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Post-emergence herbicides efficacy for weed management in *kharif* maize (*Zea mays)*

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ABSTRACT

The escalating labour prices have significantly increased the production cost of *kharif* maize in India. To address this, a field experiment was conducted (2017) to evaluate the efficacy of post-emergence herbicide in *kharif* maize (*Zea mays* L.) at ICAR-Indian Institute of Maize Research, Pusa Campus, New Delhi. The tank-mix post-emergence herbicide application, viz. tembotrione (120 g/ha) or topramezone (25.2 g/ha) at 15 DAS with 75% atrazine (750 g/ha) or as a sequential application at 25 DAS after pre-emergence (PE) 75% atrazine gave significant weed control in *kharif* maize by reducing density and dry weight. Significantly higher weed-control efficiency, weed-control index, herbicide efficiency index and lower weed persistence index were found in weed-free check, which was at par with PE atrazine (1000 g/ha) followed by hand weeding at 25 DAS and the post-emergence herbicide application of tembotrione (120 g/ha) /topramezone (25.2 g/ha) as tank-mix with 75% atrazine dose as early post-emergence at 15 DAS or as the sequential application of these combinations. Significantly lowest weed index was observed in the sequential application of tembotrione/topramezone at 25 DAS after 75% atrazine dose as PE while the highest weed index (49.3) with alone halosulfuron application. It was concluded that the application of post-emergence herbicide, viz. tembotrione (120 g/ha) /topramezone (25.2 g/ha) as tank-mix at 15 DAS with 75% dose of atrazine (750 g/ha) or as a sequential application at 25 DAS after 75% atrazine as PE found promising for better weed control and grain yield in *kharif* maize.

Keywords: Herbicide-efficiency index, Maize, Weed-control efficiency/index, Weed dynamics, Weed-persistence index

Maize (*Zea mays* L.) is the third most important crop of India after rice and wheat that occupied 9.6 m 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* 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 crop growth stages, whereas *Dactyloctenium aegyptium* toward the tasseling and crop maturity (Singh *et al.* 2015). The most critical period for crop weed competition is the first six weeks after crop planting owing to initial slow growth and wider row spacing coupled with congenial weather for weed growth may reduce yield by 28–100% (Dass *et al*. 2012). During this critical period, weeding is essentially required by chemical or non-chemical means. However, weeding by manual and mechanical means is expensive and many a time it is not possible due to continuous rains in the monsoon season.

There is a good pre-emergence herbicidal option available in maize (Singh *et al*. 2015) but the post-emergence herbicides are scarce. Topramezone and tembotrione are the selective, post-emergence herbicides in maize introduced recently. These HPPD (4-hydroxyphenylpyruvate dioxygenase) inhibiting herbicides are most effective in weeds control by bleaching of developing tissues. As the critical period of crop-weed competition extends up to 50 days these provide an easy option for herbicidal-based weed management in maize, especially in later seasons. Additionally, in the scenario of no pre-emergence weed management, the grower looks for suitable post-emergence herbicides for saving his crop from weed losses. Thus, for enhancing yield and profitability in maize cultivation of India as well as to reduce drudgery in crop cultivation identification of suitable post-emergence herbicide will be a 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 while simultaneously controlling weeds.

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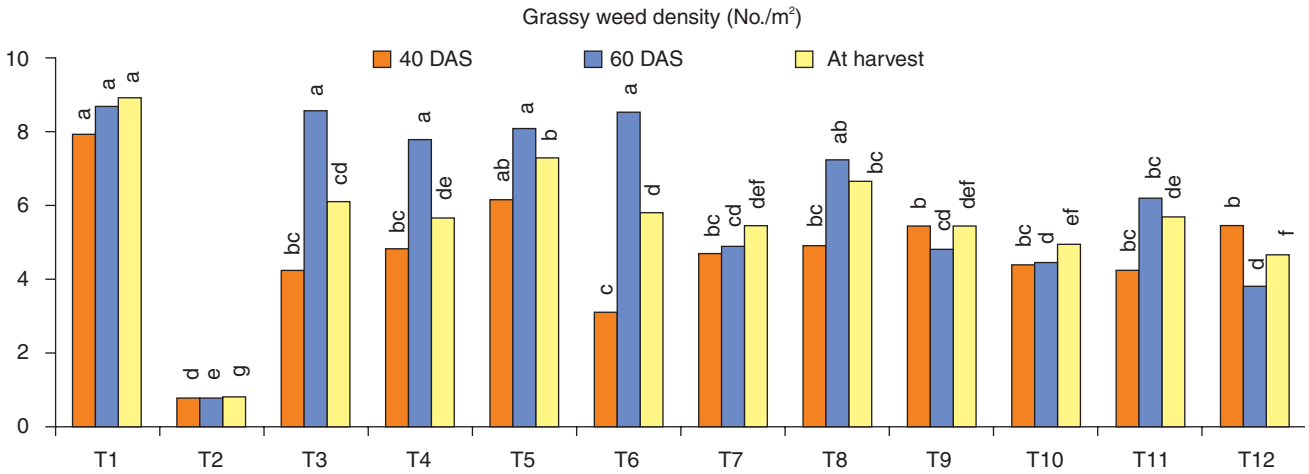

