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Herbicide options for effective weed management in zero-till maize

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ABSTRACT

A field experiment was carried out during winter seasons of 2015-16 and 2016-17 at Uttar Banga Krishi Viswavidyalaya, Pundibari, Coochbehar, West Bengal with the objective of identifying weed management options with various pre- and post-emergence herbicides in zero-till maize in rice-maize cropping system. Three pre-emergence herbicides, *viz*. pendimethalin 1.0 kg/ha, atrazine 1.0 kg/ha and control in main plots and six post-emergence treatments, *viz*. atrazine (0.5 kg/ha), tembotrione (120 g/ha), halosulfuron (90 g/ha), tembotrione (120 g/ha) + atrazine (0.5 kg/ha), halosulfuron(90 g/ha) + atrazine (0.5 kg/ha) and control in sub-plots were evaluated in a split-plot design. Results revealed that both pendimethalin and atrazine reduced the grassy weed population to a significant extent and among the pre-emergence herbicides, atrazine resulted in maximum reduction in grass weed population (69% reduction over the weedy check) at 20 days after seeding (DAS). Among the post-emergence herbicides, mixture of tembotrione + atrazine was more effective in controlling all classes of weed flora at 40 and 60 DAS. Tembotrione alone also showed a good control of grasses and broad-leaved weeds. Atrazine as pre-emergence followed by (*fb*) tembotrione + atrazine as post-emergence had significantly lower weed biomass (2.9 and 7.5 g/m^2 at 40 and 60 DAS, respectively) and this combination reduced the weed dry matter to the tune of 98.7 and 97.9% at 40 and 60 DAS, respectively which ultimately resulted in significantly higher grain yields (11.57 t/ha) with maximum net returns (` 74210/ha) and B: C ratio (2.73). A strong negative correlation between weed biomass at 60 DAS and maize grain yield clearly suggested that weed biomass accounted for 55% variation in grain yield of zero-till maize.

INTRODUCTION

Maize (*Zea mays* L.) is the third most important cereal crop after rice and wheat, which is widely grown in the world and is used as primary staple food in many developing countries. Due to the wider adaptability and high yield potential of the crop, it can be included in many cropping systems.The increasing demand for maize is rapidly transforming cropping systems in certain parts of Asia (Yakadri *et al.* 2015). Significant shifts from rice monoculture to more profitable rice- maize systems have either occurred or are emerging (IRRI and CIMMYT 2006). This northern part of West Bengal has very high yield potential of winter maize and the areas under this cropping system are escalating day by day because of its increasing demand for fish feed, poultry feed, animal feed and starch industries in the eastern part of the country.

Under conventional rice-maize system, maize is grown by manual dibbling after intensive 5-6 tillage operations which delayed the maize sowing at least 2-3 weeks. Again, number of repetitive tillage operations increases the cost of cultivation as well as fuel consumption. Dibbling requires large number of labour which further increases the cost of cultivation. The conservation agriculture (CA) based new agronomic management practices offers to tackle these challenges. CA holds tremendous potential for all size of farm and agro-ecological system, but its adaptation is probably most urgently required by small land holder (FAO 2006).The direct seeded maize in no-till/strip till/permanent beds is an alternate option through mechanized precision planting in a single pass. Zero tillage technology has turned into a great success story and seems to be one of the best technologies after green revolution (Singh *et al.*

2010). After seeding through zero till-drill, one of the major challenges is the weed management, particularly due to lack of pre- and post-emergence herbicides in the region. Changes in patterns of tillage, planting systems, and other management strategies can alter the soil environment and lead to a major change in weed flora. Herbicide use has been an extremely important component of weed management in CA systems (Bhullar *et al.* 2016). The traditional weed management comprises of hand weeding and spading simultaneously for earthing-up to make furrow and ridges at 4-5 weeks after seeding, which is labour intensive but facilitates furrow irrigation. However, weed control in the early part of the growing season is very important due to its initial slow growth rate and wider row spacing. Yield losses due to weed infestation may vary from 28-93% depending on the type of weed flora and their intensity, stage, nature and duration of crop weed competition (Sharma and Thakur 1998). Uncontrolled weeds in maize caused yield reduction in the range of 40 to 60% depending upon the intensity and types of weed flora (Sunitha and Kalyani 2012).

