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Impact of propaquizafop on weed growth, yield and economics of soybean (*Glycine max* L.) under mid hill conditions of Himachal Pradesh

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Abstract
For any new technology to be adopted by the growers, it is not only the efficacy but cost is also a concern. In the present investigation impact assessment of propaquizafop alone in combination with other herbicides is done in soybean. Propaquizafop 50g + imazethapyr 100 g/ha followed by post-emergence tank mix combination of quizalofop-ethyl 60g + chlorimuron-ethyl 4 g/ha at 20 DAS gave higher weed control efficiency, crop resistance index and lowest weed index over other treatments. Net returns due to weed control was highest in post-emergence tank mix combination of propaquizafop 50g + imazethapyr 100 g/ha followed by post-emergence tank mix combination of quizalofop-ethyl 60g + chlorimuron-ethyl 4 g/ha. Treatment/herbicidal efficiency index was highest under hand weeding followed by propaquizafop 50g + imazethapyr 100 g/ha at 20 DAS and quizalofop ethyl 60g + chlorimuron ethyl 4g/ha. Based on an overall impact index, propaquizafop 50g + imazethapyr 100 g/ha on 20 DAS followed by quizalofop ethyl 60g + chlorimuron ethy 4g/ha and propaquizafop 75 g/ha applied on 25 DAS in that order are recommended for an effective weed management in soybean under mid hill conditions of Himachal Pradesh.

Keywords: Economics, impact assessment, propaquizafop, soybean, threshold

Introduction
Soybean an important commercial crop is called "Golden Bean" or "Miracle crop" of the 21st century because of its multiple qualities. It is rich in proteins (40-42%), essential amino acids especially lycine, oil (20%) and vitamin A, B and D (Jadhav, 2014) [14]. Being a rainy season crop, weeds in general, cause competition stress on soybean growth, especially during the first 40 days after sowing. Weeds alone are responsible for reduction in seed yield of soybean to the range of 25 to 70% depending upon the weed flora and intensity. Therefore, it is important to keep the soybean crop weed free to get higher seed yield (Kewat *et al*. 2000; Kumar *et al*. 2008) [3, 4]. With the changing scenario of weed management, presently pre-emergence herbicides are not very popular among the farmers due to short time span for sowing during *kharif* season. Therefore, farmers are using post-emergence herbicides for control of grasses, sedges and broad leaf weeds. Hence, it is imperative to evaluate the efficacy of suitable post-emergence herbicides alone and in mixture for effective control of diversified weed flora in soybean. Presently, imazethapyr is reportedly very effective post emergence herbicide for controlling some grassy and broad leaf weeds in soybean but its efficacy has not been tested with propaquizafop for wide spectrum weed control in soybean. Propaquizafop control only grassy weeds whereas imazethapyr control both grassy as well as broad leaf weeds. The present study was conducted to assess the impacts and economics of propaquizafop alone and in mixture with other post emergence herbicides in soybean under mid hill conditions of Himachal Pradesh.

Material and Methods
The field experiment was conducted during *kharif* 2016 at Palampur. Agroclimatically, the experimental site falls in the mid hills sub humid zone of the state. This area is characterized by mild summers, severe winters and experiences occasional snowfall during winters. Mean weekly maximum temperature during *kharif* 2016 ranged between 31.6 °C to 23.5 °C. Mean weekly minimum temperature during *kharif* 2016 ranged between 9.9 °C to 19.5 °C. Total of 1731.6 mm rainfall was received during the crop season. The highest weekly total rainfall of 315.6 mm was recorded in 31st standard week (30 July-5 Aug) of the year. The mean relative humidity during the crop season ranged between 58 to 96.7 per cent which was optimum for soybean crop. Sunshine (hours) varied from 1.0 to 9.6 (hours) during the crop growth period.

The soil of the experimental site was silty clay loam in texture, acidic (pH 5.6) in reaction and medium in available nitrogen (333.0 kg/ha), phosphorus (9.6 kg/ha) and potassium (221.0 kg/ha). The experiment was laid out in Randomized Block Design with eleven treatments *viz.* T_1: Propaquizafop 60 g/ha at 15 DAS (Days after sowing), T_2: Propaquizafop 60 g/ha at 25 DAS, T_3: Propaquizafop 75 g/ha at 15 DAS, T_4: Propaquizafop 75 g/ha at 25 DAS, T_5: Propaquizafop 50 + imazethapyr 100 g/ha at 20 DAS, T_6: Propaquizafop 50 + chlorimuron ethyl 4 g/ha at 25 DAS, T_7: Quizalofop ethyl 60 + chlorimuron ethyl 4 g/ha, T_8: Pendimethalin 1500 g/ha as Pre-emergence, T_9: Hand weeding twice (20 & 40 DAS), T_{10}: Mechanical weeding (20 & 40 DAS) and T_{11}: Unweeded check replicated thrice.

