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Bio-efficacy and economics of pre- and post-emergence herbicides in Barley (*Hordeum vulgare* L.)

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Abstract

During *rabi* 2022-23, a field trial was carried out at the Agricultural Research Farm, Faculty of Agriculture, Maharishi Markandeshwar (Deemed to be University), Mullana-Ambala, Haryana, to assess how pre- and post-emergence herbicides influence weed suppression, crop growth, yield and profitability of barley (*Hordeum vulgare* L.) cv. 'BH 946', laid out in a randomized block design with eight treatments and three replications. Where weeds were left unchecked (weedy check), grain yield fell by 48.4% relative to the best-performing treatment, and this plot also carried the greatest weed load, with 30.9 weeds/m² and 28.7 g/m² dry weight recorded at 90 days after sowing (DAS). Among all treatments, the sequential post-emergence tank-mix of sulfosulfuron (30 g/ha) followed by metsulfuron-methyl (3 g/ha) achieved the greatest weed suppression (50.2% efficiency at 90 DAS) together with the highest grain yield (4.44 t/ha), net return (Rs 64,067/ha) and benefit:cost ratio (2.89); on most growth and yield parameters it matched two hand weeding, but at considerably lower cost. Among the alternative sequential options, pre-emergence Pyroxasulfone followed by post-emergence sulfosulfuron performed next best. No visible crop injury was observed with any herbicide treatment. Overall, the sulfosulfuron-metsulfuron-methyl tank-mix emerges as a practical and economically rewarding weed-control option for barley growers in the region.

Keywords: Barley, Benefit:cost ratio, herbicides, metsulfuron-methyl, Pyroxasulfone, sulfosulfuron, weed control efficiency

Introduction

Barley (*Hordeum vulgare* L.) ranks fourth among cereals globally after wheat, rice and maize, and is an important *rabi* crop in India valued for its adaptability to marginal and saline environments and its role in the malting and brewing industries. Its high dietary fibre content, particularly beta-glucans (17-30%), is beneficial for cholesterol and blood-glucose management, leading to its recognition as a functional food.

In the Mullana (Ambala) region of Haryana, barley productivity is severely constrained by a complex weed flora comprising grassy weeds such as *Phalaris minor* and *Cynodon dactylon*, and broadleaf weeds including *Chenopodium album*, *Melilotus alba* and *Anagallis arvensis*, which compete with the slow-establishing crop for moisture, light and nitrogen. Yield losses of 40-78% have been reported where weeds are left unmanaged during the critical period of crop-weed competition (25-60 DAS) (Tanveer *et al.* 2012)^[9]. Manual weeding, though effective, is becoming economically unviable owing to rising labour costs and scarcity, and is further complicated by weeds such as *P. minor* that morphologically mimic barley at early growth stages. Herbicides such as pyroxasulfone, sulfosulfuron and metsulfuron-methyl, applied alone, in sequence, or as tank-mixes, have shown promise for broad-spectrum control in wheat and barley (Punia *et al.* 2017, Pal and Singh 2021)^[7, 6], but their comparative performance under local conditions required evaluation. Against this background, the present investigation was planned to assess how pre- and post-emergence herbicide treatments affect the growth and yield of barley, to gauge their efficacy against the local weed spectrum, and to determine the most economical option based on the benefit:cost ratio.

Materials and Methods

The field trial was conducted at the Agricultural Research Farm, Faculty of Agriculture, Maharishi Markandeshwar (Deemed to be University), Mullana-Ambala, Haryana, situated at 30° 15' N

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latitude and 77° 02' E longitude at an elevation of 274 m, during *rabi* 2022-23; the location has a semi-arid, sub-tropical climate. The experimental soil was sandy loam in texture and mildly alkaline in reaction (pH 7.9), with low organic carbon (0.42%) and available nitrogen (185 kg/ha), and moderate levels of available phosphorus (14.5 kg/ha) and potassium (210 kg/ha).

