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Weed management effect of post-emergence herbicides on growth and productivity of maize in farmers' field under low hill zone of Himachal Pradesh

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Abstract

The experiment was performed in a randomized block design in two blocks of Hamirpur district of Himachal Pradesh with five treatments during both *kharif* and *rabi* seasons 2022 and 2023 to study the effect of post-emergence herbicides on growth and productivity of maize and wheat. The post-emergence application of herbicides tembotrione 120 g/ha and topramezone 25.2 g/ha were compared with the farmers' practice during *kharif* while the herbicides applied in *kharif* were rotated with two herbicides in wheat *viz*., clodinafop propargyl + metsulfuron methyl and metribuzin during *rabi* season. Both herbicides (tembotrione and topramezone) significantly reduced total weed count and dry weight than farmers' practices across years and locations besides significantly enhanced plant height, dry matter accumulation and crop growth rate. In both the blocks, significantly higher grain yield was recorded with tembotrione, which was at par with topramezone irrespective of different herbicides used in previous crop.

Keywords: Growth indices, maize, post-emergence herbicide, CGR, tembotrione, topramezone

Maize, the third most important cereal globally, faces reduced productivity due to abiotic stresses, weed infestation, climate change, and poor nutrition. It serves as a major income source in developing nations and provides safer fodder than sorghum, being free from oxalic and prussic acids (Zen El-Dein *et al.* 2022). In the north-western Himalayas, especially Himachal Pradesh, poor weed management severely limits maize yields. Effective weed control is critical, as delayed removal or unmanaged weeds can cause 50-75 per cent yield losses (Singh *et al.* 2020). Therefore, chemical weed management is the most economical and convenient option as compared to manual weeding because conventional cultural and manual weed management techniques are labor-intensive and time-consuming. Herbicides offer timely, effective, and cost-efficient weed control (Rana *et al*. 2004 a & b). While pre-emergence herbicides manage early-stage weeds, there is a need for broad-spectrum post-emergence options that do not hinder crop growth or yield.

Under various agronomic conditions, growth indices are essential markers of plant health and performance (Kumari *et al.* 2022, Shahu *et al.* 2024; Rana *et al.* 2025). The competitive relationship between weeds and crops has a direct impact on growth metrics. By reducing weed pressure, herbicides enable better growth indices, which are necessary to increase yield. Growth indices in maize are extremely responsive to weed management strategies and the application of efficient pre and post emergence herbicides results in notable gains (Balaji *et al.* 2023). When weed competition is present or absent, these indices also show how well crops use the resources that are available, such as light, water, and nutrients. Thus, an 'on-farm' experimentation was undertaken to assess the weed management effect of post-emergence herbicides on growth and productivity of maize in farmers field under low hill zone of Himachal Pradesh.

Materials and Methods

The experiment was conducted at the farmers' fields of Hamirpur district of Himachal Pradesh in two development blocks namely Hamirpur and Nadaun during 2022 and 2023. The experiment was laid out in randomized block design with five treatments as

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detailed in Table 1. Two blocks were randomly chosen, with each block comprising three villages. From each village, three farmers were selected, resulting in a total of nine farmers per block, which served as nine replications. The soil of the selected fields in both the blocks was sandy loam in texture, neutral in reaction, medium in organic carbon, high in available P and medium in available N and available K in both blocks. The maize variety 'DKC 7074' was used with seed rate of 20 kg/ha. The distance between plants was maintained at 20 cm, and the distance between rows was kept at 60 cm. And the gross plot size was 5.4 m × 5.0 m. The crop was sown on different dates in both blocks over the two years. In the Hamirpur block, sowing was done on 5^{th} – 10^{th} May 2022 and 8^{th} – 13^{th} May 2023, whereas in the Nadaun block, it was sown on 7^{th} – 12^{th} May 2022 and 12^{th} – 17^{th} May 2023.

A baseline survey was conducted in both blocks to assess the weed management practices followed by farmers and it was observed that the farmers' practice in Hamirpur block included one hand weeding at 35 DAS in both the crops while in Nadaun block pre-emergence application of atrazine 1.5 kg/ha in maize and post-emergence application of isoproturon 1.2 kg/ha were taken as farmers' practice.