Soybean variety 'Harit Soya' was grown with row spacing of 45 cm and a plant spacing of nearly 10 cm. The recommended dose of fertilizers for soybean was 20 kg N, 60 kg P_2O_5 and 20 kg K_2O/ha. Full dose of NPK was applied through urea, single super phosphate and muriate of potash at sowing. The herbicides were applied using Knapsack sprayer fitted with flat fan nozzle by mixing 500 litres of water per ha. The data on total weed count and dry weight were recorded at 30, 60, 90 DAS and at harvest using 0.50 m^2 quadrat. Data on weed density and weed biomass were transformed to square root transformation ($\sqrt{x+0.5}$). Economic threshold (=economic injury levels), the weed density at which the cost of treatment equals the economic benefit obtained from that treatment, was calculated after Uygur & Mennan (1995) [10]. Impact assessment of treatments was carried out after Rana and Kumar (2014) [8]. Economics of the treatments was computed based on the prevalent market prices.

Results and Discussion

Total Weed count and dry biomass

The survey of weed species in unweeded check treatment was Conducted at 30, 60 and 90 days after sowing (DAS) and at harvest. *Cyperus iria, Echinochloa colona, Polygonum alatum* and *Commelina benghalensis* had shown their occurrence at all the stages of crop growth. Data on total weed count (60 DAS) and total weed dry weight (90 DAS) at maximum population and dry matter stage respectively, have been given in Table 1. All weed control treatments gave significant reduction in total weed count as compared to weedy check. Hand weeding (20 & 40 DAS) resulted in lowest total weed count among all treatments. Kewat *et al.* (2015) [5] also reported superiority of hand weeding twice in reducing weed population. In general, post-emergence application of herbicides was better than pre-emergence application due to effective suppression of newly emerging grasses, sedges and broad leaved weeds by the application of post-emergence herbicides in soybean. Among the herbicide treatments, post-emergence application of tank mix propaquizafop 50 g/ha + imazethapyr 100 g/ha resulted in significantly lower total weed count being comparable to hand weeding (20 & 40 DAS).

Similar to weed count, weed control treatments significantly decreased total weed dry weight as compared to weedy check. Due to repeated hand weeding (20 & 40 DAS), there was better reduction in total weed dry weight until harvest which was statistically at par with post-emergence application of propaquizafop 50g + imazethapyr 100 g/ha. Post-emergence tank mix application of quizalofop-ethyl 60g + chlorimuron-ethyl 4 g/ha resulted in significantly lower total weed dry weight over other herbicidal treatments. Owing to synergetic, enhancement or additive effects, herbicidal combinations in general were better than sole application of herbicides in effectively reducing the total weed dry weight. Ram *et al.* (2013) [6] and Ram and Singh (2011) [7] also obtained minimum weed biomass in soybean with the application of imazethapyr at 75 g/ha at 20-25 DAS.

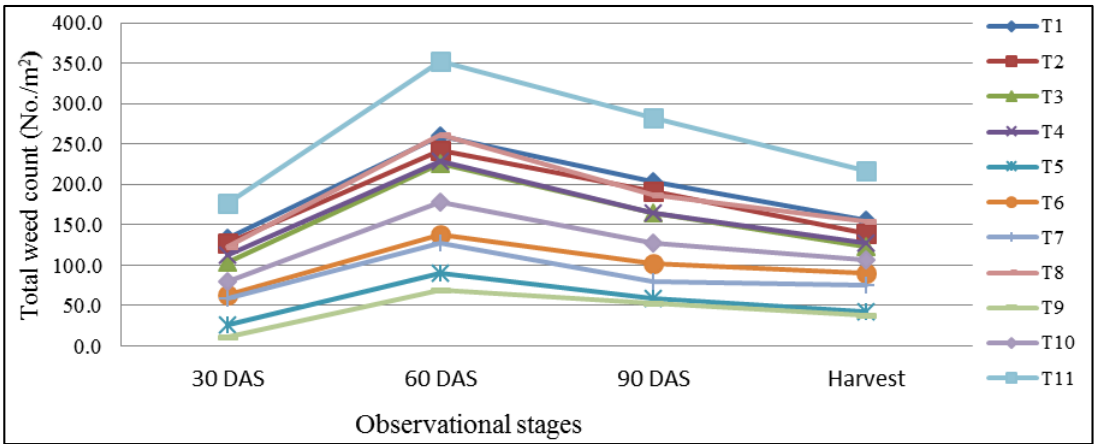

Fig 1: Effect of treatments on progressive total weed count (Number/m^2)