A randomized block design with eight treatments and three replications was adopted, using a gross plot of 4 m × 4 m and a net plot of 3.68 m × 3.68 m. Barley cv. 'BH 946' was sown during the first fortnight of November at a seed rate of 80 kg/ha with 22.5 cm row spacing, and received 60-13-17 kg N-P-K/ha, of which half the nitrogen along with the full dose of phosphorus and potassium was applied as basal, the remaining nitrogen being top-dressed at the first irrigation. Eight treatments were imposed: T₁, pyroxasulfone at 130 g/ha (pre-emergence); T₂, sulfosulfuron at 30 g/ha (post-emergence); T₃, pyroxasulfone (130 g/ha) followed by sulfosulfuron (30 g/ha); T₄, a post-emergence tank-mix of sulfosulfuron (30 g/ha) followed by metsulfuron-methyl (3 g/ha); T₅, metribuzin at 210 g/ha (post-emergence); T₆, metsulfuron-methyl at 3 g/ha (post-emergence); T₇, two hand weedings carried out at 20 and 40 DAS; and T₈, an untreated weedy check. Pre-emergence sprays were applied within 0-3 DAS and post-emergence sprays at 30-35 DAS, using a knapsack sprayer fitted with a flat-fan nozzle set to deliver a spray volume of 500 litres of water/ha.

At 30, 60 and 90 DAS, weed density and dry weight were assessed using a 0.25 m² quadrat placed at two randomly chosen spots per plot; count data were square-root transformed ($\sqrt{x+0.5}$) prior to analysis of variance, though the untransformed means are presented here. Weed control efficiency was derived from the relationship $WCE (\%) = [(WDC - WDT)/WDC] \times 100$, where WDC and WDT represent weed dry weight in the untreated weedy check and the herbicide-treated plot, respectively. Plant stand was counted at 21 DAS, while plant height, tiller number and dry matter accumulation were tracked at successive stages of crop growth; spikes/m², grains per spike, test weight, grain yield, straw yield, biological yield and harvest index were determined at crop maturity from the net plot area. All data were subjected to analysis of variance appropriate to a randomized block design following the procedure of Gomez and Gomez (1984) [3], with treatment means compared using the critical difference at the 5% probability level. Economic indices, namely cost of cultivation, gross returns, net returns and the benefit:cost (B:C) ratio, were derived using prevailing input costs and market prices of produce.

Results and Discussion

Crop growth

Plant population at 21 DAS was unaffected by herbicide treatment (79.5-81.3/m²; Table 2), confirming a uniform crop stand and the absence of phytotoxic effects of the pre-emergence herbicides pyroxasulfone and metribuzin on barley germination. Significant differences in plant height, tiller number and dry matter accumulation (DMA) emerged from 60 DAS onward. At harvest, T₄ (sulfosulfuron fb metsulfuron-methyl) recorded the tallest plants (98.1 cm), the highest tiller density (255/m²) and the greatest DMA (979.3 g/m²), on par with T₃ (pyroxasulfone fb sulfosulfuron) and T₇ (two hand weedings) but 12-18% higher than the weedy check, which recorded the lowest values for all three parameters. The superior and season-long performance of T₄ and T₃ reflects the value of combining herbicides with complementary timing to suppress both early and late weed flushes, sustaining a larger crop canopy for light interception through the season.

Yield attributes and yield

Spikes/m², grains/spike, test weight, grain yield and harvest index were significantly influenced by weed management (Table 3). T₄ produced the most spikes/m² (246.7), grains/spike (44.0) and highest test weight (41.4 g), on par with T₇ and T₃, while the weedy check recorded the lowest values for every attribute (196.7 spikes/m², 34.0 grains/spike, 35.3 g test weight). Grain yield followed the same trend, being highest under T₄ (4.44 t/ha) and harvest index (44.2%), followed by T₇ (4.31 t/ha) and T₃ (4.29 t/ha), while the weedy check yielded only 2.29 t/ha—a loss of about 48.4% relative to T₄, consistent with the yield-loss range reported for uncontrolled weed competition in barley (Tanveer *et al.* 2012) [9]. The lower harvest index of the weedy check (38.9%) indicates that weed stress impaired grain-filling more severely than vegetative growth. That T₄ matched or exceeded the labour-intensive T₇ across most growth and yield attributes demonstrates that a well-timed herbicide programme can substitute for manual weeding without yield penalty.

