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Tembotrione for post-emergence control of complex weed flora in maize

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ABSTRACT

Bio-efficacy of tembotrione 42% SC w/v (34.4% SC w/w), a new herbicide for post-emergence control of mixed weed flora in maize was evaluated during rainy seasons 2009 to 2015 at CCS Haryana Agricultural University, Regional Research Station, Karnal and also through multi-location adaptive/farmer-participatory trials. Post-emergence application of tembotrione 120 g/ha along with surfactant (1000 ml/ha) at 2-4 leaf stage was found most effective against grassy and non-grassy weeds as compared to other herbicidal treatments either applied as pre- or post-emergence (including its lower doses, atrazine and 2,4-D) resulting into the highest productivity (3.77-4.44 t/ha) and profitability (B-C ratio 1.75-1.98) of maize in on-station experiment during 2009-2010. On an average, grain yield of maize under tembotrione 120 g/ha along with surfactant (4.04-5.00 t/ha) was also better than the atrazine 500-750 g/ha (3.59-4.43 t/ha) and untreated check (2.86-3.33 t/ha) at multi-location trials during 2013-2015. There was no residual toxicity of tembotrione on succeeding wheat. Residues of tembotrione at 120 g/ha + S 1000 ml/ha and 240 g/ha + S 1000 ml/ha in raw cobs, grains and straw of maize and soil were also below detectable level during 2015.

INTRODUCTION

Maize (*Zea mays* L.) referred as "miracle crop" or the "queen" of cereals is one of the most important crop of the world and third most important crop of India after rice and wheat. It occupies an area of 9.23 mha with production of 25.66 mt and average productivity of 2.56 t/ha in the country (Anonymous 2015). In Haryana, maize area is only about 8,000-10,000 ha during last five years, but it has scopes as a potential crop in future to diversify the existing rice-wheat cropping system in the state. Maize holds potential for diversification and livelihood security as reported elsewhere (Das *et al.* 2012). But, weeds pose a major problem in rainy season maize due to congenial growth conditions primarily because of frequent rains, wide spacing and initial slow growth often inflicting huge losses ranging from 28 to 100% (Pandey *et al.* 2001, Das *et al.* 2012). Almost all types of weeds (grassy, broad-leaf weeds and sedges) infest the maize fields. Atrazine as pre-emergence is the most widely used herbicide in maize. It effectively controls broad-leaf weeds but control of sedges and some grasses remains a problem particularly in situation of variable soil moisture coupled with labour scarcity restricting the intercultural operations. Hence, there is a need for some post-emergence herbicide(s) for broad-spectrum weed control in maize. The post-emergence herbicide tembotrione 42% SC w/v (34.4% SC w/w), which belongs to triketone group, inhibits the enzyme hydroxyphenylpyruvate dioxygenase (HPPD) and is absorbed mainly by the leaves. It is co-formulated with the safener isoxadifen-ethyl as a liquid oil dispersion. It was evaluated against mixed weed flora in maize at multi-locations during 2009 to 2015 including its residues in maize and soil.

MATERIALS AND METHODS

Field experiment-1 (bio-efficacy evaluation)

A field experiment to evaluate the efficacy of tembotrione 42% SC w/v (34.4% SC w/w) for post-emergence control of mixed weed flora in maize was conducted during rainy seasons 2009 and 2010 at CCS Haryana Agricultural University, Regional Research Station, Karnal. The soil of the experimental field was clay loam in texture, low in available N, medium in P_2O_5 and high in K_2O with slightly alkaline in reaction (pH 8.1). The treatments included tembotrione 100, 110 and 120 g/ha each with 1000 ml/ha surfactant or without surfactant applied at 2-4 leaf stage (LS), atrazine 750 and 1000 g/ha applied as pre-emergence at 0-3 days after sowing (DAS), 2,4-D-Na 800 g/ha at 3 weeks after sowing (WAS), along with twice hand weeding and weedy check. The treatments were laid out in a randomized complete block design and replicated thrice. The herbicides were sprayed with knapsack sprayer fitted with flat-

fan nozzle using water volume of 500 l/ha. Tembotrione was applied at 2-4 leaf stage of the weeds (10-15 DAS). During 2009, maize hybrid *'HM-1'* was sown on 27th June and during 2010 hybrid '*HQPM-1'* was sown on 27th June with a spacing of 75 x 20 cm using seed rate of 20 kg/ha. Sowing was done on north side of the east-west ridges by dibbling method followed by irrigation up to half ridge on the next day. Plot size was 5.0 x 4.5 m during 2009 and 5.0 x 3.0 m during 2010. Density and dry weight of weeds were recorded at 30 days after treatment (DAT) and 45 DAT, respectively. Phyto-toxicity in terms of chlorosis, stunting, leaf burning and epinasty was recorded at 7, 15, 30 and 45 DAT on 0-10 scale during 2009 and 2010. Crop was raised according to package of practices of the State Agricultural University and harvested on 26th September 2009 and 28th September 2010.