The data was recorded on the plant height and dry matter accumulation at 30, 60 and 90 days after sowing and was used to calculate the different indices as given below using standard procedures and formulas given below,

The crop growth rate (CGR) ($g/m^2/day$) was calculated using the formula given below.

$$CGR\ (g/m^2/day) = \frac{W_2 - W_1}{P\ x\ (t_2 - t_1)}$$

where

W_1 & W_2: Whole plant dry weight (g) at time t_1 and t_2, respectively

P is the ground area on which W_1 & W_2 are recorded

The relative growth rate (RGR) ($mg\ g^{-1}\ day^{-1}$) was calculated using the formula given below.

$$RGR\ (mg/g/day) = \frac{(Log_e W_2 - Log_e W_1)\ x\ 1000}{t_2 - t_1}$$

Where

W_1 & W_2: Whole plant dry weight (g) at time t_1 and t_2, respectively

The species-wise weed count was recorded at monthly intervals. The total weed count was obtained by summing up the count of different weed species. For total dry weight, the samples were oven dried at 70°C till constant dry weight and then weighed & calculated.

The data obtained was statistically analyzed as per the procedure outlined by Gomez and Gomez (1984). The critical difference (CD) was estimated for parameters with significant impacts at the 5% probability level. The visualizations were generated by using PAST 5.0 software.

Results and Discussions

The most common weeds observed at monthly interval during *kharif* 2022 and 2023 in both the blocks were *Commelina benghalensis*, *Digitaria sanguinalis*, *Cyperus* sp., *Echinochloa colona*, *Ageratum conyzoides*, *Ipomoea* sp. and *Phyllanthus niruri*. Data pertaining to total weed count and total weed dry weight at maximum population stage in maize crop during *kharif* 2022 and 2023 in both blocks have been

Table 1: Details of treatments

Treatment	*kharif* (Maize)	*rabi* (Wheat)
T_1	Tembotrione 120 g/ha (25 DAS)	Clodinafop 60 g/ha + metsulfuron methyl 4 g/ha (35 DAS)
T_2	Topramezone 25.2 g/ha (25 DAS)	Clodinafop 60 g/ha + metsulfuron methyl 4 g/ha (35 DAS)
T_3	Tembotrione 120 g/ha (25 DAS)	Metribuzin 210 g/ha (35 DAS)
T_4	Topramezone 25.2 g/ha (25 DAS)	Metribuzin 210 g/ha (35 DAS)
T_5	Farmer's Practice	Farmer's Practice

presented in Table 2 and 3. Weed control treatments had a significant influence on the total weed count at the maximum weed population stage (60 DAS) as well as on the total weed dry weight at the peak biomass stage (90 DAS). At maximum population stage during both the years, treatments in which tembotrione 120 g/ha was applied as a post-emergent spray recorded significantly lower total weed count and total weed dry weight though no significant differences were observed between these treatments and treatments in which topramezone was applied at an application dose of 25.2 g/ha while farmers' practice (one hand weeding at 35 DAS) recorded significantly higher total weed count. The data also indicating that the effect of herbicides applied in the preceding wheat had no significant influence on the total weed count.

Table 2: Effect of weed control treatments on total weed count (No./m^2) and total weed dry weight (g/m^2) at maximum population stage in maize under maize-wheat cropping system in Hamirpur block

Treatments			Total weed count 60 DAS		Total weed dry weight 90 DAS	
	kharif	*rabi*	2022	2023	2022	2023
T_1	Tembotrione	Clodinafop propargyl + metsulfuron methyl	7.49 (55.56)	8.47 (71.11)	6.76 (44.77)	7.53 (55.79)
T_2	Topramezone	Clodinafop propargyl + metsulfuron methyl	8.06 (64.11)	9.13 (82.44)	7.17 (50.39)	7.94 (62.11)
T_3	Tembotrione	Metribuzin	7.53 (55.89)	8.66 (74.00)	6.85 (45.90)	7.57 (56.27)
T_4	Topramezone	Metribuzin	8.19 (66.22)	9.15 (83.00)	7.24 (51.53)	8.01 (63.23)
T_5	Farmers' practice (HW)	Farmers' practice (HW)	9.88 (96.78)	10.76 (115.11)	9.09 (81.63)	9.82 (95.60)
SEm±			0.56	0.51	0.20	0.23
CD (P=0.05)			1.61	1.48	0.58	0.65

Tembotrione 120 g/ha, Topramezone 25.2 g/ha, Hand weeding (HW) at 35 DAS (maize), Clodinafop propargyl+MSM 60+4 g/ha, Metribuzin 210 g/ha, Hand weeding (HW) at 35 DAS (wheat)

Values given in parentheses are the mean of original values, data subjected to $\sqrt{x+1}$ square root transformation

Table 3: Effect of weed control treatments on total weed count (No./m^2) and total weed dry weight (g/m^2) at maximum population stage in maize under maize-wheat cropping system in Nadaun block

