

Post-emergence herbicides enhance yield and profitability in *Kharif* maize (*Zea mays* L.)

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Abstract: A field research on ‘Evaluation of post-emergence herbicides in maize (*Zea mays* L.)’ was carried out at the research farm of ICAR-Indian Institute of Maize Research, Pusa Campus, IARI, New Delhi, India during *Kharif* season of 2017. It was found that the early post emergence tank-mix application of the pre-emergence (PE) and post-emergence (POE) herbicides and their sequential application increased crop growth parameters viz., plant population, plant height, dry matter accumulation (DMA), leaf area index (LAI) crop growth rate (CGR) and relative growth rate (RGR), yield attributes (cobs/ha, cob length, grains/row and grains/cob) in *Kharif* maize. However, no significant effects of different weed management practices were recorded on cob girth and grain rows/cob of the crop in our study. The application of the pre-emergence (PE) and post-emergence (POE) herbicides increased maize grain yield to the tune of 9.2 to 14.6 and 17.5 to 20 per cent over recommended practice (atrazine *fb* hand weeding), respectively. The increase in net returns over weedy check ranged from Rs. 15.12×10^3 (T_5) to 56.19×10^3 (T_{10})/ha and gave 3-5 times more net returns in different herbicides applied treatments. The range of the added cost in weed management with post-emergence herbicide was Rs 5.02×10^3 to 6.55×10^3 /ha over weedy check. Significantly the highest net returns (Rs. 56.19×10^3 /ha), additional net returns (Rs. 53.09×10^3 /ha) and

benefit-cost (BC) ratio (1.59) in *Kharif* maize obtained by application of 75% recommended dose of atrazine as pre-emergence followed by topramezone (25.2 g/ha) at 25 DAS which was at par with the application of 75% atrazine as pre-emergence followed by at tembotrione (120 g/ha) 25 days after sowing (DAS) and with early post-emergence tank-mix application of these combinations.

Keywords: Crop growth · Crop yield · Maize · Net returns · Post-emergence herbicide

Introduction

Maize is the third most important crop of India after rice and wheat that occupied 9.6 million ha area with average productivity of 3.0 tonnes/ha compared to the world average of 5.8 tonnes/ha. In India, maize is primarily cultivated during the *Kharif* season where weed is the most important yield-limiting factor. Maize is infested by a wide range of weed flora, viz. *Panicum spp.*, *Echinochloa colona*, *Cyperus rotundus*, *Commelina benghalensis* and *Trianthema portulacastrum* dominate during early stages of the crop growth whereas *Dactyloctenium aegyptium* toward the tasseling and maturity of the crop (Saini and Angiras, 1998). Even with a light infestation of weeds under ideal situation the weeds should be controlled throughout the crop-growing season for getting higher yield. However, the most critical period for crop weed competition are first six weeks after planting of crop because of initial slow growth and wider row spacing of maize, coupled with congenial weather conditions allow luxuriant weed growth which may reduce yield by 28–100 per cent (Pandey *et al.*, 1999; Dass *et al.*, 2012). During this critical period, weeding is

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essentially required by chemical or non-chemical means. Weeding by hands (labour) and mechanical means are expensive and many a times timely operations are not possible due to continuous rains in monsoon season. Research and development in herbicide technology has opened up new possibilities for chemical weed management practices.

There are good pre-emergence herbicidal options like, atrazine and pendimethalin are available in maize (Singh *et al.*, 2015) but the availability of post-emergence herbicides in need of the maize cultivation in south and central Asia in view of escalating labour prices. Topramezone and tembotrione are the selective, post-emergence herbicides that have been recently introduced for use in maize. These HPPD inhibiting herbicides are most effective in newly developing tissues that emerge bleached, because of failure to properly assemble photosynthetic units and thus they control weeds (Schonhammer *et al.*, 2006). The herbicide like tembotrione (Singh *et al.*, 2012) and halosulfuron along with 2,4-D are most common post-emergence herbicide used in maize worldwide (Kumar *et al.*, 2015). These provide an easy option for herbicidal-based weed management in maize especially in later seasons as the critical period of crop-weed completion extends up to 50 days whereas pre-emergence herbicides are effective up to 25–30 days. Thus, for enhancing yield and profitability in maize cultivation of India as well to reduce drudgery in crop cultivation identification of suitable post-emergence herbicide will be boon for the farmers. Thus, a study was conducted to explore the possibilities of the good option of herbicidal-based weed management in maize to improve crop growth and yield while simultaneously controlling weeds.

