)	Net energy returns (MJ/ha)	Energy ratio	Energy Productivity (Kg/MJ)	Energy Profitability (MJ/ha)	Energy Intensity (MJ/USD)	Specific energy (MJ/kg)	Human energy profitability (MJ/ha)
Foxtail millet	6758	58264	51506	8.6	0.19	7.6	11.0	5.21	59.2
Little millet	6746	55180	48433	8.1	0.11	7.1	10.9	8.96	56.0
Browntop millet	6729	78277	71548	11.6	0.23	10.6	10.3	4.44	79.5
Proso millet	6946	54427	47480	7.8	0.13	6.8	10.9	7.47	55.3
Kodo millet	6758	53266	46508	7.9	0.12	6.9	11.0	8.34	54.1
Barnyard millet	6758	101123	94365	14.9	0.24	14.0	10.6	4.24	102.7
Finger millet	7420	122824	115403	16.5	0.27	15.5	9.9	3.76	124.8
Pearl millet	9697	131249	121552	13.5	0.25	12.5	14.0	3.94	133.3
SEm $\pm$	2.4	2872	2872	0.4	0.02	0.42	0.004	0.53	2.92
CD (p=.005)	7.5	8797	8798	1.3	0.06	1.28	0.013	1.62	8.94

millet recorded significantly higher (81.8 g) and lower (13.5 g) ear heads weights per plant, respectively.

Among millets, pearl millet followed by finger millet and barnyard millet recorded significantly higher grain yield (2462 kg/ha), straw yield (7604 kg/ha) and biological yield (10066 kg/ha), while significantly lower grain yield (761 kg/ha), straw yield (3076 kg/ha) and biological yield (4117 kg/ha) were recorded with Little millet, Foxtail millet and Kodo millet, respectively. Little millet, Proso millet and Kodo millets had shown non-significant differences regarding yield performance. Foxtail millet closely followed by Brown top millet and Pearl millet recorded significantly higher harvest index (30.2 %), while Little millet recorded significantly lower harvest index (17.9 %). Except Foxtail millet and Brown top millet all millets had shown non-significant variations regarding harvest index compared to Little millet. pearl millet followed by Kodo millet and Little millet followed by Foxtail millet observed with significantly higher (6.73 g) and lower (1.94 g) test weight, respectively. Corroborative findings have

also been reported by Garg *et al.* (2020). The increase in grain yield of some millets might be due to increased photosynthetic activity, which resulted in a higher accumulation of photosynthates and their translocation to sink due to better source and sink channel (Krishna *et al.*, 2020; Reddy *et al.*, 2020). The increase in grain yield could be explained based on their beneficial effects on yield-attributing characteristics (Hemalatha *et al.*, 2021). Nalini *et al.* (2020) in a study on pearl millet, Hemalatha *et al.* (2021) in a study on kodo millet, Krishna *et al.* (2020) in a study on finger millet and Reddy *et al.* (2020) in a study on foxtail millet have also reported similar findings. Higher HI in selected millet germplasms might be due to dry matter partitioning along with an increased level of nitrogen as reported by Reddy *et al.* (2016).

Among millets, Finger millet and Proso millet took maximum (116) and minimum (69) days to mature. Brown top millet, Proso millet and Pearl millet took almost similar days upto maturity (69-73 days). Foxtail millet and Barnyard millet were matured in 78 days, while Little millet

and Kodo millet took 91-92 days for maturity (Table 2). Table 2 showed that among millets, Finger millet followed by pearl millet recorded maximum variable cost (Rs. 32523/ha), total cost (Rs. 62153/ha), while Foxtail millet recorded minimum variable cost (Rs. 22958/ha) and total cost (Rs. 50675/ha). All millets except finger millet and pearl millet recorded with variable cost Rs. 22958 to 25885/ha and total cost Rs. 50675 to 54188/ha. Finger millet found with significantly higher gross returns (Rs. 74128/ha) and net returns (Rs. 11975/ha), which were 20.3 and 176.7 percent higher compared to pearl millet, respectively. Significantly lower gross returns (Rs. 21273/ha) and net returns (Rs. -29808/ha) were recorded with Little millet. All millets except Finger millet and Pearl millet had shown negative net returns and less than one BC ratio. Finger millet recorded significantly higher B:C (1.19) closely followed by pearl millet (1.07). Similarly maximum per day net returns was recorded with Finger millet (Rs. 103.2/day/ha) closely followed by pearl millet (Rs. 60.9/day/ha). Proso millet recorded minimum net returns per day basis (Rs.- 401.6/day/ha). These results are in close conformity with the findings of Bana *et al.* (2016); Bhavani *et al.* (2021); Kumar *et al.* (2009); Garget *et al.* (2020); Krishna *et al.* (2020); Reddy *et al.* (2020).