Fig 1 Effect of post emergence herbicides application on grassy weeds density (no./m^2) at various crop growth stages in *kharif* maize.

MATERIALS AND METHODS

A field experiment was conducted during the *kharif* 2017 for evaluation of post emergence herbicides in *kharif* maize at ICAR-Indian Institute of Maize Research, Pusa Campus, New Delhi. The experimental farm used in the present study was under a maize-wheat cropping system for the last five having even topography and a good drainage facility. The study site (New Delhi) is situated at 28º 40'N latitude, 77º 11'E longitude and an altitude of about 228 m above mean sea level in a semi-arid climate. The *kharif* 2017 study period received 565 mm rainfall with mean maximum and minimum temperature of 33.8°C and 23.3°C, respectively and total evaporation was 535 mm. However, in a long dry spell, two irrigations were applied for successful crop raising. The soil of the experimental field was sandy loam in texture and alkaline in nature (*p*H 7.6), 0.38 dS/m EC, low in organic carbon (0.42%) 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 (RCBD) with three replications and 12 treatments. The 12 treatments tested were: 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. The maize cv. PMH 1 seeds were dibbled on the ridges spaced at 0.70 m (row to row) at 0.20 m spacing. The herbicide doses were calculated as per the treatments and applied as aqueous spray @ 400 l/ha water using a knapsack sprayer fitted with a flat fan nozzle. Pre-emergence herbicide atrazine @ 700 or 1000 g/ha was applied as per the treatments in T_3, T_{10}, T_{11} and T_{12} within two days after sowing of the crop. The early mixture of the pre and post-emergence herbicides as tank-mix in 400 l of water/ha at 15 DAS were applied in T_7, T_8 to T_9, respectively. Post emergence herbicides were applied at 25 DAS using 400 l water in T_4, T_5 to T_6. Pre-emergence followed by post-emergence application of herbicide was done at 25 DAS in T_{10}, T_{11} to T_{12}. Weeding was done to maintain the weed-free plot at 15, 30 and 50 days after sowing (DAS) with sickle (*khurpi*). A hand weeding was also done in T_3 treatment at 25 DAS. The recommended dose of nutrients @ 150:26.2:33.2 N:P:K kg/ha with 33% basal N for Delhi region in hybrid maize was applied at the time of sowing and the rest of N was applied in two equal splits at knee high and tasseling stage. The observation on the weed flora as grasses, broad-leaved and sedges recorded at 40, 60 and harvest. The data on weed density and their dry matter accumulation were transformed by square root transformation to follow the normal distribution before statistical analysis. The efficacy of weed management was assessed by weed index (WI), weed control efficiency (WCE), weed control index (WCI), herbicide efficiency index (HEI) and weed persistence index (WPI). Analysis

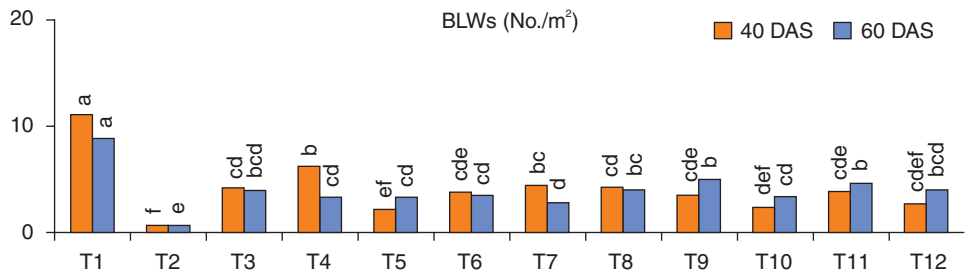

Fig 2 Effect of post emergence herbicides application on BLWs density (no./m^2) at various crop growth stages in *kharif* maize.

of variance (ANOVA) was done using SAS 9.3 software. The Least significant difference (LSD) test was used as a post hoc mean separation test (P<0.05).