Materials and methods

A field experiment was conducted during the *Kharif* season of 2017 at ICAR-Indian Institute of Maize Research, Pusa Campus, New Delhi. The experimental farm used in the present study was under maize-wheat cropping system for last five years. The study site (New Delhi) is situated at 28° 40'N latitude, 77° 11'E longitude and at an altitude 228.6 m above mean sea level. The climate of the area is semi-arid, characterized by hot summer and severe cold winter. The season that received 565 mm rainfall and mean maximum and minimum temperature of 33.8°C and 23.3°C, respectively. However,

as effective rainfall calculated by CROPWAT-FAO was only 394 mm and long dry spell and hence two irrigations were applied for successful crop cycle. The soil of experimental field was sandy loam in texture and alkaline in nature (pH 7.6), EC (dS/m at 25°C) was 0.38, low in organic carbon (0.42 per cent) and available nitrogen (236.8±23.5 kg/ha), and medium in available phosphorus (14.8±1.5 kg/ha) and potash (232.4±15.2 kg/ha). The experiment was laid out in a randomized complete block design with three replications and twelve treatments. The treatments tested were T₁: Weedy check, T₂: Weed free check, T₃: Atrazine 1000 g/ha (PE) *fb* hand weeding at 25 DAS, T₄: Topramezone 30 g/ha at 25 DAS, T₅: Halosulfuron 75 g/ha at 25 DAS, T₆: Tembotrione 150 g/ha at 25 days after sowing (DAS), T₇: Topramezone 25.2 g/ha + Atrazine 750 g/ha at 15 DAS, T₈: Halosulfuron 67.5 g/ha + Atrazine 750 g/ha at 15 DAS, T₉: Tembotrione 120 g/ha + Atrazine 750 g/ha at 15 DAS, T₁₀: Atrazine 750 g/ha (PE) *fb* Topramezone 25.2 g/ha at 25 DAS, T₁₁: Atrazine 750 g/ha (PE) *fb* Halosulfuron 67.5 g/ha at 25 DAS, T₁₂: Atrazine 750 g/ha (PE) *fb* Tembotrione 120 g/ha at 25 DAS. The single cross hybrid maize cv. PMH 1 seeds were dibbled on the ridges spaced at 0.70 meters at 0.20 meters spacing using 20 kg seed/ha. The net plot was 12.6 m². The herbicide doses were calculated as per the treatments and applied as aqueous spray @ 400 litres/ha water using knapsack sprayer fitted with a flat-fan nozzle. Hand weeding was done to maintain the weed free plot at 15 DAS, 30 DAS and 50 DAS with the help of *khurpi*. A hand weeding was also done in T₃ (as standard check) at 25 DAS. All the nutrients and plant protection practices were followed as per the recommendation. The crop growth observations of plant population, plant height, leaf area, CGR, RGR, and DMA at different stages of maize crop were taken following standard protocols to know about periodically effect of weeds on the performance of maize crop growth. The crop yield attributes and yields of crop were recorded using standard methods in all experimental plots. The economics for the cost of cultivation, gross returns, net returns, benefit cost ratio and net returns/rupee invested were worked out on the basis of prevailing market rates of the inputs and minimum wages of the labour announced as per the government in the region. Analysis of variance (ANOVA) was done to determine treatment effects by using SAS 9.3. The least significant difference (LSD) test was used as a post hoc mean separation test (P < 0.05).

Results and discussion

Crop growth performance

The initial plant stands in maize (after thinning and gap filling operation) was statistically similar in all the treatments but the final plant stand (at harvest) was statistically superior in all the weed management treatments compared to weedy check. At the harvest, the maximum number of plants was observed with T₂ (Weed free check) that were statistically similar with T₃ (atrazine 1000 g/ha (PE) *fb* hand weeding at 25 DAS) and T₇ (Topramezone 25.2 g/ha + atrazine 750 g/ha at 15 DAS) treatments. The reasons for lower plant population in these treatments could be initially the maize and weeds during *Kharif* season grows faster as most of the *Kharif* season weeds are ephemeral in nature and completes life cycle in the very short span of time.

The significantly smallest plants observed in control plots (weedy check) at all the growth stages compared to weed management treatments. At 30 DAS, the tallest plant was rerecorded with T₂ (weed free check) which was statistically at par with T₃ (standard check) and combine/sequential application of the herbicides with T₉

and T₁₂. At 60 and 90 DAS and the highest plant height was recorded with standard check that was statistically similar with T₂ (weed free check) and tank-mix application of post-emergence herbicide viz., tembotrione (120 g/ha) or topramezone (25.2 g/ha) at 15 DAS or as sequential application at 25 DAS with 75% recommended dose of the atrazine in T₇, T₉, T₁₀ and T₁₂. Our findings of enhancement in the growth parameters of maize with lesser weed competition corroborates with Kumar *et al.* (2013). However, Soltani *et al.* (2007) and Thomas *et al.* (2010) reported that plant height did not influence with doses of topramezone which indicates the specificity of this herbicide to maize having no phytotoxic effect. This could probably be due to broad-spectrum weed control which resulted in efficient utilization of resources and more biomass accumulation. Almost similar finding were reported by Subramanyam *et al.* (2007).