Table 3 revealed that among millets, significantly higher (9697 MJ/ha) and lower (6729 MJ/ha) input energy were recorded by pearl millet and browntop millet, respectively. Pearl millet closely followed by finger millet recorded significantly higher output energy (131249 MJ/ha), while Kodo millet recorded significantly lower output energy (53266 MJ/ha), which was statistically at par with foxtail millet, little millet and proso millet. Among all millets, significantly higher net energy returns (121552 MJ/ha), energy intensiveness (14.0 MJ/USD) and human energy profitability (133.3 MJ/ha) were recorded by pearl millet, while finger millet recorded significantly higher energy ratio (16.5), energy productivity (0.27), energy profitability (15.5 MJ/ha). Proso millet, kodo millet and little millet recorded lower energy budget.

**Rabi season**

Table 4 cleared that yield attributes and yield of Indian mustard was significantly affected by previous millet crops. Among all treatments, the Indian mustard sown over Pearlmillet millet recorded significantly higher plant height (220.0 cm), while shortest plants (140.2 cm) were recorded when Indian mustard was taken after Finger millet. Indian mustard recorded statistical similar plant height (203.8-206.1 cm) when it was taken after Little millet, Browntop millet and Proso millet. Indian mustard sown after Foxtail millet and Barnyard millet recorded almost similar plant height. Indian mustard sown after Pearlmillet

Table 4: Effect of millets on yield attributes and yield of Indian mustard in Hisar district of Haryana

Treatments	Indian mustard									
	Plant height (cm)	Branches/plant (no.)	Silique length (cm)	Seeds/Silique (no.)	Silique/plant (no.)	1000 seed weight (g)	Biological yield (kg/ha)	Seed yield (kg/ha)	Harvest Index (%)	
Foxtail millet - Indian mustard	194.7	12.6	4.03	10.7	251.5	5.89	16412	3252	19.9	
Little millet - Indian mustard	204.3	7.4	2.02	9.2	201.2	5.90	5682	1301	24.0	
Browntop millet - Indian mustard	206.1	12.0	4.25	9.3	186.8	6.06	14095	1957	13.8	
Proso millet - Indian mustard	203.8	13.1	4.96	10.7	223.4	6.38	14634	3044	20.8	
Kodo millet - Indian mustard	211.0	8.3	4.81	9.9	184.6	6.19	5936	1396	24.9	
Barnyard millet - Indian mustard	195.1	13.7	5.48	13.1	209.7	6.01	20412	3396	16.7	
Finger millet - Indian mustard	140.2	5.8	1.92	4.2	78.3	5.21	1523	380	25.7	
Pearl millet - Indian mustard	220.0	13.8	4.74	11.1	235.1	6.28	20666	3492	16.8	
SEM <sub>t</sub>	2.66	0.47	0.14	0.40	12.5	0.14	523	184	2.20	
CD (p=.005)	8.14	1.45	0.42	1.22	38.3	0.44	1602	565	6.79	

Table5: Effect of millets on economics of Indian mustard in Hisar district of Haryana

Treatments	Total duration (days)	Variable cost (Rs/ha)	Total Cost (Rs/ha)	Gross returns (Rs/ha)	Net returns (Rs/ha)	B:C Ratio	Per day return (Rs/day/ha)
Foxtail millet - Indian mustard	142	30675	61100	169453	108353	2.77	763
Little millet - Indian mustard	147	30675	61100	70988	9888	1.16	66
Browntop millet - Indian mustard	141	30675	61100	104103	43003	1.70	303
Proso millet - Indian mustard	142	30675	61100	158982	97882	2.60	689
Kodo millet - Indian mustard	150	30675	61100	75737	14637	1.24	98
Barnyard millet - Indian mustard	143	30675	61100	176762	115662	2.89	810
Finger millet - Indian mustard	125	30675	61100	24442	-36657	0.40	-293
Pearl millet - Indian mustard	143	30675	61100	181571	120471	2.97	845
SEm $\pm$	0.67	-	-	14363	14363	0.23	100
CD (p=.005)	2.05	-	-	43990	43990	0.72	307

