



Efficacy of different herbicides on weed dynamics and productivity of *kharif* maize (*Zea mays*) and their residual effect on succeeding wheat crop (*Triticum aestivum*)

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ABSTRACT

Weeds are the major biotic constraints in maize crop due to its wider row spacing limiting its productivity. So, a field experiment was conducted during *kharif* and *rabi* seasons of 2015 and 2016, at RRS, Karnal, Haryana to study the effect of different weed control methods on weed flora, growth and yield of *kharif* planted maize, the residual effect of different herbicides applied in maize on succeeding wheat crop. Treatments included two pre-emergence (PRE) herbicides namely atrazine 750 or 1000 g/ha and alachlor 2000 g/ha along with three post-emergence herbicides (POST) atrazine 500 g/ha, 2,4-D 500 g/ha and tembotrione 120 or 140 g/ha +S (surfactant) at 35 days after sowing (DAS) were used. Hand weeding twice at 20 and 35 DAS, weedy check and weed free treatments were also included. Major weed species infesting the experimental field were *Cyperus rotundus*, *Brachiaria reptans*, *Dactyloctenium aegyptium*, *Amaranthus viridis*, *Digera arvensis*, *Phyllanthus niruri* and *Portulaca oleracea*. Among herbicide treatments at 50 DAS, alachlor 2000 g/ha as PRE *fb* tembotrione 120 g/ha provided the highest weed control efficiency (95.1 %). Maximum grain yield (6505 and 6903 kg/ha) and yield attributes of maize were obtained in weed free treatment which was statistically at par with alachlor 2000 g/ha *fb* tembotrione 120 g/ha +S at 35 DAS (T_{13}) (6380 and 6816 kg/ha). No visual phyto-toxicity of any applied herbicide was observed on maize crop. All herbicide treatments employed in *kharif* maize, irrespective of their dose and application time did not show any residual carryover effect on succeeding wheat crop.

Key words: 2,4-D, atrazine, Alachlor, Tembotrione, Visual phytotoxicity, Weed control efficiency

In India, maize (*Zea mays* L.) is the third most important cereal crop after rice and wheat, grown on 9.63 mha area with average yield of 2.69 t/ha and accounts for nearly 9 per cent of total food grain production. Maize-wheat is the third most important cropping system after rice-wheat and rice-rice that contributes about 3% in the national food basket (Anonymous 2016). The present yield levels of maize in India are less than 50% of the world average. Low productivity of maize in India can be attributed to several limiting factors, but the poor weed management poses a major threat to crop productivity. Reduction of 27–60% in maize yield have been reported in various agro-ecologies in India (Kumar *et al.* 2012). Thus, proper weed management strategies would continue to play an important role in increasing its production and requires redesigning of weed control strategies from time to time. Maize, being a widely spaced crop, gets infested by a wide range of weed flora (Punia *et al.* 2007).

Manual weeding in maize is costly and labour-intensive method. Moreover, due to inclement weather conditions, it is

not possible to go for manual hoeing. Most of the presently available herbicides provide only narrow spectrum of weed control in maize. So, there is a need to test new herbicides alone or in combination, which are effective against complex weed flora in *kharif* maize. The knowledge on the persistence and residual effect of herbicides in soil is essential to use them safely, effectively and for non-hazardous chemical weed control schedules. So, it becomes imperative to work out safe combination and time of application of herbicides in maize without affecting the growth and yield of succeeding wheat crop.

Therefore, the present investigation was undertaken to evaluate different herbicide combinations for controlling complex weed flora in *kharif* maize and their residual effect on succeeding wheat crop.

MATERIALS AND METHODS

A field experiment was conducted during *kharif* and *rabi* seasons of 2015 and 2016 with maize-wheat cropping sequence on same fixed plots at Regional Research Station, Uchani, Karnal of CCS Haryana Agricultural University, Hisar, Haryana (India). Karnal is situated at 245 m above mean sea level with longitude of 67°58" North and latitude 29°43" East in sub-tropical zone. Total 426- and 597-mm

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rainfall was received during 2015-16 and 2016-17. The maximum and minimum temperature during the crop season varied from 13.3°C to 39.4°C and 4.6°C to 26.2 °C during first year and 16.2°C to 40.6°C and 3.4 °C to 27.7°C during second year.

