International Journal of Bio-resource and Stress Management https://ojs.pphouse.org/index.php/IJBSM

IJBSM December 2025, 16(12): 01-07

Article AR6441

Research Article

Stress Management

DOI: HTTPS://DOI.ORG/10.23910/1.2025.6441

Evaluation of Herbicides for Enhancing Yield and Economic Benefits in Barley (*Hordeum vulgare* L.)

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0009-0001-6601-6991

ABSTRACT

The research experiment was conducted during November, 2014–May, 2015, November, 2015–May, 2016 and November, 2016–May, 2017 at two locations (HAREC-Bajaura, Kullu and RWRC-Malan, Kangra) in Himachal Pradesh to evaluate different herbicides for effective weed control in barley. This experiment consisting of eleven treatments viz. Pinoxoden 30, 40 and 50 g ha^{-1}, pinoxoden 40 g ha^{-1}+metsulfuron 4 g ha^{-1} , pinoxoden 40 g ha^{-1} fb. metsulfuron 4 g ha^{-1}, pinoxoden 40 g ha^{-1}+carfentrazone 20 g ha^{-1}, isoproturon 1000 g ha^{-1}, isoproturon 750 g ha^{-1}+2, 4-D 500 g ha^{-1}, isoproturon 750 g ha^{-1}+metsulfuron 4 g ha^{-1}, weedy and weed free check was conducted in RBD with 3 replications. The results revealed that on pooled basis, at both locations, isoproturon 750 g ha^{-1}+metsulfuron 4 g ha^{-1} being at par with pinoxoden 40 g ha^{-1}+metsulfuron 4 g ha^{-1} and pinoxoden 40 g ha^{-1} fb. metsulfuron 4 g ha^{-1} resulted in significantly higher barley grain yield, which was equivalent to weed free check. Due to higher yield obtained in plots receiving application of isoproturon 750 g ha^{-1}+metsulfuron 4 g ha^{-1} at Bajaura and pinoxoden 40 g ha^{-1}+metsulfuron 4 g ha^{-1} at Malan, had fetched highest net returns and BC ratio. In on-farm trials, where three prominent treatments were tested at different locations of H.P., isoproturon 750 g ha^{-1}+metsulfuron 4 g ha^{-1} had achieved highest average grain yield of barley.

KEYWORDS: Barley, herbicides, on-farm trial, weed control, yield, economics

Citation* (VANCOUVER)*: Singh et al., Evaluation of Herbicides for Enhancing Yield and Economics Benefits in Barley (*Hordeum vulgare* L.). *International Journal of Bio-resource and Stress Management,* 2025; 16(12), 01-07. HTTPS://DOI.ORG/10.23910/1.2025.6441.

Data Availability Statement: Legal restrictions are imposed on the public sharing of raw data. However, authors have full right to transfer or share the data in raw form upon request subject to either meeting the conditions of the original consents and the original research study. Further, access of data needs to meet whether the user complies with the ethical and legal obligations as data controllers to allow for secondary use of the data outside of the original study.

Conflict of interests: The authors have declared that no conflict of interest exists.

RECEIVED on 10th June 2025 RECEIVED in revised form on 20th November 2025 ACCEPTED in final form on 07th December 2025 PUBLISHED on 23rd December 2025

