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Integrated weed management improves weed suppression, yield and profitability of sunflower (*Helianthus annuus* L.)

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Abstract
A field experiment was conducted during the *rabi* season of 2025–26 at the Research Farm, School of Agricultural Sciences, G H Raisoni University, Saikheda, Madhya Pradesh, India, to identify an effective and profitable integrated weed-management practice for sunflower. Eight treatments were evaluated in a randomized block design with three replications. The weed-free check recorded the lowest weed density (3.30 plants m^{-2}), weed dry matter (7.82 g m^{-2}) and the highest weed-control efficiency (96.0%). Among practical treatments, oxyfluorfen 30% EC at 250 g a.i. ha^{-1} as pre-emergence followed by imazethapyr 10% SL at 100 g a.i. ha^{-1} as post-emergence recorded 12.54 weeds m^{-2}, 29.70 g m^{-2} weed dry matter and 84.8% weed-control efficiency. The weed-free check produced the highest seed yield (2130 kg ha^{-1}), but it remained statistically at par with oxyfluorfen followed by imazethapyr (2075 kg ha^{-1}), intercultivation followed by hand weeding (2045 kg ha^{-1}) and pendimethalin followed by quizalofop-*p*-ethyl (2015 kg ha^{-1}). Oxyfluorfen followed by imazethapyr generated the highest net return (₹76,563 ha^{-1}) and benefit:cost ratio (2.71). The results indicate that sequential pre- and post-emergence weed control can provide seed yield comparable with repeated hand weeding while improving profitability.

Keywords: benefit: cost ratio; herbicide sequence; imazethapyr; oxyfluorfen; seed yield; weed-control efficiency.

Introduction
Sunflower is an important short-duration oilseed crop valued for its high-quality edible oil, broad adaptability and suitability for diversified cropping systems. Its wider row spacing and slow initial canopy development, however, favour rapid establishment of weeds. Early weed competition reduces the availability of moisture, nutrients, light and space and may cause substantial yield loss. Wanjari *et al.* (2001) [9] identified approximately 20–49 days after sowing as a critical period of crop–weed competition in sunflower, while Stefanić *et al.* (2023) [6] reported severe yield reductions under uncontrolled weed interference. Hand weeding is effective but costly and often constrained by labour availability. Pre-emergence herbicides suppress the first flush of weeds, whereas a selective post-emergence herbicide or mechanical operation can control later-emerging weeds. Integrated weed management therefore offers a practical means of extending the weed-free period and reducing dependence on repeated manual weeding. Previous studies have shown that sequential herbicide application and herbicide–mechanical integration can provide yield comparable with weed-free conditions while improving economic efficiency (Mohapatra *et al.*, 2020; Das *et al.*, 2023; Thambiyannan *et al.*, 2024) [2, 4, 8]. Information on the relative performance of oxyfluorfen-, oxadiargyl- and pendimethalin-based schedules under the *rabi* conditions of central India remains limited. Therefore, the present study was undertaken to evaluate their effects on weed dynamics, crop growth, yield attributes, yield and economics of sunflower.

Materials and methods
Experimental site and design
The experiment was conducted during the *rabi* season of 2025–26 at the Research Farm, School of Agricultural Sciences, G H Raisoni University, Saikheda, District Pandhurna, Madhya Pradesh. The soil was clay loam, nearly neutral to slightly alkaline, low in available

Nitrogen, medium in organic carbon and available phosphorus, and high in available potassium. Sunflower hybrid FB-Sun 777 F_1 was grown in a randomized block design with eight treatments and three replications. Gross and net plot sizes were 5.0 m × 4.0 m and 4.0 m × 3.5 m, respectively. The crop was sown at 60 cm × 30 cm spacing with a seed rate of 8 kg ha^{-1} and received 80:60:40 kg $N:P_2O_5:K_2O$ ha^{-1}.

