Evaluation of Tembotrione against Weeds in Maize (Zea mays L.) under mid Hill Conditions of Himachal Pradesh

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Abstract- **Tembotrione at 125 & 150 g/ha with surfactant applied on 20 days after sowing (DAS) and at 100, 125 & 150 g/ha without surfactant applied on 20 & 30 DAS was evaluated along with standard weed control practices viz. atrazine 1000 g/ha (pre) fb atrazine 750 g/ha (post); atrazine 1000 + pendimethalin 1000 g/ha (pre) and manual weeding thrice (20, 40 & 60 DAS) on a silty clay loam soil at Palampur during 2014 and 2015 for post emergent weed control in maize. Tembotrione at 125 and 150 g/ha with (20 DAS) and without surfactant (30 DAS) was quite effective in reducing the count of Echinochloa colona and Commelina benghalensis upto the harvest of maize. Irrespective of dose and time of application tembotrione effectively reduced the count of Polygonum alatum. Tembotrione has been found a better alternative to atrazine fb atrazine for the control of Ageratum. Tembotrione at 125 & 150 g/ha +surfactant (20 DAS) produced significantly higher yield attributes and yield of maize and was followed by tembotrione at 150 g/ha (30 DAS), tembotrione at 125 g/ha (30 DAS), tembotrione at 150 g/ha (20 DAS). Grain yield of maize was positively associated with plant height, rows/cob, grains/cob and cobs/plant and negatively associated with count of Echinochloa, Commelina, Polygonum, Ageratum and the combined of these. Uninterrupted growth of weeds reduced the grain yield of maize by 63.5%.**

Index Terms- Tembotrione, atrazine, pendimethalin, yield attributes, weeds, yield, maize.

INTRODUCTION

The maize crop in Himachal Pradesh is grown on around 3.0 lakh ha area. Weed management had a major effect on success of maize because its competitive ability is relatively low (Ghanizadeh et al. 2014). Further being a rainy season crop, it is very often characterized by a complex plurispecific weed flora, composed of grasses, sedges and broad-leaved weeds (Kolarova et al. 2014; Pannacci and Tei 2014; Rana et al. 1998; Kumar et al. 2011&2012). This weed flora has been traditionally controlled though pre-emergence applications based on atrazine because of its broad-controlled spectrum, superior residual activity, excellent crop tolerance, perceivable speed of efficacy and suitability as partner for other active ingredients (Scheulte et al. 2012; Rana et al. 1998; Kumar et al. 2011&2012). However monocultures of maize with repeated applications of the same pre-emergence herbicides have determined a strong increase in the frequency of several difficult to control weed species forcing farmers to adopt less simplified weed control strategies (Meissle et al. 2010). Under conditions of the mid hills of Himalayas Ageratum, Commelina and Brachiarria are the recent instances (Kumar et al. 2012). In particular, in order to optimize weed control efficacy and minimize the application costs, the use of complex combinations of pre and post-emergence herbicides (Kumar et al. 2012), as well as herbicide mixtures (Rana et al. 1998; Kumar et al. 2011) has become the rule rather than the exception (Pannacci et al. 2007). Such later flushes are sometimes even uprooted manually or cut down to feed livestock (Kumar et al. 2011). These strategies also represents an important tool to avoid problems related to herbicide resistance (Norsworthy et al. 2012), but it requires some preliminary information to assist farmers with the process of herbicide and dosage selection depending on floristic situation (Mathews 2006). Keeping above facts in mind, need for some alternative post-emergence herbicide which can provide broad-spectrum weed control in kharif maize without affecting crop growth and yield was felt. Therefore, the present investigation was carried out for the evaluation of post-emergence herbicide tembotrione 42% SC against mixed weed complex in maize. Tembotrione was first launched as a maize herbicide in 2007 by Bayer Crop Science (Gatzweiler et al. 2012). Tembotrione inhibits the enzyme 4-hydroxyphenylpyruvate dioxygenase (HPPD) efficiently in numerous weed species. HPPD is an enzyme of the biosynthetic pathway that converts tyrosine to plastoquinone and tocopherol. Plastoquinose is a cofactor for the phytoene desaturase, a component of the carotenoid biosynthetic pathway. The depletion of plastoquinone levels by inhibition of HPPD results in depletion of carotenoids and an absence of chloroplast development in emerging foliar tissue which then appears bleached and stunted (Hawkes 2007). As carotenoids play key role in photosynthesis and in photo-protection there is clear involvement of light in the expression of herbicidal activity of HPPD inhibitors. The performance of tembotrione as a herbicide was presented at several conferences (Zollinger and Ries 2006; Young et al. 2007; Lamori et al. 2010, Duary et al. 2015; Kumar et al. 2015) and scientific papers from abroad (Williams and Pataki 2008) and India (Singh et al. 2012). The efficacy of tembotrione against mixed weed flora in maize under mid hill conditions of Himachal Pradesh is being presented in this paper.

