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Tembotrione- a post-emergence herbicide for control of diverse weed flora in maize (*Zea mays* L.) in North-West India

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Abstract

Atrazine was the primary tool available for the control of weeds in maize. Being a pre-emergence, it provides effective control of some of the annual grasses and broadleaf weeds, but for complex weed flora, maize crop needs some post-emergence herbicide. The efficacy of tembotrione for post-emergence weed control in maize was evaluated in a field study carried out during summer seasons in 2009, 2010 and 2011 and at farmers' field in 2012. Tembotrione was applied at 100, 110 and 120 g a.i ha^{-1} along with 1000 ml ha^{-1} surfactant as post-emergence (20 days after sowing), atrazine 1000 g a.i ha^{-1} (standard) as PRE, weed free and unsprayed control were kept for comparison. Tembotrione at 110 and 120 g ha^{-1} applied with surfactant 1000 ml ha^{-1} at 20 days after sowing, significantly reduced density and biomass of grasses and broadleaf weeds as compared to its lower dose of 100 g ha^{-1}, atrazine, and unsprayed control. Tembotrione showed reduced efficacy on *. POST application of tembotrione 110-120 g ha^{-1} along with surfactant attained higher grain yields (7.33-7.40 t ha^{-1}) than atrazine 1000 g ha^{-1}, tembotrione 100 g ha^{-1} and unsprayed control and were at par with a weed-free check

Introduction

Maize is the third most important food crop, after rice and wheat, in India. It is grown in a wide range of environments, extending from extreme semi-arid to sub-humid and humid regions in India. Hence it is considered a promising option for diversifying agriculture for the North Indian states of the country, under which there is a plan to divert around 1.2 million hectares from water-guzzling paddy in the next five to seven years. It requires just 1/5th of the total water required to grow paddy and gives much higher returns (Hira, 2009). The low productivity of maize in India, as compared to other maize growing countries of the world, can be attributed to several limiting factors, of which weeds have been one of the major factors responsible for lower yield of this crop.

Weeds compete for all the resources, namely nutrients, water, sunlight, and space during the entire growth stages of maize. Their relative density also plays a significant role in reducing the yield of the crop. Being a more extensive row spaced crop coupled with frequent rains in the month of July and August in this region, weeds inflict yield losses up to 68.9% (Walia et al, 2007), by 27-60%, depending upon the growth and persistence of weed population in maize crop (Tripathi et al, 2005; Sharma and Gautam, 2006; Sunitha et al, 2010; Jat et al, 2012, Singh et al, 2015). Maize is infested with a variety of weed flora including annual and perennial grasses, sedges and broadleaf weeds. The herbicides recommended (atrazine/pendimethalin/alachlor) for weed control in maize control selected weed flora for first 3-4 weeks only and no post-emergence herbicide is available for the control of weeds. The critical period of crop-weed competition started at 30 days after sowing and ended at 60 days after sowing of spring maize in North India (Kiranjeet et al., 2016). Weeds emerging later or which escapes these herbicides, compete with the crop and inflict heavy losses in grain yield.

Atrazine is commonly used by the farmers for weed control in this crop worldwide. Being a pre-emergence herbicide, it is not effective against some of the weeds, both grass, and broadleaf weeds as well as the sedge *Cyperus rotundus*. Due to a shortage of labor; sometimes farmers skip the application of pre-emergent herbicides, they are left with no other alternative to control the weeds emerging during later stages. It provides effective control of broadleaf weeds and some of the annual grasses like *Dactyloctenium* and *Digitaria sp*. However, it is not effective against hardy weeds like *Commelina benghalensis* (Suresh et al., 2012) which are part of dominated weed flora in maize from the last few years in this region. Atrazine as the pre-emergence application was the primary weapon to control weeds in maize, but for complex weed flora, it needs to be applied in herbicide mixtures

(Walia et al., 2007; Rana et al., 1998; Suresh et al., 2012). Atrazine alone did not control *Acrachne racemosa*, *Commelina benghalensi*, and *Brachiaria reptans*, etc. in field experiments conducted in maize growing region of Punjab, India (Singh et al., 2007). Selection of weed species not controlled by atrazine is increasing in the maize-growing areas of India, especially, where the farmers are using atrazine year after year. So, it is imperative to test the efficacy of new herbicides having a different mode of action than atrazine in maize.