RESULTS AND DISCUSSION

Effect of different weed management treatments on weed density: At harvest, there was no broad-leaved weed (BLW), however, the grassy weeds and sedges recorded at all crop stages. This might be due to over-dominance of the grassy weeds and non-shade tolerance of the BLW which resulted in their nil population at maize harvest. Moreover, most of the BLW were annual while some grassy weeds and sedges were perennial. Similar findings of the different weed flora in maize were reported by Madhavi *et al*. (2014). Amongst the weed management treatments, the significantly lowest grassy weeds density was observed in T_6, T_{10} and T_{12} at 40, 60 DAS and harvest, respectively (Fig 1). These were at par with T_3 at 40 DAS; T_7 at 60 DAS and harvest stage of the crop. Overall, the grassy weed population was highest at 60 DAS across the various treatments. The dominance of grassy weed species in later crop stages was recorded due to smothering habit and only survival of these weeds under the shed of maize plants. The application of post-emergence herbicides decreases the density of the grasses due to non-disturbance of the soil which does not allow the second flush to come out. Singh *et al*. (2012) also reported a similar finding for tembotrione.

The BLWs density was the lowest in the tank-mix or sequential application of post-emergence herbicide, viz. tembotrione (120 g/ha) or topramezone (25.2 g/ha) at 15 DAS with 75% atrazine dose (750 g/ha) or at 25 DAS after PE 75% atrazine dose in T_7, T_9, T_{10} and T_{12} at various crop growth stages (Fig 2). Application of the post-emergence herbicide for weed control leads to mechanical impedance fo the second flush of weed growth. This could also be due to small mulching of the initial weed biomass gained up to 15 DAS. Similar reports of the tembotrione/topramezone for effective BLWs management in maize were reported by Singh *et al*. (2012) and Madhavi *et al.* (2014).

Effect of different weed management treatments on weed dry matter accumulation: Significantly lowest grassy weed dry matter was observed in weed-free check while significantly highest in weedy check at all maize growth stages (Table 1). Amongst herbicide treatments, at 40 DAS, the lowest grassy weed dry matter was found in T_6 which was at par with all the weed management treatments except T_5. However, at 60 DAS, it was found significantly lowest in T_{12} which was at par with T_7, T_9 and T_{10}. At harvest, it was the lowest in T_{10} which was on par with T_{12}. Lower grassy weed across the stages was found in T_7 to T_{12}. The application of post emergence herbicides not only decreased dry matter but also the density of the grasses due to non-disturbance of the soil that does not provide favourable conditions for the second flush to come out. Singh *et al*. (2012) also reported a similar finding with the tembotrione application.

Amongst the weed management treatments, the BLWs dry weight was significantly lowest with T_3 which was at par with T_{12} at 40 DAS and T_4 at 60 DAS (Table 1). The highest BLWs biomass was recorded at early crop growth stages, which decreased gradually, and there were no weed species found at maize harvest. The shading effect and weed species shift at later stages of crop caused this effect. These results show that the topramezone/tembotrione also suppresses the BLWs in maize. The broad-spectrum use of these herbicides was also reported for tembotrione (Idziak and Woznica 2014) and topramezone (Madhavi *et al.* 2014). The highest sedges weight was at initial crop growth stages, which decreased gradually (Table 1). At 40 DAS, the significantly reduced dry weight of sedges was recorded

Table 1 Effect of post emergence herbicides application on weed dry matter accumulation (g/m^2) at various crop growth stages in *kharif* maize

