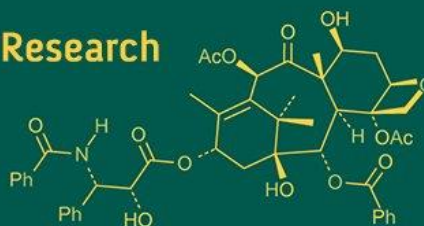


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Effect of integrated weed management practices on growth, yield attributes, and economics of rice fallow sunflower (*Helianthus annuus* L.)

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Abstract

A field experiment was conducted to evaluate the effect of different weed management treatments on the growth, physiological parameters, and economics of rice fallow sunflower (*Helianthus annuus* L.). Eight treatments comprising chemical, mechanical, and integrated weed management strategies, along with a weed-free check and an unweeded control, were assessed at 30 DAS, 60 DAS, and harvest. Results revealed that the weed-free treatment (T₇) recorded significantly superior performance for plant height, number of leaves, leaf area index, stem girth, and crop growth rate across all growth stages. Among the practically viable treatments, two inter-cultivations at 20 & 40 DAS (T₅) and the integrated herbicide treatment comprising paraquat + pendimethalin + quizalofop ethyl (T₂) were the most effective alternatives. The unweeded control recorded the poorest performance across all parameters, with a benefit-to-cost ratio below unity, confirming economic non-viability. Treatment T₂ emerged as the most cost-effective option, recording the second highest net returns (₹52,277 ha⁻¹) and B:C ratio (1.87) with a comparatively lower cost of cultivation, making it highly suitable for resource-limited farmers.

Keywords: Rice fallow sunflower, weed management, crop growth rate, benefit cost ratio, integrated weed management, relative growth rate

Introduction

Sunflower (*Helianthus annuus* L.) is one of the most important edible oilseed crops cultivated worldwide because of its high-quality oil, wide adaptability, and short duration. The seed contains 38-50% oil rich in unsaturated fatty acids, making it an important component of the human diet (Skoric *et al.*, 2007) [14]. In India, sunflower contributes significantly to the edible oil sector and offers considerable scope for enhancing domestic oilseed production (Ramesh *et al.*, 2019) [12].

India continues to face a substantial deficit in edible oil production despite being one of the world's leading oilseed-producing countries. During 2024-25, the country produced about 42.6 million tonnes of oilseeds, yet a large proportion of edible oil demand is met through imports (Government of India, 2025) [4]. Among oilseed crops, sunflower occupied approximately 0.15 million ha with a production of 0.11 million tonnes and productivity of about 750 kg ha⁻¹ during 2023-24, indicating substantial scope for productivity improvement (Directorate of Economics and Statistics, 2024) [3].

Rice-fallow lands constitute one of the largest untapped agricultural resources in India. Approximately 11.7 million hectares of rice-fallow area exist across the country, predominantly in eastern and central India (Ramesh *et al.*, 2019) [12]. Productive utilization of these lands can significantly increase cropping intensity and oilseed production without expanding cultivated land area. Sunflower has emerged as a promising crop for rice-fallow situations because of its short duration, deep root system, drought tolerance, and ability to utilize residual soil moisture effectively (Kulasekaran *et al.*, 2021) [6].

However, weed infestation remains one of the major constraints limiting sunflower productivity under rice-fallow conditions. Weeds compete with crops for moisture, nutrients, light, and space, particularly during the early stages of crop establishment, resulting in severe yield losses (Narendar & Narendar 2023) [9].

Yield reductions ranging from 30 to 70% have been reported in sunflower due to uncontrolled weed growth depending on weed flora and crop-weed competition period (Nagamani *et al.*, 2013) [7]

Manual weeding and intercultivation are effective methods of weed control; however, their adoption is increasingly constrained by labour shortages and rising labour costs (Narendar *et al.*, 2026) [8]. Herbicides offer timely and effective weed management, but sole dependence on herbicides may lead to herbicide resistance, weed flora shifts, and environmental concerns (Sai Satish *et al.*, 2025) [13]. Therefore, sustainable weed management requires integration of chemical, cultural, and mechanical approaches.