Treatments			Total weed count 60 DAS		Total weed dry weight 90 DAS	
	kharif	*rabi*	2022	2023	2022	2023
T_1	Tembotrione	Clodinafop propargyl + metsulfuron methyl	7.04 (48.89)	8.05 (63.89)	6.48 (41.07)	7.14 (50.06)
T_2	Topramezone	Clodinafop propargyl + metsulfuron methyl	7.69 (58.44)	8.65 (74.22)	6.85 (46.04)	7.57 (56.40)
T_3	Tembotrione	Metribuzin	7.19 (51.11)	8.12 (65.11)	6.47 (40.88)	7.25 (51.59)
T_4	Topramezone	Metribuzin	7.82 (60.33)	8.82 (76.89)	6.96 (47.49)	7.65 (57.65)
T_5	Farmers' practice (HW)	Farmers' practice (HW)	9.31 (85.78)	10.13 (101.89)	8.57 (72.52)	9.24 (84.50)
SEm±			0.49	0.45	0.18	0.21
CD (P=0.05)			1.41	1.30	0.53	0.61

Tembotrione 120 g/ha, Topramezone 25.2 g/ha, Atrazine 1.5 kg/ha, Clodinafop propargyl+MSM 60+4 g/ha, Metribuzin 210 g/ha, Isoproturon 1.2 kg/ha

Values given in parentheses are the mean of original values, data subjected to $\sqrt{x+1}$ square root transformation

The trend that was witnessed for total weed count and total weed dry weight in Hamirpur block was replicated in Nadaun block with tembotrione treatments, remaining at par with the topramezone treatments, recording significantly lower total weed count while famers' practice of pre-emergence application of atrazine 1.5 kg/ha recorded significantly higher total weed count. These herbicides, which are HPPD (4-hydroxyphenylpyruvate dioxygenase) inhibitors belonging to the chemical class of triketones and pyrazolones, have a broad-spectrum control, targeting a large number of weed species- annual grasses, broadleaved weeds, and sedges. Their systemic mode of action and selectivity render them extremely well-suited for application in crops such as maize, where early post-emergence application coincides with the critical weed-free period. Similar results were also found by Sepat and Singh (2024).

The data on effect of weed control treatments on plant height (cm) has been given in Table 4 (Hamirpur block) and Table 5 (Nadaun block). The herbicide treatments didn't significantly affect the plant height of maize plants at 30 days after sowing (DAS) in both the blocks during *kharif* 2022 and 2023. During first year of experimentation, significantly taller plants at 60 and 90 DAS were observed when tembotrione 120 g/ha was used as post-emergent spray which was at par with the post emergence application of topramezone. Similarly, during *kharif* 2023, significantly taller plants were noticed when post-emergence application of tembotrione was preceded by post-emergence application of clodinafop propargyl + metsulfuron methyl in wheat while, all the other treatments were statistically similar with each other. Similar trend was followed at 90 days after sowing. Tembotrione and topramezone are the broad spectrum herbicides which are HPPD (4-hydroxyphenylpyruvate dioxygenase) inhibitor that effectively controls broadleaf weeds and some grasses, leading to reduced weed competition. Based on their higher weed control performance and their effectiveness in reducing competition for critical resources, tembotrione and topramezone were found to effectively boost plant height, enabling maize plants to make better use of their resources which resulted in better nutrient uptake and crop growth. Similar findings were reported by several researchers (Maurya *et al.* 2024; Singh *et al.* 2024).

Table 4 and 5 shows the data on the effect of weed control treatments on dry matter accumulation per plant in maize crop in Hamirpur and Nadaun block. The herbicide treatments did not significantly affect the dry matter accumulation of maize plants at 30 days after sowing (DAS) in either block during *kharif* 2022 and 2023. In both blocks, during the first year of experimentation, the application of tembotrione herbicide resulted in significantly higher dry matter accumulation, which was comparable to the application of topramezone at 60 days after sowing. In *kharif* 2023, significantly higher dry matter accumulation was observed when post-emergence application of tembotrione in maize was preceded by post-emergence application of clodinafop propargyl + metsulfuron methyl in wheat, though this treatment was at par with the application of application of tembotrione preceded by post-emergence application of metribuzin as well as post-emergence application of topramezone in maize preceded by use of both herbicide combinations clodinafop propargyl + metsulfuron methyl as well as metribuzin during *rabi*. Significantly lower dry matter accumulation was observed in farmers' practice in both the blocks. Similar trend was followed at 90 DAS in both the blocks. Tembotrione suppresses weeds for a longer period of time than certain other herbicides because of its mild soil residual activity. Higher dry matter accumulation results from improved light interception, enhanced nutrient uptake and more effective photosynthesis due to less weed interference.