1. INTRODUCTION

Barley (*Hordeum vulgare* L.) is one of the most important cereals in world, acting as major food source for a significant portion of the global population that lives in colder, semi-arid climates. It is an important product for those industries that extract malt, which is used in ayurvedic medicine, baby food, beer, whisky and brandy, as well as brewing and distillation. For malt production, barley is the most popular cereal crop. Its solid grain texture and increased amylase activity further set it apart from other common cereals (Singh et al., 2016). In India, it is mainly grown in higher Himalayas (Himachal Pradesh, Jammu Kashmir and West Bengal), central parts of eastern Uttar Pradesh, eastern parts of Rajasthan and north-western parts of North Bihar (Meena et al., 2021). Barley is also cultivated for fodder, bread and making of health products (Verma et al., 2016; Sachin et al., 2025). Being an important crop of temperate regions of Himachal Pradesh, it is mostly cultivated for feed and the making of regional tribal beverages (Negi and Chopra, 2015). It is imperative to increase barley productivity in terms of both acreage and processing units. The barley crop is gaining more prominence over the past few years, especially after COVID pandemic. Also the area under the crop in H.P. is increasing at a rapid pace with more farmers opting for this nutritious crop. Barley naturally has the capacity to withstand heat, drought and other abiotic conditions as it requires little water and fertilizer (Patel et al., 2024). Use of low-yield varieties, growing in unirrigated conditions and losses due to weeds and diseases are main reasons for low barley production in the region. Similar to other crops, barley cultivation is severely hampered by weeds, which compete with the crop for resources like sunlight, water and nutrients, lowering yield and quality. The type and density of related weed flora determine the yield loss in barley (Walia and Brar, 2001). Barley production and quality are greatly reduced by weed infestation (Kanatas et al., 2020; Watson et al., 2006; Mahajan et al., 2020). So, effective weed management is one of several essential elements for increasing crop productivity (Naeem et al., 2022). Traditional cultural practices of weed management are time consuming and labour intensive. Also, farmers may fail to finish timely agricultural tasks and the adoption of intensive and multiple cropping systems. Therefore, herbicides are a cheap and simple way to control. When compared to unweeded and hand-weeded treatments, El Bawab and Kholousy (2003), found that controlling weeds with herbicide treatments increased grain production by roughly 13.6–40.3%. However in Barley, the option of herbicidal weed control is very limited. Among herbicides, 2,4-D is frequently applied to barley in order to suppress broad-leaf weeds. But the main issues with over-reliance on a single herbicide is the development of herbicide-resistant weeds and changes in the weed flora. As a result, novel herbicides with distinct mechanisms of action in varied combinations are mostly required to be used for weed control in barley (Ram et al., 2020; Yadav et al., 2018). Moreover, for wider spectrum control the strengths of two compatible herbicides with different spectrum and mechanism of action must be tested. Furthermore, to tackle the indiscriminate use of herbicides choosing suitable herbicide, its dose, time of application is the most urgent (Basu and Rao, 2020). Before recommendation, also the performance of new technology (herbicide) must be tested in term of yield and economic advantage at farmers' fields. Thus, the experiment was conducted to evaluate different herbicides for effective weed control in barley.

2. MATERIALS AND METHODS

The research experiment was conducted during November, 2014–May, 2015, November, 2015–May, 2016 and November, 2016–May, 2017 at two locations in Himachal Pradesh (research farm of Hill Agricultural Research and Extension Centre, Bajaura, Kullu and experimental farm of Rice and Wheat Research Centre, Malan, Kangra) with the main target to find out the best compatible herbicide combination for broad spectrum weed control in barley, which was not yet recommended in the state so far. Further eight, on-farm trials were laid out in five districts of Himachal Pradesh with three best treatments found in research experiments.

The experimental site of HAREC-Bajaura was located at 31°84' N latitude, 77°16' E longitude with an elevation of 1090 m above mean sea level representing Agro-climatic zone II of Himachal Pradesh and was characterized by dry hot summers, sub humid rainy season and cool winters. The region received an average annual rainfall of 873 mm annum^{-1} and major portion of rainfall was received in winters and dry spells were observed from October to December. The soil of this location was slightly acidic in reaction, medium in organic carbon, silty loam in texture, medium in available nitrogen and potassium and high in phosphorus.

Second location, RWRC, Malan, Kangra was situated at 32°07' N latitude, 76°23' E longitude with an altitude of 950 m above mean sea level in North Western Himalayas. The site represented the mid hills sub humid zone of Himachal Pradesh and was characterized by wet temperate climate with mild summers and cool winters along with high rainfall during southwest monsoons. The soil of experimental site was silty clay loam in texture and acidic in reaction. The soil was high in organic carbon and available phosphorus, medium in available nitrogen and potassium.

The experiment consisting of eleven treatments viz.

