



Economic Evaluation of Indigenous Aromatic Rice Cultivars of Manipur under Different Weed Management Practices

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Authors' contributions

This work was carried out in collaboration among all authors. Author PMS conceptualized the study, performed the experimental design, collected and analyzed the data, did sample analysis and prepared the final draft. Author EL conceptualized the study, did experimental design, prepared the final draft and did overall monitoring. Authors PSMA, LNS, KND, NSD, NOS and NUS did experimental design, data curation and prepared the final draft. All authors read and approved the final manuscript.

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ABSTRACT

A field experiment was conducted at the Agronomy Research Farm (*kharif* 2021 and 2022), College of Agriculture, Central Agricultural University, Imphal (24°81' N, 93°89' E; 790 m above MSL), to evaluate the economic performance of aromatic rice cultivars under different weed management practices in the subtropical conditions of Manipur Valley. The experiment followed a split-plot design with three replications, featuring four cultivars- Khamanui Lungra (C1), Chaphemai (C2), Nambew (C3) and Chakhao Poiraiton (C4) and five weed management strategies: W1-Manual weeding, W2-Pre emergence application of Pretilachlor 50% EC @ 450g a.i ha⁻¹ followed by post emergence application of Metsulfuron methyl 10% + Chlorimuron ethyl 10% WP @ 4g a.i ha⁻¹, W3-Pre emergence application of Pretilachlor 50% EC @ 450g a.i ha⁻¹ followed by post emergence application of Penoxsulam 2.67% @ 25 g a.i ha⁻¹, W4-Pre emergence application of Pyrazosulfuron Ethyl 10% WP @ 50 g a.i ha⁻¹ followed by post-emergence Penoxsulam 2.67% @ 25g a.i ha⁻¹ and W5-Control. Results revealed that among the cultivars, 'Chaphemai' (C2) recorded the highest plant height (196.9 cm), number of tillers per hill (11.3) and leaf area index (5.41), contributing to a superior grain yield of 4.69 t ha⁻¹. The W3 treatment was most effective in suppressing weeds and enhancing growth, yield and profitability, recording the highest grain yield (3.28 t ha⁻¹), net returns (₹1,04,062.87 ha⁻¹) and benefit-cost ratio (3.32). In contrast, the control (W5) registered the lowest yield (20.26 q ha⁻¹), net returns (₹39,785.53 ha⁻¹) and B:C ratio (1.75), highlighting the economic risk of poor weed management in aromatic rice cultivar of Manipur. Economic analysis confirmed that the combination of Chaphemai with Pretilachlor+ Penoxsulam (W3) treatment offered the most promising outcome for aromatic rice cultivation in the region, both agronomically and financially.

Keywords: *Aromatic rice; economic performance; weed management; net returns; benefit-cost ratio; Manipur valley.*

1. INTRODUCTION

Aromatic rice is highly valued for its distinctive aroma, fine grain quality and high market demand, often fetching premium prices both domestically and internationally (Sharma et al., 2021; Roy et al., 2015). Despite its economic potential, the cultivation of aromatic rice especially traditional landraces is often constrained by low productivity, susceptibility to biotic stresses and limited adaptability under rainfed and subtropical conditions such as those prevailing in the Manipur Valley (Devi et al., 2021; Shijagurumayum et al., 2018). Among the various agronomic challenges, weed infestation remains one of the most critical biological constraints in rice production, leading to yield reductions ranging from 30% to 80% depending on the intensity and species composition (Rao & Nagamani, 2013). In the absence of proper weed management, input resources such as fertilizers and water are inefficiently utilized exacerbating the already low productivity of traditional aromatic cultivars (Ziska et al., 2015). Given the resource limitations of smallholder farmers, especially in the northeastern hill region, improving economic returns through cost-effective and eco-efficient weed control strategies is imperative. Integrating genetically superior cultivars with scientifically optimized

weed management practices is known to significantly improve profitability and sustainability in rice-based systems (Pooja et al., 2021).

Therefore, the present study was undertaken to evaluate the economic performance encompassing cost of cultivation, gross returns, net returns and benefit-cost ratio of four indigenous aromatic rice cultivars under five weed management strategies in the subtropical agro-ecosystem of Manipur. By integrating both agronomic and economic perspectives, the study seeks to develop viable and scalable recommendations for enhancing the productivity and profitability of aromatic rice cultivation under smallholder farming conditions in North-East India.

