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Impact of integrated crop management technologies on productivity and energy budgeting of mustard under cluster frontline demonstrations in Eastern Rajasthan

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Abstract

Cluster Frontline Demonstrations (CFLDs) represent an effective extension approach for the systematic planning, implementation and evaluation of proven agricultural technologies under farmers' field conditions. The present investigation evaluated the performance of CFLDs during the period 2022-23 to 2024-25 to assess the impact of integrated crop management (ICM) practices in mustard, as recommended in the package of practices of Agriculture University, Kota. The study adopted a combination of experimental and before-after research designs, and a total of 400 beneficiary farmers were included under the CFLD programme. Performance of improved mustard varieties Radhika and RH-725 under CFLD plots was compared with farmers' prevailing practices (local check). The results revealed that the demonstrated plots consistently produced significantly higher seed yield than the local check across all the three years of study. On pooled basis, the mean extension gap and technology gap were observed to be 4.36 q ha^{-1} and 3.51 q ha-^{1}, respectively, indicating substantial scope for enhancing mustard productivity through improved technological interventions. Furthermore, the demonstrated plots recorded higher net returns and benefit-cost ratios compared to farmers' practices during all seasons, highlighting the economic superiority of ICM technologies. Energy analysis further substantiated the effectiveness of CFLDs, as higher energy use efficiency and energy productivity (kg MJ^{-1}) were recorded under the demonstration plots in comparison to farmers' plots, reflecting improved resource-use efficiency under integrated crop management practices. The demonstrated ICM practices significantly enhanced seed yield and net returns ($p < 0.01$) and improved energy use efficiency by 37.6% over farmers' practices.

Keywords: *CFLD, ICM, Indian mustard, economics, energy, profitability*

Introduction

Rapeseed-mustard holds significant importance due to its pivotal role as a major oilseed crop with substantial potential to bridge the widening demand-supply gap of edible oils in India. Globally, it ranks as the third most important source of edible oil, following soybean and oil palm, thereby contributing substantially to nutritional security and the oilseed economy. India ranks among the leading producers of rapeseed-mustard globally, following Canada and China, and contributes nearly 14% to the world's total production. These crops are cultivated across a wide range of agro-climatic regions, from the north-eastern and north-western hill regions to southern India. They are grown under varied conditions such as irrigated and rainfed systems, timely and late sowing, saline soils, and mixed cropping systems. Among the rapeseed-mustard crops, Indian mustard occupies approximately 80% of the total cultivated area in the country. According to Agstat at a glance 2024-25 rapeseed-mustard covered an area in India 13.26 million ha with productivity of 1444 kg ha^{-1}. Rajasthan ranks first in terms of total acreage, with the crop occupying about 5.76 million hectares, accounting for 43.43% of the total area at the national level (Directorate of Economics and Statistics, 2024).

In Rajasthan, mustard is widely cultivated by farmers due to its relatively high market prices and low water requirement. However, under changing climatic conditions, there is a growing need for appropriate technological interventions at the farm level to enhance mustard productivity and reduce the gap between potential yield and the yield realized by farmers. In Sawaimadhopur, mustard is a prominent crop of *rabi* season and it covers almost 181357 ha in 2022-23 and it decreases from 2021-22 which was 190487 ha. Productivity was also decreases from 1784 (2021-22) to 1629 kg ha^{-1} (2022-23) due to abrupt weather conditions, lack of high yielding variety and other ICM practices among farmers. Integrated Crop Management (ICM) is a comprehensive and location-specific strategy within sustainable agriculture that emphasizes the coordinated management of all production factors at the farm level. It integrates the efficient use of on-farm resources while considering socio-economic and environmental aspects, with the objective of providing safe, appropriate, and effective practices that ensure long-term agricultural productivity and sustainability (Choudhary *et al.*, 2018).

Cluster Frontline Demonstrations (CFLDs) are an important extension approach aimed at showcasing the performance and benefits of newly released agricultural technologies directly on farmers' fields across different locations within a farming system. These demonstrations involve the systematic organization of farming and extension activities to enhance farmers' understanding and adoption of improved practices. The CFLD approach is based on the principle of "seeing is believing" and facilitates the generation of scientific feedback on the performance and adaptability of demonstrated technologies under real farm conditions. CFLDs provide a distinctive platform that facilitates direct interaction between scientists and farmers, as researchers are actively engaged in the planning, implementation, and monitoring of demonstration activities. This close involvement allows scientists to obtain firsthand feedback from farmers' fields regarding crop performance and the suitability of the technologies being demonstrated under specific local conditions. Such feedback helps researchers to refine and improve research programmes accordingly. CFLDs also enable researchers and extension personnel to gain a better understanding of farmers' resources, constraints, and needs, allowing for the fine-tuning and adaptation of technologies to enhance their suitability and adoption at the farm level. In the present study, an effort has been made to assess the impact of CFLDs on integrated crop management practices of mustard in Rajasthan.