Pinoxoden 30, 40 and 50 g ha^{-1}, pinoxoden 40 g ha^{-1} +metsulfuron 4 g ha^{-1}, pinoxoden 40 g ha^{-1} fb. metsulfuron 4 g ha^{-1}, pinoxoden 40 g ha^{-1}+carfentrazone 20 g ha^{-1}, isoproturon 1000 g ha^{-1}, isoproturon 750 g ha^{-1}+2,4-D 500 g ha^{-1}, isoproturon 750 g ha^{-1}+metsulfuron 4 g ha^{-1}, weedy check and weed free, was planned in Randomized Block Design with three replications. Barley variety 'VLB 118' was sown during all the seasons of experimentation. Except weed control, all other package of practices were followed from sowing to harvesting of crop. Crop was harvested, threshed and grain yield from per plot was converted in kg ha^{-1}. Gross returns were calculated by multiplying the prevailing market price of crop with yield of each treatment. The treatment wise net returns were obtained by subtracting the cost of cultivation from gross returns. Benefit cost ratio was calculated by dividing net returns with cost of cultivation. To evaluate the treatment differences, the data were statistically analyzed in accordance with Gomez and Gomez (1984) and assessed at a 5% level of significance.

Eight on-farm trials were laid out in Kullu, Mandi, Hamirpur, Shimla and Kangra districts of Himachal Pradesh with three best treatments (viz. isoproturon 1000 g ha^{-1}(Check), isoproturon 750 g ha^{-1}+2,4-D 500 g ha^{-1} and isoproturon 750 g ha^{-1}+metsulfuron 4 g ha^{-1}) found in research experiments, and the results were expressed on average yield and advantage on percent basis.

3. RESULTS AND DISCUSSION

3.1. Yield

Year wise and pooled data pertaining to yield of barley influenced by different weed control treatments at Bajaura and Malan have been presented in Table 1. At first location (Bajaura), analysis of year wise and pooled data of three years revealed that significantly higher grain yield of barley was obtained with the application of isoproturon 750 g ha^{-1} +metsulfuron 4 g ha^{-1} (4593 kg ha^{-1}) which was statistically at par with pinoxoden 40 g ha^{-1}+metsulfuron 4 g ha^{-1}(4384 kg ha^{-1}), pinoxoden 40 g ha^{-1} fb. metsulfuron 4 g ha^{-1} (4318 kg ha^{-1}) and weed free treatment (4277 kg ha^{-1}). Isoproturon 750 g ha^{-1}+metsulfuron 4 g ha^{-1} resulted in 52.9% increase in grain yield over weedy check which had lowest grain yield of barley (3003 kg ha^{-1}). This could be explained by the fact that herbicide combinations such as isoproturon+2,4-D and pinoxaden+metsulfuron-methyl effectively controlled both grassy and broad leaf weeds and had wide spectrum weed control, whereas, individual herbicides like isoproturon, metsulfuron and 2,4-D controlled only one specific class of weeds i.e. grassy or broadleaf weeds (Bharat and Kachroo, 2007). Better development of yield attributes by reducing crop weed competition through effective control of weeds by these treatments acted as a strong sink for accumulation of photosynthates and resulted in higher grain yield of barley. Higher yields in barley with mixed application of herbicides (isoproturon+metsulfuron and isoproturon+2,4-D) compared to alone application of isoproturon were also reported by Ram and Singh (2009). Among herbicide treatments, significantly lower grain yield was recorded with alone application of pinoxoden 30 g ha^{-1} which was statistically at par with pinoxoden 40 g ha^{-1} and pinoxoden 50 g ha^{-1} as this herbicide was mostly effective against monocotyledonous grass weeds in crop.