Treatment	Grasses			BLWs		Sedges		
	40 DAS	60 DAS	At harvest	40 DAS	60 DAS	40 DAS	60 DAS	At harvest
T_1	14.33^{a}	11.02^{a}	10.34^{a}	8.96^{a}	5.93^{a}	8.88^{a}	9.17^{a}	8.09^{a}
T_2	0.81^{d}	0.77^{f}	0.83^{f}	0.71^{c}	0.71^{d}	0.71^{d}	0.73^{e}	0.84^{f}
T_3	5.38^{bc}	8.08^{b}	7.86^{c}	3.66^{b}	4.01^{b}	4.77^{bc}	3.12^{bcd}	4.34^{b}
T_4	5.03^{bc}	7.50^{bc}	7.60^{c}	4.65^{b}	3.06^{c}	4.65^{bc}	3.33^{bc}	4.22^{bc}
T_5	7.08^{b}	7.59^{bc}	9.12^{b}	2.99^{b}	3.33^{bc}	3.06^{c}	2.12^{d}	2.92^{e}
T_6	4.26^{c}	8.23^{b}	7.50^{c}	3.68^{b}	3.33^{bc}	4.34^{bc}	4.04^{b}	4.04^{bcd}
T_7	4.55^{c}	5.08^{de}	6.46^{d}	3.66^{b}	3.33^{bc}	4.77^{bc}	3.33^{bc}	3.99^{bcd}
T_8	5.46^{bc}	7.67^{b}	7.94^{c}	4.01^{b}	3.12^{bc}	3.06^{c}	2.59^{cd}	3.12^{de}
T_9	5.31^{bc}	4.81^{de}	6.04^{d}	3.30^{b}	4.04^{b}	4.05^{bc}	2.86^{bcd}	4.37^{b}
T_{10}	4.95^{bc}	4.53^{e}	5.17^{e}	3.24^{b}	3.12^{bc}	5.28^{b}	4.05^{b}	3.71^{bcde}
T_{11}	4.38^{c}	6.13^{cd}	6.54^{d}	4.26^{b}	3.54^{bc}	3.65^{bc}	2.77^{cd}	3.39^{cde}
T_{12}	4.76^{c}	4.31^{e}	5.21^{e}	3.03^{b}	3.33^{bc}	4.36^{bc}	3.50^{bc}	4.37^{b}
LSD (P=0.05)	2.16	1.52	0.73	2.13	0.94	2.15	1.19	0.94

with T_5 and T_8 compared to the weedy check. Similarly, at 60 DAS and harvest, it was observed that sedges dry weight reduced with T_5, T_8 and T_{11} having halosulfuron. Kumar *et al*. (2013) also reported similar observations of sedges control by halosulfuron, Singh *et al*. (2012) for tembotrione and Madhavi *et al*. (2014) for topramezone. The post emergence herbicides lead to decreased in dry weight of the weeds at maize harvest by 3.3, -6.5, 5.2, 15.3, 5.1, 17.3, 29.4, 17.3 and 24.5% in T_4, T_5, T_6, T_7, T_8, T_9, T_{10}, T_{11} and T_{12} respectively over the standard recommended check (T_3). So, it could be inferred that the application of the pre- and post-emergence herbicide combinations provides the season-long weed control applied either as tank-mix or as sequential application. Similar findings also reported in maize by Kumar *et al*. (2013) for halosulfuron and Bollman *et al*. (2008) for tembotrione and topramezone.

Weed control indices: At all the crop growth stages, the significantly highest weed control index (WCI) was found in the weed-free check. Amongst herbicide treatments, the significantly highest WCI was with T_{12} at 40 and 60 DAS and T_{10} at the harvest. These treatments were statistically similar with T_7, T_9 and T_{10} at 60 DAS while with T_{12} at the harvest stage. The WCI, in general, was the highest at initial crop growth stages and the lowest at the harvest across the treatments. Similar findings of the higher WCI by these post emergence herbicides in maize also reported by Madhavi *et al*. (2014) with topramezone and Singh *et al*. (2012) with tembotrione.

The post emergence herbicides have a significant effect on weed-control efficiency (WCE) in *kharif* maize (Table 2). The significantly higher WCE was found in weed-free check at all the crop growth stages which were >92.5% over the weedy check. At 40 DAS, it was significantly higher with T_{11} while at 60 DAS and harvest it was in the T_7 and T_{12} respectively. The WCE in herbicides applied treatments was higher at initial crop stages which gradually declined at later stages. The post-emergence herbicides lead to increased WCE at harvest by 14.8, 14.2, -12.1, 59.2, 13.7, 40.0, 46.9, 27.7 and 54.2% in T_4, T_5, T_6, T_7, T_8, T_9, T_{10}, T_{11} and T_{12}, respectively over the recommended check (T_3). A similar finding of the increased WCE in maize also reported by Madhavi *et al.* (2014) with topramezone and Singh *et al*. (2012) with tembotrione and Kumar *et al.* (2012) with halosulfuron. At 40 DAS, significantly higher HEI was found with T_{12} which was at par with T_9 and T_{10} while at 60 DAS it was with T_{12}, which was at par with T_9 and T_{10}. At harvest, T_{10} gave significantly higher HEI which was at par with T_9 and T_{12}. The post-emergence herbicide has a significant effect on the weed persistence index (WPI) in maize. At 40 DAS, a significantly lower WPI was found with T_{12} which was statistically similar with all post-emergence herbicide treatments. At harvest, it was significantly higher with T_{10} which was at par with T_7, T_9, T_{11} and T_{12}. The significantly lowest weed index (WI) was found in T_{10}, which was at par with T_{12}. The topramezone and tembotrione along with atrazine at 15 DAS had lower WI as compared to the weedy check. However, the highest WI