Materials and Methods

CFLDs were implemented across five blocks- Sawaimadhopur, Chauth ka Barwara, and Khandar block of Sawaimadhopur district, Rajasthan, over four consecutive *rabi* seasons (2022-23 to 2024-25). These locations were selected due to the predominance of mustard as the principal *rabi* crop. The study adopted a

$$\%\ Change\ in\ yield = \frac{Yield\ from\ Demonstrated\ Plot - Yield\ from\ Local\ check\ plot}{Yield\ from\ Local\ check\ plot} \times 100$$

$$Extension\ gap = Demonstration\ yield - Farmers'\ practice\ yield$$

$$Technology\ Gap = Potential\ Yield - Demonstration\ yield$$

$$Technology\ Index\ (\%\ Change) = \frac{Potential\ yield - demonstration\ yield}{Potential\ yield} x\ 100$$

$$Impact\ of\ CFLD\ on\ Adopters\ (\%\ Change) = \frac{No.of\ adopters\ after\ CFLD - No\ of\ Adopters\ before\ CFLD}{No.of\ Adopters\ before\ CFLD} x\ 100$$

$$Additional\ return = Return\ from\ demonstration\ plots - from\ local\ check\ plots$$

$$Benefit - Cost\ Ratio = \frac{Net\ Income\ (Rs/ha)}{Actual\ Cost\ of\ Cultivation\ (Rs/ha)}$$

$$Impact\ on\ horizontal\ Spread\ (\%\ Change) = \frac{Variety\ after\ demonstration - Variety\ before\ demonstration}{Area\ under\ recommended\ variety\ before\ demonstration} x\ 100$$

mixed research design incorporating both experimental (treatment-control) and before-after approaches to rigorously evaluate the impact of the demonstrations. The study followed a quasi-experimental design combining treatment-control comparison and before-after evaluation under farmers' field conditions. Prior to the initiation of CFLDs, a comprehensive baseline survey was conducted in the selected blocks to document prevailing mustard cultivation practices adopted by farmers. Based on farmers' willingness and active participation during baseline surveys, interactive meetings, and awareness programmes, a total of 400 mustard growers covering a cumulative area of 160 ha were selected for the demonstrations. Farmers' existing cultivation practices served as the local check. Each farmer field was treated as one experimental unit, and data were pooled year-wise for statistical analysis. Normality of data was assumed due to large sample size (n = 400).

In the demonstration plots, Integrated Crop Management (ICM) practices were implemented in accordance with the recommended Package of Practices for mustard for Agro-climatic Zone V and Zone III-B of Rajasthan. All participating farmers received structured training to ensure proper adoption of the recommended ICM technologies. Demonstration plots were established adjacent to the corresponding farmers' fields where mustard was cultivated using prevailing practices and varieties, enabling direct comparison under identical agro-ecological conditions. The specific components of the recommended ICM technologies are detailed in Table 4.

Crop yield data were systematically collected from both demonstration and local check plots immediately after harvest to quantify yield differentials and technological gaps. Economic analysis was carried out by computing costs and returns using prevailing market prices of inputs and the minimum support price (MSP) of mustard applicable for the respective years. The effectiveness of CFLDs was evaluated using standard indicators and formulas as proposed by Samui *et al*. (2000). Economic and energy-use evaluations were conducted during the 2024-25 cropping season using primary data obtained from beneficiary farmers. Input quantities and their associated energy requirements across all production stages were quantified, while total dry biomass (grain and residue) was considered as system output. Energy inputs and outputs were converted into MJ ha^{-1} using standard coefficients from the literature (Table 1). Key energy indicators, including energy use efficiency, net energy return, energy productivity, energy balance, and specific energy, were computed following established methodologies.