Table 6: Energy budgeting of mustard preceded by different millets in Hisar district of Haryana

Treatments	Input energy (MJ/ha)	Output energy (MJ/ha)	Net energy returns (MJ/ha)	Energy ratio	Energy Productivity (Kg/MJ)	Energy Profitability (MJ/ha)	Energy Intensity (MJ/USD)	Specific energy (MJ/kg)	Human energy profitability (MJ/ha)
Foxtail millet	10230	260,894	250,664	25.50	0.31	24.50	26.2	3.19	267.8
Little millet	10230	71,515	61,285	6.99	0.12	5.99	26.2	8.33	73.4
Browntop millet	10230	175,201	164,971	17.12	0.19	16.12	26.2	5.27	179.8
Proso millet	10230	197,132	186,902	19.27	0.29	18.27	26.2	3.36	202.3
Kodo millet	10230	78,849	68,619	7.70	0.13	6.70	26.2	8.18	80.9
Barnyard millet	10230	217,783	207,553	21.28	0.33	20.28	26.2	3.03	223.5
Finger millet	10230	18,681	8,450	1.82	0.03	0.82	26.2	28.16	19.1
Pearl millet	10230	260,851	250,621	25.49	0.34	24.49	26.2	3.05	267.7
SEm $\pm$	-	13,047	13,047	1.27	0.02	1.27	-	1.80	13.3
CD (p=.005)	-	39,957	39,958	3.90	0.08	3.90	-	5.51	41.0

followed by Barnyard millet-Indian mustard recorded significant higher number of branches (13.8), but second highest Seeds/siliqua (11.1), siliqua/plant (235.1) and test weight (6.28 g), while significantly lower number of branches (5.8), siliqua length (1.92 cm), seeds/siliqua (4.2) and siliqua/plant (78.3) were found with Indian mustard taken after Finger millet. Indian mustard sown after Foxtail millet, Little millet, Brown top millet and Proso millet recorded statistically similar seeds/siliqua (9.2-10.7). Significantly higher (251.5) siliqua/plant were recorded with Indian mustard sown after Foxtail millet. Indian mustard taken after Foxtail millet, Proso millet and Pearlmillet noticed statistically similar number of siliqua/plant (223.4-251.5). Similarly, almost same siliqua/plant were recorded when Indian mustard was taken after Brown top millet and Barnyard millet (184.6-209.7). Significantly higher (6.38 g) and lower (5.21 g) test weight was recorded when Indian mustard was preceded by Proso millet and Finger millet, respectively. The treatments where the Indian mustard was sown after Foxtail millet, Brown top millet, Proso millet, Kodo millet and Barnyard millet had

shown non-significant variation regarding test weight.

Indian mustard preceded by pearl millet closely followed by Barnyard millet-Indian mustard recorded significantly higher seed yield (3492 kg/ha) and biological yield (20666 kg/ha), while Indian mustard sown after Finger millet recorded significantly lower seed yield (380 kg/ha) and biological yield (1523 kg/ha). Significantly higher (25.7 %) and lower (13.8 %) harvest index was recorded with Indian mustard taken after Finger millet and Brown top millet, respectively. However, other studies reported that diversifying crop rotations were beneficial in increasing the grain yield system productivity (Miller *et al.*, 2003 and Yang *et al.*, 2014). Crop diversification showed the potential to adapt the changing climate with greater productivity and profitability. Conservation tillage in mustard based cropping systems proved better in achieving the *Kharif* as well as *Rabi* crops yield and system productivity. This climate-smart strategy of crop diversification encourages a new paradigm for sustainable and ecological intensification of mustard based

production system. The intensification of land to produce crop throughout the seasons has become a basis to sustainably increased crop production capable of feeding the increasing population with dwindling and unproductive land area (Jat *et al.*, 2024).