Tembotrione-2-[2-chloro-4-(methylsulfonyl)-3-[(2,2,2 trifluoromethoxy)methyl]benzoyl]-1,3-cyclohexanedione is a novel maize herbicide that is effective against a wide range of broadleaf and grass weeds and especially as postemergence (POST). It inhibits 4-hydroxyphenylpyruvate dioxygenase (HPPD) enzyme which catalyzes the conversion of 4-hydroxyphenylpyruvate to homogentisate leading to depletion of carotenoids and an absence of chloroplast development in emerging foliar tissue which then appears bleached and stunted (Hawkes, 2007). Postemergence (POST) herbicide application is an essential option in crops like maize, as escaped weeds or the later flushes of weeds may compete with the crop and contribute seed to the weed seed bank (Vahedi et al., 2013). The field efficacy of tembotrione as post-emergence against mixed weed flora in maize was evaluated in the present study in research experiments and at farmers' field.

Materials and Methods

Experimental site and weather conditions

A field experiment was conducted in the Department of Agronomy, Punjab Agricultural University, Ludhiana (30054'N latitude and 75048'E longitude), India during the summer season of 2009, 2010 and 2011. During 2012, different field trials were conducted at farmer's field in Patiala, Jalandhar, Gurdaspur and Kapurthala districts of Punjab. The climate of this region is sub-tropical and semi-arid with scorching and dry summer from April to June, hot and humid conditions from July to September, cold winters from November to January and mild climate during February and March. The soil of the experimental area in Ludhiana was sandy loam with available N, P, and K of 192.4, 13.6 and 157.1 kg ha-1, respectively. The soil type was medium-textured at farmer's field.

Treatments

At Ludhiana, six treatments consisting of tembotrione 42% SC at 100, 110 and 120 g a.i. ha-1 was applied by mixing with surfactant 1000 ml ha-1, atrazine 1000 g ha-1 (standard check), weed free and unsprayed control were laid in randomized complete block design with four replications. Tembotrione was applied as post-emergence (POST) 20-25 days after sowing (DAS) and atrazine as pre-emergence (PRE). The herbicide Tembotrione 42% SC was provided by Bayer Crop Science. Atrazine was applied with backpack knapsack sprayer calibrated to deliver 500 liters of spray solution per hectare with flat fan nozzle while tembotrione was applied at the volume of 375 liters spray solution per hectare using same spray set up. The plots were kept free from weeds during the critical crop-weed competition in weed-free treatment, and unsprayed control was kept in the treatments for comparison. At the farmers' field, three treatments viz., tembotrione 110 g a.i. ha-1, farmers' practice (application of atrazine 1.0 kg a.i. ha-1 or intercultural done with a tractor) and unsprayed control were kept at different locations during 2012.

Agronomic practices

The field was prepared by one plowing with disc harrow followed by two ploughings with cultivator, and each plowing was followed by planking. Maize hybrid PMH 1 cultivar was sown using 20 kg seed/ha on 4 July 2009; 15 June 2010 and 15 June 2011 by dibbling at a row to row spacing of 60 cm and plant to plant spacing of 20 cm in Ludhiana. Thinning and gap filling were done at ten days after sowing. At the farmers' field, the crop was sown in the second fortnight of June or first fortnight of July 2012. The crop was fertilized with 125 kg N, 60 kg P2O5, and 30 kg K2O/ha. The nitrogen was applied in the form of urea (46% N), P2O5 in the form of single super phosphate (16% P2O5) and K2O in the form of muriate of potash (60% K2O). The entire quantity of phosphorus and potassium and one-third of nitrogen was drilled at the time of sowing. One-third of nitrogen was top dressed at the knee-high stage and the remaining one-third at the pre-tasselling stage. Application of Decis 200 ml ha-1 was applied against stem borer using 150 liters per hectare. The harvesting of the crop was done manually when husk of more than 80 percent of the cobs turned yellowish brown, and grains became hard. Harvesting was done three days after physiological maturity of cobs in each plot. The crop was harvested at maturity when the cobs dried, and the entire plants turned yellow on 23 October 2009; 22 September 2010 and 18 October 2011 in Ludhiana and second fortnight of October 2012 in different locations at farmers' field. The cobs harvested from the net plot were dried in the sun. The shelling of the cobs was done with a maize sheller.

