Indian Journal of Weed Science (2025) **57**(4): 479–482
http://dx.doi.org/10.5958/0974-8164.2025.00084.2

RESEARCH NOTE

Weed dynamics and productivity of soybean as influenced by different post-emergent herbicides

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Received: 12 May 2025 | Revised: 19 July 2025 | Accepted: 23 July 2025

ABSTRACT

A field experiment was conducted at Punjab Agricultural University, Ludhiana and Dr J C Bakhshi Regional Research Station, Abohar, Punjab (India), during *Kharif* (rainy season) 2021to identify effective and economic post-emergent herbicide for managing weeds in soybean and improve productivity of soybean [*Glycine max* (L.) Merrill]. The experiment consisted of 12 treatments, *viz.* post-emergence application (PoE) of imazethapyr 75 g/ha; propaquizafop + imazethapyr at 75, 100, and 125 g/ha; sodium-acifluorfen + clodinafop-propargyl at 147, 196, and 245 g/ha; imazamox + imazethapyr at 42, 56 and 70 g/ha; hand weeding (HW) twice at 20 and 40 days after sowing (DAS) and weedy check. A randomized complete block design with three replications was used. The lowest weed density and highest soybean biological and seed yield were recorded with HW twice, which was statistically at par with imazamox + imazethapyr 70 g/ha PoE at 15-20 DAS. It was concluded that imazamox + imazethapyr 70 g/ha PoE at 15-20 DAS improves the soybean seed yield with highest benefit:cost ratio, due to effective broad spectrum weed control.

Keywords: Imazamox + imazethapyr**,** Post-emergent herbicides, Soybean, Weed management

Soybean [*Glycine max* (L.) Merrill] is an important legume crop worldwide. Its global production reached 353.2 million tonnes (mt) from 139.4 million hectares (mha) area, with an average yield of 2.53 t/ha. India produced 15.2 mt from 13.1 mha area, with a productivity of 1.02 t/ha (FAOSTAT 2025). Soybean seeds are rich in protein (36-43%) and oil (18-24%), containing high levels of polyunsaturated fatty acids, especially Omega 6 and Omega 3 (Kumar *et al.* 2022). Weeds pose a significant challenge to soybean productivity, reducing yields by 50-76% (Virk *et al.* 2018) due to competition for light, moisture, and nutrients, and by harboring pests. Soybean's low competitiveness during early growth and its rainy-season cultivation makes it vulnerable to weed infestations. Economic losses due to weeds in Indian soybean were estimated at USD 1559 million (Gharde *et al.* 2018). Manual weeding is challenging due to labour shortages and frequent heavy rainfall; therefore, using herbicides a more viable option (Rajput and Kasana 2020).

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Although pendimethalin continues to be widely used as a pre-emergence herbicide in soybean, its efficacy diminishes when application is delayed (Virk *et al.* 2018). Post-emergence herbicides, applied within 15-20 days of sowing, offer a more effective solution for weed control during critical crop-weed competition periods. The post-emergence application (PoE) of imazethapyr + imazamox at 80 g/ha proved highly effective in managing both dominant grassy and broad-leaved weeds, resulting in the highest greengram seed yield (Gupta *et al.* 2019). The need for effective control of the diverse weed flora necessitates the use of various herbicide combinations (Patel *et al.* 2021) and to study the efficacy of different post-emergence herbicides on weeds and productivity of soybean under different agro-climatic regions. Hence, this study was conducted with an objective to identify effective and economic post-emergent herbicide for managing weeds in soybean and improve soybean productivity.