The highest LAI (Table 2) was recorded under weed free check treatment, which was at par with T₁₀ and the other weed management treatments (T₃, T₇ and T₁₂). Alike plant height, significantly lower LAI was recorded in T₁ (weedy check treatment) at all growth stages. However, at 90 DAS, the LAI was statistically similar in all the treatments, which could be due to lesser weed population

Table 1. Effect of post-emergence herbicides application on the plant population and plant height of *Kharif* maize

Treatment	Plant population ($\times 10^3$ plants/ha)		Plant height (cm)		
	Initial	At harvest	30 DAS	60 DAS	90 DAS
T ₁	71.40	54.1 ^f	44.56 ^g	131.44 ^f	141.96 ^f
T ₂	71.51	70.5 ^a	78.33 ^a	172.00 ^{ab}	185.76 ^{ab}
T ₃	71.45	69.2 ^{ab}	69.33 ^{abc}	173.56 ^a	187.44 ^a
T ₄	71.53	59.93 ^d	54.78 ^{ef}	159.22 ^{bcde}	171.96 ^{bcde}
T ₅	71.19	58.19 ^e	57.33 ^{def}	149.89 ^e	161.88 ^e
T ₆	71.22	60.56 ^d	51.90 ^{fg}	168.78 ^{abc}	182.28 ^{abc}
T ₇	71.52	69.19 ^{ab}	66.46 ^{bcd}	161.78 ^{abcde}	174.72 ^{abcde}
T ₈	71.49	67.92 ^{bc}	60.22 ^{cdef}	155.67 ^{cde}	168.12 ^{cde}
T ₉	71.11	68.98 ^b	75.94 ^{ab}	162.89 ^{abcde}	175.92 ^{abcde}
T ₁₀	71.28	68.88 ^b	66.67 ^{bcd}	167.56 ^{abcd}	180.96 ^{abcd}
T ₁₁	71.59	67.26 ^c	63.56 ^{cde}	154.11 ^{de}	166.44 ^{de}
T ₁₂	71.37	68.81 ^b	77.56 ^a	173.89 ^a	187.80 ^a
p-Value	0.537	<.0001	<.0001	<.0001	<.0001
LSD (P=0.05)	NS	1.45	9.79	13.79	14.89

Note: T₁: Weedy check, T₂: Weed free check, T₃: Atrazine 1000 g/ha (PE) *fb* hand weeding at 25 DAS, T₄: Topramezone 30 g/ha at 25 DAS, T₅: Halosulfuron 75 g/ha at 25 DAS, T₆: Tembotrione 150 g/ha at 25 DAS, T₇: Topramezone 25.2 g/ha + atrazine 750 g/ha at 15 DAS, T₈: Halosulfuron 67.5 g/ha + atrazine 750 g/ha at 15DAS, T₉: Tembotrione 120 g/ha + atrazine 750 g/ha at 15 DAS, T₁₀: Atrazine 750 g/ha (PE) *fb* topramezone 25.2 g/ha at 25 DAS, T₁₁: Atrazine 750 g/ha (PE) *fb* halosulfuron 67.5 g/ha at 25 DAS, T₁₂: Atrazine 750 g/ha (PE) *fb* tembotrione 120 g/ha at 25 DAS. Means followed by a similar lower case letter within a column are not significantly different according to least significant difference test (P=0.05).

and biomass accumulation in these treatments at various crop growth stages. The dry matter accumulation (Table 2 & Figure 1) was recorded with T_{10} , T_{11} and T_{12} , which was on par with T_2 and T_8 at 30 DAS. However, at 60 and 90 DAS it was similar in all weed management treatments, it might be due to more resource availability in absence of the intense crop-weed competition the higher crop growth and dry matter accumulation was recorded in the better weed control plots (Subramanyam, 1998).

The highest CGR and RGR (Table 3) at 0-30 DAS was recorded in herbicides application treatments with T_{10} ,

which was statistically on par with T_8 , T_{11} and T_{12} and it was at par with all weed management treatments at 30-60 and 60-90 DAS. At 30-60 DAS the highest RGR was in T_{12} (atrazine *fb* tembotrione). At 60-90 DAS, RGR was statistically similar. In all the cases, the CGR and RGR were lowest in control treatments where no application of herbicides was done. It indicates that the weed management is very essential for the higher growth rate of maize and can cause significant reduction in biomass accumulation in maize if weed management is ignored in its production. The similar findings of the enhanced growth with lesser weed completion were also observed by Sinha *et al.* (2001).

Table 2. Effect of post-emergence herbicides application on leaf area index and dry matter accumulation of *Kharif* maize