Sampling and observations

Weed densities and biomass were assessed during the growing season within 0.5 m × 0.5m quadrat (two quadrats per plot), at 45 days after sowing. For biomass, weeds were cut close to the ground level, put in paper bags, dried in an oven for 72 hours at 600C, and biomass was recorded. The weed data were subjected to square root transformation before analysis. Weed index was calculated using the formula X-Y/X where X is grain yield in the weed-free plot, and Y is the yield in treatment plot.

Five representative cobs from each plot were taken, and their length was measured with the scale in centimeters. Girth (Diameter) of the cobs taken for measuring length was measured with the help of a Vernier Caliper from the base, center and the top and mean value was multiplied with the value of π (3.14) to get average cob girth. The data was recorded at the time of crop harvest from the center rows of each plot. The cobs were shelled, dried, and weighed. The grain yield was recorded in t ha-1 at 14% moisture content.

SDS-PAGE and chip electrophoresis

Zeins were separated using SDS-PAGE and Experion chip electrophoresis. SDS-PAGE electrophoresis was carried out in 12% polyacrylamide gels, prepared with PlusOne 40% Acrylamide (GE Healthcare, ref. 17-1303-01), according to Laemmli and Favre (1973) with modifications, using a Hoefer SE 600 system. Amersham Low Molecular Weight (ref.17-0446-01) Markers were used to calibrate the gel run and to determine apparent MW of zein fractions (GE Healthcare, 2006). The proteins were fixed in a solution with 30% of ethanol and 10% of acetic acid and stained in Coomassie solution with 0.02% Brilliant Blue R, 30% methanol and 10% acetic acid. Chip electrophoresis was performed using the Experion automated electrophoresis system. Zein extracts were prepared using the Experion Pro260 analysis kit. The Pro260 ladder with internal lower and upper markers was used to calibrate experion virtual gels (Bio-Rad, 2010).

Statistical analysis

Data were analyzed using the GLM procedure in SAS version 9.3 to evaluate the differences between treatments (SAS 9.3). Where the ANOVA indicated that treatment effects were significant, means were separated at a 5% level of significance with Fisher's Protected Least Significant Difference (LSD) test. Weed density and weed biomass data were square root transformed. Where the ANOVA indicated significant treatment effects, means were separated at $P \leq 0.05$ and adjusted with Fisher's Protected least significant difference (LSD) test.

Results and Discussion

Effect on weeds

Maize was not affected by the application of tembotrione (100-110-120-1000 g ha-1) with surfactant: no phytotoxicity was observed 7-15-30-45 days after spraying at all doses during the three years (2009-2010-2011) which indicated that tembotrione was safe to maize crop at all the tested doses. (data not shown). High level of tolerance of maize to tembotrione was also reported (Hinz et al., 2005 and Hora et al., 2005).

The experimental field had a natural population of grass, broadleaf, and sedges viz. Dactyloctenium aegyptium, Echinochloa colonum, Acrachne racemosa, Eleusine indica, Digitaria sanguinalis, Commelina benghalensis, Cynodon dactylon, Eragrostis tenella

Table 1 Effect of weed control treatments on weed density at 45 days after sowing during 2009