Field experiment-2 (residual phyto-toxicity evaluation)

For crop phyto-toxicity on maize and residual toxicity on wheat crop, an experiment was laid out at Regional Research Station (RRS), Karnal during rainy seasons 2011 and 2012. The treatments included tembotrione 42% SC w/v (34.4% SC w/w) 120 g/ha + S, tembotrione 240 g/ha + S and untreated check laid out in a randomized completely block design and replicated thrice. The plot size was 5.0 x 4.5 m. Maize hybrid '*HM-4*' was sown on 27th June 2011 and 29th June 2012 with a row spacing of 75 cm using a seed rate of 20 kg/ha. Plant × plant spacing was maintained at 20 cm. Herbicide was applied at 15 DAS. Crop was raised according to package of practices of the State University. Crop phyto-toxicity on maize was recorded at 15 and 30 DAT on 0-10 scale. After harvest of maize, the succeeding wheat (*Var. HD2967*) was sown on 12th and 10th November during 2011 and 2012 using a seed rate of 100 kg/ha with a row spacing of 20 cm without disturbing the original layout. Residual phyto-toxicity on wheat was recorded at 30 and 45 DAS on 0-10 scale.

Adaptive/farmer-participatory trials

Adaptive/farmer-participatory trials were also conducted in Ambala, Karnal, Kaithal, Kurukshetra and Panchkula districts of Haryana during 2013-2015. The treatments included tembotrione 42%SC w/v (34.4% SC w/w) 120 g/ha + S (1000 ml/ha) at 2-4 LS, atrazine 50%WP 500-750 g/ha at 0-3 DAS and untreated check with plot size of ½ acre each. These adaptive trials were at 8, 8 and 6 locations (which served as number of replications) during rainy seasons of 2013, 2014 and 2015.

RESULTS AND DISCUSSION

Effect on weeds

Weed flora of the field consisted of mainly *Dactyloctenium aegyptium, Brachiaria reptans, Digitaria sanguinalis, Leptochloa chinensis, Echinochloa colona* among grasses and *Euphorbia hirta* and *Amaranthus viridis* among broad-leaf weeds, and *Cyperus rotundus* was the only sedge.

Density of grassy **(Table 1)**, broad-leaf (BLW) and sedges **(Table 2)** and dry weight of weeds (**Table 3)** decreased with successive increase in dose of the tembotrione 42% SC w/v (34.4% SC w/w) from 100 to 120 g/ha with or without surfactant. Addition of surfactant to tembotrione was realized essential to attain its satisfactory efficacy; as the density and dry weight of weeds decreased significantly when it was applied with surfactant at all the doses. Addition of surfactant was also realized essential to achieve satisfactory weed control efficacy of tembotrione against mixed weed flora in maize earlier also (Singh *et al.* 2012). Tembotrione with surfactant provided effective control of all type of weeds including *Cyperus rotundus* with maximum efficacy at tembotrione 120 g/ha + surfactant 1000 ml/ha. Tembotrione 120 g/ha + S resulted in significantly lower density of *Dactyloctenium aegyptium*, *Brachiaria reptans*, *Digitaria sanguinalis*, total grassy weeds and *Cyperus rotundus* in comparison to 100 and 110 g/ha + S. Similarly tembotrione 110 g/ha + S was superior to tembotrione 100 g/ha + S in reducing the density of these weeds. However, the differences among the three doses of tembotrione when applied with surfactant were not always significant in respect of density of grassy weeds *Leptochloa chinensis* and *Echinochloa colona*, and BLW. Tembotrione 120 g/ha + S resulted in significantly lower dry weight of grassy weeds and sedges as compared to 100 g/ha + S during both the years and tembotrione 110 g/ha + S during 2010. However, the differences between 120 g/ha + S and 110 g/ha + S in respect of dry weight of grassy weeds and sedges were non-significant during 2009. Similarly tembotrione 110 g/ha + S was at par with 100 g/ha + S in respect of dry weight of grassy weeds and sedges except 110 g/ha + S being superior during 2010. All the doses of tembotrione applied with surfactant were similar to each other in respect of dry weight of BLW.