The information from the beneficiary farmers regarding the adoption of recommended technologies, varietal replacement, and horizontal spread of recommended variety was collected with a structured and pre-tested interview schedule at the end of the four consecutive CFLDs. A two-way ANOVA was used to determine whether the mean results obtained from the demonstrated plots for different parameters (grain yield, cost of cultivation, and net returns) of mustard cultivation, significantly differed from local check plots or not.

$$Net\ energy\ (MJ/ha) = Energy\ output - Energy\ input$$

$$Energy\ use\ efficiency = Energy\ output\ (MJ/ha)\ /\ Energy\ input\ (MJ/ha)$$

$$Energy\ productivity\ (kg/MJ) = \frac{Economic\ yield}{Energy\ input}$$

$$Energy\ intensiveness\ (MJ/INR) = \frac{Energy\ input}{Cost\ of\ cultivation}$$

$$Energy\ profitability = \frac{Net\ energy}{Energy\ input}$$

$$Specific\ energy\ (MJ/kg) = \frac{Energy\ input}{Seed\ yield}$$

$$Energy\ intensity\ in\ physical\ terms\ (MJ/kg) = \frac{Total\ energy\ input}{Total\ biological\ yield}$$

$$Energy\ intensity\ in\ in\ economic\ terms\ (MJ/INR) = \frac{Total\ energy\ output}{Cost\ of\ cultivation}$$

Table 1: Energy equivalent of inputs and outputs in production of mustard

Particulars	Unit	Energy Equivalent(MJ unit^{-1})	References
A. Inputs			
Human labour	MJ h^{-1}	1.96	Choudhary *et al*., 2021
Machinery	MJ h^{-1}	62.70	Choudhary *et al*., 2021
Diesel	MJ l^{-1}	56.31	Choudhary *et al*., 2017
Nitrogen (N)	MJ kg^{-1}	60.6	Choudhary *et al*., 2021
Phosphorus (P)	MJ kg^{-1}	11.1	Choudhary *et al*., 2021
Sulphur (S)	MJ kg^{-1}	01.12	Gokdogan and Erdogan,2021
Micronutrient (Zn)	MJ kg^{-1}	8.40	Kumar *et al*., 2021
Water for irrigation	MJ m^{-3}	1.02	Choudhary *et al*., 2021
Seed	MJ kg^{-1}	14.7	Parihar *et al*., 2013
Bio-inoculant	MJ kg^{-1}	14.5	Mihov and Tringovska., 2010
Insecticide	MJ kg^{-1}	184.63	Choudhary *et al*., 2017
Fungicide	MJ kg^{-1}	97.00	Choudhary *et al*., 2021
Herbicide	MJ kg^{-1}	254.45	Choudhary *et al*., 2021
B. Output			
Seed (Mustard)	MJ kg^{-1}	14.7	Parihar *et al*., 2013
By product (kg) straw	MJ kg^{-1}	12.50	Parihar *et al*., 2013
Total			

Results and Discussion

The yield performance of mustard under Cluster Front Line Demonstrations (CFLDs) and farmers' practice (local check) is presented in Table 2 and Fig. 1. The CFLDs were conducted over an area of 160 ha involving 400 farmers during three consecutive *rabi* seasons (2022-23 to 2024-25). Across all the years, mustard grown under CFLD plots consistently recorded significantly higher seed yield compared to local check plots. The seed yield under CFLDs was 18.10, 22.20 and 22.60 q ha^{-1} during 2022-23, 2023-24 and 2024-25, respectively, whereas the corresponding yields under farmers' practice were 15.54, 16.95 and 17.31 q ha^{-1}. On a year-wise basis, the adoption of integrated crop management (ICM) practices under CFLDs resulted in yield advantages of 16.89%, 31.45% and 31.06% over farmers' practices, clearly indicating the superior performance of the demonstrated technologies under farmers' field conditions. The magnitude of yield improvement increased markedly during the second and third years, reflecting improved farmer familiarity and better execution of the recommended practices. The higher productivity recorded under CFLD plots can be attributed to the combined effect of improved mustard varieties (Radhika and RH-725) along with the adoption of recommended seed rate, optimum plant geometry, seed treatment, balanced nutrient management, need-based irrigation scheduling and integrated pest management. In contrast, lower yields under farmers' practices were mainly associated with the use of higher seed rates, dense crop stand and early irrigation at 25-30 DAS, which promoted excessive vegetative growth at the expense of reproductive development, resulting in poor yield attributes.