Treatments

Table 1: Treatment details

Treatment	Description
T_1	Weedy check
T_2	Oxyfluorfen 30% EC (PE) @ 250 g a.i. ha^{-1} + hand weeding at 20 DAS
T_3	Oxadiargyl 80% WP (PE) @ 175 g a.i. ha^{-1} + hand weeding at 20 DAS
T_4	Pendimethalin 30% EC (PE) @ 1.0 kg a.i. ha^{-1} + hand weeding at 20 DAS
T_5	Pendimethalin 30% EC (PE) @ 1.0 kg a.i. ha^{-1} fb quizalofop-*p*-ethyl 5% EC (PoE) @ 50 g a.i. ha^{-1}
T_6	Oxyfluorfen 30% EC (PE) @ 250 g a.i. ha^{-1} fb imazethapyr 10% SL (PoE) @ 100 g a.i. ha^{-1}
T_7	Intercultivation at 20 DAS + hand weeding at 40 DAS
T_8	Weed-free check with hand weedings at 20, 40 and 60 DAS

Observations and statistical analysis

Weed density and weed dry matter were recorded at harvest using quadrats. Weed-control efficiency was calculated from the reduction in weed dry matter relative to the weedy check. Plant height, leaf area index, head diameter, filled seeds head^{-1}, test weight, seed yield, stalk yield, biological yield and harvest index were recorded using standard procedures. Gross return was calculated from seed and stalk values, net return as gross return minus cost of cultivation, and benefit:cost ratio as gross return divided by cost of cultivation. Data were subjected to analysis of variance for a randomized block design, and treatment means were compared using the critical difference at P = 0.05.

Results and discussion

Weed flora and weed suppression

The field was infested with a mixed flora of grasses, broad-leaved weeds and sedges. Broad-leaved weeds formed 60.0% of the population, followed by grasses (33.5%) and sedges (6.5%). Weed-management treatments significantly affected weed density, weed dry matter and weed-control efficiency (Table 2). The weed-free check recorded the minimum weed density and dry matter because repeated hand weedings continuously removed newly emerged weeds. Among practical treatments, T_6 recorded the lowest weed density and dry matter and remained statistically comparable with T_7 and T_5. The performance of T_6 can be attributed to suppression of the first weed flush by oxyfluorfen and control of later-emerging weeds by imazethapyr. Similar advantages of sequential herbicide application were reported by Mohapatra *et al.* (2020) [4].

Table 2: Effect of integrated weed management on weed parameters

Treatment	Weed density (number m^{-2})	Weed dry matter (g m^{-2})	WCE (%)
T_1	82.50	195.40	0.0
T_2	31.10	73.67	62.3
T_3	25.82	61.15	68.7
T_4	28.54	67.98	65.2
T_5	17.16	40.64	79.2
T_6	12.54	29.70	84.8
T_7	14.68	35.17	82.0
T_8	3.30	7.82	96.0
SEm±	2.10	4.85	2.61
CD (P=0.05)	6.34	14.65	7.89