Treatment	Leaf area index (LAI)			Dry matter accumulation (g/plant)		
	30 DAS	60 DAS	90 DAS	30 DAS	60 DAS	90 DAS
T_1	1.65 ^g	3.10 ^f	2.23	20.00 ^e	39.33 ^b	90.07 ^b
T_2	2.80 ^a	5.35 ^a	3.04	39.67 ^{ab}	98.33 ^a	225.18 ^a
T_3	2.46 ^{bc}	4.84 ^{abc}	2.37	37.67 ^{abc}	91.00 ^a	208.39 ^a
T_4	2.06 ^{ef}	3.79 ^e	2.45	31.67 ^{bcd}	94.67 ^a	216.79 ^a
T_5	1.93 ^{fg}	3.83 ^e	2.47	24.67 ^{de}	89.67 ^a	205.34 ^a
T_6	2.20 ^{cdef}	3.95 ^{de}	2.53	30.67 ^{cd}	96.00 ^a	219.84 ^a
T_7	2.42 ^{bcd}	4.97 ^{abc}	2.68	36.67 ^{abc}	95.00 ^a	217.55 ^a
T_8	2.12 ^{def}	4.45 ^{bcde}	2.88	40.67 ^a	90.67 ^a	207.63 ^a
T_9	2.28 ^{cde}	4.52 ^{bcd}	2.25	35.67 ^{abc}	88.33 ^a	202.28 ^a
T_{10}	2.37 ^{cde}	5.03 ^{ab}	2.85	41.33 ^a	95.67 ^a	219.08 ^a
T_{11}	2.35 ^{cde}	4.36 ^{cde}	2.67	40.67 ^a	96.67 ^a	221.37 ^a
T_{12}	2.73 ^{ab}	4.97 ^{abc}	2.90	41.00 ^a	97.00 ^a	222.13 ^a
p-Value	<.0001	<.0001	0.1236	0.0001	<.0001	<.0001
LSD (P=0.05)	0.325	0.661	NS	8.17	17.18	39.35

Note: T_1 : Weedy check, T_2 : Weed free check, T_3 : Atrazine 1000 g/ha (PE) *fb* hand weeding at 25 DAS, T_4 : Topramezone 30 g/ha at 25 DAS, T_5 : Halosulfuron 75 g/ha at 25 DAS, T_6 : Tembotrione 150 g/ha at 25 DAS, T_7 : Topramezone 25.2 g/ha + atrazine 750 g/ha at 15 DAS, T_8 : Halosulfuron 67.5 g/ha + atrazine 750 g/ha at 15DAS, T_9 : Tembotrione 120 g/ha + atrazine 750 g/ha at 15 DAS, T_{10} : Atrazine 750 g/ha (PE) *fb* topramezone 25.2 g/ha at 25 DAS, T_{11} : Atrazine 750 g/ha (PE) *fb* halosulfuron 67.5 g/ha at 25 DAS, T_{12} : Atrazine 750 g/ha (PE) *fb* tembotrione 120 g/ha at 25 DAS. Means followed by a similar lowercase letter within a column are not significantly different according to least significant difference test (P=0.05).

Figure 1. Effect of post-emergence herbicide application on dry matter accumulation in *Kharif* maize at various crop stages.

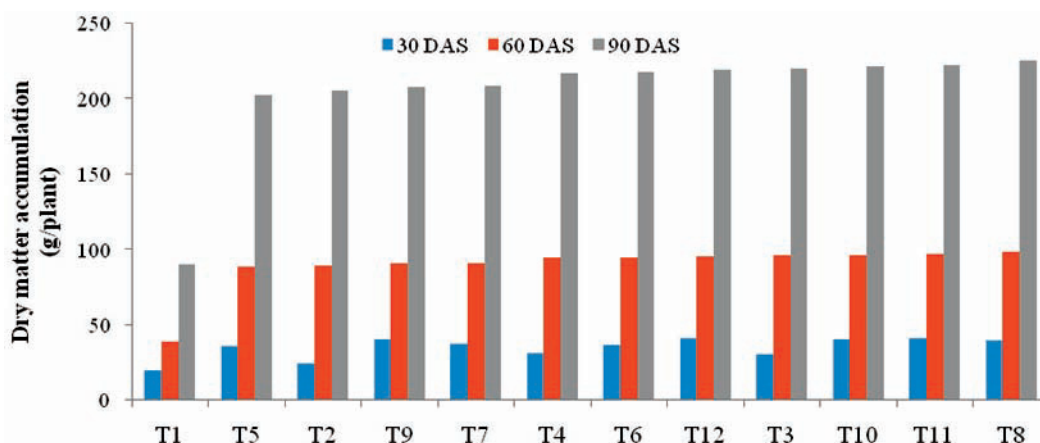


Table 3. Effect of post-emergence herbicides application on crop growth rate and relative growth rate of *Kharif* maize

Treatment	Crop growth rate (g/plant/day)			Relative growth rate (mg/g/day)		
	0–30 DAS	30–60 DAS	60–90 DAS	0–30 DAS	30–60 DAS	60–90 DAS
T ₁	0.67 ^e	0.64 ^b	1.69 ^b	43.32 ^e	53.08 ^b	65.07 ^b
T ₂	1.32 ^{ab}	1.96 ^a	4.23 ^a	53.20 ^{ab}	66.41 ^a	78.40 ^a
T ₃	1.26 ^{abc}	1.78 ^a	3.91 ^a	52.33 ^{abc}	65.14 ^a	77.14 ^a
T ₄	1.06 ^{bcd}	2.10 ^a	4.07 ^a	49.96 ^{bc}	65.86 ^a	77.85 ^a
T ₅	0.82 ^{de}	2.17 ^a	3.86 ^a	46.10 ^{de}	65.06 ^a	77.05 ^a
T ₆	1.02 ^{cd}	2.18 ^a	4.13 ^a	49.47 ^{cd}	66.04 ^a	78.03 ^a
T ₇	1.22 ^{abc}	1.94 ^a	4.09 ^a	51.99 ^{abc}	65.89 ^a	77.88 ^a
T ₈	1.36 ^a	1.67 ^a	3.90 ^a	53.63 ^a	65.15 ^a	77.14 ^a
T ₉	1.19 ^{abc}	1.76 ^a	3.80 ^a	51.64 ^{abc}	64.74 ^a	76.74 ^a
T ₁₀	1.38 ^a	1.81 ^a	4.11 ^a	53.85 ^a	65.93 ^a	77.93 ^a
T ₁₁	1.36 ^a	1.87 ^a	4.16 ^a	53.56 ^a	66.13 ^a	78.13 ^a
T ₁₂	1.37 ^a	1.87 ^a	4.17 ^a	53.73 ^a	66.15 ^a	78.15 ^a
p-Value	0.0001	0.0021	<.0001	<.0001	<.0001	<.0001
LSD (P=0.05)	0.27	0.58	0.74	3.53	2.82	2.82