A total of seventeen treatments comprising pre-emergence application of atrazine (750 or 1000 g/ha) or alachlor (2000 g/ha) and post emergence application of atrazine (500 g/ha), alachlor (1000 g/ha), 2,4-D (500 g/ha) and tembotrione (120/140 g/ha) and hand weeding at 20 and 35 DAS along with weed free and weedy check (Table 1) were laid out in randomized block design with

three replications.

Two seeds per hill of single cross maize hybrid HQPM-1 were hand dibbled at a spacing of 20 cm on top of ridge having 70 cm row to row spacing on 1st July during 2015 and on 25th June during 2016. In maize, N at 150 kg/ha was applied in three equal splits at sowing, knee high stage and at 50% tasseling stage during both the seasons. Full dose of P₂O₅, K₂O and ZnSO₄ at 60, 60 and 25 kg/ha respectively, were applied at the time of planting before opening of ridges.

Pre emergence herbicides were sprayed 1 day after sowing of *kharif* maize, whereas post emergence herbicides

Table 1 Effect of different weed control treatments on weed density and weed control efficiency at 50 DAS in *kharif* maize (Pooled data of two years)

Treatment	Dose (g/ha)	Time of application (DAS)	Weed density (No./m ²)				WCE
			<i>Cyperus rotundus</i>	<i>Brachiaria reptans</i>	<i>Dactyloctenium aegyptium</i>	Broadleaf weeds	
T ₁ Atrazine	750	PRE	12.3 (151.3)	7.8 (60.7)	7.7 (60.0)	3.8 (13.3)	50.8
T ₂ Atrazine	1000	PRE	12.0 (143.3)	7.6 (56.7)	6.6 (42.7)	3.5 (11.3)	55.7
T ₃ Atrazine <i>fb</i> atrazine	750 <i>fb</i> 500	PRE & 35 DAS	11.8 (140.0)	6.0 (34.7)	5.8 (32.7)	2.9 (7.3)	67.3
T ₄ Atrazine <i>fb</i> 2, 4-D	750 <i>fb</i> 500	PRE & 35 DAS	10.0 (99.3)	7.8 (60.0)	8.2 (68.0)	2.4 (4.7)	52.2
T ₅ Atrazine <i>fb</i> one hoeing	1000	PRE & 35 DAS	8.1 (65.3)	3.5 (11.3)	5.4 (32.0)	2.6 (6.0)	87.1
T ₆ One hoeing <i>fb</i> atrazine	500	20 & 35 DAS	10.7 (115.3)	3.9 (14.0)	3.8 (14.0)	2.4 (4.7)	86.9
T ₇ Alachlor	2000	PRE	8.7 (75.3)	7.4 (54.7)	6.3 (39.3)	2.9 (7.3)	63.1
T ₈ Alachlor <i>fb</i> one hoeing	2000	PRE & 35 DAS	8.1 (64.7)	3.5 (11.3)	3.0 (8.0)	2.6 (6.0)	92.1
T ₉ Alachlor <i>fb</i> 2, 4-D	2000 <i>fb</i> 500	PRE & 35 DAS	8.8 (77.3)	7.0 (48.7)	6.6 (44.0)	2.4 (4.7)	64.1
T ₁₀ Atrazine + alachlor	375 & 1000	PRE	9.4 (88.0)	6.1 (36.0)	8.1 (66.7)	2.9 (7.3)	58.2
T ₁₁ Tembotrione +S	120 +1000	35 DAS	5.3 (27.3)	4.0 (15.3)	2.8 (7.3)	1.0 (0.0)	93.7
T ₁₂ Tembotrione +S	140 +1000	35 DAS	5.2 (26.7)	3.9 (14.0)	3.0 (8.7)	1.0 (0.0)	94.3
T ₁₃ Alachlor <i>fb</i> tembotrione +S	2000 <i>fb</i> 120+1000	PRE & 35 DAS	4.8 (22.7)	3.5 (11.3)	2.5 (6.0)	1.0 (0.0)	95.1
T ₁₄ Atrazine <i>fb</i> tembotrione +S	1000 <i>fb</i> 120+1000	PRE & 35 DAS	5.1 (25.5)	3.7 (12.7)	3.0 (8.0)	1.0 (0.0)	94.2
T ₁₅ Hoeing		20 & 35 DAS	8.0 (64.0)	3.6 (12.0)	3.1 (8.7)	2.6 (6.0)	91.5
T ₁₆ Weedy check			12.4 (154.7)	11.8 (138.7)	11.1 (124.7)	5.0 (24.0)	-
T ₁₇ Weed free			1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	100.0
SE(m) ±			0.20	0.14	0.33	0.10	
CD (P=0.05)			0.57	0.40	0.94	0.28	