To address the weed management problems in zero-till maize, different weed management options with various pre- and post-emergence herbicides were evaluated.

MATERIALS AND METHODS

The experiment was carried out at Uttar Banga Krishi Viswavidyalaya, Pundibari, Coochbehar (26°24’02.2"N latitude, 89°23’21.7"E longitude and at an elevation of 43 meters above mean sea level) during winter seasons of 2015-16 and 2016-17. The soil was sandy loam in texture with good drainage facility with 0.90% organic C, 127.50 kg/ha of mineralizable N, 17.3 kg/ha of available phosphorus, 122.9 kg/ha of available potassium with a pH of 5.54. The experiment was laid out in a split-plot design. Three pre-emergence herbicides, *viz*. pendimethalin at 1.0 kg/ha, atrazine at 1.0 kg/ha, and no application were taken in main plots while six post-emergence treatments, *viz*. atrazine (0.5 kg/ha), tembotrione (120 g/ha), halosulfuron (90 g/ha), tembotrione (120 g/ha) + atrazine (0.5 kg/ha), halosulfuron (90 g/ha) + atrazine (0.5 kg/ha), and no application were taken in sub-plots, each replicated thrice. Glyphosate 41% S.L. at 3.75 litre/ha was applied 7 days prior to sowing for killing the existing weed flora. Seeds of hybrid maize ‘*DKC 9081*’ of 150-155 days duration were placed in lines 60 cm apart through a 9 tyne National Agromake zero-till seed-cum-fertilizer drill and a seed to seed distance of 20 cm was maintained. The fertilizer dose was kept at 170 kg nitrogen, 80 kg phosphorus and 100 kg potassium/ha. Nitrogen was applied in three splits (30 kg/ha as basal through 10-26-26 complex fertilizer at the time of seeding with drill, 70 kg/ha at 4 weeks after sowing and rest 70 kg/ha at 7 weeks after sowing). Full dose of phosphorus (80 kg/ha) along with 80% potassium (80 kg/ha) were applied with 10-26-26 complex fertilizer at the time of seeding with drill, while the rest 20% potassium (20 kg/ha) was applied during second top-dressing.

Herbicides were applied with knapsack sprayer fitted with a flat-fan nozzle and water as a carrier at 500 litre/ha for pre-emergence spray and at 375 litre/ha for post-emergence spray. A three nozzles boom with flat-fan nozzle tip was used for spraying. Tank mix herbicides were properly mixed in stock solution prior to adding in spray tank avoiding mixing the herbicides directly in spray tank. Quadrates (50 x 50 cm) were established in each plot after pre-emergence applications, 1-2 days after seeding. Initial weed count was taken from four permanent quadrates before application of post-emergence herbicides. For weed count and weed biomass at 20 days after post-emergence herbicide application, count was taken from all four permanent quadrates and weed biomass from only two random quadrates. Weed count and biomass at 40 days after post-emergence herbicide application were taken from the two remaining permanent quadrates. Weeds were cut at ground level, washed with tap water, sun-dried, oven-dried at 70 degree centigrade for 48 hours, and then weighed. Grain yield was measured from the entire plot area of 15 m^2 and expressed in kg/ha at 14% moisture.

Data on weed density was subjected to $(\sqrt{x+1})$ square root transformation to normalize the distribution. Mean separations for different treatments under different parameters were performed using Least Significance Difference (LSD p=0.05) test. Entire statistical analysis was carried out using Statistical Analysis System (SAS) software (version 9.2). Economics of the treatments was computed based on the existing market price.

RESULTS AND DISCUSSION

Weed flora

The weed flora emerged during the period of experimentations included grasses like *Cynodon dactylon* and *Digitaria ciliaris*; sedges like *Cyperus iria* and *Cyperus rotundus*; broad-leaved like

Polygonum pensylvanicum, Polygonum persicaria, Polygonum orientale, Stellaria media, Chenopodium album, Ageratum conyzoides, Solanum nigrum, Physalis minima, etc. During the initial period, grass weeds dominated the weed flora along with some sedge, whereas broad-leaved weeds especially *Polygonum* spp. emerged at 20 days after seeding and remained continuous throughout the growth stages. Earlier, Mukherjee and Rai (2016) reported the severe infestation of *Polygonum* spp. in dibbled maize under zero till condition.