Note: T₁: Weedy check, T₂: Weed free check, T₃: Atrazine 1000 g/ha (PE) *fb* hand weeding at 25 DAS, T₄: Topramezone 30 g/ha at 25 DAS, T₅: Halosulfuron 75 g/ha at 25 DAS, T₆: Tembotrione 150 g/ha at 25 DAS, T₇: Topramezone 25.2 g/ha + atrazine 750 g/ha at 15 DAS, T₈: Halosulfuron 67.5 g/ha + atrazine 750 g/ha at 15DAS, T₉: Tembotrione 120 g/ha + atrazine 750 g/ha at 15 DAS, T₁₀: Atrazine 750 g/ha (PE) *fb* topramezone 25.2 g/ha at 25 DAS, T₁₁: Atrazine 750 g/ha (PE) *fb* halosulfuron 67.5 g/ha at 25 DAS, T₁₂: Atrazine 750 g/ha (PE) *fb* tembotrione 120 g/ha at 25 DAS. Means followed by a similar lower case letter within a column are not significantly different according to least significant difference test (P=0.05).

Yield attributes

The data on yield attributes are presented in Table 4. The significantly higher cobs were recorded in T₂ while the highest bareness (39.0 per cent) was registered in control (weedy check). However, in other treatments of weed management, the bareness ranged from 2.03 to 6.41 per cent only. The cobs/ha in standard checks i.e. atrazine 1000 g/ha (PE) *fb* hand weeding at 25 DAS were statistically similar with application of post-emergence herbicide treatments (T₇, T₉, T₁₀ and T₁₂). Similarly, the increase in the cob length in the range of 30.7 to 42.3 per cent in all weed management treatments over weedy check might be due to higher LAI and the dry matter accumulation in absence of crop-weed also reported by Walia *et al.* (2007). The grain rows/cob was found non-significant but weed management practices influenced grains per row and grains per cob in maize. The cob girth could be more genetically linked and thus was not changed with the various management practices could be the probable reason for the statistically similar in weedy check and other treatments (Sanodiya *et al.*, 2013). The highest grains/row and grains/cob were registered with T₂ which was statistically similar to T₁₂ and other post-emergence

herbicide application treatments. Significantly the highest 1000-grains weight in maize was recorded with T₁₂. The more weed competition might also lead to decreased seed size and thus decreased 1000-grain weight while it increased the kernel weight in more resource available plots with the lesser crop-weed competition. The similar observation reported by Gopinath and Kundu (2008).

Crop yield

The cob yield of maize increased significantly with the weed-free check (T₂), which was on par with T₇, T₉, T₁₀ and T₁₂ in the range of 33.2 (T₅) to 135.2 (T₁₀) per cent over weedy check. Similarly, significantly the highest stover yield with application of atrazine (PE) *fb* topramezone (POE) at 25 DAS (T₁₀), which was on par with T₂, T₇, T₉, T₁₁ and T₁₂. Increased in the range from 16.2 (T₅) to 62.1 (T₁₀) per cent over weedy check. The grain yield as an economic produce in maize increased significantly with weed free check (T₂), which was on par with T₁₀ and T₁₂. The increase in the grain and biological yield in *Kharif* maize over weedy check were 63 to 208 and 22.1 (T₅) to 87.2 (T₁₀) per cent, respectively (Table 5 & Figure 2), which were almost more than

Table 4. Effect of post-emergence herbicides application on yield attributes of *Kharif* maize