The data on effect of weed control treatments on growth indices and yield in maize crop in Hamirpur and Nadaun block has been given in Table 6 and 7. Crop growth rate was significantly influenced by the weed control treatments in maize crop. In Hamirpur block, between 30-60 DAS and 60-90 DAS significantly higher CGR was observed when tembotrione was applied which was statistically similar to herbicide topramezone during both the years of experimentation. Whereas, relative growth rate was not significantly affected by the effect of different weed control treatments during both the years at different stages.

In Nadaun block, the application of tembotrione 120 g/ha resulted in a significantly higher CGR during

Table 4: Effect of weed control treatments on growth at different stages of observation in maize under maize-wheat cropping system in Hamirpur block

Treatments			Plant height (cm)						Dry matter accumulation (g/plant)					
			30 DAS		60 DAS		90 DAS		30 DAS		60 DAS		90 DAS	
	kharif	*rabi*	2022	2022	2023	2023	2022	2023	2022	2023	2022	2023	2022	2023
T_1	Tembotrione	Clodinafop propargyl + Metsulfuron methyl	44.6	41.4	144.2	141.5	240.3	236.2	14.2	11.7	55.4	54.2	164.2	160.5
T_2	Topramezone	Clodinafop propargyl + Metsulfuron methyl	42.7	40.4	141.1	138.7	235.5	230.7	13.7	11.0	54.0	50.6	161.0	154.4
T_3	Tembotrione	Metribuzin	43.5	42.8	145.7	140.6	238.2	234.4	14.0	12.3	56.2	52.9	162.7	159.8
T_4	Topramezone	Metribuzin	41.8	39.9	139.2	139.7	232.2	227.6	13.4	10.4	53.5	51.8	157.9	153.2
T_5	Farmers' practice (HW)	Farmers' practice (HW)	41.1	39.4	130.1	129.6	217.9	212.2	12.5	9.9	44.5	42.7	142.5	139.1
SEm ±			0.8	0.8	2.5	2.6	3.9	4.0	0.6	0.6	1.0	0.9	3.1	3.0
CD (P=0.05)			NS	NS	7.3	7.6	11.2	11.5	NS	NS	2.9	2.7	8.9	8.7

Tembotrione 120 g/ha, Topramezone 25.2 g/ha, Hand weeding (HW) at 35 DAS (maize), Clodinafop propargyl + MSM 60+4 g/ha, Metribuzin 210 g/ha, Hand weeding (HW) at 35 DAS (wheat)

Table 5: Effect of weed control treatments on growth at different stages of observation in maize under maize-wheat cropping system in Nadaun block

Treatments			Plant height (cm)						Dry matter accumulation (g/plant)					
			30 DAS		60 DAS		90 DAS		30 DAS		60 DAS		90 DAS	
	kharif	*rabi*	2022	2022	2023	2023	2022	2023	2022	2023	2022	2023	2022	2023
T_1	Tembotrione	Clodinafop propargyl + Metsulfuron methyl	52.3	50.6	160.2	154.6	251.5	246.1	16.5	16.1	69.3	65.6	177.6	173.6
T_2	Topramezone	Clodinafop propargyl + Metsulfuron methyl	51.6	48.7	156.4	149.3	246.2	242.5	15.3	14.7	67.7	63.5	170.8	168.4
T_3	Tembotrione	Metribuzin	53.5	49.8	158.7	151.6	250.4	243.8	17.1	15.2	68.1	66.1	173.2	172.8
T_4	Topramezone	Metribuzin	50.8	48.4	154.6	148.6	249.2	240.9	14.4	13.9	66.0	62.9	171.3	167.2
T_5	Farmers' practice (atrazine)	Farmers' practice (isoproturon)	49.7	47.1	146.1	140.5	225.8	221.2	13.9	12.8	57.2	54.3	154.1	151.0
SEm ±			0.9	0.8	2.6	2.5	4.4	4.0	0.8	0.8	1.3	1.2	2.9	3.0
CD (P=0.05)			NS	NS	7.4	7.2	12.7	11.4	NS	NS	3.7	3.5	8.4	8.8

Tembotrione 120 g/ha, Topramezone 25.2 g/ha, Atrazine 1.5 kg/ha, Clodinafop propargyl + MSM 60+4 g/ha, Metribuzin 210 g/ha, Isoproturon 1.2 kg/ha

Table 6: Effect of weed control treatments on growth indices and yield at different stages of observation in maize under maize-wheat cropping system in Hamirpur block