Table 1: Effect of treatments on total weed count (Number/m^2), total weed dry matter accumulation (g/m^2) of weeds weed control efficiency (%) and seed yield (kg/ha)

Treatment	Dose (g/ha)	TOA (DAS)	Total weed count (60 DAS)	Total weed dry weight (90 DAS)	Weed control efficiency	Seed yield
Propaquizafop	60	15	16.1 (259.0)	17.8 (297.6)	20.75	1164
Propaquizafop	60	25	15.6 (242.4)	17.5 (284.3)	23.81	1340
Propaquizafop	75	15	15.0 (224.9)	16.9 (263.5)	27.77	1411
Propaquizafop	75	25	15.2 (229.3)	16.5 (248.0)	30.33	1481
Propaquizafop + imazethapyr	50+100	20	9.5 (90.1)	7.9 (75.2)	83.54	2222
Propaquizafop + chlorimuron ethyl	50+4	20	11.7 (136.8)	11.6 (157.9)	75.42	1834
Quizalofop ethyl + chlorimuron ethyl	60+4	15	11.3 (127.9)	9.3 (102.6)	79.68	2063
Pendimethalin	1500	Pre-	16.2 (260.6)	13.2 (178.1)	63.67	1675
Hand weeding	-	20 & 40	8.3 (68.7)	7.4 (60.3)	86.18	2363

Mechanical weeding	-	20 & 40	13.4(178.6)	13.9 (173.9)	57.22	1570
Weedy check	-	-	18.8 (359.5)	21.0 (417.1)	0.00	1023
CD (P=0.05)			1.2	1.0		450

*Value in parentheses are the means of original values. Data transformed to square root transformation ($\sqrt{x+0.5}$); TOA= Time of application; pre, pre-emergence

Hand weeding twice resulted in highest weed control efficiency due to effective frequent removal of the weeds. Among the various herbicide treatments, maximum weed control efficiency (85.54%) was of tank mix combination of propaquizafop 50g + imazethapyr 100 g/ha followed by quizalofop-ethyl 60g + chlorimuron-ethyl 4 g/ha.

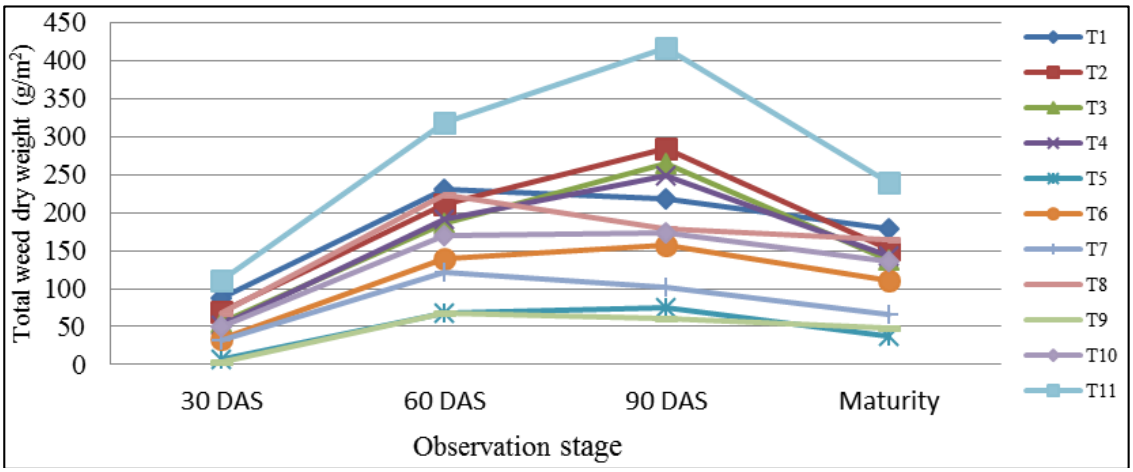

Fig 2: Effect of treatments on progressive total weed dry weight (g/m^2)

Seed yield

Seed yield was negatively associated with total weed count (r= 0.931**, significant at 1% level of significance) and total weed dry weight (r= 0.965**) showing high competitiveness of weeds in soybean.