Table 1: Effect of different treatments on grain yield (kg ha^{-1}) of barley in research trials conducted at HAREC, Bajaura and RWRC Malan

Treatments	HAREC, Bajaura				RWRC Malan			
	Year-1	Year-2	Year-3	Pooled	Year-1	Year-2	Year-3	Pooled
Pinoxoden 30 g ha^{-1}	3838	4091	2986	3638	2520	2235	2166	2307
Pinoxoden 40 g ha^{-1}	3859	4277	3232	3789	2672	2274	2312	2419
Pinoxoden 50 g ha^{-1}	4242	4301	3129	3890	2627	2264	2437	2443
Pinoxoden 40 g ha^{-1}+Metsulfuron 4 g ha^{-1}	3994	5311	3848	4384	2944	2453	2983	2794
Pinoxoden 40 g ha^{-1} fb. Metsulfuron 4 g ha^{-1}	3949	5259	3747	4318	2691	2470	2904	2688
Pinoxoden 40 g ha^{-1}+Carfentrazone 20 g ha^{-1}	4516	4284	3286	4028	2823	2562	2477	2620
Isoproturon 1000 g ha^{-1}	4726	4326	3355	4136	2425	2369	2617	2470
Isoproturon 750 g ha^{-1}+2,4-D 500 g ha^{-1}	4372	4881	3424	4226	2260	2714	2736	2570
Isoproturon 750 g ha^{-1}+Metsulfuron 4 g ha^{-1}	4341	5396	4043	4593	2407	2536	3005	2650
Weedy check	2904	3513	2590	3003	1373	1400	1689	1487
Weed free	3833	5221	3780	4277	2585	2328	2745	2553
CD (p=0.05)	600	428	550	318	483	359	403	234

At second location (Malan), application of pinoxoden 40 g ha^{-1}+metsulfuron 4 g ha^{-1} resulted in significantly higher grain yield of barley (2794 kg ha^{-1}) which was statistically at par to the yield obtained with the application of pinoxoden 40 g ha^{-1} fb. metsulfuron 4 g ha^{-1} (2688 kg ha^{-1}), isoproturon 750 g ha^{-1}+metsulfuron 4 g ha^{-1} (2650 kg ha^{-1}), pinoxoden 40 g ha^{-1}+carfentrazone 20 g ha^{-1} (2620 kg ha^{-1}) and isoproturon 750 g ha^{-1}+2,4-D 500 g ha^{-1} (2570 kg ha^{-1}). The higher yield in these treatments might be attributed to better control of both grassy and broad leaf weeds. Effective control of different categories of weeds by said herbicidal treatments resulted in better utilization of different resources by the crop contributing in getting higher grain yield. Sardana (2001) reported that application of isoproturon+2,4-D effectively controlled different weeds as compared to alone application of 2,4-D in wheat. The increment in yield over weedy check under pinoxoden 40 g ha^{-1}+metsulfuron 4 g ha^{-1} was 87.9%. Herbicide treatments of alone application of pinoxoden irrespective of any of the doses resulted in lower grain yields as observed in first location. Also in recently conducted study by Kumari et al. (2023) at Punjab, it was found that application of pinoxaden at 40 g ha^{-1}+carfentrazone-ethyl at 20 g ha^{-1} being at par with pinoxaden 40 g ha^{-1}+carfentrazone-ethyl 20 g ha^{-1}, pinoxaden 40 g ha^{-1}, pinoxaden 40 g ha^{-1}+2, 4-D 500 g ha^{-1} and weed free resulted in significantly higher grain, straw and biological yield of barley. Similarly, Parita et al. (2021) reported that in wheat crop under the same mid hill conditions of Himachal Pradesh as under present study carried on barley, pinoxaden 0.060+metsulfuron 0.04 kg ha^{-1} (post.) followed clodinafop 0.060+metsulfuron 0.004 kg ha^{-1} were effective for controlling the same type of weed flora. The results suggested that pinoxaden 0.060+metsulfuron 0.004 kg ha^{-1} (post.) following clodinafop 0.060+metsulfuron 0.004 kg ha^{-1} (post) was proved to be the best broad-spectrum herbicide combinations in order to minimize the competitive effect of diverse weed flora in wheat crop and achieving higher grain yield. Similar results were reported by Chand and Puniya (2017), where alone application of pinoxoden in wheat resulted in lower weed control efficiency as compared to other herbicide combinations due to narrow spectrum of weed control. In same crop, Kumari et al. (2013) also recorded higher grain yield with herbicide combination of isoproturon+2,4-D, as compared to single herbicide application.