Treatments			Crop growth rate (g/m^2/day)				Relative growth rate (mg/g/day)				Grain yield	
			30-60 DAS		60-90 DAS		30-60 DAS		60-90 DAS		(q/ha)	
	kharif	*rabi*	2022	2023	2022	2023	2022	2023	2022	2023	2022	2023
T_1	Tembotrione	Clodinafop propargyl + Metsulfuron methyl	1.37	1.41	3.63	3.55	45.34	51.66	36.25	36.22	41.01	39.45
T_2	Topramezone	Clodinafop propargyl + Metsulfuron methyl	1.34	1.32	3.57	3.46	46.13	51.35	36.46	37.17	39.66	38.79
T_3	Tembotrione	Metribuzin	1.41	1.35	3.55	3.57	46.61	48.66	35.39	36.87	40.57	40.18
T_4	Topramezone	Metribuzin	1.34	1.38	3.48	3.38	46.35	53.99	36.06	36.12	38.85	37.92
T_5	Farmers' practice (HW)	Farmers' practice (HW)	1.07	1.09	3.26	3.21	42.45	48.56	38.76	39.38	34.23	34.06
SEm ±			0.04	0.04	0.09	0.10	1.61	1.96	0.91	1.11	0.85	0.80
CD (P=0.05)			0.11	0.10	0.28	0.30	NS	NS	NS	NS	2.46	2.31

Tembotrione 120 g/ha, Topramezone 25.2 g/ha, Hand weeding (HW) at 35 DAS (maize), Clodinafop propargyl + MSM 60+4 g/ha, Metribuzin 210 g/ha, Hand weeding (HW) at 35 DAS (wheat)

Table 7: Effect of weed control treatments on growth indices and yield at different stages of observation in maize under maize-wheat cropping system in Nadaun block

Treatments			Crop growth rate (g/m^2/day)				Relative growth rate (mg/g/day)				Grain yield	
			30-60 DAS		60-90 DAS		30-60 DAS		60-90 DAS		(q/ha)	
	kharif	*rabi*	2022	2023	2022	2023	2022	2023	2022	2023	2022	2023
T_1	Tembotrione	Clodinafop propargyl + Metsulfuron methyl	1.76	1.65	3.61	3.60	48.20	47.40	31.38	32.44	46.55	44.18
T_2	Topramezone	Clodinafop propargyl + Metsulfuron methyl	1.75	1.63	3.44	3.50	50.04	48.87	30.86	32.53	44.07	42.70
T_3	Tembotrione	Metribuzin	1.70	1.70	3.50	3.56	46.14	49.13	31.15	32.03	45.61	43.84
T_4	Topramezone	Metribuzin	1.72	1.63	3.51	3.48	51.65	51.07	31.79	32.59	44.98	41.96
T_5	Farmers' practice (atrazine)	Farmers' practice (isoproturon)	1.44	1.38	3.23	3.22	47.08	48.21	33.03	34.09	41.15	39.13
SEm ±			0.05	0.04	0.08	0.07	2.02	1.85	0.94	0.78	0.87	0.78
CD (P=0.05)			0.14	0.12	0.24	0.19	NS	NS	NS	NS	2.51	2.26

Tembotrione 120 g/ha, Topramezone 25.2 g/ha, Atrazine 1.5 kg/ha, Clodinafop propargyl + MSM 60+4 g/ha, Metribuzin 210 g/ha, Isoproturon 1.2 kg/ha

kharif 2022, and it was statistically comparable to the treatments in which topramezone was used as post-emergent spray. Farmers' practice recorded significantly lower CGR. During second year of study, when post-emergence application of tembotrione in maize preceded by post-emergence application of metribuzin in wheat recorded significantly higher CGR of maize though this treatment was at par with application of tembotrione preceded by post-emergence application of clodinafop propargyl + metsulfuron methyl as well as post-emergence application of topramezone in maize preceded by use of both herbicide combinations clodinafop propargyl + metsulfuron methyl as well as metribuzin between 30-60 DAS. Between 60-90 DAS, during first year of study tembotrione resulted significantly higher CGR while application of topramezone was comparable. During *kharif* 2023, the application of tembotrione in maize followed by the post-emergence application of clodinafop propargyl + metsulfuron methyl in wheat, which was comparable to the application of tembotrione in maize preceded by the post-emergence