Treatment	Cobs ('000/ha)	Bareness (%)	Cob length (cm)	Cob girth (cm)	Grain rows per cob	Grains per row	Grains per cob	1000–grains weight (g)
T ₁	32.96 ^e	39.04 ^a	14.83 ^b	13.47	13.56	26.00 ^f	352.00 ^e	226.67 ^d
T ₂	69.94 ^a	0.76 ^e	18.73 ^a	13.60	14.22	35.89 ^a	510.30 ^a	278.33 ^b
T ₃	67.52 ^b	2.41 ^{cde}	20.81 ^a	14.63	14.22	34.11 ^{abcde}	485.33 ^{abc}	280.00 ^b
T ₄	56.33 ^d	5.96 ^b	20.24 ^a	14.48	14.11	32.00 ^{de}	451.48 ^{cd}	266.67 ^{bc}
T ₅	54.89 ^d	5.66 ^b	20.07 ^a	14.09	14.00	31.78 ^e	444.89 ^d	260.00 ^c
T ₆	56.67 ^d	6.41 ^b	19.93 ^a	14.38	14.00	32.78 ^{cde}	458.89 ^{cd}	270.00 ^{bc}
T ₇	67.41 ^b	2.58 ^{cde}	20.64 ^a	14.04	14.00	34.22 ^{abcd}	479.11 ^{abcd}	266.67 ^{bc}
T ₈	64.30 ^c	5.34 ^b	20.33 ^a	14.42	13.56	33.00 ^{bcde}	447.41 ^d	263.33 ^{bc}
T ₉	65.67 ^{bc}	4.78 ^{bc}	21.10 ^a	14.31	13.78	34.67 ^{abc}	477.04 ^{abcd}	280.00 ^b
T ₁₀	67.48 ^b	2.03 ^{de}	20.57 ^a	14.31	14.00	34.00 ^{abcde}	475.26 ^{bcd}	270.00 ^{bc}
T ₁₁	64.67 ^c	3.82 ^{bcd}	20.00 ^a	14.36	14.00	32.78 ^{cde}	458.89 ^{cd}	276.67 ^{bc}
T ₁₂	67.19 ^b	2.36 ^{cde}	19.38 ^a	14.38	14.22	35.22 ^{ab}	500.78 ^{ab}	298.33 ^a
p-Value	<.0001	<.0001	0.0021	0.2892	0.6211	<.0001	<.0001	<.0001
LSD(P=0.05)	0.97	2.68	2.39	NS	NS	2.43	34.98	18.27

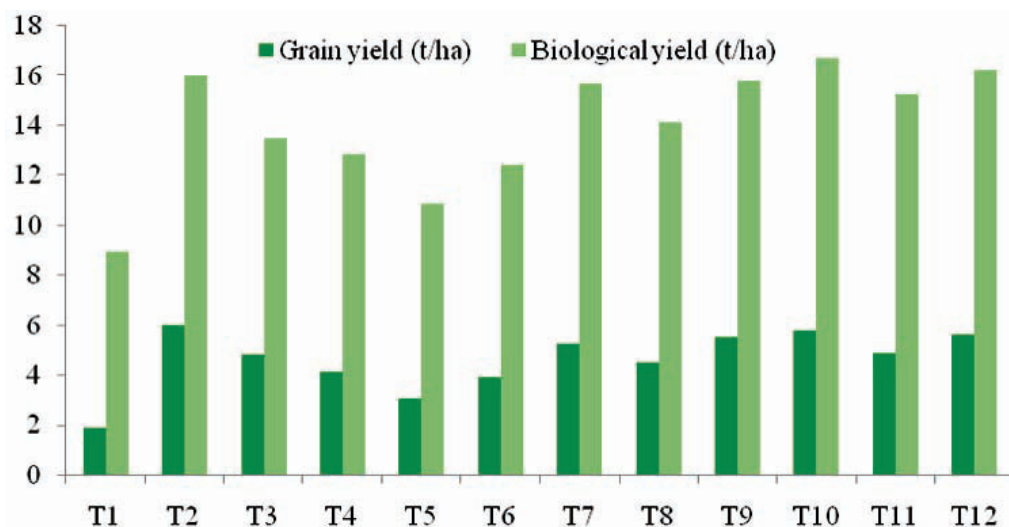
Note: T₁: Weedy check, T₂: Weed free check, T₃: Atrazine 1000 g/ha (PE) *fb* hand weeding at 25 DAS, T₄: Topramezone 30 g/ha at 25 DAS, T₅: Halosulfuron 75 g/ha at 25 DAS, T₆: Tembotrione 150 g/ha at 25 DAS, T₇: Topramezone 25.2 g/ha + atrazine 750 g/ha at 15 DAS, T₈: Halosulfuron 67.5 g/ha + atrazine 750 g/ha at 15DAS, T₉: Tembotrione 120 g/ha + atrazine 750 g/ha at 15 DAS, T₁₀: Atrazine 750 g/ha (PE) *fb* topramezone 25.2 g/ha at 25 DAS, T₁₁: Atrazine 750 g/ha (PE) *fb* halosulfuron 67.5 g/ha at 25 DAS, T₁₂: Atrazine 750 g/ha (PE) *fb* tembotrione 120 g/ha at 25 DAS. Means followed by a similar lower case letter within a column are not significantly different according to least significant difference test (P=0.05).