Treatment	Dose (g ha^{-1})	Weed density (No. m^{-2})						
		E. colonum	*D. aegyptium*	*D. sanguinalis*	*T. potulacastrum*	*A. viridis*	*E. microphylla*	*C. rotundus*
Tembotrione + surfactant*	100	3.9 (14)**c	3.2 (9.3)b	2.2 (4.0)b	1.7 (2.0)a	0.7 (1.2)a	1.3 (1.5)c	5.3 (27.5)c
Tembotrione + surfactant	110	2.8 (7.0)b	3.1 (8.3)b	2.1 (3.7)b	1.4 (1.0)a	1.0 (0.0)a	1.0 (0.0)a	4.9 (23.3)b
Tembotrione + surfactant	120	2.4 (5.0)b	3.4 (5.0)b	1.7 (2.0)b	1.4 (1.0)a	1.0 (0.0)a	0.7 (1.2)a	4.0(14.7)b
Atrazine	1000	6.5 (42.0)d	3.2 (9.0)b	3.0 (8.0)c	1.0 (0.0)a	1.3 (1.5)b	1.4 (1.0)c	4.5 (19.3)b
Weed free	-	1.0 (0.0)a	1.0 (0.0)a	1.0 (0.0)a	1.0 (0.0)a	1.0 (0.0)a	1.0 (0.0)a	1.0 (0.0)a
Unsprayed Control	-	8.5 (71.7)e	60.0 (7.8)c	45.0 (6.8)d	4.7 (22.3)b	2.8 (7.0)c	2.4 (4.7)d	45.0 (6.8)d

*surfactant 1000 ml ha^{-1}
** Numbers within parenthesis are original means. Data was subjected to square root transformation
Least square means within a column followed by the same letter do not differ significantly according to Fisher's protected least significant difference (LSD) test where $P < 0.05$.

among grasses; Trianthema portulacastrum, Mollugo sp., Phyllanthus niruri, Euphorbia hirta, Euphorbia microphylla, Digera arvensis, Amaranthus viridis, Rhyncosia capitata, Cucumis trigonus among broadleaf weeds and Cyperus rotundus among sedges over the years etc. (Tables 1, 2 and 3).

C. rotundus and reduced weed biomass as compared to atrazine (Table 1). Balyan et al. (1994) reported poor control of Echinochloa colonum with atrazine. Atrazine and tembotrione at higher doses of 110 and 120 g ha^{-1} recorded effective control of Dactyloctenium aegyptium, Trianthema portulacastrum, and

Table 2 Effect of weed control treatments on weed density at 45 days after sowing during 2010

		Weed density (No. m-2)				
Treatment	**Dose (g ha-1)**	**2010**				
		C. benghalensis	***D. aegyptium***	***D. sanguinalis***	***T. potulacastrum***	***C.rotundus***
Tembotrione+surfactant	100	3.9 (14.3)c	3.0 (8.0)c	3.1 (8.3)d	2.5 (5.3)c	5.0 (24.0)c
Tembotrione+surfactant	110	3.1 (8.3)b	2.9 (7.7)bc	2.5 (5.3)c	2.1 (3.3)c	4.9 (22.7)b
Tembotrione+surfactant	120	2.4 (5.0)b	2.1 (3.3)b	1.7 (2.0)b	1.6 (1.7)b	4.7 (21.0)b
Atrazine	1000	4.6 (20.0)d	4.2 (16.7)d	3.5 (11.7)d	2.5 (5.3)c	4.1 (15.7)b
Weed free	-	1.0 (0)a	1.0 (0)a	1.0 (0)a	1.0 (0)a	1.0 (0)a
Unsprayed control	-	7.1 (50.0)e	6.8 (44.7)e	3.6 (12.3)d	8.3 (3.05)d	6.4 (40.1)d

*surfactant 1000 ml ha^{-1}
** Numbers within parenthesis are original means. Data was subjected to square root transformation
Least square means within a column followed by the same letter do not differ significantly according to Fisher's protected least significant difference (LSD) test where P < 0.05.