*Original values are in parenthesis and before statistical analysis were subjected to square root transformation ($\sqrt{x+1}$)

were sprayed 35 DAS during both the experimental years. Herbicides were sprayed with manually operated knapsack sprayer fitted with electric motor and flat fan nozzle using 300 litres of water per ha. Weed free plots were kept free from weeds by manual hoeing at 20, 35 and 50 DAS during both the years.

In sequence, wheat (var. WH-1105) was sown on same fixed plots on 29th and 25th November in the two crop seasons by seed cum fertilizer drill with rows at spacing of 20 cm using 100 kg/ha seed rate. In wheat, recommended dose of N, P₂O₅ and K₂O at 150, 60 and 60 kg/ha, respectively was applied during both the years. Full dose of P₂O₅ and K₂O and half dose of N were applied before sowing and remaining half dose of N was top dressed after first irrigation.

Species wise weed density was recorded using 0.5 m × 0.5 m quadrat at 50 days after sowing of maize. The weeds taken out to count weed density (No./m²) species wise were oven dried and weight was expressed as g/m². Weed control efficiency (WCE) of each treatment was calculated using the formula (Mani *et al.* 1973).

Data of all the observations in both years were pooled before statistical analysis. Data on weed density and weed

dry weight was square root transformed before analysis. Where the F test was significant (at 5% level of significance), the critical difference (CD) was used to compare mean (P=0.05).

RESULTS AND DISCUSSION

Weed flora

The major weeds appeared in the experimental field at all the stages of observation were *Cyperus rotundus* among sedges, *Amaranthus viridis*, *Digera arvensis*, *Phyllanthus niruri* and *Portulaca oleracea* among broad leaf weeds, *Brachiaria reptans* and *Dactyloctenium aegyptium* as grassy weeds. Grasses constitute 59.6% of weed flora followed by sedges (35%) and broadleaf (5.4%) at 50 days after sowing (Table 1).

All the weed control treatments significantly reduced the density of all weeds over weedy check at 50 DAS. Minimum density of *C. rotundus* was in treatment alachlor 2000 g/ha followed by (*fb*) tembotrione 120 g/ha +S at 35 DAS (T₁₃) at par with T₁₄, T₁₁ and T₁₂. Atrazine applied either pre or post-emergence was not effective in controlling *C. rotundus* in *kharif* maize. The lowest density of *D. aegyptium* and

Table 2 Effect of different weed control treatments on grain yield, gross return, total variable cost, ROVC and B:C of *kharif* maize (Pooled data of two years)