2. MATERIALS AND METHODS

The field study was conducted at the Agronomy Research Farm, College of Agriculture, Central Agricultural University, Imphal, during the Kharif seasons of 2021 and 2022. The site, located at 790 m above mean sea level, experiences a humid subtropical climate of the typical northeastern hill ecosystems. The climatic data during the study period indicated distinct seasonal variations. Rainfall peaked between

June and August, with the highest in August (~250 mm), while minimal rainfall occurred in the winter months. Maximum and minimum temperatures remained relatively stable, ranging from ~22°C to ~32°C, whereas relative humidity (RH) was highest during the monsoon (above 75%). Sunshine hours were lowest during peak monsoon and increased post-monsoon and winter months (Fig. 1). The soil was sandy loam, acidic (pH 5.2), low in nitrogen, medium in phosphorus, and high in potassium, which is representative of many rice-growing soils in Manipur. The weather data were obtained from ICAR Manipur Centre, Lamphelpat, Imphal.

The experimental layout followed a split-plot design with three replications, consistent with weed-crop competition studies in rice. The main plot factor included four aromatic rice cultivars: C1- Khamanui Lumgra, C2 - Chaphemai, C3- Nambew, C4 -Chakhao Poireiton along with Sub-plot treatments included five weed management strategies: W1-Manual weeding, W2-Pre emergence application of Pretilachlor 50% EC @ 450g a.i ha⁻¹ followed by post emergence application of Metsulfuron methyl 10% + Chlorimuron ethyl 10% WP @ 4g a.i ha⁻¹, W3-Pre emergence application of Pretilachlor 50% EC @ 450g a.i ha⁻¹ followed by post emergence application of Penoxsulam 2.67% @ 25g a.i ha⁻¹,

W4-Pre emergence Pyrazosulfuron Ethyl 10% WP @ 50g a.i ha⁻¹ followed by post emergence Penoxsulam 2.67% @ 25g a.i ha⁻¹ and W5-Unweeded control. Each experimental plot measured 5 m × 2 m. Transplanting was carried out using 25-day-old seedlings, maintaining a spacing of 20 cm × 10 cm between rows and hills. Fertilizers were applied at 60:40:30 kg ha⁻¹ (N:P₂O₅:K₂O), with nitrogen applied in three split doses- one basal and two top-dressings at maximum tillering and panicle initiation stages. The pre-emergence herbicides were applied uniformly within 3 days after transplanting (DAT) using a knapsack sprayer fitted with a flat-fan nozzle, ensuring adequate soil moisture for activation. Post-emergence herbicides (Almix / Penoxsulam) were applied at 20 DAT targeting actively growing weeds under moist soil conditions, while ensuring no rainfall or irrigation for 24 hours post-application. Growth parameters recorded included plant height, number of tillers per hill, and leaf area index (LAI), measured at 30, 60, 90, and 120 days after transplanting (DAT). Plant height was measured from the base to the tip of the tallest leaf, tillers per hill were counted from 10 hills per plot and averaged per hectare. LAI was computed using the formula by Yoshida et al., 1976.

$$LAI = \frac{\text{Total Leaf Area per Hill (cm}^2\text{)}}{\text{Ground Area per Hill (cm}^2\text{)}}$$