Table 5. Effect of post-emergence herbicides application on yields, shelling and harvest index of *Kharif* maize

Treatment	Cob yield (t/ha)	Stover yield (t/ha)	Grain yield (t/ha)	Shelling (%)	Harvest index (%)
T ₁	3.07 ^h	5.86 ^f	1.87 ^h	61.04 ^c	20.94 ^f
T ₂	7.43 ^a	8.59 ^{abc}	6.01 ^a	80.68 ^a	37.45 ^a
T ₃	6.06 ^{cde}	7.43 ^{de}	4.80 ^{cde}	79.22 ^{ab}	35.66 ^{ab}
T ₄	5.35 ^{ef}	7.51 ^{cde}	4.12 ^{ef}	77.21 ^{ab}	31.98 ^d
T ₅	4.09 ^g	6.81 ^{ef}	3.04 ^g	74.49 ^b	27.84 ^e
T ₆	5.02 ^{fg}	7.40 ^{de}	3.93 ^f	78.48 ^{ab}	31.64 ^d
T ₇	6.66 ^{abcd}	9.04 ^{ab}	5.24 ^{bc}	78.76 ^{ab}	33.39 ^{cd}
T ₈	5.86 ^{def}	8.29 ^{bcd}	4.49 ^{def}	77.11 ^{ab}	31.65 ^d
T ₉	6.90 ^{abc}	8.91 ^{ab}	5.50 ^{abc}	79.71 ^{ab}	34.82 ^{bc}
T ₁₀	7.22 ^{ab}	9.50 ^a	5.76 ^{ab}	79.96 ^a	34.45 ^{bc}
T ₁₁	6.41 ^{bcd}	8.88 ^{ab}	4.87 ^{cd}	76.15 ^{ab}	31.90 ^d
T ₁₂	7.00 ^{abc}	9.23 ^{ab}	5.64 ^{ab}	80.49 ^a	34.72 ^{bc}
p-Value	<.0001	<.0001	<.0001	<.0001	<.0001
LSD (P=0.05)	0.97	1.09	0.73	5.35	2.15

Note: T₁: Weedy check, T₂: Weed free check, T₃: Atrazine 1000 g/ha (PE) *fb* hand weeding at 25 DAS, T₄: Topramezone 30 g/ha at 25 DAS, T₅: Halosulfuron 75 g/ha at 25 DAS, T₆: Tembotrione 150 g/ha at 25 DAS, T₇: Topramezone 25.2 g/ha + atrazine 750 g/ha at 15 DAS, T₈: Halosulfuron 67.5 g/ha + atrazine 750 g/ha at 15DAS, T₉: Tembotrione 120 g/ha + atrazine 750 g/ha at 15 DAS, T₁₀: Atrazine 750 g/ha (PE) *fb* topramezone 25.2 g/ha at 25 DAS, T₁₁: Atrazine 750 g/ha (PE) *fb* halosulfuron 67.5 g/ha at 25 DAS, T₁₂: Atrazine 750 g/ha (PE) *fb* tembotrione 120 g/ha at 25 DAS. Means followed by a similar lower case letter within a column are not significantly different according to least significant difference test (P=0.05).

Figure 2. Effect of post-emergence herbicides application on grain and biological yields of *Kharif* maize



double than weedy check. The enhancement in the growth attributes might have lead to increased cob and stover yield in these treatments in our study. Kumar *et al.* (2013) reported yield enhancement in atrazine + halosulfuron @ 1.0 kg *a.i.*/ha + 90 g *a.i.*/ha as (POE) application in zero-till maize. The significantly lowest shelling percentage and harvest index of maize were recorded with weedy check and the highest were recorded with T₂, which was at par with all other weed management practices except T₅

which shows that the better weed management has the potential for a better source-sink relationship also reported by Sanodiya *et al.* (2013).

Economics

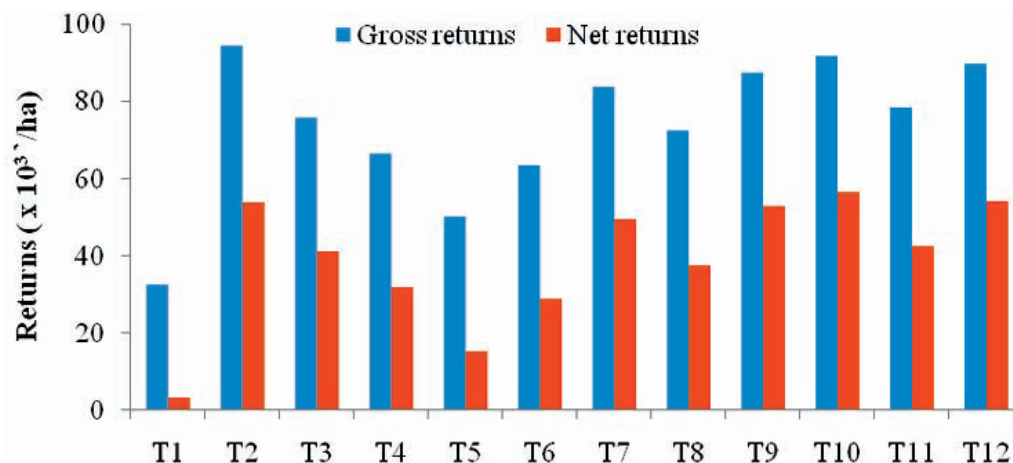
The application of post-emergence herbicides gave the highest net returns of Rs. 56.19 ×10³/ha (T₁₀) which was at par with T₁₂. However, the lowest net returns were

Table 6. Effect of post-emergence herbicides application on economics of *Kharif* maize production