MATERIALS AND METHODS

A field experiment consisting of 12 weed control treatments viz., tembotrione 100, 125 and 150 g/ha each applied on 20 & 30 DAS of maize; tembotrione 125 & 150 g/ha + surfactant applied on 20 DAS of maize; atrazine 1000 g/ha (pre) fb atrazine 750 g/ha (post); atrazine 1000 + pendimethalin 1000 g/ha (pre); manual weeding thrice (20, 40 & 60 DAS) and weedy check (Table 1) was laid out in randomized block design with three replications. The soil of the experimental site was silty clay loam in texture, acidic (pH 5.6) in reaction, and medium in available nitrogen (333.0 kg/ha), phosphorus (9.6 kg/ha) and potassium (221.0 kg/ha). The site (Palampur) lies in sub-temperate humid zone of Himachal Pradesh (NARP zone II), which is characterized by mild summers and severe winters. The area experiences occasional snowfall during winter. The average total annual rainfall received at the centre is around 2693.4 mm, out of which 74.4 per cent is received during monsoon period (June to Sept.), 17.3 per cent during December to March and 8.3 per cent during October-November. May and June are the hottest months having a mean maximum temperature of 30.0 oC and 29.6 oC, respectively and mean minimum temperature of 20.0 oC and 20.0 oC, respectively. December and January are the coldest months having a mean maximum temperature of 14.4 oC and 16.6 oC, respectively and mean minimum temperature of 5.9 oC and 6.6 oC. The average total annual evaporation from US open pan evaporimeter is 1097.0 mm and mean rate of evaporation per day range from 1.6 mm in January-February to 3.7 mm per day during April-May. Mean relative humidity remains between 60.3 to 75.4% from June to September and 50.5 to 60.4% for rest of the period. The maize variety KH 101 was sown on 2 June 2014 and 04 June 2015 keeping row to row spacing of 60 cm and plant to plant spacing of 20 cm (approximately 20 kg/ha seed rate). The crop was fertilized with 120 kg N, 60 kg P2O5 and 40 kg K2O/ha through urea, single super phosphate and muriate of potash, respectively. The required quantity of half N and whole P2O5 and 40 kg K2O was drilled at sowing. The remaining half N was band placed in two equal splits at knee high and tasseling stages. Herbicides as per treatment were applied with backpack power sprayer using 600 litre water/ha. Rest of the packages of practices was as per the recommendations of the university. Weed count (60 DAS and at harvest) was recorded at two spots using a quadrate of 50 cm x 50 cm. Yields were harvested from net plot on 18 September 2014 and 20 September 2015. Yield attributes were recorded at/after harvest.

The data obtained were subjected to statistical analysis by analysis of variance (ANOVA) for the randomized block design to test the significance of the overall differences among the treatments by the "F" test and conclusion was drawn at 5% probability level. Standard error of mean was calculated in each case. When the 'F' value from analysis of variance tables was found to be significant, the critical difference (LSD) was computed to test the significance of the difference between the two treatments.

RESULTS AND DISCUSSION

The major weeds in the experimental field at the harvest of maize were Echinochloa colona (22.6 and

29.0% during 2014 and 2015, respectively), Commelina benghalensis (19.4 and 19%), Polygonum alatum (24.2 and 18.3%) and Ageratum conyzoides (29.0 and 27.9%). Ageratum conyzoides was appeared at silking stage of maize. The other weeds viz. Cynodon dactylon, Brachiaria ramose, Panicum dichotomiflorum, Gallinsoga parviflora and Phajalis minima showed their little infestation and as a whole constituted 4.8 and 5.8% of the total weed flora in the unweeded check.