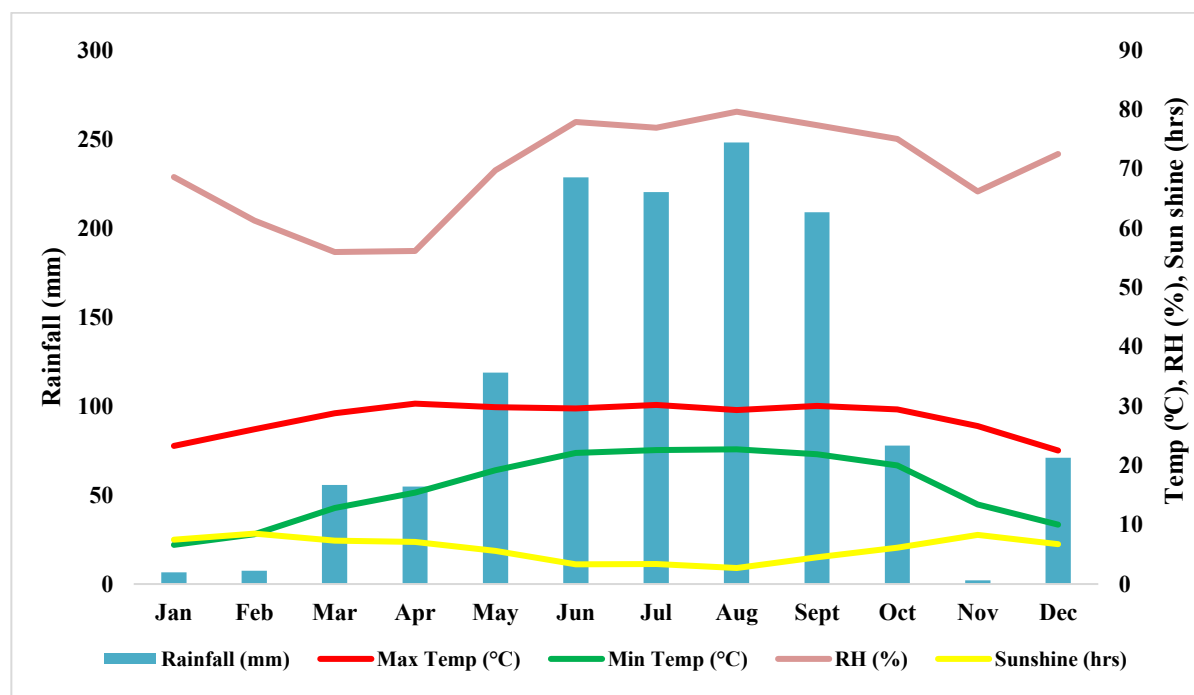


Fig. 1. Meteorological data recorded during the course of investigation (2021-22)
(Source ICAR Manipur Centre, Lamphelpat, Imphal)

Grain yield was recorded from the net plot area, sun-dried, and converted to $q\ ha^{-1}$. Economic analysis included computation of total cost of cultivation, gross return, net return and benefit-cost (B:C) ratio based on prevailing market rates for grain and straw. Data were statistically analyzed using ANOVA for a split-plot design as per Gomez and Gomez (1984), and treatment means were compared using LSD at 5% significance level.

3. RESULTS AND DISCUSSION

3.1 Growth Parameters

Plant height was significantly influenced by both cultivars and weed management practices across all growth stages. Among the cultivars, *Chaphemai* (C2) consistently exhibited the tallest plants, attaining a height of 58.3 cm at 30 DAT, which progressively increased to 196.9 cm at 120 DAT. This was statistically superior to other cultivars at all stages. It was followed by *Chakhao Poireiton* (C4), which recorded 194.1 cm at 120 DAT. In contrast, *Nambew* (C3) showed the lowest plant height (107.6 cm at 120 DAT), remaining significantly shorter throughout. Among weed management treatments, W3 (Pretilachlor + Penoxsulam) recorded the highest plant height at all intervals, with a maximum of 152.1 cm at 120 DAT, which was significantly superior to W5 (control) that recorded only 146.3 cm. The increase in plant height under W3 may be attributed to efficient weed suppression and better nutrient and moisture availability, thereby facilitating vigorous vertical growth (Table 1). These findings are supported by Kumari et al., (2018), who reported enhanced plant height in rice under effective weed control regimes (Islam et al., 2022).

Leaf Area Index (LAI): The leaf area index increased significantly with crop age and was markedly influenced by both cultivars and weed management. *Chakhao Poireiton* (C4) and *Chaphemai* (C2) showed comparable and significantly higher LAI values throughout. *Chakhao Poireiton* attained the highest LAI of 5.46 at 90 DAT, followed closely by *Chaphemai* (5.41), while *Khamanui Lungra* (C1) recorded the lowest (3.49). With respect to weed management, W3 again proved to be the most effective, registering the highest LAI of 4.56 at 120 DAT, followed by W4 (4.58) and W2 (4.48). The minimum LAI was recorded in W5 (4.08). The superior LAI under W3 and W4 could be due to reduced competition for light, nutrients and

water, allowing greater leaf expansion and light interception. Similar patterns were reported by Patel and Ghosh (2019), who linked higher LAI in rice to effective weed control indicating reduced competition and improved resource uptake.