A field experiment was conducted during *Kharif* (rainy) 2021 at Research Farm of Pulses Section, Department of Plant Breeding and Genetics, Punjab Agricultural University (PAU), Ludhiana and Dr J C Bakhshi Regional Research Station, Abohar, PAU Ludhiana. The soil of the experimental sites had a pH of 7.3 and 7.1, organic carbon content of 0.22 and 0.38%, available phosphorus of 24.0 and 13.5 kg/ha

and available K of 274.3 and 267.2 kg/ha at Ludhiana and Abohar, respectively. A total 770.6 and 127.8 mm rainfall was received at Ludhiana and Abohar, respectively during the crop growing season. Both experiments were arranged in a randomized complete block design with three replications. There were 12 treatments viz., post-emergence application (PoE) of imazethapyr 75 g/ha; propaquizafop + imazethapyr at 75, 100, and 125 g/ha; sodium acifluorfen + clodinafop propargyl at 147, 196, and 245 g/ha; imazamox + imazethapyr at 42, 56, and 70 g/ha; hand weeding (HW) twice at 20 and 40 days after sowing (DAS) and a weedy check. Before sowing, a pre-sowing irrigation was applied and the field was ploughed twice followed by *(fb)* planking for seedbed preparation. Soybean variety '*SL 958*' was sown on 4th June, 2021 at Abohar and 10th June, 2021 at Ludhiana with seed rate of 75 kg/ha, row spacing of 45 cm and plant to plant spacing of 5 cm. Herbicides were sprayed at 15-20 days, *i.e*. on 25th June at Ludhiana and 22nd June at Abohar in 2021, after crop emergence using 375 litres of water/ha using a knapsack sprayer fitted with a flat fan nozzle. Hand weeding was done manually using khurpa in the hand weeding twice treatment, while in the weedy check, weeds were not removed throughout the crop season. A total of 31.25 kg/ha nitrogen and 60 kg/ha phosphorus were applied using urea and SSP during sowing as basal.

The weed density was measured at 30 and 60 DAS using a 50 × 50 cm quadrat by randomly placing quadrat at two places in each of the plot. The number of weeds within the quadrat was counted specie-wise and converted to number per square meter. Weed control efficiency (WCE) was estimated from the total weed population (weed density) at 30 and 60 DAS using the equation:

$$\text{Weed control efficiency (\%)} = \frac{\text{Weed population in weedy check (no./m}^2\text{)} - \text{Weed population in treated plot}}{\text{Weed population in weedy check (no./m}^2\text{)}}$$

The weight of sun-dried bundles of crop from each plot was measured prior to threshing and recorded as the biological yield/plot and converted into t/ha. After sun drying, the crop from each plot was threshed and seed yield from each plot was weighed separately and converted into t/ha. The harvest index was calculated as the ratio of seed yield to biological yield:

$$\text{Harvest index (\%)} = \frac{\text{Seed yield}}{\text{Biological yield}} \times 100$$

The benefit-cost (B:C) ratio was calculated by dividing net returns with total variable costs. Data were analysed with RStudio using ANOVA for a randomized complete block design (R 2024). Weed density was transformed using square root and means were compared via Duncan's multiple range test (DMRT) at the 0.05 level. Data on weed density were square root transformed and means were compared via DMRT at the 5% level of significance (p=0.05).

Effect on weeds

At Ludhiana, the predominant weed species were: *Digitaria sanguinalis*, *Dactyloctenium aegyptium*, *Commelina benghalensis*, and *Acrachne racemosa among grassy weeds*, *Trianthema portulacastrum* among broad-leaved weeds and *Cyperus rotundus* among sedges (**Table 1**). At Abohar, the major weeds were *Digitaria sanguinalis* and *Dactyloctenium aegyptium* among grassy weeds, *Trianthema portulacastrum* and *Digera arvensis* among broad-leaved weeds and *Cyperus rotundus* dominant among sedges.