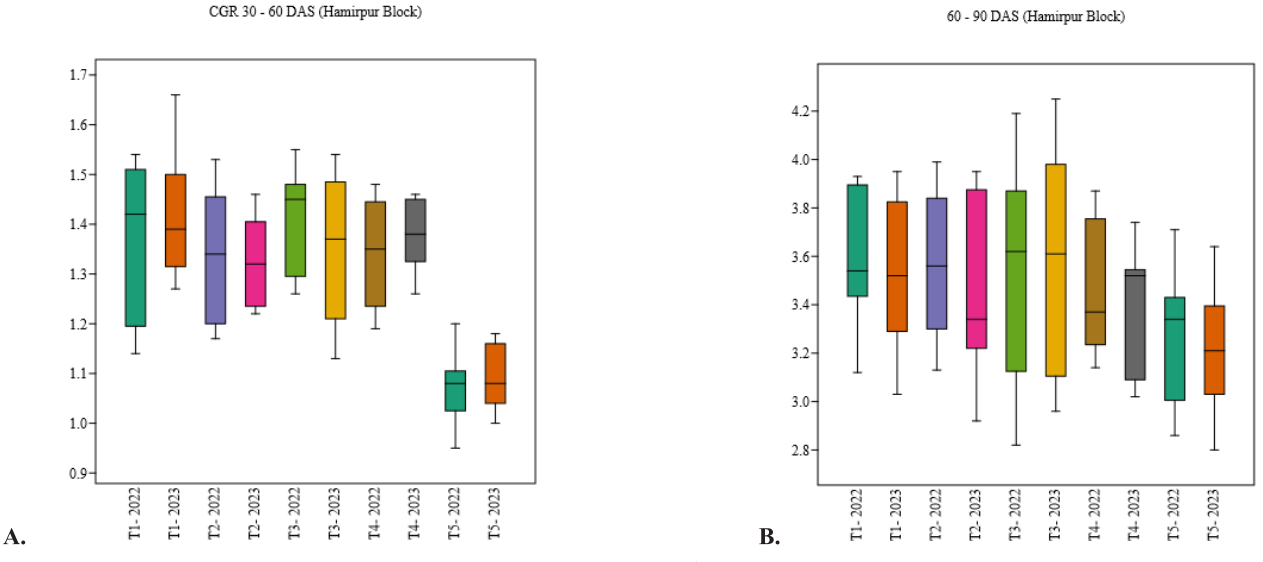

Fig 1: Effect of weed control treatments on crop growth rate (g/m^2/day) in maize (Hamirpur block); at A- 30-60 DAS & B- 60-90 DAS

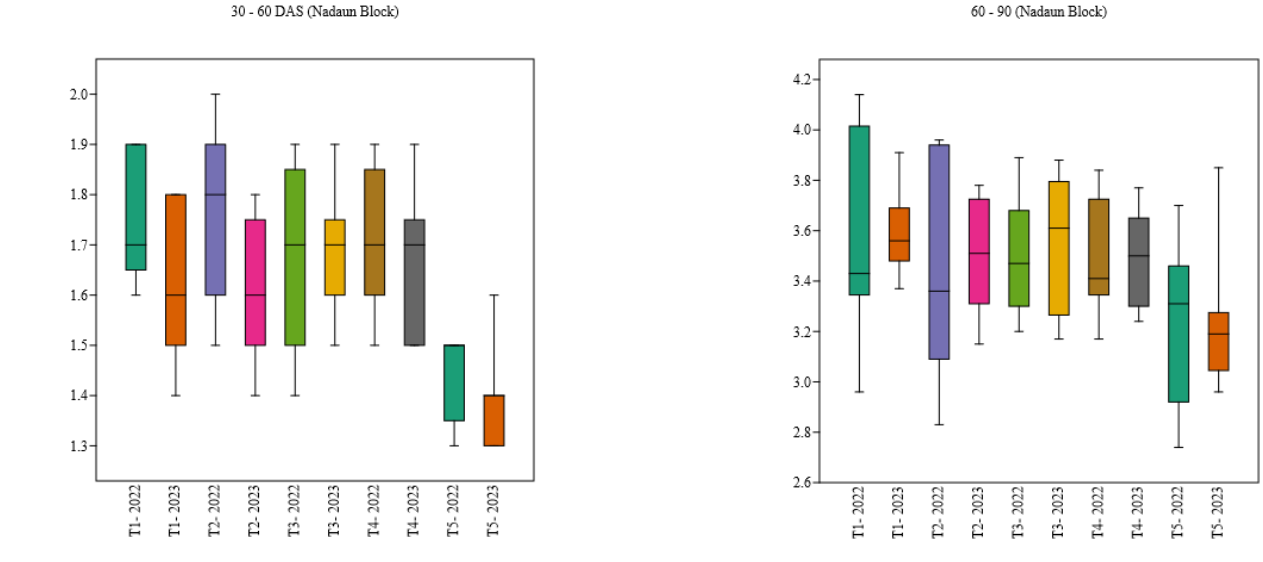

Fig 2: Effect of weed control treatments on crop growth rate (g/m^2/day) in maize (Nadaun block); A- 30-60 DAS & B- 60-90 DAS