Table 2 Effect of post emergence herbicides application on weed control efficiencies indices at various crop growth stages in *kharif* maize

Treatment	Weed control index			Weed-control efficiency (%)			Herbicide efficiency index (HEI)			Weed persistence index (WPI)			Weed index (%)
	40 DAS	60 DAS	At harvest	40 DAS	60 DAS	At harvest	40 DAS	60 DAS	At harvest	40 DAS	60 DAS	At harvest	
T_2	95.74^{a}	94.84^{a}	92.81^{a}	95.37^{a}	94.89^{a}	92.49^{a}				1.72^{a}	1.12	0.96^{bcd}	19.46^{cde}
T_3	57.54^{b}	38.50^{ef}	31.61^{de}	51.40^{bcd}	35.58^{ef}	30.65^{f}	8.72^{bcd}	4.14^{d}	3.34^{de}	0.79^{bc}	0.93	0.97^{bcd}	30.35^{bc}
T_4	56.44^{b}	43.18^{def}	33.84^{d}	42.26^{d}	40.85^{def}	42.56^{bcd}	6.61^{cd}	3.73^{d}	2.78^{ef}	0.58^{bc}	0.93	1.34^{a}	49.30^{a}
T_5	55.90^{b}	45.16^{de}	27.13^{e}	50.67^{bcd}	40.63^{def}	35.52^{ef}	3.54^{d}	2.13^{d}	1.20^{f}	0.87^{b}	0.89	1.28^{a}	34.37^{b}
T_6	62.67^{b}	37.39^{f}	35.27^{d}	57.07^{bc}	31.26^{f}	39.59^{cde}	8.77^{bcd}	2.92^{d}	2.69^{ef}	0.77^{bc}	0.84	1.16^{ab}	12.32^{def}
T_7	59.75^{b}	55.76^{bc}	41.90^{c}	47.78^{bcd}	56.66^{b}	37.50^{de}	11.53^{abc}	9.34^{ab}	5.47^{c}	0.64^{bc}	1.06	0.87^{cd}	24.25^{bcd}
T_8	60.48^{b}	44.13^{def}	35.14^{d}	55.55^{bc}	40.45^{def}	37.55^{de}	9.02^{bcd}	4.50^{cd}	3.30^{de}	0.80^{bc}	0.92	1.10^{abc}	8.18^{ef}
T_9	60.90^{b}	55.76^{bc}	43.33^{c}	52.21^{bcd}	49.81^{bcd}	39.00^{de}	14.01^{ab}	10.05^{a}	6.20^{bc}	0.67^{bc}	0.78	0.86^{cd}	3.07^{f}
T_{10}	57.57^{b}	55.99^{bc}	51.86^{b}	51.73^{bcd}	52.25^{bc}	45.48^{bc}	13.06^{ab}	10.93^{a}	9.21^{a}	0.83^{bc}	0.87	0.78^{d}	18.16^{cde}
T_{11}	60.48^{b}	50.28^{cd}	43.38^{c}	57.75^{b}	45.45^{cde}	42.73^{bcd}	10.73^{bc}	6.96^{bc}	5.04^{cd}	0.91^{b}	0.83	0.99^{bcd}	5.55^{f}
T_{12}	62.65^{b}	58.32^{b}	48.35^{b}	45.98^{cd}	54.87^{bc}	46.57^{b}	16.88^{a}	11.94^{a}	5.77^{ab}	0.49^{c}	0.85	0.95^{bcd}	<.0001
LSD (P=0.05)	11.06	7.66	4.61	11.39	9.95	6.15	6.05	2.66	1.91	0.38	NS	0.27	19.46

was found with the application of halosulfuron at 25 DAS that was followed by the only post-emergence application of tembotrione and topramezone in T_6 and T_4, respectively. Madhavi *et al*. (2014) also report the improvement in some of these weed control indices with the application of these post emergence herbicides.

The application of tembotrione (120 g/ha) /topramezone (25.2 g/ha) as tank-mix as early post-emergence at 15 DAS or as a sequential application at 25 DAS with 75% recommended atrazine dose (750 g/ha) gives significantly better weed control and enhances the yield of the maize. However, only post-emergence application of these herbicides at 25 DAS was not found beneficial in *kharif* maize.

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