At Ludhiana, at 30 DAS, imazethapyr 75 g/ha recorded the highest relative density of grassy weeds (72.1%), indicating its lower efficacy against this group. The grassy weed dominance (65–70%) was observed in propaquizafop + imazethapyr and sodium-acifluorfen + clodinafop treated plots. Imazamox + imazethapyr caused greater reduction in density of grassy weeds by 66.7–67.7% and sedges by 23–24%. At 60 DAS, sodium-acifluorfen + clodinafop 245 g/ha was most effective on broad-leaved weeds and caused the highest suppression of broad-leaved and sedge weeds. Likewise, imazamox + imazethapyr 70 g/ha and propaquizafop + imazethapyr 125 g/ha effectively managed non-grassy weeds, with over 93% of the total weed density being grassy.

At Abohar, at 30 DAS, grassy weeds were dominant in all treatments (52.4–63.5%), with the highest in imazamox + imazethapyr. Sodium-acifluorfen + clodinafop and propaquizafop + imazethapyr showed better management of grasses. Broad-leaved weeds remained below 18.5% under all herbicides, while their complete control was achieved with hand weeding twice. Sedge weeds proportion was highest with hand weeding twice (41.7%) and lowest with imazamox + imazethapyr 70 g/ha (24.1%). At 60 DAS, grassy weeds remained dominant, especially with imazamox + imazethapyr (up to 86.2%). Sodium-acifluorfen + clodinafop effectively reduced sedges (7.4%) with moderate grassy weed infestation. Propaquizafop + imazethapyr showed balanced weed control, with 68–69% reduction in grassy weeds density and lower density of broad-leaved and sedge weeds.

The lowest density of grassy weeds, broad-leaved weeds and sedges and the highest WCE at 30 and 60 DAS (**Table 2**) was observed with HW twice at both locations. Imazamox + imazethapyr 70 g/ha recorded the lowest density of grassy and broad-leaved weeds and the highest WCE at 30 and 60 DAS followed by sodium-acifluorfen + clodinafop-propargyl 245 g/ha, propaquizafop + imazethapyr 125 g/ha and imazethapyr 75 g/ha at 15-20 DAS. The sedges were effectively controlled by imazamox + imazethapyr 70 g/ha followed by imazethapyr 75 g/ha at 20 DAS at both locations. Weed control efficiency increased at 60 DAS due to reduction in growth of weeds and improvement in growth of crop, which helped in suppressing the weeds. The higher WCE at 60 and 90 DAS in soybean was reported with imazethapyr + imazamox at 100 g/ha at 20 DAS followed by one hoeing at 35 DAS by Rajput et al. (2019). The efficacy of imazethapyr + imazamox 80 g/ha PoE in managing weeds in black gram was reported earlier (Rana *et al.* 2019).

Effect on soybean

Biological and seed yield were significantly influenced by different treatments of weed control (**Table 2**). Hand weeding twice recorded the highest soybean biological yield and seed yield, statistically similar to imazamox + imazethapyr 70 g/ha at 15-20 DAS, at both the locations due to better growth as a consequence of lesser crop-weed competition, which ultimately shifted the nutrients, light, water and space in favour of the crop. The lowest yield was recorded in the weedy check due to more weed density, which resulted in more competition of weeds with crop thereby reducing its growth. Weeds caused 46.7% and 51.2% soybean yield reduction in weedy check when compared to hand weeding twice, at Ludhiana and Abohar, respectively. Herbicides significantly affected the harvest index at Abohar but not at Ludhiana, which could be due to the large difference in rainfall between the locations. Limited rainfall at Abohar (127.8 mm) caused moisture stress that intensified weed competition and reduced seed filling, while Ludhiana's ample rainfall (770.6 mm) minimized stress, resulting in less variation in harvest index across treatments.