Economics

Economic returns did not mirror biological performance for all treatments (Table 4). Although T₇ achieved yields comparable to T₄, its cultivation cost (Rs 52,500/ha) was much higher owing to labour requirement, giving the lowest B:C ratio (1.82) among weed-managed treatments and net returns of only Rs 42,873/ha. T₄ combined high yield with moderate input cost (Rs 33,850/ha), giving the highest net returns (Rs 64,067/ha) and B:C ratio (2.89) of all treatments, about Rs 21,000/ha more profitable than hand weeding. The weedy check, despite the lowest cultivation cost, gave the poorest economics overall (B:C ratio 1.65), showing that omitting weed control results in a net financial loss under prevailing labour costs.

Weed density, weed dry weight and weed control efficiency

Weed density and dry weight increased through the season in all treatments but rose sharply in the weedy check, reaching 30.9/m² and 28.7 g/m² at 90 DAS, about four times higher than under T₄ (Table 5). T₄ gave the most consistent suppression across sampling dates, remaining statistically comparable to T₇ and significantly lower than the solo pre-emergence treatments T₁ and T₅. Correspondingly, T₄ recorded the highest WCE at every stage, remaining above 50% even at 90 DAS. WCE and grain yield were positively associated across treatments, with T₄ and T₃ recording both the highest WCE and the highest yields, confirming that suppression of weed biomass rather than weed number is the more direct determinant of yield. The consistently superior performance of the sulfosulfuron + metsulfuron-methyl tank-mix reflects the complementary spectrum of the two active ingredients against the mixed grassy and broadleaf flora at the site, corroborating similar reports in wheat and barley (Punia *et al.* 2017, Pal and Singh 2021) [7, 6].

Season-long weed competition, when left unchecked, cost barley growers roughly 48.4% of their grain yield, driven by the high weed density and biomass that built up by 90 DAS. Among the options tested, the post-emergence tank-mix of sulfosulfuron (30 g/ha) and metsulfuron-methyl (3 g/ha) delivered the best combination of weed suppression, grain yield, net returns and B:C ratio, matching two hand weedings while costing substantially less, and is therefore recommended for barley growers in Haryana and comparable agro-climatic zones. Where growers prefer to include a residual pre-emergence component, pyroxasulfone followed by sulfosulfuron offers a suitable alternative; none of the herbicide treatments produced any visible crop injury.

Table 1: Herbicide treatments imposed in the barley field experiment

Treatment	Dose (kg a.i./ha)	Time of application
T ₁ : Pyroxasulfone	0.130	Pre-emergence (0-3 DAS)
T ₂ : Sulfosulfuron	0.030	Post-emergence (30-35 DAS)
T ₃ : Pyroxasulfone fb sulfosulfuron	0.130 fb 0.030	PE fb POE
T ₄ : Sulfosulfuron fb metsulfuron-methyl	0.030 + 0.004	Post-emergence (30-35 DAS)
T ₅ : Metribuzin	0.210	Post-emergence (30-35 DAS)
T ₆ : Metsulfuron-methyl	0.004	Post-emergence (30-35 DAS)
T ₇ : Two hand weedings	—	20 and 40 DAS
T ₈ : Weedy check (no weed control)	—	—

PE = pre-emergence; POE = post-emergence; DAS = days after sowing; fb = followed by.