Tembotrione at 110 and 120 g ha^{-1} gave effective control of all the grasses and, broadleaf weeds and significantly reduced the weed density and biomass as compared to atrazine and unsprayed control. It was effective against Commelina, which was not controlled by atrazine. Atrazine provided excellent control of few kinds of grass viz. Dactyloctenium, Digitaria, and all the broadleaf weeds. During 2009, tembotrione at 110 and 120 g ha^{-1} recorded significantly higher density of all the weeds except Dactyloctenium aegyptium, Trianthema portulacastrum, Echinochloa colonum, and Amaranthus Viridis. These three these weeds are still a significant problem in many maize fields. During 2009, tembotrione 110 and 120 g ha^{-1} recorded significantly less density of E. colonum than tembotrione 100 g ha^{-1}. Atrazine and all doses of the tembotrione recorded a similar density of D. aegyptium. However effective control of D. sanguinalis was recorded by all doses of tembotrione than atrazine. Both the used herbicides tembotrione and atrazine were at par concerning the population of T. portulacastrum. All the tested doses effectively controlled A. Viridis as compared to atrazine. Tembotrione at 110 and 120 g ha^{-1} provided

Table 3 Effect of weed control treatments on weed density at 45 days after sowing during 2011

Treatment	**Dose (g ha^{-1})**	**Weed density (No. m^{-2})**		
		D.aegyptium	***C. benghalensis***	***C. rotundus***
Tembotrione+surfactant	100	6.2 (38)c	4.3 (22)c	5.4 (31)c
Tembotrione+surfactant	110	3.2 (14)b	4.1 (16)c	3.6 (19)b
Tembotrione+surfactant	120	2.6 (8)b	3.8 (16)b	4.3 (22)b
Atrazine	1000	9.0 (79)d	5.5 (28)d	6.2 (39)c
Weed free	-	1.0 (0)a	1.0 (0)a	1.0 (0)a
Unsprayed control	-	10.3 (107)d	5.3 (27)d	5.1 (28)c

*surfactant 1000 ml ha^{-1}
** Numbers within parenthesis are original means. Data was subjected to square root transformation
Least square means within a column followed by the same letter do not differ significantly according to Fisher's protected least significant difference (LSD) test where P < 0.05.

Table 4 Effect of weed control treatments on total weed biomass at 45 days after sowing

Treatment	Dose (g ha^{-1})	Total weed biomass (q ha^{-1})		
		2009	2010	2011
Tembotrione +surfactant	100	3.97 (14.8)d	4.25 (17.07)d	4.67 (20.87)d
Tembotrione +surfactant	110	3.30 (9.9)c	3.94 (14.60)c	4.25 (17.10)c
Tembotrione +surfactant	120	3.02 (8.1)b	3.04 (8.30)b	3.51 (11.33)b
Atrazine	1000	3.83 (13.7)d	4.32 (17.67)d	4.81 (22.17)d
Weed free	-	1.0 (0)a	1.0 (0)a	1.0 (0)a
Unsprayed Control	-	5.28 (26.9)e	5.96 (34.53)e	5.62 (30.57)e

*surfactant 1000 ml ha^{-1}
** Numbers within parenthesis are original means. Data was subjected to square root transformation
Least square means within a column followed by the same letter do not differ significantly according to Fisher's protected least significant difference (LSD) test where $P < 0.05$.

tembotrione, where effective control of weeds was obtained.

Effect on crop

Pooled data of three-year research trials indicated a similar number of rows per cob, cob length, cob girth, and grain yield where tembotrione was applied at 110-120 g ha^{-1}. Averaged over the years, tembotrione at all the doses, atrazine 1000 g ha^{-1}, and weed-free treatment yielded significantly higher grain yield over unsprayed control (Table 5). Tembotrione at 110 and 120 g ha^{-1} recorded significantly higher maize grain yield than its lower dose of 100 g ha^{-1} and were at par with a weed-free check. The grain yield with a lower dose of tembotrione 100 g ha^{-1} was higher than atrazine. The increase in herbicide dose implemented the weed control efficacy and increased the maize grain yield attributes like several rows per cob, cob length and cob girth which reflected in higher grain yield as compared to treatments having lower weed control and unsprayed control. Tembotrione at 100, 110 and 120 g ha^{-1} increased the grain yield by 5.3, 10.4 and 11.4 percent, respectively as compared with atrazine. Weed index was lower in tembotrione 120 g ha^{-1} (1.60) followed by 110 g ha^{-1} (2.53). Higher weed index was obtained in unsprayed control, which means that the yield loss caused by weeds is higher in this plot (Table 5). A pigment synthesis inhibitor tembotrione (42% SC), which is a post-emergent broad-spectrum