Indian mustard sown after Kodo millet took significantly higher days (150) to mature, while Indian mustard preceded by Finger millet reported with significantly lower days (125) upto maturity. Except Little millet, Kodo millet and Finger millet, all millets took statistically same days (141-143) to mature (Table 5). Table 5 illustrated that same amount of total cost (Rs. 61100/ha) and variable cost (Rs. 30675) was incurred for sowing of Indian mustard in all crop rotations studied as similar inputs and agronomic practices were followed. Indian mustard sown after all millets except Finger millet recorded economic returns with B:C more than one. Among all crop rotations, Indian mustard preceded by Pearlmillet closely followed by Barnyard millet-Indian mustard recorded with significantly higher gross returns (Rs. 181571/ha), net returns (Rs. 120471/ha), B:C (2.97) and per day returns (Rs.845/day/ha), while Indian mustard taken after Finger millet recorded with significantly lower gross returns (Rs. 24,442/ha), net returns (Rs. -36,657/ha), B:C (0.40) and per day returns (Rs.293/day/ha). Indian mustard sown after Foxtail millet, Barnyard millet and Pearlmillet recorded statistically at par gross as well as net returns. Corroborative findings have also been reported by Meena *et al.* (2021).

Table 6 revealed that Indian mustard sown over different millets recorded same amount of input energy and energy intensiveness as similar package of practices and costs were followed. Among all treatments, Indian mustard sown over foxtail millet closely followed by Indian mustard taken after pearl millet recorded significantly higher output energy (260894 MJ/ha), net energy returns (250664 MJ/ha), energy ratio (25.50), energy profitability (24.50 MJ/ha) and human energy profitability (267.8 MJ/ha), while Indian mustard sown over finger millet recorded significantly lower energy budget in the form of different energy based indices.

**Total crop rotation**

Table 7 illustrated that among all crop rotations, Finger millet/Kodo millet-Indian mustard crop rotations closely followed by Little millet- Indian mustard took significantly higher crop duration (241 days), while Proso millet- Indian mustard crop rotation closely followed by Pearlmillet/Browntop millet- Indian mustard recorded with significantly lower crop duration (211 days). Pearlmillet-Indian mustard and Little millet- Indian mustard rotation

Table 7 : Economics of millet based crop rotations with Indian mustard in Hisar district of Haryana

Treatments	Total duration (days)	Indian Mustard Equivalent Yield (Kg/ha)	Variable Cost (Rs/ha)	Total Cost (Rs/ha)	Gross returns (Rs/ha)	Net returns (Rs/ha)	B:C Ratio	Per day return (Rs/day/ha)
Foxtail millet - Indian mustard	220	4028	53633	111775	212407	100632	1.90	457
Little millet - Indian mustard	239	1648	53973	112183	92257	-19925	0.82	-83
Browntop millet - Indian mustard	214	2672	56560	115288	143986	28698	1.24	133
Proso millet - Indian mustard	211	3467	55455	113963	184130	70167	1.61	332
Kodo millet - Indian mustard	241	1814	53843	112028	100630	-11397	0.89	-47
Barnyard millet - Indian mustard	221	4293	55148	113595	225835	112240	1.98	508
Finger millet - Indian mustard	241	1776	63198	123253	98726	-24526	0.80	-101
Pearl millet - Indian mustard	214	4637	59138	118380	243178	124798	2.05	584
SE <sub>md</sub>	0.83	303	-	-	15333	15333	0.13	70
CD (p=0.05)	2.56	929	-	-	46958	46959	0.40	213

Table 8 : Energy budgeting of millet based crop rotations with Indian mustard in Hisar district of Haryana

Treatments	Input energy (MJ/ha)	Output energy (MJ/ha)	Net energy returns (MJ/ha)	Energy ratio	Energy productivity (Kg/MJ)	Energy Profitability (MJ/ha)	Energy Intensiveness (MJ/USD)	Specific energy (MJ/kg)	Human energy profitability (MJ/ha)
Foxtail millet-Indian mustard	16,989	313,360	296,371	18.44	0.24	17.44	17.0	4.17	160.0
Little millet - Indian mustard	16,977	127,161	110,184	7.49	0.12	6.49	17.0	8.25	64.9
Browntop millet - Indian mustard	16,959	254,106	237,147	14.98	0.21	13.97	16.2	4.80	129.7
Proso millet - Indian mustard	17,177	244,608	227,431	14.24	0.20	13.23	16.7	4.97	124.9
Kodo millet - Indian mustard	16,989	132,600	115,611	7.80	0.13	6.81	16.9	7.72	67.7
Barnyard millet - Indian mustard	16,989	317,980	300,992	18.71	0.29	17.71	16.6	3.44	162.3
Finger millet - Indian mustard	17,651	141,519	123,868	8.01	0.13	7.02	15.5	7.51	72.2
Pearl millet - Indian mustard	19,928	391,173	371,245	19.62	0.29	18.63	18.4	3.46	199.7
SEM <sub>t</sub>	86	12,500	12,500	0.72	0.02	0.71	0.07	0.52	6.3
CD (p=005)	266	38,284	38,284	2.21	0.06	2.18	0.2	1.61	19.5