The linear relationship between weed count (60 DAS) and dry weight (90 DAS) (x) and seed yield (Y) of maize is given here as under:

Weed count

$Y = 2569 - 4.6x$ (R^2= 0.931)... (1)

Weed dry weight

$Y = 2438 - 3.8x$ (R^2= 0.965)… (2)

Equation 1 and 2 explain that over 93 & 96% of the variation in seed of soybean due to count and dry weight of weeds, respectively, could be explained by these regression equations. With unit increase in weed count/m^2 or weed dry weight (g/m^2), the grain yield of soybean reduced by 4.6 and 3.8 kg/ha, respectively.

Post-emergence application of propaquizafop at 75 g/ha significantly increased the seed yield of soybean than its application at 60 g/ha both on 15 & 25 DAS. But, combined tank mixture application of propaquizafop + imazethapyr had more seed yield than other chemical treatments. Tank mixed propaquizafop 50g + imazethapyr 100 g/ha and quizalofop-ethyl 60g + chlorimuron-ethyl 4 g/ha at 20 DAS were as good as hand weeding (20 and 40 DAS) in increasing seed yield of soybean. Kumat *et al*. (2008) reported similar findings.

Economic threshold

The economic threshold levels of weeds at the current prices of treatment application and the crop production on the basis of weed infestation in soybean have been given in Table 2. The economic threshold levels varied from 13-87.5 g/m^2 when determined after Stone and Pedigo and 4-19/m^2 after Uygur and Mennan.

Table 2: Effect of treatments on economic studies

Treatment	Dose (g/ha)	TOA (DAS)	GR (INR/ha)	COC (INR /ha)	GRwc (INR /ha)	Cwc (INR /ha)	NRwc (INR /ha)	MBCR	Gt	Et	
										SP	UM
Propaquizafop	60	15	48378	27917	7688	1638	6050	3.69	109	13	16
Propaquizafop	60	25	54396	27917	13706	1638	12069	7.37	109	13	12
Propaquizafop	75	15	57146	28177	16456	1898	14558	7.67	127	15	12
Propaquizafop	75	25	62409	28177	21719	1898	19822	10.44	127	15	11
Propaquizafop + imazethapyr	50 + 100	20	87030	29649	46340	3370	42971	12.75	225	26.5	6
Propaquizafop + chlorimuron ethyl	50 + 4	20	72923	27956	32233	1677	30556	18.22	112	13.5	4
Quizalofop ethyl + chlorimuron ethyl	60 + 4	15	80780	28821	40090	2542	37548	14.77	169	20	5
Pendimethalin	1500	Pre-	64012	29129	23322	2850	20473	7.18	190	22.5	8
Hand weeding	-	20 & 40	92247	37279	51557	11000	40558	3.69	733	87.5	18
Mechanical weeding	-	20 & 40	66053	31279	25363	5000	20363	4.07	333	39.5	19
Weedy check	-	-	40690	26279	0	0	0	0.00	0	0	0

TOA, time of application; GR – Gross returns; COC – Cost of cultivation; Gt - gain threshold; Et - Economic threshold; Et - (S and P) - economic threshold after Stone and Pedigo; Et (U and M) – Economic threshold after Uyger and Mennan; GRwc - Gross return over weedy check (INR/ha); CWC - cost of weed control (INR/ha); NRwc - Net return over weedy check; MBCR - marginal benefit cost ratio;

It was indicated that any increase in cost of weed control would lead to higher values of economic threshold, whereas an increase in price of crop produce would result in lowering the economic threshold. Hand weeding had higher values of economic threshold than the herbicidal treatments due to higher wages. The lowest application cost was under propaquizafop 60g/ha or propaquizafop + chlorimuron ethyl and thus the lowest values of economic threshold.