The highest harvest index was recorded with HW twice which was statistically similar to imazethapyr 75 g/ha, propaquizafop + imazethapyr,

Table 1. Effect of different weed management treatments on weed density at 30 and 60 days after seeding (DAS) in Ludhiana (LDH) and Abohar (ABH)

Treatment	Grassy weeds				Broad-leaved weeds				Sedges			
	30 DAS		60 DAS		30 DAS		60 DAS		30 DAS		60 DAS	
	LDH	ABH	LDH	ABH	LDH	ABH	LDH	ABH	LDH	ABH	LDH	ABH
Imazethapyr 75 g/ha	10.7^{c} (114.6)	7.8^{b} (60.0)	8.1^{c} (66.6)	5.5^{d} (29.3)	3.6^{c} (12.0)	4.4^{b} (18.6)	1.0^{c} (0.0)	2.5^{c} (5.3)	5.7^{c} (32.0)	5.1^{c} (25.3)	2.7^{d} (6.6)	3.4^{d} (10.6)
Propaquizafop + imazethapyr 75 g/ha	11.2^{b} (124.0)	8.2^{b} (66.7)	8.2^{c} (66.6)	7.0^{b} (48.0)	4.3^{b} (17.3)	4.1^{c} (16.0)	1.0^{c} (0.0)	2.2^{c} (4.0)	6.9^{b} (48.0)	6.4^{ab} (40.0)	4.7^{b} (21.3)	4.3^{b} (17.3)
Propaquizafop + imazethapyr 100 g/ha	10.7^{c} (113.3)	7.9^{b} (61.3)	7.4^{d} (54.6)	6.1^{c} (36.0)	3.9^{b} (14.6)	4.0^{c} (14.6)	1.0^{c} (0.0)	1.9^{d} (2.7)	6.4^{b} (41.3)	5.7^{b} (32.0)	3.4^{c} (10.6)	3.8^{c} (13.3)
Propaquizafop + imazethapyr 125 g/ha	9.9^{d} (97.3)	7.4^{c} (53.3)	6.3^{e} (38.6)	4.6^{f} (20.0)	3.6^{c} (12.0)	3.7^{e} (13.3)	1.0^{c} (0.0)	1.5^{e} (1.3)	6.1^{c} (37.3)	5.6^{b} (30.6)	1.8^{e} (2.6)	3.0^{d} (8.0)
Sodium-acifluorfen + clodinafop-propargyl 147 g/ha	10.6^{c} (110.0)	8.0^{b} (64.0)	9.1^{b} (82.6)	6.6^{b} (42.6)	4.1^{b} (16.0)	4.6^{b} (20.0)	1.5^{b} (1.3)	3.6^{b} (12.0)	5.7^{d} (32.0)	5.7^{b} (32.0)	2.5^{d} (5.3)	2.7^{e} (6.6)
Sodium acifluorfen + clodinafop-propargyl 196 g/ha	9.9^{d} (98.6)	7.6^{c} (57.3)	8.2^{c} (68.0)	5.5^{d} (29.3)	3.6^{c} (12.0)	4.1^{c} (16.0)	1.0^{c} (0.0)	2.2^{c} (4.0)	5.6^{d} (30.6)	5.6^{b} (30.6)	1.8^{e} (2.6)	2.5^{e} (5.3)
Sodium-acifluorfen + clodinafop-propargyl 245 g/ha	9.6^{e} (92.0)	7.2^{cd} (50.7)	7.4^{d} (54.6)	5.1^{e} (25.3)	3.6^{c} (12.0)	3.9^{e} (14.6)	1.0^{c} (0.0)	2.2^{c} (4.0)	5.2^{e} (26.6)	5.6^{b} (30.6)	1.4^{f} (1.3)	1.8^{g} (2.6)
Imazamox + imazethapyr 42 g/ha	9.8^{de} (96.0)	7.2^{cd} (52.0)	7.9^{d} (62.6)	6.6^{b} (42.6)	3.9^{b} (14.6)	3.9^{e} (14.6)	1.0^{c} (0.0)	1.9^{d} (2.7)	5.8^{c} (33.3)	4.9^{c} (22.6)	2.5^{d} (5.3)	2.2^{f} (4.0)
Imazamox + imazethapyr 56 g/ha	9.2^{f} (84.0)	6.9^{d} (46.7)	6.7^{e} (45.3)	5.9^{c} (34.6)	3.6^{c} (12.0)	3.6^{f} (12.0)	1.0^{c} (0.0)	1.9^{d} (2.7)	5.5^{c} (29.3)	4.7^{c} (21.3)	1.8^{e} (2.6)	2.2$_{f}$ (4.0)
Imazamox + imazethapyr 70 g/ha	8.5^{g} (72.0)	6.5^{d} (41.3)	5.2^{f} (26.6)	4.1^{g} (16.0)	3.2^{d} (9.3)	3.2^{g} (9.3)	1.0^{c} (0.0)	1.5^{e} (1.3)	5.1^{e} (25.3)	4.1^{d} (16.0)	1.4^{f} (1.3)	1.8^{g} (2.6)
Hand weeding twice	3.8^{h} (13.3)	2.9^{e} (8.0)	4.1^{g} (16.0)	3.2^{h} (12.0)	1.0^{e} (0.0)	1.0^{h} (0.0)	1.0^{c} (0.0)	1.5^{e} (1.3)	3.6^{f} (12.0)	2.5^{e} (5.3)	2.7^{b} (6.6)	2.5^{e} (5.3)
Weedy check	12.4^{a} (153.3)	8.7^{a} (76.0)	15.0^{a} (228.0)	10.2^{a} (102.7)	4.7^{a} (22.6)	5.3^{a} (26.6)	5.8^{a} (33.3)	6.1^{a} (36.0)	7.6^{a} (57.3)	6.7^{a} (44.0)	8.4^{a} (69.3)	7.9^{a} (61.3)