Treatment		Dose (g/ha)	Time of application (DAS)	Grain yield* (kg/ha)		Gross return (₹/ha)	Total variable cost (₹/ha)	ROVC (₹/ha)	B:C
				2015	2016				
T ₁	Atrazine	750	PRE	4730	5080	66012	38554	27458	1.71
T ₂	Atrazine	1000	PRE	5140	5500	71594	38737	32857	1.85
T ₃	Atrazine <i>fb</i> atrazine	750 <i>fb</i> 500	PRE & 35 DAS	5560	5940	77380	38921	38459	1.99
T ₄	Atrazine <i>fb</i> 2, 4-D	750 <i>fb</i> 500	PRE & 35 DAS	4840	5190	67482	38770	28712	1.74
T ₅	Atrazine <i>fb</i> one hoeing	1000	PRE & 35 DAS	5807	6193	80739	43882	36856	1.84
T ₆	One hoeing <i>fb</i> atrazine	500	20 & 35 DAS	5930	6280	82147	43515	38632	1.89
T ₇	Alachlor	2000	PRE	5620	5790	76752	40312	36439	1.90
T ₈	Alachlor <i>fb</i> one hoeing	2000	PRE & 35 DAS	6150	6570	85584	45457	40127	1.88
T ₉	Alachlor <i>fb</i> 2, 4-D	2000 <i>fb</i> 500	PRE & 35 DAS	5480	5860	76295	40529	35766	1.88
T ₁₀	Atrazine + alachlor	375 & 1000	PRE	5330	5690	74141	39432	34709	1.88
T ₁₁	Tembotrione +S	120 +1000	35 DAS	5819	6187	80777	41515	39263	1.95
T ₁₂	Tembotrione +S	140 +1000	35 DAS	5860	6244	81438	42118	39319	1.93
T ₁₃	Alachlor <i>fb</i> tembotrione +S	2000 <i>fb</i> 120+1000	PRE & 35 DAS	6380	6816	88787	43825	44962	2.03
T ₁₄	Atrazine <i>fb</i> tembotrione +S	1000 <i>fb</i> 120+1000	PRE & 35 DAS	5940	6350	82691	42250	40442	1.96
T ₁₅	Hoeing		20 & 35 DAS	6180	6625	86158	48292	37866	1.78
T ₁₆	Weedy check			2950	3278	41918	38002	3916	1.10
T ₁₇	Weed free			6505	6903	90209	53437	36771	1.69
SE(m) ±				247	255				
CD (P=0.05)				714	738				

*The data of maize grain yield was not pooled and year wise data is given.

B. reptans was in treatment T₁₃ at par with T₁₁, T₁₂, and T₈. At 50 DAS, treatments T₁₃, T₁₄, T₁₁ and T₁₂ were free from broadleaved weeds. Similar finding was also observed by Swetha *et al.* (2015).

The highest WCE of total weeds among different herbicidal treatments was recorded in treatment T₁₃ (95.1%) closely followed by treatments (T₁₄) (94.2 %) and T₁₁ and T₁₂ (93.7 and 94.3%, respectively). More than 90 % WCE was also observed in treatments alachlor 2000 g/ha as PRE *fb* hoeing (92.1 %) and hoeing twice at 20 and 35 DAS (91.5 %).

No phytotoxicity of the applied herbicides was found on maize crop at 15, 30 and 45 DAS during both years. So, it is clear from this study that all the herbicides alone or tank mixed or in sequential application were safe without any adverse effect on crop plants. Similar results have been reported by Singh *et al.* (2012b).

Grain yield of kharif maize

Difference in grain yield due to different weed control treatments was found to be significant during both the years (Table 2). The highest grain yield (6505 and 6903 kg/ha) was recorded under weed free treatment and lowest (2950 and 3278 kg/ha) under weedy check during *kharif* 2015 and 2016, respectively. Weedy check resulted into nearly

54.6 and 52.5% reduction in the grain yield of *kharif* maize as compared to weed free treatment during both the years. The treatments T₁₃, T₁₅ and T₈ produced grain yield at par with weed free (6505 and 6903 kg/ha). This might be due to the reduced crop-weed competition and congenial environment for better growth of plants resulting in higher yield in herbicidal treatments. Similar results were reported by Kaur *et al.* (2016).

Economic analysis of kharif maize

Pooled analysis of economics in *kharif* maize revealed that the highest and the lowest gross returns were recorded under weed free and weedy check treatments, respectively (Table 2). Among herbicide treatments, higher gross returns and return over variable cost were recorded in treatments T₁₃ followed by T₈ and T₁₄. Maximum total variable cost was under weed free treatment followed by hoeing twice at 20 and 35 DAS (T₁₅), T₈ and T₅. Due to inclusion of hoeing, total variable cost is higher in the above treatments. The higher total variable cost in weed free treatment is due to higher expenditure on frequent manual hoeing and higher cost of labour during both the years. The highest B: C ratio was computed in treatment T₁₃ followed by T₃ and T₁₄. Similar results have been reported by Sarma and Gautam (2006).