Treatment	Gross returns (×10 ³ Rs./ha)	Net returns (×10 ³ Rs./ha)	BC ratio	Added cost (‘000 Rs/ha)	Additional return over a weedy check (‘000 Rs./ha)	Additional return over a weedy check (Rs./Rs. invested)
T ₁	32.50 ^h	3.09 ^g	0.11 ^g	-	-	-
T ₂	94.17 ^a	53.52 ^{ab}	1.32 ^{abc}	11.23	50.42 ^{ab}	4.49 ^d
T ₃	75.79 ^{cde}	41.03 ^{cd}	1.18 ^{bcd}	5.35	37.93 ^{cd}	7.09 ^{bc}
T ₄	66.28 ^{ef}	31.61 ^{de}	0.91 ^{de}	5.26	28.51 ^{de}	5.42 ^{cd}
T ₅	50.07 ^g	15.12 ^f	0.43 ^f	5.54	12.02 ^f	2.17 ^e
T ₆	63.46 ^f	28.58 ^e	0.82 ^e	5.47	25.48 ^e	4.66 ^d
T ₇	83.76 ^{abc}	49.32 ^{abc}	1.43 ^{ab}	5.02	46.22 ^{abc}	9.21 ^a
T ₈	72.26 ^{def}	37.32 ^{de}	1.07 ^{cde}	5.53	34.22 ^{de}	6.19 ^{cd}
T ₉	87.24 ^{ab}	52.81 ^{ab}	1.53 ^a	5.02	49.71 ^{ab}	9.90 ^a
T ₁₀	91.64 ^a	56.19 ^a	1.59 ^a	6.04	53.09 ^a	8.79 ^{ab}
T ₁₁	78.34 ^{bcd}	42.38 ^{bcd}	1.18 ^{bcd}	6.55	39.28 ^{bcd}	6.00 ^{cd}
T ₁₂	89.56 ^a	54.11 ^a	1.53 ^a	6.04	51.01 ^a	8.45 ^{ab}
p-Value	<.0001	<.0001	<.0001	-	<.0001	<.0001
LSD (P=0.05)	11.15	11.15	0.31	-	11.72	1.99

Note: T₁: Weedy check, T₂: Weed free check, T₃: Atrazine 1000 g/ha (PE) *fb* hand weeding at 25 DAS, T₄: Topramezone 30 g/ha at 25 DAS, T₅: Halosulfuron 75 g/ha at 25 DAS, T₆: Tembotrione 150 g/ha at 25 DAS, T₇: Topramezone 25.2 g/ha + atrazine 750 g/ha at 15 DAS, T₈: Halosulfuron 67.5 g/ha + atrazine 750 g/ha at 15DAS, T₉: Tembotrione 120 g/ha + atrazine 750 g/ha at 15 DAS, T₁₀: Atrazine 750 g/ha (PE) *fb* topramezone 25.2 g/ha at 25 DAS, T₁₁: Atrazine 750 g/ha (PE) *fb* halosulfuron 67.5 g/ha at 25 DAS, T₁₂: Atrazine 750 g/ha (PE) *fb* tembotrione 120 g/ha at 25 DAS. Means followed by a similar lower case letter within a column are not significantly different according to least significant difference test (P=0.05).

Figure 3. Effect of post-emergence herbicides application on gross and net returns of *Kharif* maize



recorded in control (Rs. $3.09 \times 10^3/\text{ha}$). The mean increase in net returns ranged from Rs. 15.12 (T_5) to 56.19 (T_{10}) $\times 10^3/\text{ha}$ across the herbicides applied treatments, which gave three to five times more net returns compared to weedy check. The significantly highest BC ratio was observed in the T_{10} that was at par with T_2 , T_7 , T_9 and T_{12} . The added cost and additional return showed in Table 6 & Figure 3. The uniform cost of Rs. 29,410/ha was incurred in maize cultivation. The range of the added cost in weed management was Rs. 5.02 to $6.55 \times 10^3/\text{ha}$. The significantly highest additional net returns were found in the PE atrazine fb POE application of topramezone and tembotrione with T_{10} and T_{12} . The additional returns Rs./Rs. invested was found significantly highest with T_9 which was at par with T_7 . The increase in the net returns was due to increase in grain and stover yields of maize in these treatments as compared to weedy check which leads to enhanced returns in maize cultivation as the range of the added cost in weed management was Rs. 5.02 to $6.55 \times 10^3/\text{ha}$ only. Singh *et al.* (2012) also reported enhancement in net returns from maize with the use of the tembotrione. The economic viability of the post-emergence herbicide application became more relevant in the scenario of the escalating farm labour prices.

Conclusion

The application of post-emergence herbicide viz., tembotrione (120 g/ha) / topramezone (25.2 g/ha) as tank-mix as early post-emergence at 15 DAS or as sequential application at 25 DAS with 75% recommended dose of the atrazine (750 g/ha) gave significantly enhanced crop growth, yield and net returns in *Kharif* maize. Thus, these

post-emergence herbicides could be adopted for higher productivity and profitability in *Kharif* maize production.

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