Weed infestation was another major yield-limiting factor in the study area, with predominant weeds including *Chenopodium album*, *Orobanche spp.*, *Rumex dentatus*, *Melilotus indicus*, *Convolvulus arvensis* and *Asphodelus tenuifolius*. Effective weed control in CFLD plots was achieved through timely pre-emergence application of pendimethalin followed by crop smothering, which substantially reduced weed-crop competition. In contrast, inadequate and delayed weed management under farmers' practice resulted in higher weed pressure and associated yield losses. Overall, the results clearly demonstrate that the adoption of ICM practices through CFLDs significantly enhanced mustard productivity by optimizing crop establishment, nutrient use and weed management under semi-arid farming conditions. Results are in close conformity with Yadav *et al.*, 2025, Kumar *et al*., 2024. An extension gap of 2.56, 5.25 and 5.29 q ha^{-1} was observed during 2022-23, 2023-24 and 2024-25, respectively, indicating a substantial yield advantage of CFLD plots over farmers' practices. The widening of the extension gap during the later years highlights the increasing effectiveness of integrated crop management (ICM) technologies under farmers' field conditions. These results suggest considerable scope for enhancing mustard productivity through the dissemination and adoption of improved practices. The observed extension gap can be effectively narrowed through targeted extension interventions such as cluster frontline demonstrations, farmer trainings, field visits and continuous technical backstopping, thereby facilitating wider adoption of ICM technologies. The findings are also closely related to Meena *et al*. (2020) and Vishal *et al*. (2022).

The technological gap varied across the study years, with a minimal gap of 0.36 q ha^{-1} recorded during 2022-23 with the variety Radhika, whereas comparatively higher gaps of 3.79 and 3.39 q ha^{-1} were observed during 2023-24 and 2024-25, respectively. The technological gap, defined as the difference between potential yield and yield achieved under CFLD plots, serves as an indicator of the effectiveness of technology transfer under farmers' field conditions. The narrow gap recorded during 2022-23 reflects efficient implementation of CFLD interventions and better adoption of integrated crop management (ICM) practices, enabling yields close to the varietal potential. The subsequent reduction in the technological gap during 2024-25 compared to 2023-24 further indicates improved refinement, adaptability and dissemination of CFLD-based ICM technologies over time. Similar findings were recorded by Tiwari *et al.*, 2017 and Chaudhary *et al.*, 2018. The technology index was recorded as 1.95%, 14.60% and 13.04% during 2022-23, 2023-24 and 2024-25, respectively. The lower technology index in 2022-23 indicates better feasibility and higher performance of the demonstrated technologies under farmer's field conditions. The subsequent reduction in the technology index during 2024-25 compared to 2023-24 further reflects improved adoption and effectiveness of integrated crop management practices under CFLDs.

The economic analysis of mustard production under CFLD and farmers' practice plots is presented in Table 3. The pooled average cost of cultivation was marginally higher under CFLD plots (Rs. 23,840 ha^{-1}) compared to farmers' practice (Rs. 20,402 ha^{-1}), primarily due to the inclusion of micronutrients (zinc and sulphur), pre-emergence herbicides and integrated pest management inputs as part of the recommended ICM package. However, the difference in cultivation cost between the two systems remained relatively small, as farmers' practice also involved higher expenditures on costly hybrid seeds, imbalanced fertilizer use and non-recommended management practices. Despite the slightly higher input cost, CFLD plots recorded substantially higher economic returns. The pooled average gross return under CFLDs was Rs. 113, 397 ha^{-1}, which was markedly higher than [1] 89,566 ha^{-1} obtained under farmers' practice. Correspondingly, net returns were significantly higher in CFLD plots (Rs. 89,557 ha^{-1}) compared to local check plots (Rs. 69,164

Table 2: Yield performance and gap analysis of mustard grown under CFLDs and prevailing farmers' practices local check plots

Year	Demonstration area (ha)	Demonstrations (no.)	Seed yield (q ha^{-1})			Increase over local check plots (%)	Extension gap (q ha^{-1})	Technological gap (q ha^{-1})	Technology index (%)
			Potential yield	CFLD Plots	Local check plots				
2022-23	20	50	18.47	18.10	15.54	16.89	2.56	0.36	1.95
2023-24	40	100	26.00	22.20	16.95	31.45	5.25	3.79	14.60
2024-25	100	250	26.00	22.60	17.31	31.06	5.29	3.39	13.04
Average	-	-	-	20.96	16.60	26.46	4.36	2.51	9.86
Total	160	400	-	-	-	-	-	-	-