recorded significantly higher (4637 kg/ha) and lower (1648 kg/ha) Indian Mustard Equivalent Yield, respectively. Maximum variable cost (Rs. 63,198/ha) and total cost (Rs.1,23253/ha) for cultivation of both crops in rotation was reported with Finger millet-Indian mustard rotation, which was closely followed by Pearlmillet-Indian mustard and Browntop millet-Indian mustard rotations. All crop rotations except Little millet/Kodo millet/Finger millet followed by Indian mustard were proved economically profitable having B:C more than one. Among all crop rotations, Pearlmillet-Indian mustard closely followed by Barnyard millet-Indian mustard recorded significantly higher gross returns (Rs. 243178/ha), net returns (Rs. 124798/ha), B:C (2.05) and per day returns (Rs. 584/day/ha). Finger millet-Indian mustard crop rotation closely followed by Little millet/Kodo millet- Indian mustard rotation reported with significantly lower net returns (Rs. -24,526/ha), B:C (0.80) and per day returns (Rs. -101/day/ha).Corroborative findings have also been reported by Jat *et al.* (2024) and Choudhary *et al.* (2016).

Table 8 illustrated that all crop rotations except pearl millet/ finger millet/proso millet followed by Indian mustard recorded statistically similar input energy. Pearl millet-Indian mustard rotation recorded significantly higher input energy (19928 MJ/ha), while browntop millet-Indian mustard rotation found with lower input energy (16959 MJ/ha). Significantly higher output energy (391173 MJ/ha) was recorded with pearl millet- Indian mustard closely followed by barnyard millet- Indian mustard rotation, while little millet - Indian mustard rotation recorded minimum output energy (127161 MJ/ha). Among all crop rotations, pearl millet- Indian mustard closely followed by barnyard millet- Indian mustard rotation recorded significantly higher net energy returns (371245 MJ/ha), energy ratio (19.62),energy productivity (0.29 kg/MJ), energy profitability (18.63 MJ/ha), energy intensiveness (18.4 MJ/USD) and human energy profitability (199.7MJ/ha), while little millet - Indian mustard rotation recorded significantly lower net energy returns (110184 MJ/ha), energy ratio (7.49), energy productivity (0.12 kg/MJ), energy profitability (6.49 MJ/ha) and human energy profitability (64.9 MJ/ha).These results were in conformity with the findings of Kumar *et al.* (2022) for pearl millet-wheat rotation, Choudhary *et al.* (2017) for pearl millet-mustard rotation and Dhaka *et al.* (2017).

## Conclusion

During *Kharif* season among all millets (foxtail millet, little millet, browntop millet, proso millet, kodo millet, barnyard millet, finger millet and pearl millet) tested, Pearlmillet was found most suitable, which produced significantly higher grain yield (2462 kg/ha), biological yield (10066 kg/ha),

net energy returns (121552 MJ/ha), Energy intensiveness (14.0 MJ/USD), human energy profitability (133.3 MJ/ha) compared to all other millets might be due to its maximum test weight (6.7 g), plant height (190.5 cm) and lower duration (71 days). Although Finger millet recorded second highest seed yield (1971 kg/ha) and it was most profitable with maximum net returns (Rs. 11975/ha) and B:C (1.19) but it was not fit in rotation with Indian mustard due to its long duration (116 days) as it delayed Indian mustard sowing by 39 days. In *rabi* season Indian mustard sown after Pearlmillet recorded significantly higher seed yield (3492 kg/ha), biological yield (20666 kg/ha), net returns (Rs. 120471/ha) and B:C (2.97) compared to other crop rotations might be due to significantly higher plant height (220.0 cm), branches/plant (13.8) and second highest silique/plant (235.1), test weight (6.28 g) but Indian mustard sown after Foxtail millet recorded higher net energy returns (250664 MJ/ha), energy ratio (25.50), energy profitability (24.50 MJ/ha) and human energy profitability (267.8 MJ/ha). Considering economics and Mustard Equivalent Yield, it is concluded that Little millet/Kodo millet/Finger millet followed by Indian mustard rotations are uneconomical might be due to long *Kharif* crop duration, delayed sowing of *Rabi* crop and less yield obtained.