Atrazine also provided good control of grassy and broad-leaf weeds during 2009 but control of grassy weeds was less during 2010. It was not effective against sedges. Efficacy of atrazine

Table 1. Effect of tembotrione on density (no. /m^2)* of grassy weeds in maize at 30 days after application

Treatment	Dose (g/ha)	Time of application	*Dactyloctenium aegyptium*		*Brachiaria reptans*		*Leptochloa chinensis*	*Echinochloa colona*	*Digitaria sanguinalis*	Total grassy weeds	
			2009	2010	2009	2010	2009	2009	2010	2009	2010
Tembotrione+S	100+1000	2-4 LS	3.31(10.0)	2.51(5.3)	3.00(8.0)	4.28(17.3)	1.24(0.7)	1.24(0.7)	3.68(12.7)	4.51(19)	6.02(35)
Tembotrione+S	110+1000	2-4 LS	3.00(8.0)	2.24(4.0)	2.76(6.7)	3.51(11.3)	1.24(0.7)	1.24(0.7)	3.08(8.7)	4.12(16)	5.00(24)
Tembotrione+S	120+1000	2-4 LS	1.90(2.7)	1.66(2.0)	1.73(2.0)	3.00(8.0)	1.24(0.7)	1.24(0.7)	2.20(4.0)	2.63(6)	3.87(14)
Tembotrione	100	2-4 LS	5.79(32.7)	3.21(9.3)	5.31(27.3)	5.25(26.7)	2.20(4.0)	1.90(2.7)	5.24(26.7)	8.21(67)	7.97(63)
Tembotrione	110	2-4 LS	5.11(25.3)	3.11(8.7)	4.93(23.3)	5.13(25.3)	2.07(3.3)	1.73(2.0)	4.71(21.3)	7.40(54)	7.50(55)
Tembotrione	120	2-4 LS	5.31(27.3)	2.51(5.3)	4.79(22.0)	4.71(21.3)	2.07(3.3)	1.73(2.0)	4.43(18.7)	7.45(55)	6.80(45)
2,4-D Na	800	3 WAS	6.85(46.0)	4.99(24.0)	6.50(41.3)	6.70(44.0)	2.65(6.0)	2.24(4.0)	4.92(23.3)	9.91(97)	9.60(91)
Atrazine	750	0-3 DAS	2.73(8.0)	3.40(10.7)	2.54(6.7)	5.13(25.3)	1.24(0.7)	1.00(0.0)	3.77(13.3)	3.60(15)	7.09(49)
Atrazine	1000	0-3 DAS	1.82(2.7)	3.21(9.3)	1.82(2.7)	4.58(20.0)	1.00(0.0)	1.00(0.0)	3.09(8.7)	2.33(5)	6.24(38)
Two hand weeding		20&40 DAS	1.00(0.0)	1.00(0.0)	1.00(0.0)	1.00(0.0)	1.00(0.0)	1.00(0.0)	1.00(0.0)	1.00(0)	1.00(0)
Weedy check			6.81(45.3)	3.78(13.3)	6.30(38.7)	6.60(42.7)	2.37(4.7)	2.07(3.3)	5.19(26.0)	9.64(92)	9.11(82)
LSD (p=0.05)			1.03	0.50	0.87	0.48	0.48	0.42	0.61	1.43	0.53

*Original figures in parentheses were subjected to square root transformation ($\sqrt{x+1}$) before statistical analysis; Abbreviations: S, surfactant, LS, leaf stage, WAS, weeks after sowing, DAS, days after sowing

Table 2. Effect of tembotrione on density (no. /m^2)* of broad-leaf weeds and sedges in maize at 30 days after application