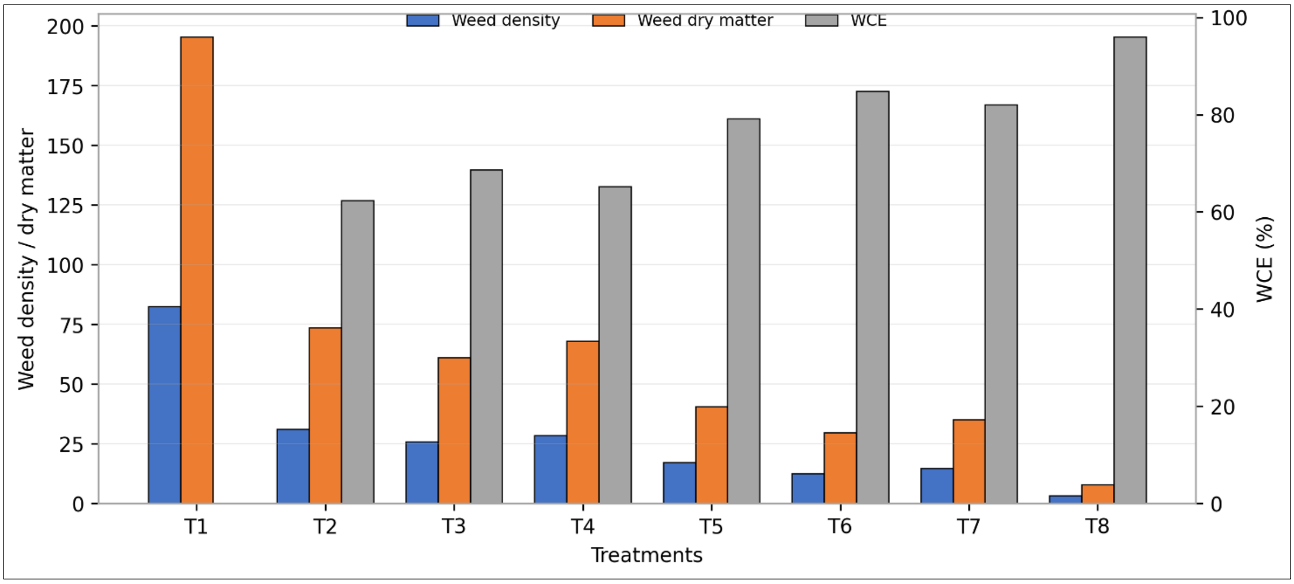

Fig 1: Weed response to integrated weed-management treatments.

Growth and yield attributes

Effective weed suppression improved crop growth and yield attributes (Table 3). The weed-free check recorded the tallest plants, maximum leaf area index, largest head diameter, highest number of filled seeds head^{-1} and greatest test weight. Treatments T_6, T_7 and T_5 remained statistically comparable with the weed-free check for most traits. Reduced competition under these treatments improved access to nutrients, water and light, which supported canopy development, assimilate production and seed filling. The weedy check recorded the lowest values because season-long competition restricted crop growth. Comparable improvement in plant height, head diameter and seed filling under integrated weed management was reported by Bharati *et al.* (2020) and Thambiyannan *et al.* (2024) [1, 8].

Table 3: Effect of integrated weed management on growth and yield attributes

Treatment	Plant height (cm)	LAI	Head diameter (cm)	Filled seeds head^{-1}	Test weight (g)
T_1	136.2	2.45	12.3	626	42.6
T_2	157.8	3.18	15.8	806	49.3
T_3	164.6	3.45	16.9	865	51.4
T_4	160.5	3.32	16.4	828	50.2
T_5	181.6	4.12	19.8	1108	57.3
T_6	186.8	4.38	20.9	1148	58.7
T_7	184.1	4.22	20.4	1135	58.0
T_8	194.2	4.65	21.6	1192	60.1
SEm±	4.25	0.12	0.57	30.6	1.15
CD (P=0.05)	12.84	0.37	1.72	92.7	3.48

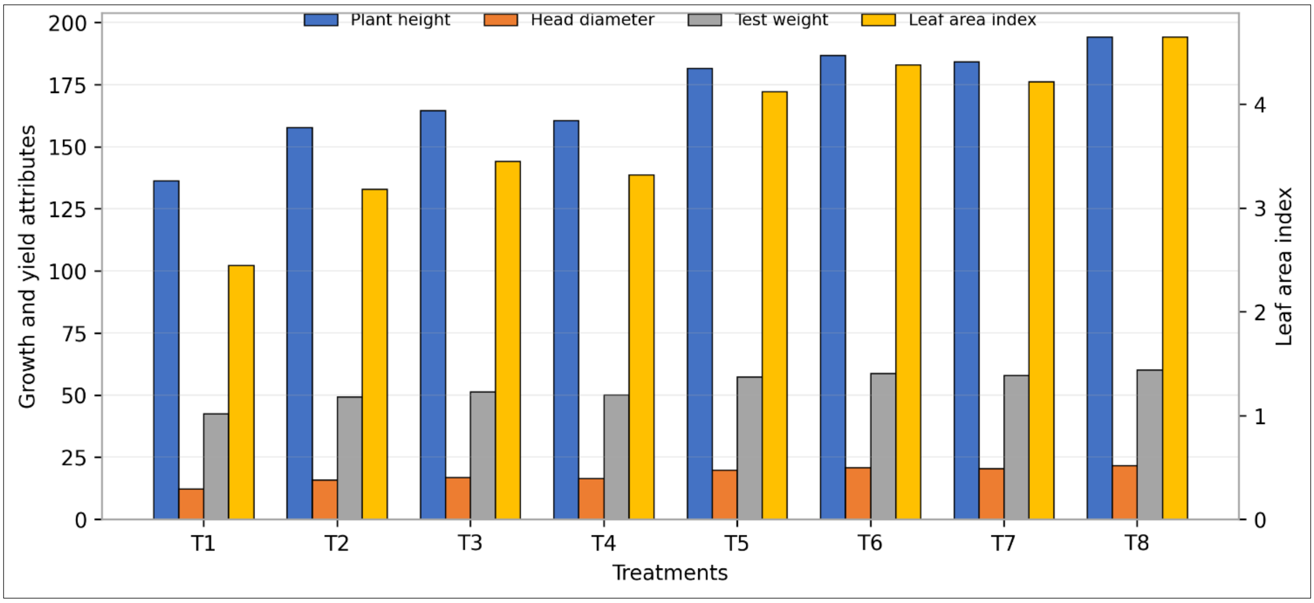

Fig 2: Growth and yield attributes of sunflower under integrated weed management.