Number of Tillers per Hill: The number of tillers per hill increased up to 120 DAT and showed significant differences among cultivars and weed control practices. *Chaphemai* (C2) produced the highest tiller count at all growth stages, reaching a maximum of 11.38 tillers per hill at 120 DAT, which was significantly higher than all other cultivars. It was followed by *Chakhao Poireiton* (C4) with 8.52 tillers per hill, while *Khamanui Lungra* (C1) produced the lowest (6.65). Weed management treatments also had a marked impact, with W3 again outperforming others. W3 recorded the maximum tiller production (9.15 tillers/hill at 120 DAT), which was statistically higher than W5 (7.6). The improved tiller count in W3 is likely due to early and sustained weed suppression, reducing crop-weed competition during critical growth periods. Rathod et al., (2024) also reported that weed management practices, particularly the combination of pre-emergence and post-emergence herbicides, significantly improved tiller production and overall plant growth in rice by effectively suppressing weed pressure during critical growth stages (Mohapatra, et al., 2024).

3.2 Yield Attributes and Productivity

Grain Yield: Grain yield was significantly affected by both cultivars and weed management practices. Among the cultivars, *Chaphemai* (C2), (Fig. 2) recorded the highest grain yield ($4.69\ t\ ha^{-1}$), which was significantly superior to all others. It was followed by *Chakhao Poireiton* (C4) ($3.02\ t\ ha^{-1}$), whereas *Khamanui Lungra* (C1) recorded the lowest yield ($1.68\ t\ ha^{-1}$).

Among the weed management treatments, W3 (Pretilachlor + Penoxsulam) resulted in the highest grain yield ($3.28\ t\ ha^{-1}$), which was significantly superior to W5 (control) and also better than W1 (manual weeding) (Table 2). The sequential use of pre-emergence and post-emergence herbicides effectively reduced weed interference, resulting in enhanced nutrient and light availability and greater grain production because of better source-sink balance. Similar observations were demonstrated by Sumekar et al., (2025) that sequential application of pretilachlor followed by penoxsulam resulted in the highest grain yield among all treatments,

highlighting the effectiveness of this combination in managing weeds and improving rice productivity.

Straw Yield (t ha^{-1}): Straw yield also varied significantly among cultivars and weed management treatments. *Chakhao Poireiton* (C4) recorded the highest straw yield (8.80 t ha^{-1}), followed by *Chaphemai* (C2) (7.81 t ha^{-1}). The lowest was observed in *Nambew* (C3) (4.43 t ha^{-1}).

Among weed control treatments, W3 registered the highest straw yield (7.06 t ha^{-1}), followed by W2 (6.66 t ha^{-1}) and W1 (6.20 t ha^{-1}). The lowest straw yield was recorded under W5 (5.47 t ha^{-1}). Higher straw production in W3 may be attributed to improved vegetative biomass due to early and effective weed suppression, which enhances light and nutrient availability. Similar results are also concluded by Khare et al., (2014), who found higher straw yield in penoxsulam-treated rice fields under similar conditions.

Harvest Index (%): Harvest index (HI) was significantly influenced by cultivars but not by weed management practices (CD at 5% – NS). Among the cultivars, *Chaphemai* (C2) recorded the highest HI (34.67%), followed by *Nambew* (C3) (30.95%), indicating a more efficient partitioning of dry matter to economic yield. In contrast, *Khamanui Lungra* (C1) and *Chakhao Poireiton* (C4) recorded comparatively lower HI values of 27.4% and 27.89%, respectively.

Although differences among weed control treatments in HI were not statistically significant, numerically W3 recorded the highest HI (31.23%), followed by W4 (30.68%), while the lowest was in W5 (29.29%). These results suggest that effective weed control, while improving overall yield, also contributes to improved source-sink dynamics and harvest index efficiency. Sen et al. (2020) also found higher harvest index values under sequential herbicide applications in rice, reinforcing these findings.

3.3 Economic Performance of Aromatic Rice Cultivars and Weed Management Practices

Economic evaluation is fundamental in determining the sustainability and adoption potential of agronomic technologies. In the present study, economic indicators including cost of cultivation, gross returns, net returns and benefit-cost (B:C) ratio were assessed across

four aromatic rice cultivars and five weed management treatments (Table 3).