Treatment	Dose (g/ha)	Time of application	Broad-leaf weeds				Sedges (*Cyperus rotundus*)	
			Euphorbia hirta	*Amaranthus viridis*	Total BLW			
			2009	2009	2009	2010	2009	2010
Tembotrione+S	100+1000	2-4 LS	1.49(1.3)	1.24(0.7)	1.66(2.0)	1.66(2.0)	7.50(55.3)	5.26(26.7)
Tembotrione+S	110+1000	2-4 LS	1.49(1.3)	1.00(0.0)	1.49(1.3)	1.00(0.0)	5.44(28.7)	3.69(12.7)
Tembotrione+S	120+1000	2-4 LS	1.24(0.7)	1.00(0.0)	1.24(0.7)	1.00(0.0)	3.24(12.0)	2.58(6.0)
Tembotrione	100	2-4 LS	1.73(2.0)	1.24(0.7)	1.90(2.7)	2.51(5.3)	8.88(78.0)	7.72(58.7)
Tembotrione	110	2-4 LS	1.49(1.3)	1.00(0.0)	1.49(1.3)	1.24(0.7)	8.72(75.3)	6.13(36.7)
Tembotrione	120	2-4 LS	1.49(1.3)	1.00(0.0)	1.49(1.3)	1.00(0.0)	7.54(56.0)	5.62(30.7)
2,4-D Na	800	3 WAS	1.00(0.0)	1.00(0.0)	1.00(0.0)	1.00(0.0)	1.87(4.0)	4.57(20.0)
Atrazine	750	0-3 DAS	1.24(0.7)	1.00(0.0)	1.24(0.7)	1.00(0.0)	9.21(84.0)	5.80(32.7)
Atrazine	1000	0-3 DAS	1.00(0.0)	1.00(0.0)	1.00(0.0)	1.00(0.0)	9.36(86.7)	5.43(28.7)
Two hand weeding		20 and 40 DAS	1.00(0.0)	1.00(0.0)	1.00(0.0)	1.00(0.0)	1.00(0.0)	1.00(0.0)
Weedy check			3.78(13.3)	1.90(2.7)	4.12(16.0)	3.11(8.7)	9.03(86.7)	6.45(40.7)
LSD (p=0.05)			0.53	0.36	0.60	0.43	1.33	0.64

*Original figures in parentheses were subjected to square root transformation ($\sqrt{x+1}$) before statistical analysis; Abbreviations: BLW, broad-leaf weeds, S, surfactant, LS, leaf stage, WAS, weeks after sowing, DAS, days after sowing

increased with increase in its dose from 750 to 1000 g/ha (**Tables 1-3**). Tembotrione 120 g/ha + S was at par with atrazine 1000 g/ha during 2009 but superior during 2010 in respect of density and dry weight of grassy weeds, whereas it was superior to atrazine 750 g/ha during both the years. Tembotrione 110-120 g/ha + S was similar to atrazine 750-1000 g/ha in respect of density of BLW; but superior in respect of density of sedges during both the years. Density and dry weight of grassy weeds under tembotrione 100-110 g/ha + S was lower than atrazine 750-1000 g/ha except being at par with atrazine 750 g/ha and higher than atrazine 1000 g/ha during 2009. 2, 4-D Na 800 g/ha provided good control of BLW and sedges but it was ineffective against grassy weeds. Tembotrione 100-120 g/ha was similar to atrazine and 2,4-D Na treatments in respect of density and dry weight of BLW. Dry weight of *Cyperus rotundus* under tembotrione 120 g/ha + S was similar to 2, 4-D Na during 2009 but lower during 2010 and was significantly lower than the atrazine treatments during both the years. Post-emergence application of tembotrione 120 g/ha along with surfactant was found most effective against grassy and non-grassy weeds as compared to other herbicides either applied as pre- or post-emergence (Singh *et al*. 2012) and even as good as weed free check (Singh *et al*. 2017).

Grain yield of maize

Tembotrione 120 g/ha + S 1000 ml/ha provided the maximum grain yield (3.77 t/ha during 2009 and 4.44 t/ha during 2010) and was superior to all other herbicidal treatments (**Table 3**). However, grain yield of maize under tembotrione 110 g/ha + S 1000 ml/ha (3.31 t/ha during 2009 and 4.00 t/ha during 2010) was at par with two hand weeding during 2009, but was inferior to hand weeding during 2010 and tembotrione 120 g/ha + S during both the years. Post-emergence application of tembotrione 120 g/ha along with surfactant has been reported most effective against complex weed flora resulting into the highest grain yield of maize earlier also (Singh *et al*. 2012). The benefit-cost ratio (1.75-1.98) was also highest under tembotrione 120 g/ha + S during both the years

Table 3. Effect of tembotrione on dry weight of weeds at 45 days after herbicide application, grain yield of maize and B-C ratio