Integrated Weed Management (IWM) has been recognized as an environmentally sound and economically viable strategy for maintaining weed populations below economic threshold levels while reducing dependence on any single weed control method (Parameswari *et al.*, 2025) [11]. Several studies have demonstrated that integration of pre-plant, pre-emergence, and post-emergence herbicides with mechanical weed control significantly improves weed suppression, crop growth, nutrient uptake, and yield in oilseed crops (Choudhary *et al.*, 2022) [1]

Apart from reducing weed competition, effective weed management enhances nutrient uptake and nutrient-use efficiency by minimizing nutrient depletion by weeds and increasing nutrient availability to the crop (Narendar *et al.*, 2026) [8]. Consequently, improvements in growth attributes, yield components, seed yield, and economic returns have been reported under integrated weed management systems compared with sole herbicide or manual weed control practices (Choudhary *et al.*, 2022) [1]. Nath *et al.* (2024) [10] emphasized the need for diversified and integrated weed management approaches. In this context, IWM represents the most sustainable and environmentally responsible strategy for managing weeds in sunflower.

Although several studies have evaluated individual weed management practices in sunflower, information on integrated weed management strategies under rice-fallow ecosystems remains limited. Therefore, the present investigation was undertaken to evaluate the effect of integrated weed management practices on growth, yield attributes, yield, and economics of rice-fallow sunflower (*Helianthus annuus* L.) and to identify an efficient and economically viable weed management strategy for sustainable sunflower production.

Materials and Methods

A field experiment entitled “Effect of Integrated Weed Management Practices on Growth, Yield Attributes, and Economics of Rice Fallow Sunflower (*Helianthus annuus* L.)” was conducted during summer 2022 at the Instructional Farm of Odisha University of Agriculture and Technology (OUAT), Bhubaneswar (20°27' N, 85°79' E; 25.9 m AMSL). The experimental soil was sandy loam in texture (73.8% sand, 14.1% silt, and 12.8% clay) with pH 5.12, medium available nitrogen (132.16 kg ha⁻¹), low available phosphorus (2.50 kg ha⁻¹), and high available potassium (262.30 kg ha⁻¹). The experiment comprised eight weed management treatments: T₁-paraquat before sowing + one intercultivation at 35 DAS; T₂-paraquat before sowing + pendimethalin (1.0 kg a.i. ha⁻¹, PE) + quizalofop-ethyl (37.5 g a.i. ha⁻¹, PoE at 20 DAS); T₃-pendimethalin (1.0 kg a.i.

ha⁻¹, PE) + one intercultivation at 30 DAS; T₄-pendimethalin (1.0 kg a.i. ha⁻¹, PE) + quizalofop-ethyl (37.5 g a.i. ha⁻¹, PoE at 20 DAS); T₅-two intercultivations at 20 and 40 DAS; T₆-one intercultivation at 20 DAS followed by one hand weeding at 30-35 DAS; T₇-weed-free; and T₈-unweeded control. Sunflower was sown on 30 January 2022 and harvested on 2nd May 2022. Pre-emergence herbicides were applied within 48 h of sowing, while post-emergence application was carried out at 20 DAS. All other agronomic practices were followed as per OUAT recommendations. Biometric observations were recorded from five randomly selected plants in each treatment and the mean values were subjected to statistical analysis.

Results and Discussions

Effect of Weed Management Treatments on Plant Height

Plant height of sunflower was significantly influenced by weed management practices at all growth stages (Table 1). The weed-free treatment (T₇) consistently recorded the highest plant height at 30 DAS (39.8 cm), 60 DAS (148.3 cm), and harvest (159.3 cm), and was significantly superior to all other treatments. Among the weed management practices, two intercultivations (T₅) and one intercultivation followed by hand weeding (T₆) produced taller plants and ranked next to the weed-free treatment. Among the herbicide-based treatments, T₂ (paraquat + pendimethalin + quizalofop-ethyl) recorded greater plant height than T₁, T₃, and T₄. The unweeded control (T₈) consistently recorded the lowest plant height throughout the crop growth period. Enhanced plant height under effective weed management treatments may be attributed to reduced crop-weed competition and improved availability of nutrients, moisture, and light, whereas uncontrolled weed growth adversely affected vegetative growth and plant development. The results are in confirmatively with Tadavi *et al.*, (2017) [15].

Effect of Weed Management Treatments on Number of Leaves per Plant

Number of leaves at 30, 60 DAS and at Harvest

The number of leaves per plant was significantly influenced by weed management practices at all growth stages (Table 1). The weed-free treatment (T₇) consistently recorded the highest number of leaves at 30 DAS, 60 DAS, and harvest, followed by two intercultivations (T₅) and one intercultivation coupled with hand weeding (T₆), which remained statistically comparable. Among the herbicide-based treatments, T₂ (paraquat + pendimethalin + quizalofop-ethyl) produced a higher leaf count than T₁, T₃, and T₄. The unweeded control (T₈) recorded the lowest number of leaves throughout the crop growth period. Increased leaf production under effective weed management treatments may be attributed to reduced crop-weed competition and improved availability of growth resources, whereas unchecked weed growth restricted leaf initiation and development, resulting in lower leaf counts. The results are in agreement with Tadavi *et al.*, (2017) [15].