Yield response

Seed, stalk and biological yields differed significantly among treatments (Table 4). The weed-free check produced the highest seed yield (2130 kg ha^{-1}), but remained statistically at par with T_6, T_7 and T_5. The comparable yield under these integrated treatments resulted from sustained weed suppression, greater leaf area, larger heads and improved seed filling. The weedy check produced only 1180 kg ha^{-1} seed yield, representing a 44.6% reduction relative to the weed-free check. Harvest index was not significantly influenced, indicating that the treatments altered total biomass and seed yield in similar proportions. Selvakumar *et al.* (2018), Das *et al.* (2023) and Sujathamma *et al.* (2026) [2, 5, 7] similarly observed that integrated treatments produced yields close to repeated hand weeding.

Table 4: Effect of integrated weed management on yield of sunflower

Treatment	Seed yield (kg ha^{-1})	Stalk yield (kg ha^{-1})	Biological yield (kg ha^{-1})	Harvest index (%)
T_1	1180	2925	4105	28.75
T_2	1712	3990	5702	30.02
T_3	1835	4238	6073	30.22
T_4	1755	4120	5875	29.87
T_5	2015	4670	6685	30.14
T_6	2075	4820	6895	30.09
T_7	2045	4755	6800	30.07
T_8	2130	4982	7112	29.95
SEm±	51.3	128.7	168.4	1.21
CD (P=0.05)	155.2	389.4	509.4	NS

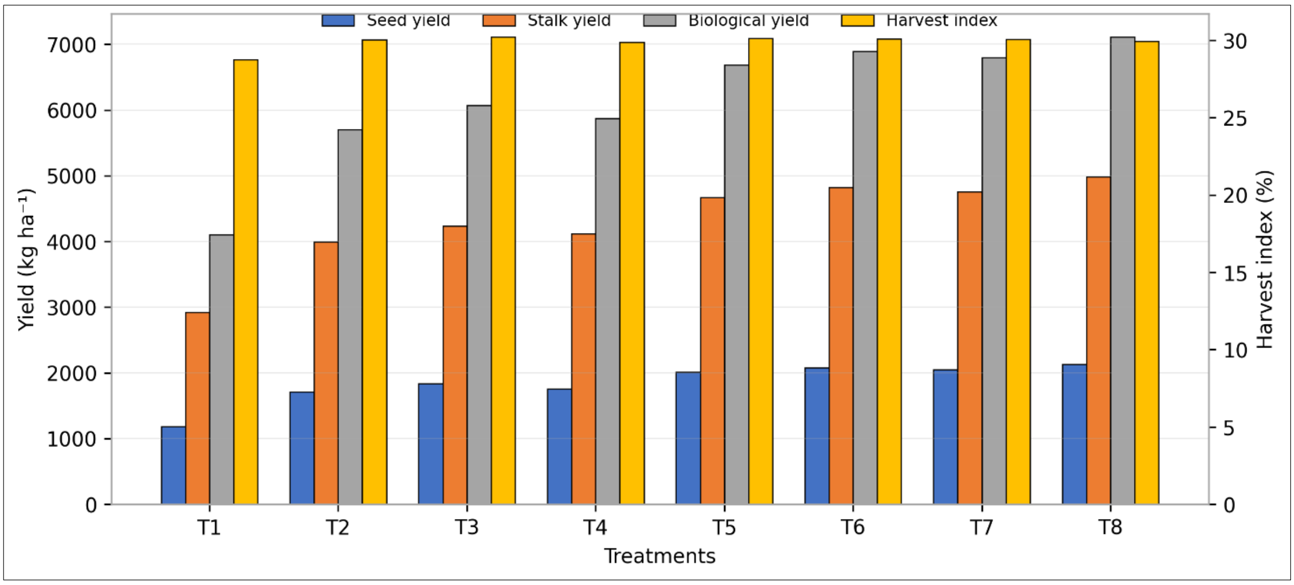

Fig 3: Yield response of sunflower to integrated weed-management treatments.