Effect of Aromatic Rice Cultivars: The economic performance of rice cultivars revealed significant differences ($p \leq 0.05$) in terms of profitability. Among the cultivars, C2 (*Chaphemai*) consistently exhibited superior economic returns, with a pooled gross return of ₹1,86,406.67 ha^{-1} , net return of ₹1,43,013.53 ha^{-1} , and a B:C ratio of 4.22. This can be attributed to its higher yield potential, market preference for aromatic grains and compatibility with modern agronomic practices. Similar economic superiority of improved aromatic cultivars has been reported by Patra et al. (2024), who highlighted the profitability of high-yielding aromatic varieties under sustainable nutrient and establishment management in eastern India. C4 (*Chakhao Poireiton*) followed closely, registering a net return of ₹1,36,460.20 ha^{-1} and a B:C ratio of 4.06. The cultivar not only performed well in terms of grain yield but also benefited from its niche value as a traditional black rice variety, fetching a premium in local markets. In contrast, C1 (*Khamanui Lungra*) exhibited the lowest net return of ₹22,726.87 ha^{-1} and a B:C ratio of 1.50, reflecting lower economic viability despite its low input costs. C3 (*Nambew*) provided moderate returns (net return: ₹44,940.20 ha^{-1} ; B:C ratio: 2.00), indicative of its intermediate yield performance and limited economic competitiveness under subtropical valley conditions. The statistical significance of cultivar differences in economic returns (CD for net return = ₹6172.04; B:C = 0.14) underlines the importance of genotype selection in maximizing returns. Das et al., (2023) also concluded that herbicide use in crop production is generally economically beneficial, primarily due to reduced labour costs and higher crop yields resulting from effective weed control; and the cost-benefit analysis revealed that herbicide-based weed management often outperforms manual or mechanical methods in terms of profitability.

The economic viability of aromatic rice cultivation has been consistently demonstrated through higher net returns, favourable input-output ratios and strong market demand relative to non-aromatic counterparts. These cultivars are often preferred by farmers due to their superior price realization, reduced input intensity, and comparatively lower production risks, making them a profitable and sustainable option in aromatic rice-based production systems (Kabir et al., 2020).

Table 1. Effect of cultivars and weed management practices on growth parameters of aromatic rice in Manipur

Cultivar	Plant Height (cm)				Leaf Area Index (LAI)				No. of Tillers per Hill			
	30 DAT	60 DAT	90 DAT	120 DAT	30 DAT	60 DAT	90 DAT	120 DAT	30 DAT	60 DAT	90 DAT	120 DAT
C1	37.7	53.5	105.4	99.3	0.73	1.5	2.88	3.49	3.7	5.58	6	6.65
C2	58.3	113.3	194.3	196.9	1.29	2.44	4.75	5.41	4.9	10.28	10.4	11.38
C3	30.7	91.5	97	107.6	0.8	1.64	2.68	3.19	3.76	6.01	6.35	6.9
C4	56.5	111.7	190.5	194.1	1.27	2.74	4.93	5.46	4.42	7.55	7.94	8.52
SEM ($\pm$)	0.2	0.4	0.5	0.4	0.1	0.14	0.22	0.19	0.02	0.07	0.09	0.1
CD (p=0.05)	0.7	1.4	1.7	1.4	0.33	0.49	0.76	0.67	0.06	0.24	0.31	0.35
Weed Management												
W1	45.8	85.1	146.1	148.1	1.01	2.09	3.73	4.25	4.1	7.14	8.12	8.93
W2	47.1	87	147.1	148.7	1.01	2.04	3.84	4.48	4.24	7.16	7.2	7.78
W3	49.2	93.9	148.7	152.1	1.08	2.14	3.92	4.56	4.46	7.84	8.28	9.15
W4	47.9	88.7	150	151.2	1.06	2.16	3.95	4.58	4.36	7.55	7.53	8.35
W5	43.8	81.7	144.4	146.3	0.95	1.97	3.62	4.08	3.81	7.09	7.24	7.6
SEM ($\pm$)	0.2	0.3	0.4	0.03	0.01	0.03	0.04	0.08	0.06	0.08	0.08	0.09
CD (p=0.05)	0.6	0.9	1.1	0.1	0.04	0.08	0.13	0.22	0.17	0.24	0.24	0.28

**Fig. 2. Different varieties of rice cultivar in the experimental plot**

Table 2. Effect of cultivars and weed management practices on yield parameters of aromatic rice in Manipur

Cultivar	Grain Yield (t ha ⁻¹)	Straw yield (t ha ⁻¹)	Harvest Index (%)
C1	1.68	4.92	27.4
C2	4.69	7.81	34.67
C3	2.24	4.43	30.95
C4	3.02	8.8	27.89
SEM (±)	0.04	0.06	0.56
CD (p=0.05)	0.15	0.19	1.95
Weed Management			
W1	2.76	6.2	30.04
W2	2.98	6.66	29.9
W3	3.28	7.06	31.23
W4	3.14	6.2	30.68
W5	2.37	5.47	29.29
SEM (±)	0.07	0.09	0.58
CD (p=0.05)	0.2	0.25	NS