Economics

Because of higher yield, weed control treatments resulted in higher gross returns over weedy check. Gross returns due to weed control were highest in hand weeding twice (20 & 40 DAS) followed by post-emergence tank mix combination of propaquizafop 50g + imazethapyr 100 g/ha. Net returns due to weed control was highest in post-emergence tank mix combination of propaquizafop 50g + imazethapyr 100 g/ha followed by post-emergence tank mix combination of quizalofop-ethyl 60g + chlorimuron-ethyl 4 g/ha. Marginal benefit cost ratio was highest under post-emergence application of propaquizafop 50g + chlorimuron-ethyl 4 g/ha followed by post-emergence applicaton of quizalofop-ethyl 60g + chlorimuron-ethyl 4 g/ha, post-emergence tank mix combination of propaquizafop 50g + imazethapyr 100 g/ha and post-emergence application of sole propaquizafop at 75 g/ha. The superior performance of above treatments was ascribed to higher grain and straw yield of soybean crop. Aggarwal *et al*. (2014) [1] obtained higher gross income, net benefit income and benefit: cost ratio in soybean with application of imazethapyr at 100 g/ha. Panda *et al*. (2015) [5] also found that post-emergence application of propaquizafop 53 g+ imazethapyr mixture 80 g/ha or higher rate fetched higher net monetary returns and benefit: cost ratio.

Impact assessment

Weed persistence index (WPI) was lowest in treatment quizalofop ethyl 60g + chlorimuron ethyl 4g/ha and crop resistance index (CRI) was highest under the propaquizafop 50g + imazethapyr 100 g/ha at 20 DAS (Table 3). Weed management index (WMI), agronomic management index (AMI) and integrated weed management index (IWMI) were higher in sole application of treatments propaquizafop at the rate of 60 g/ha at 25 DAS than the hand weeding. Treatment/herbicidal efficiency index was highest under hand weeding followed by propaquizafop 50g + imazethapyr 100 g/ha at 20 DAS and quizalofop ethyl 60g + chlorimuron ethyl 4g/ha. Weed intensity was lowest and crop intensity was more in hand weeding thrice than other treatments.

Table 3: Impact assessment indices and economic thresholds under different weed management practices in soybean

Treatment	Dose (g/ha)	TOA (DAS)	WPI	CRI	WMI	AMI	IWMI	HEI	WIN	CIN	OLI
Propaquizafop	60	15	0.99	1.52	7.63	6.63	7.13	0.16	60.9	39.1	0.77
Propaquizafop	60	25	1.00	1.67	7.82	6.82	7.32	0.37	58.5	41.5	0.93
Propaquizafop	75	15	1.01	1.80	7.15	6.15	6.65	0.47	55.8	44.2	0.95
Propaquizafop	75	25	0.97	1.92	6.79	5.79	6.29	0.57	56.1	43.9	0.99
Propaquizafop + imazethapyr	50 + 100	20	0.79	5.53	3.48	2.48	2.98	3.13	40.1	59.9	1.37
Propaquizafop + chlorimuron ethyl	50 + 4	20	0.88	3.24	4.01	3.01	3.51	1.44	48.3	51.7	1.15
Quizalofop ethyl + chlorimuron ethyl	60 + 4	15	0.73	4.35	3.62	2.62	3.12	2.30	47.4	52.6	1.24
Pendimethalin	1500	Pre-	0.73	2.67	4.40	3.40	3.90	1.02	56.2	43.8	0.93
Hand weeding	-	20 & 40	0.80	6.18	3.57	2.57	3.07	3.71	38.4	61.6	1.37
Mechanical weeding	-	20 & 40	0.92	2.36	4.57	3.57	4.07	0.81	53.2	46.8	0.90
Weedy check	-	-	1.00	1.00	0.00	0.00	0.00	0.00	64.4	35.6	0.35

WPI - Weed persistence index; CRI - Crop resistance index; WMI - Weed management index; AMI - Agronomic management index; IWMI - Integrated Weed management index; HEI - Treatment/Herbicide efficiency index; WI – weed index; Win - Weed intensity; Cin - Crop intensity; OIi - overall impact index

Highest weed intensity and lowest crop intensity were recorded in weedy check. Overall impact index (OIi), which was drawn taking together different indices as well as per cent control of weeds, yield and economic parameters to have a valid inference and conclusion. The OIi was highest under hand weeding thrice being similar to propaquizafop 50g + imazethapyr 100 g/ha applied on 20 DAS followed by quizalofop ethyl 60g + chlorimuron ethy 4g/ha followed propaquizafop 75 g/ha applied on 25 DAS. Similar results have also been reported by Kumar *et al*. (2008) [8].

Thus for an effective and economical weed management in soybean propaquizafop 50g + imazethapyr 100 g/ha on 20 DAS followed by quizalofop ethyl 60g + chlorimuron ethy 4g/ha and propaquizafop 75 g/ha applied on 25 DAS in that order must be the strategic components in any integrated weed management programmes under mid hill conditions of Himachal Pradesh.

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