(*CFLDs-Cluster frontline demonstrations)

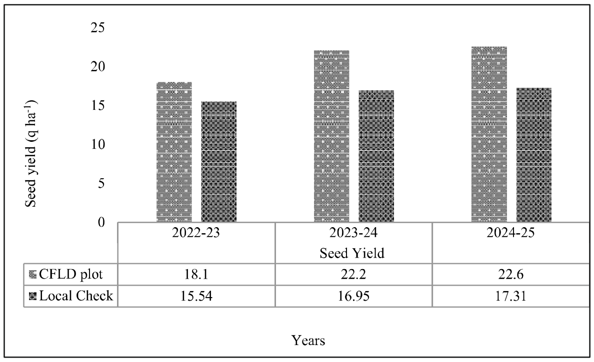

Fig. 1: Yield Performance of mustard grown under CFLDs and prevailing farmers' practices local check plots

ha^{-1}). The benefit-cost ratio (B:C) further confirmed the economic superiority of CFLD-based ICM practices, with a pooled mean of 4.73 under CFLDs as against 4.38 under farmers' practice. The enhanced profitability under CFLD plots can be largely attributed to higher seed yield and improved market value of the produce, associated with bold seed size, darker seed colour and higher oil content (40.7%) compared to farmers' produce. Results are closely related with Sharma *et al*., 2024, Kuamr *et al.*, 2024. Additional return of Rs. 9862 ha^{-1}, Rs. 25414 ha^{-1} and Rs. 25903 ha^{-1} was found under CFLD plots due to high yield and higher market prices.

Table 3: Economic analysis of mustard production technologies under CFLDs and local check plots (Farmers' practice)

Year	Average cost of cultivation (Rs. ha^{-1})		Average gross return (Rs. ha^{-1})		Average net return (Rs. ha^{-1})		Additional return (Rs. ha^{-1})	BC Ratio	
	CFLD plots (q ha^{-1})	Local check plots (q ha^{-1})	CFLD plots (q ha^{-1})	Local check plots (q ha^{-1})	CFLD plots (q ha^{-1})	Local check plots (q ha^{-1})		CFLD plots (q ha^{-1})	Local check plots (q ha^{-1})
2022-23	22987	19876	91450	78477	68463	58601	9862	3.97	3.94
2023-24	23546	20345	120998	92383	97452	72038	25414	5.13	4.54
2024-25	24987	20987	127743	97840	102756	76853	25903	5.11	4.66
Average	23840	20402	113397	89566	89557	69164	20393	4.73	4.38

The impact of CFLDs on the adoption of recommended mustard cultivation technologies is summarized in Table 4. Adoption levels increased markedly for all components of the ICM package, with the highest adoption observed for improved varieties, followed by fertilizer management, seed rate, weed management, seed treatment, irrigation management, spacing and method of sowing. The rapid adoption of improved varieties was primarily driven by their superior yield performance and higher net returns, which encouraged both beneficiary and neighbouring farmers to adopt these varieties through field days and farmer-scientist interactions.

CFLDs also enhanced farmers' knowledge and adoption of key management practices, including seed treatment with imidacloprid for effective control of early-stage cutworm infestation and balanced nutrient management, particularly the application of sulphur and zinc. Weed management, which was previously neglected, showed substantial improvement following demonstrations of pre-emergence pendimethalin application combined with crop smothering, resulting in reduced weed competition and improved yields. Improved adoption of recommended irrigation scheduling and optimum plant spacing (30×10 cm) further contributed to better crop performance under CFLD plots. These results are closely related with Kumar *et al.* (2024).

The horizontal spread of improved mustard varieties increased substantially from 20 ha during 2022-23 to 8,349 ha in 2025-26 among CFLD farmers as well as neighbouring farmers motivated by the demonstrated performance of the improved varieties. This expansion was facilitated by the concerted efforts of Krishi Vigyan Kendra, Sawaimadhopur through frontline demonstrations, farmer trainings, scientist visits, field interactions and method demonstrations. By 2025-26, the improved varieties occupied nearly 5.35% of the total mustard cultivated area in the district, indicating the significant impact of CFLDs on technology dissemination and adoption. These data of horizontal spread were collected with field survey of 2025. Similar results were found with Kumar and Jakhar (2022) and Jha *et al.* (2021).