Thus, it is concluded that Pearlmillet-Indian mustard (total duration of 214 days) closely followed by Barnyard millet/Foxtail millet- Indian mustard rotations recorded with significantly higher Indian Mustard Equivalent Yield (4637 kg/ha), net returns (Rs. 124798/ha), B:C (2.05), per day returns (Rs.584/day/ha), net energy returns (371245 MJ/ha), energy ratio (19.62), energy profitability (18.63 MJ/ha), energy productivity (0.29 kg/MJ) and human energy profitability (199.7 MJ/ha) was found most economical and suitable crop rotation for sandy loam areas of Hisar district of Haryana (India).

## References

- Bana RS, Pooniya V, Choudhary AK, Rana KS and Tyagi VK. 2016. Influence of organic nutrient sources and moisture management on productivity, bio-fortification and soil health in pearlmillet (*Pennisetum glaucum*) + clusterbean (*Cyamopsis tetragonaloba*) intercropping system of semi-arid India. *Ind J Agric Sci*, **86**: 1418-1425.
- Bhat BV, Hariprasanna K, Sooganna and Ratnavathi CV. 2023. Global and Indian scenario of millets. *IndFarming*, **73**:16-18.
- Bhavani U, Reddy MM, Padmaja B and Saidanaik D. 2021. Effect of nitrogen levels and varieties on economics and yield of little millet (*Panicum sumatrense*) under rainfed conditions. *Ind J Agron*, **66**: 509-511.
- Bhuvra HM and Detroja AC. 2018. Influence of nutrient management with organic manures on productivity, profitability and quality of pearl millet (*Pennisetum glaucum*)-chickpea (*Cicer arietinum*) sequence. *Ind J Agron*, **63**: 300-306.
- Choudhary M, Rana KS, Bana RS, Ghasal PC, Choudhary GL, Jakhar P and Verma RK. 2017. Energy budgeting and carbon footprint of pearl millet mustard cropping system under conventional and conservation agriculture in rainfed semi-arid agro-ecosystem. *Energy*, **141**: 1052-1058.
- Choudhary M, Rana KS, Rana DS and Bana RS. 2016. Tillage and crop residue effects in rainfed pearl millet (*Pennisetum glaucum*) in conjunction with sulphur fertilization under pearl millet-Indian mustard (*Brassica juncea*) cropping system. *Ind J Agron*, **61**: 15-19.
- Dhaka AK, Kumar S, Pannu RK, Malik K, Singh B and Ramprakash. 2017. Production potential, energy efficiency and economics of wheat (*Triticum aestivum*) succeeding fodder sorghum intercropped in seed crop of dhaincha (*Sesbania aculeata*). *Ind J Agric Sci*, **87**: 225-233.
- Dhaka BK, Anisha, Dinesh, Raj R, Dhaka P and Kamal. 2023. Integrated Weed Management in Minor Millets: A Review. *Int J Plant Soil Sci*, **35**: 676-690.
- Dhaka BK, Dhaka P, Singh B, Kamal, Anisha and Dhaka AK. 2023a. Intercropping Options for Sustainable Minor Millet Production: A Review. *Int J Environ Climate Change*, **13**:89-100.
- Faiz MA, Bana RS, Choudhary AK, Laing AM, Bansal R, Bhatia A, Bana RC, Singh YV, Kumar V, Bamboriya SD, Padaria RN, Khaswan SL and Dabas JPS. 2022. Zero tillage, residue retention and system intensification with legumes for enhanced pearl millet productivity and mineral biofortification. *Sustainability*, **14**:543.
- Garg K, Gupta AK, Yadav P and Yadav S. 2020. Effect of nutrient-management practices on yield, nutrient uptake and economics in finger millet (*Eleusine coracana*) and pearl millet (*Cenchrus americanus*). *Ind J Agron*, **65**: 372-376.
- Hemalatha S, Reddy GP, Chandarika V, Naidu MVS and Sagar GK. 2021. Growth and yield attributes of kodo millet (*Paspalum scrobiculatum* L.) as influenced by integrated nitrogen management. *Andhra Pradesh J Agric Sci*, **7**: 134-138.
- Jat R, Singh H, Choudhary R, Meena M and Rai P. 2024. Conservation agriculture practices in Indian mustard