Weed count

A perusal of the data presented in Table 1 revealed significant variation in the count of Echinochloa colonum and Commelina benghalensis both at 60 DAS and at harvest. All treatments were significantly superior to weedy check in reducing the count of these weeds. Singh et al. (2012) also reported superiority of tembotrione with and without surfactant in controlling Echinochloa. The lower dose of tembotrione was as good as manual weeding thrice in influencing the count of both of these weeds. Atrazine fb atraine and atrazine + pendimethalin also significantly reduced the count of these weeds but were comparatively less effective than tembotrione. The effectiveness of atrazine fb atrazine and atrazine + pendimethalin against Echinochloa and Commelina has been reported earlier from this location (Kumar et al. 2011; 2012).

Irrespective of dose and time of application, tembotrione effectively reduced the count of P. alatum at both the stages during both the years over other treatments (Table 2). All rates of tembotrione with or without surfactant were at par with each other in reducing the count of this weed. The other treatments were also superior to weedy check in reducing the count of Polygonum. The effective control of Polygonum with atrazine as double nock and its mixture with pendimethalin has been documented (Rana et al. 1998; Kumar et al. 2011&2012). All treatments were significantly superior to weedy check in reducing the count of A. conyzoides. Tembotrione 125 and 150 g/ha with (on 20 DAS) and without surfactant (30 DAS) was significantly superior to other treatments. The other doses of tembotrione were also superior to manual weeding thrice in reducing the count of A. conyzoides. Generally atrazine is recommended as a double knock for the control of Ageratum because of its survival due to its pre-emergence application as the weed appears at tesseling stage of maize growth. A single dose of tembotrione is found suffice and a better alternative of atrazine. Moreover, the second application of atrazine which has to be applied on the foliage of Ageratum in the standing crop of maize has been a difficult task. The use of tembotrione will likely to avoid it.

Yield attributes and grain yield

Weed control treatments brought about significant variation in crop height (Table 3). Owing to superior control of weeds, all treatments were significantly superior to weedy check in increasing maize crop height. Significantly taller plants of maize were recorded under tembotrione 150 g/ha applied on 30 DAS. However, this was at par with tembotrione at 125 g/ha applied on 30 DAS, tembotrione 125&150 g/ha applied on 20 DAS, atrazine fb atrazine (1000 g + 750 g/ha) and atrazine + pendimethalin (1000 g +1000 g/ha).

Weed control treatments did not significantly influence cobs per plant. However, number of rows per cob, number of grains per rows and number of grains/cob were significantly influenced due to treatments. All the above yield attributes were significantly improved due to weed control treatments over the unweeded check. Tembotrione 125 & 150 g/ha + surfactant produced significantly higher all the above yield attributes over other treatments. Tembotrione 150 g/ha applied on 30 DAS, tembotrione 125 g/ha applied on 30 DAS, and tembotrione 150 g/ha applied on 20 DAS were the other superior treatments in influencing the yield attributes of maize. Increase in yield attributes after effective control of the weeds with tembotrione and other treatments has been reported (Duary et al. 2015; Rana et al. 1998; Kumar et al. 2011 & 2012).

Improvement in growth and yield attributes after the weeds controlled effectively were ultimately reflected in grain yield of maize. All treatments were significantly superior to weedy check in increasing the grain yield of maize. Similar to yield attributes, the grain yield of maize was significantly higher with application of tembotrione 150 g/ha + surfactant and tembotrione 125 g/ha + surfactant applied on 20 DAS and tembotrione 150 g/ha applied on 30 DAS as compared to all other treatments. The magnitude in increase in yield due to these treatments over unweeded check was 192.5, 189.4 and 178.3%. Other treatments were also found significantly superior to unweeded check. Manual weeding was found to be statistically similar to atrazine fb atrazine and atrazine + pendimethalin. Grain yield of maize was positively associated with plant height (r=0.915** and 0.964** during 2014 and 2015, respectively; **significant at 1% level of significance), rows/cob (r=0.954** and 0.827**), grains/row (r= 0.894** and 0.987**), grains/cob (r=0.843** and 0.816**) and cobs/plant (r=0.386 and 0.592*, *significant at 5% level of significant). The grain yield of maize was negatively associated with the count of Echinochloa (r= -0.906** and -0.963**), Commelina (r = -0.907** and -0.927**), Polygonum (r= -0.780** and -0.857**), Ageratum (r = -0.775** and -0.923**) and total weeds (r= -0.849** and -0.934**). The increase in yield due to effective control of weeds with tembotrione (Zollinger and Ries 2006; Young et al. 2007; Lamori et al. 2010, Duary et al. 2015; Kumar et al. 2015; Williams and Pataki 2008; Singh et al. 2012) and herbicide mixtures (Rana et al. 1998; Kumar et al. 2011 and 2012) have been amply documented.