Table 3 Effect of different weed control treatments done in *kharif* maize on visual toxicity, plant population, crop dry weight and grain yield of wheat (Pooled data of two years)

Treatment	Dose (g/ha)	Time of application (DAS)	Visual phytotoxicity		Plant population per m.r.l. at 20 DAS	Crop dry weight (g) at 50 DAS	No. of effective tillers/m ²	Grain yield (kg/ha)
			15 DAS	30 DAS				
T ₁ Atrazine	750	PRE	0 (0)	0 (0)	49.4	225.7	387	5511
T ₂ Atrazine	1000	PRE	0 (0)	0 (0)	49.8	229.7	388	5527
T ₃ Atrazine <i>fb</i> atrazine	750 <i>fb</i> 500	PRE & 35 DAS	0 (0)	0 (0)	48.7	217.7	390	5463
T ₄ Atrazine <i>fb</i> 2, 4-D	750 <i>fb</i> 500	PRE & 35 DAS	0 (0)	0 (0)	50.3	217.7	386	5502
T ₅ Atrazine <i>fb</i> one hoeing	1000	PRE & 35 DAS	0 (0)	0 (0)	47.9	223.8	395	5523
T ₆ One hoeing <i>fb</i> atrazine	500	20 & 35 DAS	0 (0)	0 (0)	47.2	227.2	392	5537
T ₇ Alachlor	2000	PRE	0 (0)	0 (0)	49.2	230.5	386	5591
T ₈ Alachlor <i>fb</i> one hoeing	2000	PRE & 35 DAS	0 (0)	0 (0)	50.1	220.5	393	5612
T ₉ Alachlor <i>fb</i> 2, 4-D	2000 <i>fb</i> 500	PRE & 35 DAS	0 (0)	0 (0)	50.1	226.0	387	5601
T ₁₀ Atrazine + alachlor	375 & 1000	PRE	0 (0)	0 (0)	49.8	215.7	388	5646
T ₁₁ Tembotrione +S	120 +1000	35 DAS	0 (0)	0 (0)	49.2	227.2	388	5583
T ₁₂ Tembotrione +S	140 +1000	35 DAS	0 (0)	0 (0)	49.8	219.2	386	5603
T ₁₃ Alachlor <i>fb</i> tembotrione +S	2000 <i>fb</i> 120 + 1000	PRE & 35 DAS	0 (0)	0 (0)	49.7	222.3	390	5698
T ₁₄ Atrazine <i>fb</i> tembotrione +S	1000 <i>fb</i> 120 + 1000	PRE & 35 DAS	0(0)	0(0)	48.9	221.5	394	5711
T ₁₅ Hoeing		20 & 35 DAS	0 (0)	0 (0)	48.3	219.0	394	5621
T ₁₆ Weedy check			0 (0)	0 (0)	49.2	223.8	376	5558
T ₁₇ Weed free			0 (0)	0 (0)	51.1	232.0	395	5780
SE(m) ±			-	-	0.92	5.14	3.86	104
CD (P=0.05)			-	-	NS	NS	NS	NS

Effect on wheat crop

No visual toxicity of herbicide applied in previous *kharif* maize crop was observed in wheat crop at different crop growth stages (15 and 30 DAS) during both the years (Table 3). Similar results were obtained by Yadav *et al.* (2003) and Yadav (2017). The different weed control treatments applied in *kharif* maize had no significant effect on plant population, crop dry weight, effective tillers per m² and grain yield of succeeding wheat crop during *rabi* 2015-16 and 2016-17. These results are in line with Singh *et al.* (2012a).

On the basis of two years study, it can be inferred that pre-emergence application of alachlor 2000 g/ha *fb* sequential application of tembotrione 120 g/ha at 35 DAS with WCE of 95.1% provided excellent control of complex weed flora in *kharif* maize which was at par with the application of atrazine 1000 g/ha PRE *fb* tembotrione 120 g/ha + S. Maximum grain yield during both the years was found in weed free which was statistically at par with treatments, alachlor 2000 g/ha *fb* tembotrione 120 g/ha, hoeing twice at 20 and 35 DAS and alachlor 2000 g/ha *fb* one hoeing. None of the herbicide alone or in sequence had phytotoxic effect on maize crop.

Maximum B:C was observed in alachlor 2000 g/ha *fb* tembotrione 120 g/ha (2.03). No residual carryover effect of any treatment applied in maize was observed on succeeding wheat crop as evident from growth parameters, yield attributes and yield of wheat.

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