Original data in parenthesis. Data was transformed by square root transformation before statistical analysis, n=3. Transformed means superscripted with same alphabets within a row are not significantly different from each other based on Duncan's multiple range test at p=0.05.

Table 2. Effect of weed management treatments on weed control efficiency, soybean, yield, harvest index and B:C ratio in Ludhiana (LDH) and Abohar (ABH)

Treatment	Weed control efficiency (%)				Seed yield (t/ha)		Stover yield (t/ha)		Biological yield (t/ha)		Harvest index (%)		B:C ratio	
	30 DAS		60 DAS											
	LDH	ABH	LDH	ABH	LDH	ABH	LDH	ABH	LDH	ABH	LDH	ABH	LDH	ABH
Imazethapyr 75 g/ha	31.9^{e}	28.0^{fg}	77.4^{ef}	77.4^{de}	1.70^{b}	1.32^{bc}	4.83^{ab}	5.28^{abcd}	6.54^{ab}	6.60^{bc}	26.09^{a}	20.13^{abc}	1.58^{ab}	1.06^{bc}
Propaquizafop + imazethapyr 75 g/ha	18.6^{g}	15.9^{i}	73.0^{f}	65.2^{g}	1.39^{de}	1.01^{ef}	4.18^{bc}	5.17^{abcd}	5.57^{cde}	5.99^{de}	25.19^{a}	17.17^{cd}	1.07^{e}	0.59^{fg}
Propaquizafop + imazethapyr 100 g/ha	27.1^{f}	24.8^{gh}	80.1^{de}	73.9^{e}	1.49^{cd}	1.15^{cde}	4.36^{b}	5.18^{abcd}	5.86^{cd}	6.34^{cde}	25.46^{a}	18.20^{bcd}	1.17^{bcde}	0.75^{cde}
Propaquizafop + imazethapyr 125 g/ha	37.1^{d}	31.6^{ef}	87.3^{bc}	85.4^{bc}	1.71^{b}	1.34^{bc}	4.94^{ab}	5.39^{abc}	6.65^{ab}	6.74^{bc}	25.94^{a}	20.00^{abc}	1.45^{bcd}	0.98^{bc}
Clodinafop-propargyl + sodium-acifluorfen 147 g/ha	31.8^{e}	19.6^{hi}	72.4^{f}	69.3^{f}	1.23^{ef}	1.04^{def}	3.86^{c}	4.70^{d}	5.09^{e}	5.75^{e}	24.31^{a}	18.26^{bcd}	0.87^{f}	0.64^{ef}
Clodinafop-propargyl + sodium-acifluorfen 196 g/ha	39.4^{cd}	28.1^{fg}	78.1^{de}	80.6^{cd}	1.42^{de}	1.10^{de}	3.89^{c}	4.82^{cd}	5.32^{de}	5.93^{de}	26.88^{a}	18.58^{bcd}	1.12^{de}	0.70^{def}
Clodinafop-propargyl + Sodium acifluorfen 245 g/ha	43.8^{bc}	34.1^{de}	83.1^{cd}	84.1^{bc}	1.56^{bcd}	1.24^{bcd}	4.09^{bc}	5.07^{bcd}	5.65^{cde}	6.31^{cde}	27.84^{a}	19.65^{abc}	1.29^{bcde}	0.89^{bcd}