The impact of integrated crop management (ICM) practices on the energy budgeting of mustard is presented in Table 6, which summarizes the total energy equivalents of various inputs and outputs under CFLD and local check plots. In the CFLD plots, the highest share of input energy was attributed to nitrogen fertilization, followed sequentially by diesel, machinery, herbicides, irrigation water, seed, and human labour.

Table 4: Impact of cluster frontline demonstrations in adoption of recommended mustard cultivation technologies (Total no. of beneficiary farmers / n = 400)

Particulars	Recommended ICM technologies	Adopters of the recommended technology (no.)		Change of adopters (no.)	Impact (% change)
		Before demonstration	After demonstration		
Variety	Improved variety -Radhika, RH-725	00	400	+400	**
Seed Rate	5 Kg/ha	126	367	+241	191.26
Seed Treatment	Seed Treatment with Mencozeb @ 2 g/kg seed & Imidacloprid 48% FS 6 ml kg^{-1} seed	172	395	+223	129.65
Time of Sowing	15^{th} to 30^{th} October	319	392	+73	22.88
Spacing	30 cm X 10 cm	298	400	+102	34.22
Method of Sowing	Use of seed cum fertilizer drill	298	400	+102	34.22
Weed Management	Pre-emergence spray of Pendimethalin (30 EC) @ 3.3 lt ha^{-1}	00	153	+153	**
Fertilizer management	Application of nitrogen, phosphorus, zinc and sulphur @ 80, 40, 5, and 40 kg per hectare basal and application of N fertilizer in two split doses.	59	373	+314	532.20
Irrigation Management	One at the time of flowering, another one at the time of pod formation *i.e.* 65-70 days after sowing	221	378	+50	71.04
Pest Management	Imidacloprid 17.8 SL @ 250 ml/ha	156	298	+142	91.02

(**As the initial number of the beneficiary was 0, the impact was calculated from the absolute change in the number of the beneficiaries rather than percentage change)

Table 5: Impact of ICM technology on horizontal spread of Radhika and RH-725 variety of Mustard in the district

Year	Area of Mustard in district (ha)	Area improved variety after ICM demonstrations (ha)	Share of improved variety after ICM demonstrations (%)
2022-23	181357	20.00	0.01
2023-24	156000	230.00	0.147
2024-25	156000	1265.00	0.810
2025-26	156000	8349.00	5.35

Similarly, in the local check plots, nitrogen accounted for the maximum energy input, followed by diesel, machinery, phosphorus, seed, and irrigation water. The total input energy requirement under CFLD plots was 8,919.40 MJ ha^{-1}, which was 6.5% lower than that recorded in the local check plots (9,501.71 MJ ha^{-1}). The higher input energy observed in the local check plots was mainly due to the excessive application of nitrogen and phosphorus fertilizers, higher seed rates, and increased use of machinery associated with excessive tillage operations. In contrast, although the CFLD plots involved additional energy inputs through the application of micronutrients, herbicides, insecticides, fungicides, and other crop protection measures, the adoption of recommended doses under integrated and sustainable management practices resulted in a more efficient energy input system.

With respect to output energy, the total output energy was considerably higher under CFLD plots (106,672.00 MJ ha^{-1}) compared to the local check plots (82,533.20 MJ

Table 6: Impact of integrated crop management practices on energy budgeting of mustard

Particulars	CFLD plots (Total energy equivalents, MJ ha^{-1})	Local check (Total energy equivalents, MJ ha^{-1})
A. Inputs		
Human labour	58.8 (0.65)	50.96 (0.53)
Machinery	611.325 (6.85)	689.7 (7.25)
Diesel	1801.92 (20.20)	1970.85 (20.74)
Nitrogen (N)	4848 (54.35)	6060 (63.77)
Phosphorus (P)	444 (4.97)	510.6 (5.37)
Sulphur (S)	44.8 (0.50)	0 (0)
Micronutrient (Zn)	42 (0.47)	0 (0)
Water for irrigation	102 (1.14)	102 (1.07)
Seed	73.5 (0.82)	117.6 (1.23)
Bio-inoculant	0.51 (0.005)	0 (0)
Insecticide	51.69 (0.57)	0 (0)
Fungicide	1.164 (0.01)	0 (0)
Herbicide	839.685 (9.41)	0(0)
Total	8919.40	9501.71
B. Output		
Seed (kg)	33222.00	25445.70
By product (kg)	73450.00	57087.50
Total	106672.00	82533.20
C. Net energy (MJ ha^{-1})	97752.60	73031.49
D. Energy use efficiency	11.96	8.69
E. Employment days	35.00	26.00
F. Energy productivity (kgMJ^{-1})	0.25	0.18
G. Energy profitability	10.96	8.69
H. Specific energy (MJkg^{-1})	3.95	5.49
I. Energy intensity in physical terms (MJkg^{-1})	0.08	0.12
J. Energy intensity in economic terms (MJINR^{-1})	4.27	3.93