- (*Brassica juncea*)-based cropping systems for enhanced productivity and profitability. *Ind J Agric Sci*, **94**: 678-683.
- Jeeva G, Suhasini B, Pramitha L, Jency JP, Joshi P, Ravikesavan R and Elango D. 2024. Unlocking the potential of Kodo millet: reviving an indigenous super grain for tomorrow's nutrition. *Planta*, **259**:140.
- Krishna KV, Deepthi CH, Reddy MD, Raju PS and Pal A. 2020. Effect of Nitrogen and Phosphorus Levels on Growth and Yield of Finger Millet [*Eleusine coracana* (L.)] During Summer. *Ind J Agric Res*, **54**: 227-231.
- Kumar A, Chugh LK, Yadav DV, Malik RS and Kumar LCM. 2016. Effect of farmyard manure, organic manure and balanced fertilizers application on the productivity and soil fertility in pearl millet (*Pennisetum glaucum*)-mustard (*Brassica juncea*) cropping sequence in sandy loam soil of semi-arid regions. *Ind J Agric Sci*, **86**: 220-226.
- Kumar A, Hooda RS, Yadav HP, Chugh LK, Kumar M and Gera R. 2009. Compensating nutrient requirement in pearl millet (*Pennisetum glaucum*)–wheat (*Triticum aestivum*) cropping system through manures and biofertilizers in semi-arid regions of Haryana. *Ind J Agric Sci*, **79**: 767-771.
- Kumar A, Singh D and Mahapatra SK. 2022. Energy and carbon budgeting of the pearl millet-wheat cropping system for environmentally sustainable agricultural land use planning in the rainfed semi-arid agro-ecosystem of Aravalli foothills. *Energy*, **246**: 123389.
- Kumar S, Gopinath KA, Sheoran S, Meena RS, Srinivasarao C, Bedwal S, Jangir CK, Mrunalini K, Jat R and Praharaj CS. 2023. Pulse-based cropping systems for soil health restoration, resources conservation, and nutritional and environmental security in rainfed agroecosystems. *Front Microbiol*, **13**:1041124.
- Meena SL, Bana RS, Sepat S and Dass A. 2021. System productivity and economics as influenced by cropping system and nutrient management. *Ind J Agric Sci* **91**: 1470-1475.
- Miller PR, Gan Y, McConkey BG and McDonald CL. 2003. Pulse crops for the northern Great Plains: II. Cropping sequence effects on cereal, oilseed, and pulse crops. *Agron, J* **95**: 980-986.
- Nalini N, Vani KP, Devi KBS, Babu PS and Reddy SN. 2020. Production Potentials of Pearl Millet Based Crop Sequence as Influenced by INM, Dates of Sowing and Fertilizer Levels in Southern Telangana Zone. *Curr J Applied Sci Technol*, **39**: 92-103.
- Reddy MUM, Roja M, Reddy MD and Barman S. 2020. Effect of nitrogen and phosphorus management on growth and yield of foxtail millet [*Setaria italica* L.] during summer season in Odisha, India. *Ind J Agric Res*, **54**: 242-246.
- Reddy SBP, Madhuri KVN, Venkaiah K, Prathima T. 2016. Effect of nitrogen and potassium on yield and quality of pearl millet (*Pennisetum glaucum* L.). *Int J Agric Innovations Res*, **4**: 678-681.
- Sammauria R, Meena OP, Yadav MR, Gupta KC, Gupta AK and Yadav HL. 2020. Crop diversification of predominant Pearl millet based cropping system for higher productivity, resource-use efficiency and profitability in Semi-Arid Rajasthan. *Legume Res-An Int J*, **43**: 568-572.
- Singh P, Arora K, Kumar S, Gohain N and Sharma RK. 2023. Indian millets trade potential-cum-performance: Economic perspective. *Ind J Agric Sci*, **93**: 200-204.
- Yadav MR, Parihar CM, Jat SL, Singh AK, Kumar Rakesh, Yadav RK, Parihar MD, Makarana G and Jat ML. 2017. Impact of legume intensified crop rotations and tillage practices on maize productivity vis-à-vis C and N dynamics of a sandy loam soil in north-western Indo-Gangetic Plains of India. *Legume Res-An Int J*, **40**: 1028-1037.
- Yang X, Gao W, Zhang M, Chen Y and Sui P. 2014. Reducing agricultural carbon footprint through diversified crop rotation systems in the North China Plain. *J Cleaner Prod*, **76**:131–139.