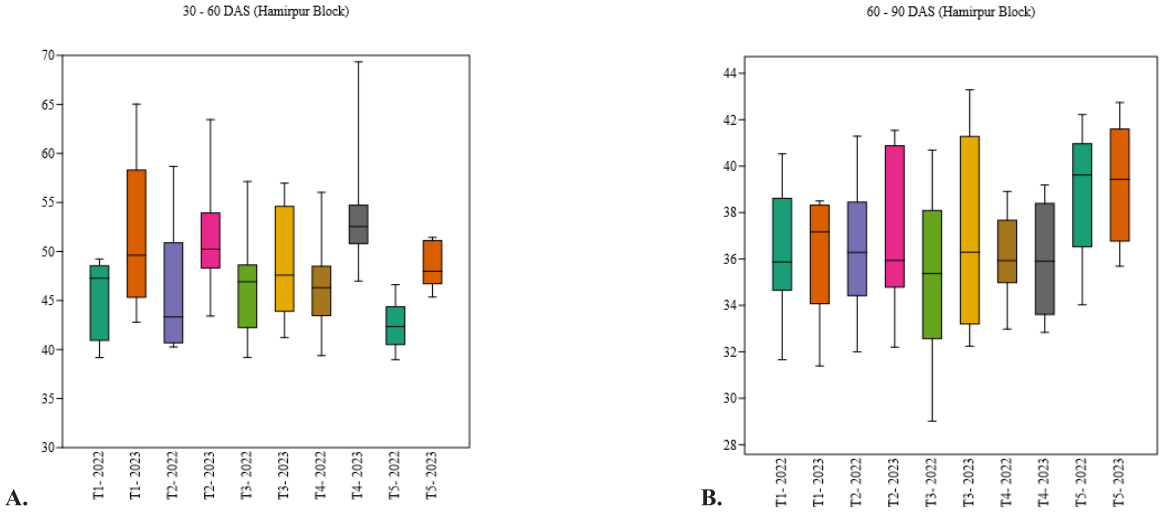

Fig 3: Effect of weed control treatments on relative growth rate (mg/g/day) in maize (Hamirpur block); at A- 30-60 DAS & B- 60-90

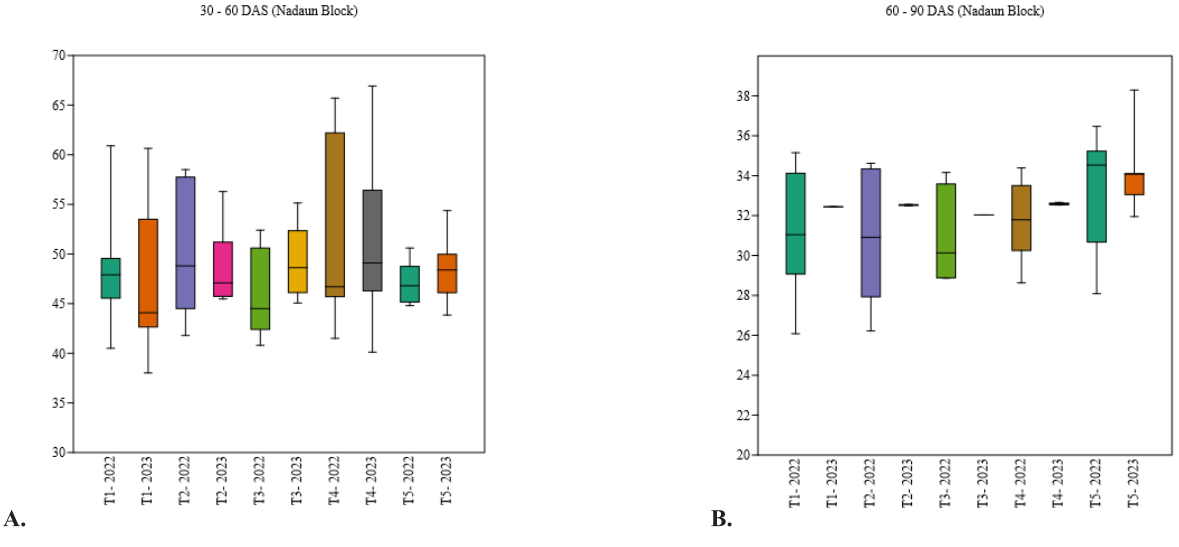

Fig 4: Effect of weed control treatments on relative growth rate (mg/g/day) in maize (Nadaun block); at A- 30-60 DAS & B- 60-90