The finding of the present investigation conclusively inferred that for controlling complex plurispecific weed flora in maize, tembotrione 125-150 g/ha with (20 DAS) or without (30 DAS) surfactant is quite a good alternative to pre followed by post herbicide applications as well as herbicide mixtures.

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Table 1. Effect of treatments on count (No/m2) of grassy weeds in maize

Treatment	Dose (g/ha)	Time of application (DAS)	*Echinochloa*				*Commelina*			
			60 DAS		*At harvest*		*60 DAS*		*At harvest*	
			2014	*2015*	*2014*	*2015*	*2014*	*2015*	*2014*	*2015*
Tembotrione	100	20	2.2 (4.0)	2.4 (4.6)	2.0 (3.2)	2.1 (3.5)	1.6 (1.7)	1.5 (1.4)	1.8 (2.2)	1.8 (2.4)
Tembotrione	125	20	2.1 (3.6)	2.0 (3.2)	1.7 (2.0)	1.8 (2.4)	1.6 (1.5)	1.5 (1.4)	1.8 (2.1)	1.8 (2.2)
Tembotrione	150	20	1.9 (2.9)	1.9 (2.8)	1.7 (1.9)	1.7 (2.0)	1.6 (1.5)	1.5 (1.4)	1.7 (1.9)	1.7 (2.0)
Tembotrione	100	30	1.9 (2.8)	1.9 (2.8)	1.6 (1.7)	1.4 (1.0)	1.5 (1.2)	1.6 (1.5)	1.7 (1.8)	1.7 (1.9)
Tembotrione	125	30	1.5 (1.4)	1.6 (1.5)	1.4 (1.1)	1.6 (1.6)	1.5 (1.2)	1.6 (1.5)	14 (1.0)	1.5 (1.3)
Tembotrione	150	30	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.5 (1.2)	1.5 (1.3)
Tembotrione	125+S	20	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.4 (1.1)	1.4 (1.1)
Tembotrione	150+S	20	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)
Atrazine fb atrazine	1500+750	0-3fb 20	3.1 (8.9)	2.9 (7.5)	2.1 (3.5)	2.9 (7.9)	2.4 (4.7)	2.6 (5.8)	2.2 (3.9)	3.3 (9.6)
Atrazine + pendimethalin	1000+1000	0-3	3.3 (9.7)	3.1 (8.6)	3.2 (9.5)	3.1 (8.9)	2.6 (5.9)	2.8 (6.9)	2.9 (7.3)	3.4 (10.9)
Manual Weeding (3)			2.4 (4.6)	2.1 (3.5)	2.7 (6.6)	2.2 (3.9)	2.3 (4.5)	1.9 (2.5)	2.2 (3.8)	3.3 (9.6)
Weedy Check			4.4 (18.0)	4.5 (19.2)	3.9 (14.0)	5.5 (29.0)	3.6 (12.0)	3.4 (10.6)	3.6 (12.0)	3.8 (13.1)
SEm ±			0.2	0.04	0.19	0.1	0.25	0.13	0.22	0.12
LSD (P=0.05)			0.6	0.12	0.54	0.3	0.65	0.39	062	0.36

Data subjected to square root transformation ($\sqrt{(x+1)}$); Values given in parentheses are the original means; DAS=days after sowing;

Table 2. Effect of treatments on count (No/m2) of broad-leaved weeds at harvest of maize