Economics

The weed-free check generated the highest gross return, but repeated hand weeding increased the cost of cultivation. T_6 recorded the highest net return (₹76,563 ha^{-1}) and benefit:cost ratio (2.71), followed closely by T_5. Thus, maximum biological productivity did not correspond to maximum profitability. The superior economic performance of sequential herbicide treatments agrees with findings of Bharati *et al.* (2020), Mohapatra *et al.* (2020) and Mahapatra *et al.* (2025) [1, 3, 4].

Table 5: Economics of integrated weed-management treatments

Treatment	Cost of cultivation (₹ ha⁻¹)	Gross return (₹ ha⁻¹)	Net return (₹ ha⁻¹)	B:C ratio
T_1	34,800	69,288	34,488	1.99
T_2	41,100	100,145	59,045	2.44
T_3	42,100	107,282	65,182	2.55
T_4	42,100	102,705	60,605	2.44
T_5	43,600	117,830	74,230	2.70
T_6	44,792	121,355	76,563	2.71
T_7	53,650	119,608	65,958	2.23
T_8	53,200	124,623	71,423	2.34

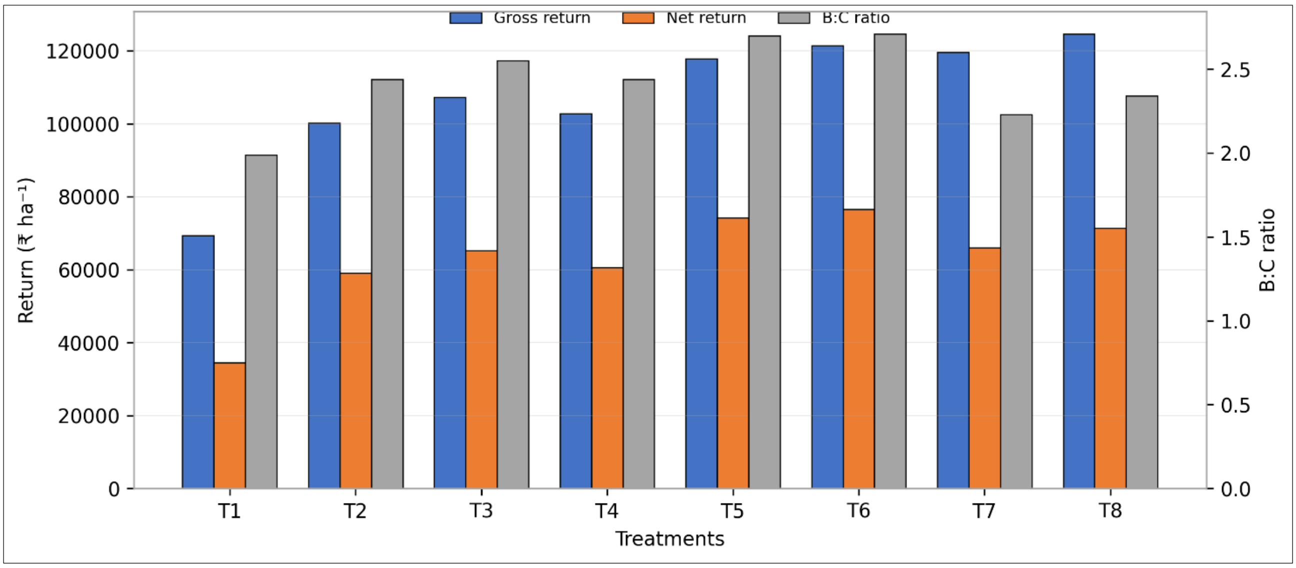

Fig 4: Economics of integrated weed-management treatments.

Conclusion

The weed-free check provided the greatest weed suppression and the highest numerical seed yield. However, oxyfluorfen 30% EC at 250 g a.i. ha^{-1} as pre-emergence followed by imazethapyr 10% SL at 100 g a.i. ha^{-1} as post-emergence produced statistically comparable seed yield and recorded the highest net return and benefit:cost ratio. This sequence was therefore the most remunerative treatment under the experimental conditions. Because the study was conducted for one season and at one location, the treatment should be validated across environments and used only where crop tolerance and herbicide registration permit.

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