Effect of Weed Management Treatments on Leaf Area Index (LAI)

Leaf Area Index at 30, 60 DAS and at Harvest

Leaf Area Index (LAI)

Leaf Area Index (LAI), an important indicator of crop

growth and photosynthetic efficiency, was significantly influenced by different weed management treatments throughout the crop growth period (Table 1). The weed-free treatment (T₇) consistently recorded the highest LAI, followed by two inter-cultivations (T₅) and one inter-cultivation followed by hand weeding (T₆), indicating the effectiveness of these practices in promoting canopy development. Among the herbicide treatments, T₂ maintained comparatively higher LAI values than T₁, T₃, and T₄, suggesting better weed control and improved crop growth. In contrast, the unweeded control (T₈) recorded the lowest LAI at all growth stages due to intense weed competition for essential resources. LAI increased from 30 to 60 DAS as a result of active vegetative growth and declined towards harvest because of natural leaf senescence. However, treatments with effective weed management maintained higher LAI throughout the crop growth period. Overall, the results indicate that efficient weed control enhanced canopy development and sustained crop growth, resulting in improved photosynthetic potential [(Nagamani *et al.*, 2013); Kalaiyarasan *et al.*, (2019)]^[7, 5]

Effect of Weed Management Treatments on Relative Growth Rate (RGR)

Relative Growth Rate (RGR)

Relative Growth Rate (RGR), which reflects the efficiency of dry matter accumulation per unit of existing biomass, was significantly influenced by different weed management treatments throughout the crop growth period (Table 2). However, the variation among treatments was relatively narrow compared to other growth parameters. During the early growth stage, comparatively higher RGR values were observed in T₄, T₈, and T₃, while the remaining treatments recorded similar values. As the crop advanced from vegetative growth to reproductive development, RGR declined progressively across all treatments. This reduction is a normal physiological phenomenon associated with crop maturation, as the rate of new biomass production decreases relative to the accumulated plant biomass. During the later growth stages, treatments such as T₁, T₂, T₅, and T₆ maintained relatively higher RGR, whereas weed-free and mechanically managed treatments sustained marginally greater growth efficiency up to harvest. Despite these differences, the overall declining trend in RGR was evident across all treatments. The results indicate that while weed management practices influenced RGR to some extent, crop age had a greater effect on this parameter. The progressive decline in RGR from 30 DAS to harvest conforms to the well-established concept of ontogenic drift, where relative growth efficiency decreases as the crop matures. (Devendra Kumar 2015)^[2]

Effect of Weed Management Treatments on Crop Growth Rate (CGR)

Crop Growth Rate (CGR)

Crop Growth Rate (CGR), an important indicator of dry matter accumulation per unit area, was significantly influenced by different weed management treatments throughout the crop growth period (Table 2). Effective weed

control generally enhanced CGR by improving resource availability and promoting better crop growth. The weed-free treatment (T₇) consistently recorded higher CGR values, particularly during the early and later stages of crop growth, followed by two inter-cultivations (T₅) and one inter-cultivation combined with hand weeding (T₆). Among the herbicide treatments, T₁ and T₂ exhibited comparatively higher CGR during the active vegetative phase, indicating efficient dry matter production under these treatments. In contrast, the unweeded control (T₈) generally recorded lower CGR, reflecting the adverse effects of weed competition on crop growth. CGR increased from 30 to 60 DAS across treatments, corresponding to the grand growth phase characterized by rapid canopy expansion and biomass accumulation. Thereafter, CGR declined towards harvest as the crop shifted from vegetative growth to reproductive development and grain filling. Nevertheless, weed-free and mechanically managed treatments maintained relatively higher CGR up to harvest, demonstrating their ability to sustain dry matter production throughout the crop growth period. Overall, the results highlight the importance of effective weed management in enhancing crop growth and biomass accumulation, thereby improving the productive potential of rice-fallow sunflower (Devendra Kumar 2015)^[2].