Imazamox + imazethapyr 42 g/ha	38.1^{cd}	38.8^{cd}	78.7^{de}	75.4^{de}	1.45^{d}	1.34^{bc}	4.33^{b}	5.06^{bcd}	5.79^{cd}	6.41^{cd}	25.23^{a}	20.97^{abc}	1.18^{cde}	1.04^{bc}
Imazamox + imazethapyr 56 g/ha	46.2^{bc}	44.4^{c}	85.4^{bc}	79.4^{cd}	1.68^{bc}	1.40^{b}	4.40^{ab}	5.23^{abcd}	6.08^{bc}	6.64^{bc}	27.84^{a}	21.22^{abc}	1.47^{bc}	1.11^{ab}
Imazamox + imazethapyr 70 g/ha	54.3^{b}	54.7^{b}	91.4^{b}	89.2^{b}	1.92^{ab}	1.62^{ab}	4.88^{ab}	5.53^{ab}	6.81^{ab}	7.15^{ab}	28.28^{a}	22.66^{ab}	1.77^{a}	1.38^{a}
Hand weeding twice at 20 and 40 DAS	89.2^{a}	90.4^{a}	93.1^{a}	90.8^{a}	2.07^{a}	1.72^{a}	5.09^{a}	5.71^{a}	7.16^{a}	7.44^{a}	29.04^{a}	23.26^{a}	1.67^{ab}	1.27^{ab}
Weedy check	0.0	0.0	0.0	0.0	1.10^{f}	0.84^{f}	4.00^{bc}	4.90^{cd}	5.11^{e}	5.74^{e}	21.67^{a}	14.94^{d}	0.76^{f}	0.41^{g}

Data are represented as mean, n=3. Means superscripted with same alphabets within a row are not significantly different from each other based on Duncan's multiple range test at $\sqrt{x+0.5}$. DAS = days after seeding

and sodium-acifluorfen + clodinafop- propargyl at Abohar. The higher soybean seed yield was observed with imazethapyr + imazamox 100 g/ha PoE at 20 DAS + hoeing at 35 DAS in soybean (Deshkari *et al* 2019) and with imazethapyr + imazamox 40 g/ha in blackgram (Yadav *et al.* 2015).

At Ludhiana, imazamox + imazethapyr 70 g/ha PoE at 15–20 DAS recorded the highest B:C ratio (**Table 2**), which was statistically at par with imazethapyr 75 g/ha and hand weeding twice at 20 and 40 DAS. At Abohar, the highest B:C ratio was recorded with imazamox + imazethapyr 70 g/ha, which was comparable with imazamox + imazethapyr 56 g/ha and hand weeding twice.

In conclusion, imazamox + imazethapyr at 70 g/ha PoE at 15-20 DAS significantly reduced the density of dominant weeds recording higher weed control efficiency which resulted in higher soybean seed yield and B:C ratio.

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