Values in parentheses represent percentage contribution to total input energy ha^{-1}). This enhancement in output energy under CFLD was primarily attributed to higher seed and straw yields coupled with lower total input energy requirements. The energy analysis revealed a clear advantage of the CFLD plot over the local check plot in terms of energy efficiency and productivity. The CFLD plot recorded substantially higher net energy (97,752.60 MJ ha^{-1}) compared to the local check (73,031.49 MJ ha^{-1}), indicating superior energy gains from the improved production practices. Energy use efficiency was also markedly higher under CFLD (11.96) than the local check (8.69), reflecting more efficient conversion of input energy into output energy. Employment generation was greater in the CFLD plot, requiring 35 employment days as against 26 days in the local check, highlighting its higher labour engagement potential. Energy productivity was enhanced in the CFLD plot (0.25 kg MJ^{-1}) compared to the local check (0.18 kg MJ^{-1}), suggesting greater yield per unit of energy input. Similarly, energy profitability was higher under CFLD (10.96) than the local check (8.69), demonstrating improved economic returns relative to energy invested.

In contrast, the local check exhibited higher specific energy (5.49 MJ kg^{-1}) and energy intensity in physical terms (0.12 MJ kg^{-1}) compared to the CFLD plot (3.95 MJ kg^{-1} and 0.08 MJ kg^{-1}, respectively), indicating greater energy consumption per unit of output. Energy intensity in economic terms was marginally higher in the CFLD plot (4.27 MJ INR^{-1}) than the local check (3.93 MJ INR^{-1}), suggesting slightly higher energy investment per unit monetary return under CFLD. Overall, the CFLD plot proved to be more energy-efficient, productive, and profitable than the local check plot. Results are closely related with Sharma *et al.* (2025) and Kumar *et al.* (2024). The reduced specific energy and physical energy intensity observed under CFLD plots further indicate lower energy consumption per unit of output, suggesting a potential reduction in the carbon footprint of mustard production. Optimized fertilizer use, rational irrigation scheduling, and improved crop protection measures under ICM not only enhanced productivity but also promoted energy-efficient and environmentally sustainable production systems. Therefore, CFLDs can be considered an effective extension approach for promoting climate-resilient and sustainable oilseed production in semi-arid regions.

Table 7: Statistical comparison of seed yield and net returns between demonstration and local practices across years

Parameter	Year	Demo Mean	Local Mean	T value	P Value	Significance
Seed Yield(q ha^{-1})	2022-23	18.10	15.54	17.824	0.00	**
	2023-24	22.20	16.95	33.088	0.00	**
	2024-25	22.60	17.31	48.832	0.00	**
Net return(Rs ha^{-1})	2022-23	68463	58601	17.824	0.00	**
	2023-24	97452	72038	33.088	0.00	**
	2024-25	102756	76853	48.832	0.00	**

Table 7 demonstrates that, across all the years, CFLD (demonstration) plots recorded significantly higher seed yield and net returns compared to local practices. The very high t-values and p-values (<0.01) indicate that the differences between treatments were statistically highly significant () for both parameters in all years. These results clearly establish that the adoption of ICM practices under CFLD led to a significant improvement in seed yield as well as net returns, thereby proving the economic and productivity advantages of ICM for farmers.

Conclusion

The study clearly establishes that Cluster Frontline Demonstrations (CFLDs) involving Integrated Crop Management (ICM) practices significantly improved mustard productivity, profitability, and energy-use efficiency under farmers' field conditions in Sawai Madhopur, Rajasthan. Across all study years, CFLD plots recorded significantly higher seed yield and net returns than farmers' practices ($p<0.01$), confirming the economic and productive superiority of ICM technologies. The observed extension and technology gaps indicate substantial scope for yield enhancement through effective technology dissemination. Improved energy use efficiency, higher net energy returns, and greater adoption and horizontal spread of improved varieties further highlight the effectiveness of CFLDs. Overall, CFLDs proved to be an efficient extension tool for promoting sustainable and profitable mustard production.