Table 5- Effect of weed control treatments on yield parameters and grain yield of maize (pooled data of three years)

Treatment	Dose (g ha-1)	No. of rows per cob	Cob length (cm)	Cob girth (cm)	Maize grain yield (t ha-1)	Weed Index
Tembotrione +surfactant	100	11.7b	7.8c	5.8b	6.99b	7.05
Tembotrione +surfactant	110	13.8a	8.1b	6.5a	7.33a	2.53
Tembotrione +surfactant	120	14.4a	8.4b	6.6a	7.40a	1.60
Atrazine	1000	10.8b	7.3d	5.4c	6.64c	11.70
Weed free	-	14.4a	8.8a	6.5a	7.52a	-
Unsprayed Control	-	9.3c	7.2d	5.0d	5.96d	20.75

*surfactant 1000 ml ha-1
Least square means within a column followed by the same letter do not differ significantly according to Fisher's protected least significant difference (LSD) test where $P < 0.05$

Table 6- Effect of different herbicides on different weed species and grain yield of maize at farmers' field in 2012 (means of five locations)

Treatment	Weed density (No. m-2)	Grain yield (t ha^{-1})	Variable cost (Rs ha^{-1})	Gross returns (Rs ha^{-1})	Net returns (Rs ha^{-1})	B:C
Tembotrione 110 g ha^{-1} at 20 DAS	7.02a	5.43a	35151.0	53253.2	18102.2	0.50
Farmers' Practice (atrazine 1.0 kg ha^{-1} /interculture 20 DAS)	15.66b	5.00b	35790.1	49019.6	13229.5	0.38
Unsprayed Control	402.04c	3.81c	34767.6	37318.4	2550.8	0.06

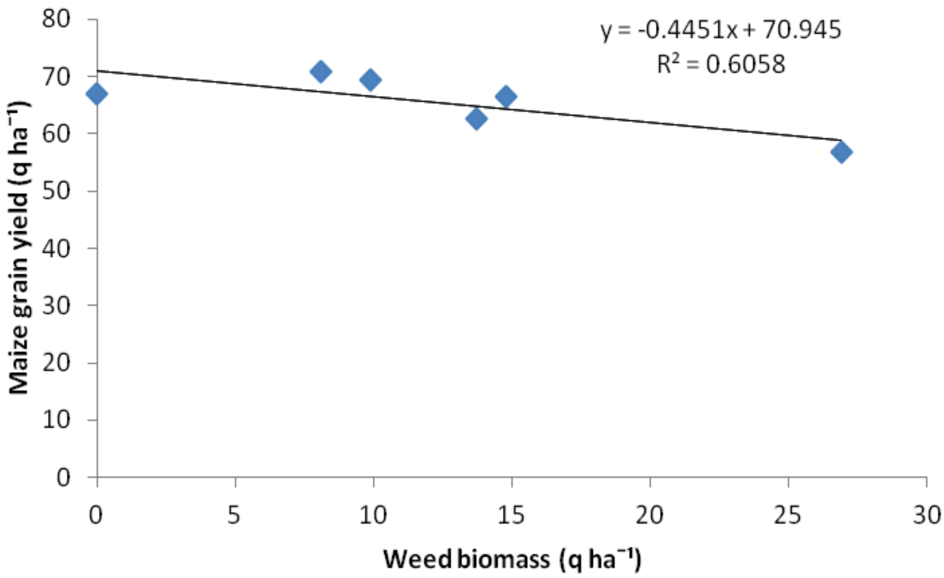

Figure 1 Effect of weed biomass on grain yield of maize during 2009

recorded significantly lower weed biomass than its lower dose of 100 g ha-1 and atrazine 1000 g ha-1 (Table 4). Efficacy of tembotrione at 110-120 g ha-1 against broadleaf weeds and grasses has been reported earlier by Singh et al., (2012). During 2011, D. aegyptium was effectively controlled by tembotrione at 110 and 120 g ha-1 than atrazine. Tembotrione and atrazine showed poor results on C. rotundus from 2009 to 2011.