Weed density

Grass weeds density at 20 days after seeding (DAS), following pre-emergence application of pendimethalin and atrazine, was reduced as compared to no pre-emergence application (**Table 1**). Both pendimethalin and atrazine reduced the grassy weed population to a significant extent and among the herbicides, atrazine resulted in maximum reduction in grass weed population (69% reduction over the weedy check) at 20 DAS. Deshmukh *et al.* (2009) reported similar results of lowest weed population with pre-emergence atrazine in maize. Chopra and Angiras (2008) also reported that atrazine as pre-emergence was found promising in reducing weed biomass. Assessment of weed density at 40 and 60 DAS also showed good efficacy of these herbicides.Though there was not much sedge in the experimental field, but the density of sedges following the application of pre-emergence herbicides was also lower than the weedy check in all dates. Application of pre-emergence atrazine had also a great impact in controlling the broad-leaved weeds as reflected from the weed density data at 20 DAS. Among the post-emergence herbicides, tembotrione + atrazine was more effective in controlling all sorts of weed flora at 40 and 60 DAS. Tembotrione alone also showed a good control of grasses and broad-leaved weeds. In our study, the pre-emergence application of atrazine helped to prevent the germination and establishment of the initial flush of grass weeds and small-seeded broad-leaf weeds as the atrazine treated plots were largely free from these weeds for initial 20 DAS. However, atrazine alone could not prevent the establishment of weeds at later stages for which post-emergence herbicides had to be applied. Under the circumstances, tembotrione alone or tembotrione+ atrazine had a greater control on wide-spectrum of weed flora. Among the other post-emergence herbicides, atrazine alone was also quite effective in controlling the broad-leaved weeds.

Weed biomass and WCE

Weed biomass at 40 and 60 DAS varied significantly among various herbicide combinations. The control plots had the highest weed dry matter (226.8 and 353.4 g/m^2 at 40 and 60 DAS, respectively). Atrazine as pre-emergence *fb* tembotrione + atrazine as post-emergence had significantly lower weed dry matter production (2.9 and 7.5 g/m^2 at 40 and 60 DAS, respectively). This combination reduced the weed dry matter to the tune of 98.7 and 97.9% as revealed from maximum WCE (**Table 2**). Mukherjee and Rai (2016) reported higher WCE with pre-emergence atrazine followed by post-emergence atrazine in dibbled maize under zero-till condition. At 40 and 60 DAS, application of tembotrione alone as post-emergence with pre-emergence atrazine or pendimethalin also recorded lower weed dry weight which was at par with the application of atrazine as pre-emergence *fb* tembotrione + atrazine as post-emergence. Tembotrione alone or in combination with atrazine as

Table 1. Weed density at different stages under various herbicides combinations (pooled over 2 years)

Treatment	Grasses (no./m^2)			Sedges (no./m^2)			Broad-leaves (no./m^2)		
	20 DAS	40 DAS	60 DAS	20 DAS	40 DAS	60 DAS	20 DAS	40 DAS	60 DAS
Pre-emergence herbicides									
No Pre-emergence	10.85(116.7)	6.74(44.4)	7.40(53.8)	3.19(9.18)	1.38(0.90)	1.41(0.99)	5.49(29.1)	2.61(5.81)	3.05(8.30)
Pendimethalin 1000 g/ha	6.65(43.2)	5.50(29.2)	6.71(44.0)	3.06(8.36)	1.00(0)	1.09(0.19)	4.24(17.0)	2.42(4.86)	2.50(5.25)
Atrazine 1000 g/ha	6.09(36.1)	5.24(26.5)	6.03(35.4)	1.99(2.96)	1.00(0)	1.00(0)	2.62(5.9)	2.10(3.41)	1.93(2.72)
LSD (p=0.05)	0.18	0.14	0.16	0.15	0.04	0.03	0.16	0.07	0.08
Post-emergence herbicides									
No application	7.78(59.5)	9.08(81.4)	10.26(104.3)	2.83(7.01)	1.76(2.10)	1.83(2.35)	4.12(16.0)	5.06(24.60)	5.16(25.63)
Atrazine 500 g/ha	7.79(59.7)	5.05(24.5)	5.85(33.2)	2.60(5.76)	1.00(0)	1.00(0)	4.07(15.6)	1.00(0)	1.66(1.76)
Tembotrione 120 g/ha	7.94(62.0)	3.64(12.2)	4.82(22.2)	2.72(6.40)	1.00(0)	1.00(0)	4.08(15.6)	1.00(0)	1.00(0)
Halosulfuron 90 g/ha	7.94(62.0)	8.24(66.9)	8.39(69.4)	2.70(6.29)	1.00(0)	1.00(0)	4.17(16.4)	4.22(16.81)	4.56(19.79)
Tembotrione + atrazine 120 + 500 g/ha	7.82(60.1)	2.42(4.9)	3.49(11.2)	2.62(5.86)	1.00(0)	1.00(0)	4.18(16.5)	1.00(0)	1.00(0)
Halosulfuron + atrazine 90 + 500 g/ha	7.82(60.1)	6.53(41.6)	7.51(55.4)	2.60(5.76)	1.00(0)	1.00(0)	4.09(15.7)	2.01(3.04)	1.57(1.46)
LSD (p=0.05)	NS	0.21	0.23	NS	0.05	0.05	NS	0.09	0.12