It is clear from the data that the trend of grain yield of barley in different treatments was similar at both locations, however, lower yield was recorded in all the treatments at second location (Malan) as compared to first location (Bajaura). This was due to the fact that the soils of Bajaura were near neutral, the most preferable soil for barley cultivation, while, the soils at Malan were towards acidic. Another reason could be comparatively low temperature and prolonged growing period at Bajaura conditions.

3.2. Economics

Year wise and pooled data on economics of different weed control treatments at both locations are presented in Table 2. At Bajaura, highest gross returns (₹ 100895 ha^{-1}), net returns (₹ 76495 ha^{-1}) and BC ratio (3.14) were obtained in isoproturon 750 g ha^{-1}+metsulfuron 4 g ha^{-1} treated plots. This treatment was followed by pinoxoden 40 g ha^{-1} +metsulfuron 4 g ha^{-1} and isoproturon 750 g ha^{-1}+2,4-D 500 g ha^{-1} in descending order in terms of returns and

Table 2: Effect of different weed control treatments on economics of barley in research trials conducted at HAREC Bajaura and RWRC Malan (Pooled data of 3 years)

Treatments	HAREC, Bajaura			RWRC Malan		
	Gross return (₹ ha^{-1})	Net return (₹ ha^{-1})	BC ratio	Gross return (₹ ha^{-1})	Net return (₹ ha^{-1})	BC ratio
Pinoxoden 30 g ha^{-1}	79070	54990	2.28	51105	27025	1.12
Pinoxoden 40 g ha^{-1}	82335	58095	2.40	53535	29295	1.21
Pinoxoden 50 g ha^{-1}	84600	60200	2.47	54145	29745	1.22
Pinoxoden 40 g ha^{-1}+Metsulfuron 4 g ha^{-1}	96260	71720	2.92	61910	37370	1.52
Pinoxoden 40 g ha^{-1} fb. Metsulfuron 4 g ha^{-1}	94770	69230	2.71	59820	34280	1.34
Pinoxoden 40 g ha^{-1}+Carfentrazone 20 g ha^{-1}	87920	63280	2.57	57550	32910	1.34
Isoproturon 1000 g ha^{-1}	90540	66275	2.73	54800	30535	1.26
Isoproturon 750 g ha^{-1}+2,4-D 500 g ha^{-1}	92140	67890	2.80	57050	32800	1.35
Isoproturon 750 g ha^{-1}+Metsulfuron 4 g ha^{-1}	100895	76495	3.14	58750	34350	1.41
Weedy check	64545	41945	1.86	32805	10205	0.45
Weed free	94155	63555	2.08	56295	25695	0.84

1US$=INR 63.69, INR 66.91, INR 64.42 (average value of the harvesting month May of 2015, 2016, 2017) benefit cost ratio. Negi and Chopra (2015) also reported similar results in barley, where net returns were higher under isoproturon+metsulforon as compared to application of isoproturon alone. The percent increment in benefit cost ratio in above three treatments over weedy check was 68.8, 56.9 and 50.3, respectively. Singh et al. (2018) also found higher monetary returns with herbicide combinations as compared to their sole applications in wheat.

At Malan, pinoxoden 40 g ha^{-1}+metsulfuron 4 g ha^{-1} resulted in highest gross returns (₹ 61910 ha^{-1}), net returns (₹ 37370 ha^{-1}) and BC ratio (1.52), which were closely followed by isoproturon 750 g ha^{-1}+metsulfuron 4 g ha^{-1} and isoproturon 750 g ha^{-1}+2,4-D 500 g ha^{-1}. The higher gross returns obtained under these treatments were due to higher grain yield under these treatments which, fetched higher monetary values as compared to others. Due to involvement of less cost of cultivation and higher net returns, the higher values for B C ratio were obtained under these treatments. Lowest benefit cost ratio was recorded under weedy check, which was followed by weed free treatment at both locations. Lower benefit in weedy check was due to lower yields resulting in lower returns. Being labour intensive, weed free treatment resulted in highest cost of cultivation, therefore had lower profitability. Under the same mid hill conditions of Himachal Pradesh, Rana et al. (2016) also reported the superiority of pinoxaden fb. metsulfuron methyl (40 fb. 4 g ha^{-1}) and pinoxaden+metsulfuron methyl (40+4 g ha^{-1}) over hand weeding for effectively controlling the weed flora, which resulted in achieving significantly higher grain yield, net returns and net returns rupee^{-1} invested in wheat crop. Hari et al. (2020) also concluded from their study that among different tested herbicidal treatments in wheat, the magnitude of net returns and the benefit-cost ratio was higher with the applications of isoproturon 750 g ha^{-1}+2,4-D (Na salt) 500 g ha^{-1}, pinoxaden 40 g ha^{-1}+carfentrazone 20 g ha^{-1}, isoproturon 750 g ha^{-1}+metsulfuron 4 g ha^{-1} and pinoxaden 40 g ha^{-1} followed by metsulfuron 4 g ha^{-1} and in weed-free over rest of the treatments. It was evident from the data that the treatment effect on net returns was similar at both the locations. Higher grain yield at first location (Bajaura) as compared to second location resulted in fetching higher net return at first location over the latter.