Effect of Weed Management Treatments on Economics of Sunflower Cultivation

Economics

The economics of sunflower cultivation was markedly influenced by different weed management practices (Table 3). The cost of cultivation varied depending on the intensity and type of weed control measures adopted. The weed-free treatment (T₇) incurred the highest cost of cultivation due to repeated hand weedings, whereas the unweeded control (T₈) recorded the lowest cost owing to the absence of weed management operations. Weed management practices significantly improved gross returns, net returns, and benefit-to-cost (B:C) ratio over the unweeded control. The highest gross returns (₹1, 29, 844 ha⁻¹), net returns (₹61, 641 ha⁻¹), and B:C ratio (1.90) were recorded under the weed-free treatment (T₇), reflecting its superior yield performance. Among the managed treatments, T₂ (paraquat + pendimethalin + quizalofop ethyl) emerged as a highly profitable option, recording gross returns of ₹1, 12, 200 ha⁻¹, net returns of ₹52, 277 ha⁻¹, and a B:C ratio of 1.87. Similarly, two inter-cultivations at 20 and 40 DAS (T₅) also resulted in higher economic returns with a B:C ratio of 1.84. In contrast, the unweeded control (T₈) recorded the lowest gross returns (₹50, 727 ha⁻¹), net returns (₹4, 876 ha⁻¹), and B:C ratio (0.91), indicating poor economic viability due to severe yield reduction caused by weed competition. Overall, effective weed management substantially enhanced the profitability of rice-fallow sunflower, with the weed-free treatment proving most remunerative, while T₂ offered a cost-effective and economically attractive alternative under practical farming conditions. The results are in line with Tadavi *et al.*, (2017)^[15] and Thambiyanan *et al.*, (2024)^[16].

Table 1: Plant height, No. of leaves and Leaf area index (LAI) of sunflower at different growth stages as influenced by integrated weed management

S. No.	Treatment	Plant height			No. of leaves			Leaf area index		
		30 DAS	60 DAS	Harvest	30 DAS	60 DAS	Harvest	30 DAS	60 DAS	Harvest
01.	Paraquat spray before sowing + one Inter-cultivation at 35 DAS	30.0	128.0	136.3	12.8	26.6	12.9	0.33	2.28	1.14
02.	Paraquat spray before sowing pendimethalin 1.0 kg a.i ha ⁻¹ as pre-emergence spray + Quizalofop ethyl 10EC @ 37.5 g ai ha ⁻¹ at 20 DAS as directed postemergence spray on weeds	30.6	129.0	140.0	13.3	27.2	14.2	0.36	2.36	1.21
03.	Pendimethalin @ 1.0 kg a.i ha ⁻¹ as pre-emergence spray + one inter-cultivation at 30 DAS	29.0	124.0	134.0	11.7	26.0	11.0	0.32	2.01	1.01
04.	pendimethalin 1.0 kg a.i ha ⁻¹ as pre-emergence spray + Quizalofop ethyl 10EC @ 37.5 g ai ha ⁻¹ at 20 DAS as directed postemergence spray on weeds	29.0	117.3	129.0	11.0	23.1	10.6	0.30	1.85	0.97
05.	Two inter-cultivation at 20 & 40 DAS	34.3	137.0	145.6	13.7	28.3	14.9	0.37	2.82	1.41
06.	One inter-cultivation at 20 DAS and 1 hand weeding at 30-35 DAS	31.3	130.6	139.6	13.6	27.5	14.3	0.37	2.666	1.37
07.	Weed free	39.8	148.3	159.3	14.1	31.4	15.3	0.39	2.97	1.70
08.	Control	22.0	91.0	114.3	9.3	16.5	8.6	0.28	1.42	0.83
	S.Em.(±)	2.10	7.36	7.97	0.78	1.74	0.74	0.04	1.42	0.83
	CD (p = 0.05)	6.3	22.3	24.1	2.3	5.2	2.2	0.12	0.68	0.16

Table 2: Relative Growth Rate (g g⁻¹day⁻¹) and Crop Growth Rate (gday⁻¹m⁻²) of sunflower at different stages as influenced by integrated weed management.