Tembotrione at 110 and 120 g ha^{-1} recorded significantly less population of this weed than its lower dose and atrazine during 2010 and 2011. During 2009 to 2011, with each increment in the dose of tembotrione, total weed biomass was decreased and significantly less than atrazine. Due to significantly less weed density in tembotrione higher dose, significantly less weed biomass was recorded. Weed-free plots recorded nil weed density and biomass due to hand weeding throughout the crop season.

Effect on crop

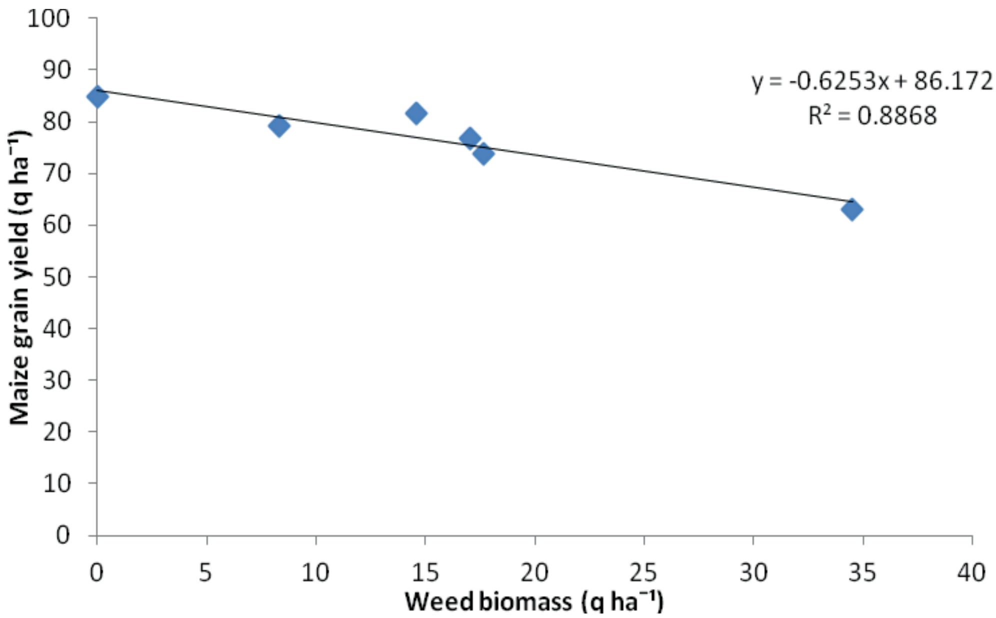

Figure 2 Effect of weed biomass on grain yield of maize during 2010

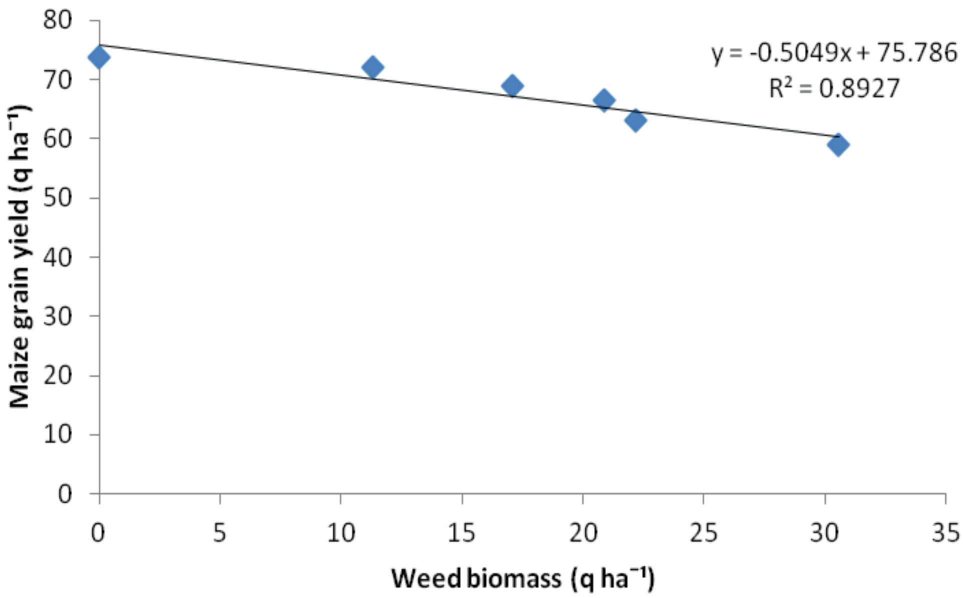

Figure 3 Effect of weed biomass on grain yield of maize during 2011

Pooled data of three-year research trials indicated a similar number of rows per cob, cob length, cob girth, and grain yield where tembotrione was applied at 110-120 g ha-1. Averaged over the years, tembotrione at all the doses, atrazine 1000 g ha-1, and weed-free treatment yielded significantly higher grain yield over unsprayed control (Table 5). Tembotrione at 110 and 120 g ha-1 recorded significantly higher maize grain yield than its lower dose of 100 g ha-1 and were at par with a weed-free check. The grain yield with a lower dose of tembotrione 100 g ha-1 was higher than atrazine. The increase in herbicide dose implemented the weed control efficacy and increased the maize grain yield attributes like several rows per cob, cob length and cob girth which reflected in higher grain yield as compared to treatments having lower weed control and unsprayed control. Tembotrione at 100, 110 and 120 g ha-1 increased the grain yield by 5.3, 10.4 and 11.4 percent, respectively as compared with atrazine. Weed index was lower in tembotrione 120 g ha-1 (1.60) followed by 110 g ha-1 (2.53). Higher weed index was obtained in unsprayed control, which means that the yield loss caused by weeds is higher in this plot (Table 5). A pigment synthesis inhibitor tembotrione (42% SC), which is a post-emergent broad-spectrum systemic herbicide of triketone group has been tested and proved to be successful in managing all the categories of weeds infesting the maize fields during later stages. Singh et al., (2012) also reported that post-emergence application of tembotrione 120 g ha-1 along with surfactant (1000 ml ha-1) was found most effective to control the grassy as well as non-grassy weeds as compared to other herbicidal treatments either applied as pre- or post-emergence with maximum weed control efficiency (90%). Efficacy of tembotrione increases when used with surfactant against mixed weed flora compared to when used alone.