Treatment	Dose (g/ha)	Time of application	Dry weight of weeds (g/m^2)						Grain yield (t/ha)		B: C ratio	
			Grassy weeds		BLW		Sedges					
			2009	2010	2009	2010	2009	2010	2009	2010	2009	2010
Tembotrione+S	100+1000	2-4 LS	43.4	52.4	0.9	1.2	26.7	6.4	3.11	3.56	1.55	1.69
Tembotrione+S	110+1000	2-4 LS	34.5	33.1	1.3	0.0	14.4	4.2	3.31	4.00	1.61	1.84
Tembotrione+S	120+1000	2-4 LS	13.7	16.1	0.6	0.0	8.3	1.5	3.77	4.44	1.75	1.98
Tembotrione	100	2-4 LS	88.3	93.1	5.1	2.5	40.3	15.6	2.62	2.78	1.38	1.42
Tembotrione	110	2-4 LS	84.8	86.7	3.2	0.5	27.9	9.7	2.64	3.06	1.38	1.52
Tembotrione	120	2-4 LS	69.7	76.4	2.1	0.0	25.6	5.4	2.75	3.39	1.41	1.62
2,4-D Na	800	3 WAS	165.6	187.8	0.0	0.0	2.9	9.3	2.27	1.65	1.35	1.08
Atrazine	750	0-3 DAS	54.8	115.4	0.6	0.0	59.0	18.3	3.15	2.59	1.66	1.42
Atrazine	1000	0-3 DAS	10.7	82.8	0.0	0.0	44.6	17.3	3.30	2.97	1.69	1.54
Two hand weeding		20&40 DAS	0.0	0.0	0.0	0.0	0.0	0.0	3.56	4.50	1.48	1.75
Weedy check			160.7	196.5	6.0	5.7	36.4	20.0	1.77	1.72	1.20	1.14
LSD (p=0.05)			20.9	15.3	2.3	1.0	15.2	2.6	0.44	0.40	-	-

Abbreviations: BLW, Broad-leaf weeds, S, Surfactant, LS, Leaf stage, WAS, Weeks after sowing, DAS, Days after sowing

Table 4. Performance of tembotrione against weeds in maize under adaptive/farmer-participatory trials (2013 to 2015)

Treatment	Dry weight of weeds (g/m^2)			Grain yield of maize (t/ha)		
	2013	2014	2015	2013	2014	2015
Tembotrione+S 120 g/ha	15	5	2	5.00	4.04	4.46
Atrazine 500-750 g/ha*	58	52	54	4.43	3.59	3.68
Untreated check	261	255	230	3.33	2.86	2.95
LSD (p=0.05)	55	40	60	0.36	0.25	0.24

*Atrazine 500 g/ha at 1, 3 and 1 locations in 2013, 2014 and 2015, respectively. Locations in 2013(8): 1(Gola), 1(Majri Jattan),3(Azimgarh, Bhagal and Rasina), 1(Danghali) and 1(Uchani) in Ambala, Punchkula, Kaithal, Kurukshetra and Karnal districts, respectively. Locations in 2014(8): Majri Jattan(3), Basolan(1), Khera(2) and Rathpur(2) in Punchkula district. Locations in 2015(6): Majri Jattan(3) and Baar(3) in Punchkula district.

(**Table 3**), and it was realized to be the best treatment.

Adaptive/farmer-participatory trials

The data from adaptive/farmer-participatory trials indicated that tembotrione 42% SC w/v (34.4% SC w/w) 120 g/ha + S (1000 ml/ha) provided very good control (94-99%) of all type of weeds and the reduction in dry weight of weeds was more than the check atrazine 50%WP (78-82%) across three seasons (2013-2015); however, the differences were significant in 2014 (**Table 4**). On an average, grain yield of maize under tembotrione (4.04-5.00 t/ha) was better than the atrazine treatment (3.59-4.43 t/ha) and untreated check (2.86-3.33 t/ha).

Phyto-toxicity on maize and residual toxicity on wheat

There was no phyo-toxicity of tembotrione 100-120 g/ha (with or without surfactant) on maize in terms of chlorosis, stunting, leaf burning and epinasty at 7, 15, 30 and 45 DAT in field experiment-1 during 2009 and 2010 (data not given). Also, there was no phyto-toxicity of tembotrione at 120 and 240 g/ha (with surfactant) on maize at 15 and 30 DAT and no residual phyto-toxicity on succeeding crop of wheat during 2011 and 2012 in field experiment-2 (data not given). Singh *et al.* (2012) also reported that there was no phyto-toxicity of tembotrione on maize and succeeding crop of mustard in rotation.

Based on present investigation, it can be concluded that tembotrione 120 g/ha + S 1000 ml/ha applied at 2-4 leaf stage provided satisfactory control of all type of weeds (grassy weeds, broad-leaf weeds and sedges) in rainy season maize without causing any crop phyto-toxicity on maize and consequently, it resulted into higher grain yield and profitability. Addition of surfactant was realized a must to attain satisfactory efficacy of tembotrione against mixed weed flora in maize. There was no phyto-toxicity of tembotrione 120 and 240 g/ha on maize and also no residual toxicity on succeeding crop of wheat. Residues of tembotrione at 120 g/ha + S 1000 ml/ha and 240 g/ha + S 1000 ml/ha in raw cobs, grains and straw of maize and soil were also below detectable level.

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