S. No.	Treatment	Relative Growth Rate (g g ⁻¹ day ⁻¹)			Crop Growth Rate (gday ⁻¹ m ⁻²)		
		30 DAS	60 DAS	Harvest	30 DAS	60 DAS	Harvest
01.	Paraquat spray before sowing + one Inter-cultivation at 35 DAS	0.12	0.07	0.01	6.0	9.5	5.4
02.	Paraquat spray before sowing pendimethalin 1.0 kg a.i ha ⁻¹ as pre-emergence spray + Quizalofop ethyl 10EC @ 37.5 g ai ha ⁻¹ at 20 DAS as directed postemergence spray on weeds	0.12	0.07	0.01	6.1	9.4	4.3
03.	Pendimethalin @ 1.0 kg a.i ha ⁻¹ as pre-emergence spray + one inter-cultivation at 30DAS	0.13	0.06	0.02	6.1	7.1	6.2
04.	pendimethalin 1.0 kg a.i ha ⁻¹ as pre-emergence spray + Quizalofop ethyl 10EC @ 37.5 g ai ha ⁻¹ at 20 DAS as directed postemergence spray on weeds	0.16	0.06	0.01	6.5	7.1	5.6
05.	Two inter-cultivation at 20 & 40 DAS	0.12	0.07	0.02	6.7	8.6	8.1
06.	One inter-cultivation at 20 DAS and 1 hand weeding at 30-35 DAS	0.12	0.07	0.01	6.5	8.5	6.8
07.	Weed free	0.12	0.06	0.02	7.4	8.2	9.8
08.	Control	0.15	0.06	0.01	5.9	9.4	5.3
	S.Em. (±)	0.013	0.019	0.004	0.43	1.38	1.78
	CD (p = 0.05)	0.02	0.02	0.012	1.3	4.1	5.3

Table 3: Production economics as influenced by integrated weed management practices in of paddy fallow Sunflower

S. No.	Treatment	Cost of cultivation	Gross Returns	Net Returns	B:C ratio
01.	Paraquat spray before sowing + one Inter-cultivation at 35 DAS	61888	105724	43836	1.71
02.	Paraquat spray before sowing pendimethalin 1.0 kg a.i ha ⁻¹ as pre-emergence spray + Quizalofop ethyl 10EC @ 37.5 g ai ha ⁻¹ at 20 DAS as directed postemergence spray on weeds	59923	112200	52277	1.87
03.	Pendimethalin @ 1.0 kg a.i ha ⁻¹ as pre-emergence spray + one inter-cultivation at 30DAS	61888	100952	39064	1.63
04.	pendimethalin 1.0 kg a.i ha ⁻¹ as pre-emergence spray + Quizalofop ethyl 10EC @ 37.5 g ai ha ⁻¹ at 20 DAS as directed postemergence spray on weeds	58363	99308	40945	1.70
05.	Two inter-cultivation at 20 & 40 DAS	63478	116491	53013	1.84
06.	one inter-cultivation at 20 DAS and 1 hand weeding at 30-35 DAS	66628	113864	47236	1.71
07.	Weed free	68203	129844	61641	1.9
08.	Control	55603	50727	4876	0.91

Conclusion

The present investigation conclusively establishes that weed competition exerts a severe and economically devastating impact on rice fallow sunflower, significantly suppressing plant height, leaf number, leaf area index, stem girth, and crop growth rate at all stages of crop development. Among all treatments evaluated, the weed-free treatment

consistently delivered the highest biological and economic performance; however, its dependence on repeated hand weeding makes it labour-intensive and less practical under large-scale farming conditions. The integrated herbicide treatment T₂ (paraquat spray before sowing + pendimethalin 1.0 kg a.i. ha⁻¹ as pre-emergence + quizalofop ethyl 37.5 g a.i. ha⁻¹ at 20 DAS) emerged as the most practically viable

and economically efficient option, recording net returns of ₹52, 277 ha⁻¹ and a B:C ratio of 1.87 with a relatively lower cost of cultivation. Two inter-cultivations at 20 & 40 DAS (T₅) also performed commendably. The unweeded control, with a B:C ratio of 0.91, demonstrated that complete neglect of weed management renders sunflower cultivation economically unviable. It is therefore concluded that timely integrated weed management combining pre-emergence and post-emergence herbicides is indispensable for maximising productivity and profitability in rice fallow sunflower.

Future Scope of Research

The present study opens several avenues for further investigation in weed management of rice fallow sunflower. Future research should explore the long-term residual effects of repeated herbicide applications particularly pendimethalin and quizalofop ethyl on soil microbial communities, organic matter dynamics, and subsequent crop performance under rice fallow systems. Studies integrating newer post-emergence herbicides and tank mixtures with bio-herbicides or allelopathic crop residues could offer more sustainable and environmentally benign weed control options. Research on weed-crop competition thresholds and critical periods of weed interference specific to rice fallow sunflower across different agro-climatic zones would help refine site-specific recommendation packages. Additionally, the economic analysis could be extended to include labour availability constraints and climate variability, which significantly influence the feasibility of mechanical weed control. Investigations under changing climate scenarios, including erratic rainfall and rising temperatures affecting weed species composition and density, would further strengthen the scientific basis for developing future-ready, resilient weed management strategies for this important oilseed cropping system.

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