References

Chaudhary RP, Chaudhary GK, Prasad R, Singh R and Chaudhary AK. 2018. Impact assessment of front line demonstrations on mustard crop. *Int J Curr Microbiol Applied Sci* **7**: 4737-4742.

Choudhary AK, Bana RS and Pooniya V. 2018. Integrated crop management practices for enhancing productivity, resource-use efficiency, soil health and livelihood security, p 229, ICAR-Indian Agricultural Research Institute, New Delhi.

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 agroecosystem. *Energy* **141**: 1052-1058.

Choudhary RL and Behera UK. 2021. Optimization of conservation agriculture and nitrogen nutrition in maize-wheat cropping system: Assessment of productivity, energy indicators, nutrient apparent balance and economics. *J Soil Water Conserv* **20**: 88-99.

Gokdogan O and Erdogan O. 2021. Determining the energy use efficiency and greenhouse gas emissions (GHG) in olive farming. *Eur J Science Technol* **23**: 717-724.

Government of India. 2024. *Agricultural statistics at a glance 2024*. Ministry of Agriculture and Farmers Welfare, Department of Agriculture and Farmers Welfare, Economics, Statistics and Evaluation Division, New Delhi.

Jha AK, Mehta BK, Kumari M and Chatterjee K. 2021. Impact of frontline demonstrations on mustard in Sahibganj district of Jharkhand. *Ind J Ext Edu* **57**: 28-31.

Kumar S and Jakhar DK. 2022. Impact of frontline demonstrations on mustard crops in Sirsa district of Haryana. *Ind J Ext Edu* **58**: 192-195.

Kumar S, Singh DK, Sharma G, Aswal S, Dhaka BL, Sharma N and Seema. 2024. Impact of integrated crop management practices on productivity, profitability and energy budgeting of mustard in South-Eastern Rajasthan. *J Oilseed Brassica* **15**: 107-113.

Meena RK, Singh B, Meena RK and Shinde KP. 2020. Impact of frontline demonstrations on mustard production and profitability in Sri Ganganagar district of Rajasthan, India. *Global J Bio Science Biotechnol* **9**: 106-110.

Mihov M and Tringovska I. 2010. Energy efficiency improvement of greenhouse tomato production by applying new biofertilizers. *Bulgarian J Agric Sci* **16**: 454-458.

Parihar CM, Bhakar RN, Rana KS, Jat ML, Singh AK, Jat SL, Parihar MD and Sharma S. 2013. Energy scenario, carbon efficiency, nitrogen and phosphorus dynamics of pearl millet-mustard system under diverse nutrient and tillage management practices. *Afr J Agric Res* **8**: 903-915.

Samui SK, Maitra S, Roy DK, Mondal AK and Saha D. 2000. Evaluation of frontline demonstration on groundnut (*Arachis hypogaea* L.) in Sundarbans. *J Ind Soc Coastal Agric Res* **18**: 180-183.

Sharma A, Choudhary RS, Jetawat RPS, Sharma A, Prajapati K, Kumar S and Singh H. 2024. Impact evaluation of cluster frontline demonstrations on mustard productivity and profitability in Sirohi district of Rajasthan. *Int J Res Agron* **SP-7**: 80-84.

Sharma N, Dhaka BL, Meena BL, Ankita A, Kumar S, Meena RK and Gupta V. 2025. Energy use efficiency and economics of chickpea production: A comparison of integrated crop management and farmers' practices in Rajasthan. *Legume Res* **1**: 1-10. doi: 10.18805/LR-5562.

Tiwari DK, Chandra V, Pandey SK, Sahay R, Singh A and Singh AK. 2017. Effect of frontline demonstration on production, profitability and social impact on mustard cultivation. *Bull Environ Pharmacology Life Sci* **6**: 134-137.

Vishal M, Ahirvar RP, Sahare KV, Pandre NK, Dhumketi K and Minakshi M. 2022. Impact of cluster frontline demonstrations (CFLD) on yield enhancement of mustard (*Brassica juncea*) in tribal district of Mandla, Madhya Pradesh. *The Pharma Innov* **11**: 118-123.

Yadav NK, Pandey NK, Tiwari D, Shalini and Somwanshi SPS. 2025. Impact of cluster front line demonstration on mustard productivity in Lalitpur district of Uttar Pradesh. *J Oilseed Brassica* **16**: 202-206.