Application of tembotrione at 110 g ha-1 produced a significantly higher maize grain yield (5.43 t ha-1) as compared to farmers' practice (5.00 t ha-1) during 2012 (Table 6). The maize grain yield was significantly reduced (3.81 t ha-1) in unsprayed control as the weed density was significantly high in the control plot. The weed density was significantly reduced in tembotrione 110 g ha-1 than farmer practice (atrazine 1.0 kg ha-1/ interculture by tractor) as the weeds compete for light, moisture, nutrients, etc., which ultimately led to a reduction in grain yield. Due to less grain yield in unsprayed control, farmers got lower net returns as compared to where tembotrione herbicide was used. Significantly higher returns of 18102.2 Indian Rupees (Rs) per hectare were obtained in tembotrione with B:C ratio of 0.5. The data presented in Table 6 indicated that gross returns, net returns, and benefit: cost ratio gradually increased with the application of herbicide tembotrione, where effective control of weeds was obtained.

Correlation and Regression

Regression analysis indicated that there was a significant negative linear relationship between grain yield and weed biomass at 45 days after sowing. In regression analysis, the equations y = -0.4451x + 70.945 (Figure

1), y = -0.6253x + 86.172 (Figure 2) and y = -0.5049x + 75.786 (Figure 3) were found to be fit for the maize grain yield and weed biomass where y is grain yield and x is weed biomass. Correlation between grain yield and weed biomass at 45 days after sowing was, respectively, R^2 = 0.6058 (Figure 1), R^2 = 0.8868 (Figure 2) and R^2 = 0.8927 (Figure 3) which indicated a high degree of negative correlation between weed biomass and grain yield.

Conclusions

From this study, it is concluded that tembotrione 110-120 g ha^{-1} applied as post-emergence at 20 days after sowing can be used for effective control of grasses and broadleaf weeds in maize.

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