3.3. *On farm trials*

Data regarding to the performance of promising herbicide treatments on grain yield of barley in on-farm trials conducted in different districts of Himachal Pradesh were presented in Table 3. Due to better results of isoproturon based herbicide treatments in term of yield and economics in barley during first two years, on-farm trials with three herbicide treatments, viz.isoproturon1000 g ha^{-1} (check), isoproturon 750 g ha^{-1}+2,4-D 500 g ha^{-1} and isoproturon 750 g ha^{-1}+metsulfuron 4 g ha^{-1} were conducted. Data on average grain yield of different farmers revealed that the isoproturon 750 g ha^{-1}+metsulfuron 4 g ha^{-1} treatment had resulted in highest grain yield of barley (2948 kg ha^{-1}), which was followed by isoproturon 750 g ha^{-1}+2,4-D 500 g ha^{-1} (2719 kg ha^{-1}). The percent increase in grain yield due to isoproturon 750 g ha^{-1}+metsulfuron 4 g ha^{-1} and isoproturon 750 g ha^{-1}+2,4-D 500 g ha^{-1} was 17.92 and 8.76%, respectively over isoproturon 1000 g ha^{-1}. Kumar et al. (2010) reported the superiority of herbicide combinations over alone application of herbicides on yield attributes. Singh et al. (2005) has also reported that herbicide combinations are effective in managing complex weed flora. In a similar experiment, isoproturon+2,4-D and isoproturon+metsulfuron resulted in higher grain yield as compared to alone application of isoproturon (Khippal et al., 2016).

Table 3: Performance of promising herbicide treatments on grain yield (kg ha^{-1}) of barley in on-farm trials conducted in different districts of Himachal Pradesh

OFT	Isoproturon 1000 g ha^{-1}	Isoproturon 750 g ha^{-1}+2,4-D 500 g ha^{-1}	Isoproturon 750 g ha^{-1}+Metsulfuron 4 g ha^{-1}
1.	2725	3050	3380
2.	2475	2630	2850
3.	3150	3420	3780
4.	2620	2860	3240
5.	2050	2280	2435
6.	2450	2620	2800
7.	2650	2840	2960
8.	1880	2050	2140
Average grain yield (kg ha^{-1})	2500	2719	2948
% increase in grain yield	-	8.76	17.92

4. CONCLUSION

Barley, though competitive, suffered yield loss from crop-weed competition. Herbicide use improved weed control and crop performance. Field experiments showed that combining herbicides yielded better results. Two effective combinations viz. isoproturon 750 g ha^{-1}+metsulfuron 4 g ha^{-1} and pinoxaden 40 g ha^{-1}+metsulfuron 4 g ha^{-1} enhanced grain yield and economic returns. Depending on chemical availability, either combination could be applied at the 3–4 leaf stage of weeds for optimal production and profitability in barley cultivation.

5. ACKNOWLEDGEMENT

The financial help rendered by ICAR, All India Coordinated Research Project on Wheat and Barley, Indian Institute of Wheat and Barley Research, Karnal for carrying out the research work is highly acknowledged.

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