Table 2: Effect of pre- and post-emergence herbicides on plant population, plant height, tiller number and dry matter accumulation in barley

Treatment	Plant popn. (no./m ² , 21 DAS)	Plant height (cm, harvest)	Tillers (no./m ² , harvest)	Dry matter (g/m ² , harvest)
T ₁ : Pyroxasulfone 130 g/ha	80.1	93.0	216.0	964.1
T ₂ : Sulfosulfuron 30 g/ha	81.0	96.2	225.3	973.7
T ₃ : Pyroxasulfone fb sulfosulfuron	81.1	98.1	244.7	975.9
T ₄ : Sulfosulfuron fb metsulfuron-methyl	81.3	98.1	255.0	979.3
T ₅ : Metribuzin 210 g/ha	80.3	94.0	220.3	966.2
T ₆ : Metsulfuron-methyl 3 g/ha	80.8	95.1	223.0	969.2
T ₇ : Two hand weedings	79.5	97.2	259.0	978.1
T ₈ : Weedy check	79.5	82.9	208.3	854.2
SEm±	1.47	1.95	6.10	18.50
CD (P=0.05)	NS	5.71	17.90	55.98

DAS = days after sowing; NS = non-significant.

Table 3: Effect of pre- and post-emergence herbicides on yield attributes, grain yield and harvest index of barley

Treatment	Spikes (no./m ²)	Grains/ spike	Test wt. (g)	Grain yield (t/ha)	Harvest index (%)
T ₁ : Pyroxasulfone 130 g/ha	240.0	41.7	39.0	3.77	43.3
T ₂ : Sulfosulfuron 30 g/ha	243.7	42.7	40.5	4.14	43.9
T ₃ : Pyroxasulfone fb sulfosulfuron	245.3	43.0	41.1	4.29	44.1
T ₄ : Sulfosulfuron fb metsulfuron-methyl	246.7	44.0	41.4	4.44	44.2
T ₅ : Metribuzin 210 g/ha	241.0	42.0	39.5	3.98	43.8
T ₆ : Metsulfuron-methyl 3 g/ha	244.3	42.3	40.1	4.07	43.9
T ₇ : Two hand weedings	245.0	43.5	41.2	4.31	44.0
T ₈ : Weedy check	196.7	34.0	35.3	2.29	38.9
SEm±	4.25	0.65	0.55	0.06	0.55
CD (P=0.05)	12.50	2.00	1.65	0.17	1.67

Table 4: Economics of weed management practices in barley

Treatment	Cultivation cost (Rs/ha)	Gross returns (Rs/ha)	Net returns (Rs/ha)	B:C ratio
T ₁ : Pyroxasulfone 130 g/ha	34,900	83,905	49,005	2.40
T ₂ : Sulfosulfuron 30 g/ha	33,500	91,534	58,034	2.73
T ₃ : Pyroxasulfone fb sulfosulfuron	35,600	94,468	58,868	2.65
T ₄ : Sulfosulfuron fb metsulfuron-methyl	33,850	97,917	64,067	2.89
T ₅ : Metribuzin 210 g/ha	33,050	88,118	55,068	2.67
T ₆ : Metsulfuron-methyl 3 g/ha	32,950	89,972	57,022	2.73
T ₇ : Two hand weedings	52,500	95,373	42,873	1.82
T ₈ : Weedy check	32,500	53,573	21,073	1.65

Table 5: Weed density, weed dry weight and weed control efficiency (WCE) at 90 DAS as influenced by pre- and post-emergence herbicides in barley

Treatment	Weed density (no./m ² , 90 DAS)	Weed dry wt. (g/m ² , 90 DAS)	WCE (% , 90 DAS)
T ₁ : Pyroxasulfone 130 g/ha	13.70	10.02	34.5
T ₂ : Sulfosulfuron 30 g/ha	10.73	8.67	44.3
T ₃ : Pyroxasulfone fb sulfosulfuron	9.47	7.01	49.2
T ₄ : Sulfosulfuron fb metsulfuron-methyl	7.77	5.55	50.2
T ₅ : Metribuzin 210 g/ha	13.00	9.50	37.8
T ₆ : Metsulfuron-methyl 3 g/ha	12.13	8.73	41.8
T ₇ : Two hand weedings	8.92	8.30	48.7
T ₈ : Weedy check	30.92	28.70	0.0
CD (P=0.05)	0.74	0.60	11.63

*Analysis on $\sqrt{(x+0.5)}$ transformed values; original means presented.

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