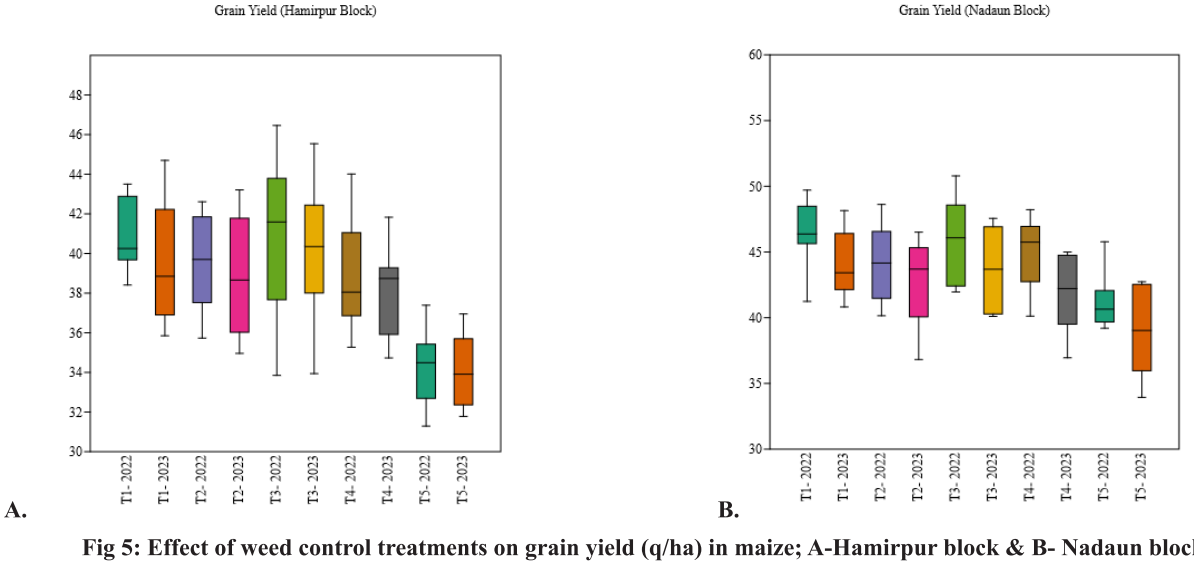

Fig 5: Effect of weed control treatments on grain yield (q/ha) in maize; A-Hamirpur block & B- Nadaun block

application of metribuzin in wheat and as well as with the application of topramezone in maize prior to the use of both herbicide combinations. Farmers' practice recorded significantly lower CGR. Relative growth rate was not significantly influenced by the weed control treatments at different stages during both the years. Tembotrione considerably increased crop growth rate (CGR) in comparison to other treatments by efficiently reducing weed density and biomass and increasing maize's ability to utilize resources (light, moisture, and nutrients). Its effectiveness in managing intricate weed flora helped to boost maize growth. These observations corroborate with the finding of Sharma *et al.* (2023).

The data presented in table 6 and 7 showed that different weed control treatments significantly affected the grain yield in both the blocks. In Hamirpur block, during *kharif* 2022 post-emergence application of both the new herbicides tested i.e., tembotrione 120 g/ha and topramezone 25.2 g/ha, remaining at par with each other, recorded significantly higher grain yield of maize as compared to farmers' practice. Similar trend was observed in the second year of the study, when the application of tembotrione followed by the application of metribuzin in wheat resulted in a significantly higher grain yield of maize. However, this treatment was comparable to the application of tembotrione preceded by the application of clodinafop propargyl + metsulfuron methyl as well as topramezone in maize that was preceded by the use of both herbicide combinations. In Nadaun block, similar findings were noticed that tembotrione resulted significantly higher grain yield, which was at par with the herbicide topramezone during both the years irrespective of effect of herbicides used in preceding wheat crop.

Conclusion

Present study revealed that the post-emergence application of any of the herbicides tested (tembotrione @ 120 /ha or topramezone @ 25.2 g/ha) at 25 DAS resulted in significantly lower total weed count as well as weed dry weight besides resulting higher growth and productivity of maize. Thus, these two herbicides can be a potential option for weed management of mixed weed flora in maize for boosting the crop productivity.

Conflict of interest: The authors declare that there is no conflict of interest among the authors in this research paper.

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