Treatment	Dose (g/ha)	Time of application (DAS)	Polygonum				*Ageratum*	
			60 DAS		At harvest		*At harvest*	
			2014	2015	2014	*2015*	*2014*	*2015*
Tembotrione	100	20	1.3 (0.6)	1.2 (0.5)	2.0 (3.1)	2.0 (3.2)	1.7 (2.0)	2.0 (3.1)
Tembotrione	125	20	1.3 (0.6)	1.2 (0.5)	1.0 (0.0)	1.6 (1.5)	1.4 (1.0)	2.0 (3.0)
Tembotrione	150	20	1.2 (0.5)	1.2 (0.5)	1.0 (0.0)	1.6 (1.6)	1.4 (1.0)	1.4 (0.4)
Tembotrione	100	30	1.2 (0.4)	1.1 (0.3)	10 (0.0)	1.6 (1.6)	1.4 (1.0)	1.3 (0.8)
Tembotrione	125	30	1.1 (0.3)	1.1 (0.3)	10 (0.0)	1.2 (0.4)	1.0 (0.0)	1.0 (0.0)
Tembotrione	150	30	1.0(0.0)	1.0 (0.0)	10 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)
Tembotrione	125+S	20	1.0(0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)
Tembotrione	150+S	20	1.0(0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)
Atrazine fb atrazine	1500+750	0-3fb 20	2.7 (6.1)	2.9 (7.3)	2.8 (8.0)	3.0 (8.2)	3.3 (10.0)	3.3 (9.5)
Atrazine +pendimethalin	1000+1000	0-3	2.9 (7.9)	3.1 (8.6)	3.2 (9.6)	3.1 (8.6)	3.9 (14.9)	3.3 (10.1)
Manual Weeding(3)			2.2 (3.9)	2.0 (3.2)	1.95 (2.8)	1.9 (2.5)	2.2 (3.8)	1.9 (2.8)
Weedy Check			3.4 (10.6)	3.5 (11.3)	4.0 (15.0)	3.7 (12.6)	4.3 (18.0)	4.5 (19.2)
SEm ±			0.1	0.2	0.24	0.40	0.10	0.04
LSD (P=0.05)			0.4	0.5	0.71	0.12	0.30	0.13

Values given in the parentheses are the original means; DAS=days after sowing ; Data subjected√ x+1 transformation

Table 3. Effect of doses and time of application of tembotrione on yield attributes and grain yield of maize

Treatment	Dose (g/ha)	Time of application (DAS)	Plant height (cm)		Cobs/plant		Rows/cob		Grains/row		Grains/cob		Grain yield kg/ha	
			2014	2015	2014	2015	2014	2015	2014	2015	2014	2015	2014	2015
Tembotrione	100	20	210	226	1.0	1.0	12.8	11	25.7	32	329	320	4266	3960
Tembotrione	125	20	211	227	1.2	1.2	13.6	11	28.6	34	389	381	4460	3971
Tembotrione	150	20	212	227	1.0	1.0	13.6	11	32.0	34	517	498	5016	4091
Tembotrione	100	30	214	230	1.0	1.0	12.8	11	26.6	35	341	343	4768	4097
Tembotrione	125	30	218	230	1.5	1.5	13.2	12	32.0	36	446	443	4971	4035
Tembotrione	150	30	220	234	1.5	1.5	13.6	12	36.4	36	524	529	5066	4261
Tembotrione	125+S	20	213	234	1.2	1.5	14.3	14	38.0	42	558	553	5260	4810
Tembotrione	150+S	20	213	234	1.2	1.5	14.6	14	38.4	43	566	550	5320	4950

Atrazine fb atrazine	1500+750	0-3fb 20	216	219	1.0	1.0	12.0	12	30.2	31	425	421	4590	3499
Atrazine + Pendimethalin	1000+1000	0-3	218	219	1.0	1.0	12.0	12	27.2	30	397	301	4443	3510
Manual Weeding(3)		20,40 &60 DAS	215	229	1.0	1.0	12.9	12	28.6	35	372	380	4570	3966
Weedy Check			176	201	1.0	1.0	8.0	9	16.2	18	210	222	1817	1932
SEm ±			1.4	1.1	0.5	0.3	0.10	0.16	1.1	0.7	20	21	105	119
LSD (P=0.05)			4.2	3.5	NS	NS	0.29	0.50	2.9	2.9	57	60	316	367