Table 3. Effect of cultivars and weed management practices on economic parameters of aromatic rice in Manipur

Cultivar	Cost of cultivation (₹ ha ⁻¹)	Gross return (₹ ha ⁻¹)	Net Returns (₹ ha ⁻¹)	B:C Ratio
C1	1681.67	65626.67	22726.87	1.50
C2	4688.83	186406.67	143013.53	4.22
C3	2237	86973.33	44940.2	2.00
C4	3016.67	177940	136460.2	4.06
SEM (±)	44.52	2011.76	1783.59	0.04
CD (p=0.05)	154.07	6961.61	6172.04	0.14
Weed Management				
W1	2760	123550	78821.2	2.74
W2	2980.83	133125	92399.53	3.14
W3	3277.92	146383.33	104062.87	3.32
W4	3142.71	136941.67	93221.2	2.96
W5	2368.75	106183.33	65421.2	2.57
SEM (±)	69.15	2111.84	3182.14	0.07
CD (p=0.05)	199.18	6083.5	9166.65	0.20

Effect of Weed Management Practices: Weed control strategies had a pronounced impact on the profitability of aromatic rice cultivation. Among the five weed management treatments, W3 (sequential application of Pretilachlor 50% EC @ 450 g a.i. ha⁻¹ followed by Penoxsulam 2.67% @ 25 g a.i. ha⁻¹) produced the highest pooled net return of ₹1,04,062.87 ha⁻¹ and B:C ratio of 3.32, outperforming all other treatments. This indicates that sequential herbicide application effectively suppresses both grassy and broadleaf weeds, leading to increased productivity and economic returns. The result also aligns with Mahajan and Chauhan (2017), who demonstrated consistent economic advantages of this approach over manual weeding or single herbicide treatments in diverse Indian rice ecosystems. W2 (Pretilachlor + Almix) also demonstrated strong economic viability, with net returns of ₹92,399.53 ha⁻¹ and a B:C ratio of 3.14. Moderate economic outcomes were observed under W1 (manual weeding) and W4 (Saathi + Penoxsulam). Although W4 showed relatively high gross returns, the increased labour cost of manual weeding led to reduced net returns. Notably, W5 (control) exhibited the lowest net return of ₹65,421.20 ha⁻¹ and a B:C ratio of 2.57, reflecting the detrimental effects of unchecked weed growth. Heisnam et al., (2017), concluded that, timely weed management by application of selective pre-emergence and post-emergence herbicides significantly enhances the economic feasibility of transplanted rice cultivation under rainfed conditions, herbicide combinations not only reduce weed biomass effectively but also lead to substantial improvements in grain yield, net returns, and benefit-cost ratios in rice-based systems of North-East India.

Benefit-Cost Ratio (B:C): The benefit-cost analysis revealed that C2 (Chaphemai) attained the highest B:C ratio (4.22), followed by C4 (Chakhao Poireiton) (4.06), while C1 (Khamanui Lungra) recorded the lowest (1.50). Among weed treatments, W3 led with a B:C ratio of 3.32, significantly outperforming W1 (2.74) and W5 (2.57). These outcomes confirm that judicious integration of cost-effective weed control and high-performing cultivars can maximize farm profitability.

Herbicide use in crop production has been demonstrated to significantly improve weed control efficiency, grain yield, and economic returns across various agro-ecological settings. Compared to manual or unweeded systems,

herbicide-based weed management offers higher cost-benefit ratios, with net return gains ranging from 4–12% over manual weeding and up to 247% over unweeded controls. When applied judiciously and integrated within a broader weed management strategy, herbicides serve as a profitable and sustainable tool without causing adverse effects on soil microorganisms or long-term ecosystem health (Das et al., 2023).

4. CONCLUSION

The study clearly demonstrates that both cultivar selection and weed management practices significantly influence the economic performance of aromatic rice cultivation under subtropical conditions of Manipur. Among the cultivars, 'Chaphemai' consistently outperformed others in terms of yield and profitability, owing to its superior agronomic traits and market demand. Similarly, the sequential application of Pretilachlor followed by Penoxsulam (W3) emerged as the most effective weed management strategy, offering the highest grain and straw yield, net returns, and benefit-cost ratio. These results affirm that the integration of high-yielding aromatic cultivars with scientifically optimized herbicide combinations can substantially enhance productivity and farm profitability. The findings provide a viable pathway for sustainable aromatic rice intensification in the hill ecosystems of Northeast India, especially under smallholder conditions.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declares that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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