DAS= Days after seeding. Figures in the parentheses are original values. Data subjected to $(\sqrt{x+1})$square root transformation

Table 2. Weed biomass and weed control efficiency under various herbicides combination (pooled over 2 years)

Pre-emergence herbicides	Post- emergence herbicides	Weed biomass (g/m^2) 40 DAS	Weed biomass (g/m^2) 60 DAS	WCE (%) 40 DAS	WCE (%) 60 DAS
No application	No application	226.8	353.4	-	-
	Atrazine	16.5	57.0	92.7	83.9
	Tembotrione	9.9	36.8	95.7	89.6
	Halosulfuron	98.8	240.0	56.4	32.1
	Tembotrione + atrazine	8.5	12.3	96.3	96.5
	Halosulfuron + atrazine	36.5	68.6	83.9	80.6
Pendimethalin	No application	136.4	194.3	39.9	45.0
	Atrazine	20.0	47.9	91.2	86.5
	Tembotrione	9.8	26.3	95.7	92.5
	Halosulfuron	100.7	178.8	55.6	49.4
	Tembotrione + atrazine	3.3	14.6	98.6	95.9
	Halosulfuron + atrazine	46.8	67.9	79.4	80.8
Atrazine	No application	111.6	152.2	50.8	56.9
	Atrazine	19.1	68.4	91.6	80.7
	Tembotrione	6.4	13.7	97.2	96.1
	Halosulfuron	84.5	83.5	62.7	76.4
	Tembotrione + atrazine	2.9	7.5	98.7	97.9
	Halosulfuron + atrazine	50.5	59.3	77.8	83.2
LSD(p=0.05)	Pre-emergence	2.8	3.8	-	-
	Post-emergence	4.1	5.5	-	-
	Pre X post-emergence	9.3	12.4	-	-

DAS= Days after seeding; For dose please see Table 1

a post-emergence without any pre-emergence herbicides application also had a significant impact in reducing the weed dry matter. Except halosulfuron, all the post-emergence herbicides recorded superior WCE values. It can be said that tembotrione alone or in combination with atrazine as post-emergence only even without any pre-emergence herbicides would be a potential option for broad-spectrum weed control in zero-till maize.

Yield and economics

The treatment receiving atrazine as pre-emergence and tembotrione + atrazine as post-emergence recorded significantly higher grain yields (11.57 t/ha). It was followed by tembotrione + atrazine as post-emergence with pre-emergence pendimethalin (10.65 t/ha) and tembotrione alone as post-emergence in combination with pre-emergence atrazine (10.63 t/ha), being at par with each other (**Table 3**). Triveni *et al.* (2017) reported the maximum grain yields in maize under this combination of herbicides. The treatments in which only pre-emergence herbicides were applied recorded lower grain yields than the treatments with only post-emergence application and the lowest grain yield was recorded with weedy check (4.14 t/ha). All sequential herbicide treatments resulted in better yield as compared to single application of a pre-emergence or post-emergence herbicides. It was observed that maize faced severe weed competition particularly from broad-leaved weeds if there was no application of post-emergence herbicides. However, after the spray of post-emergence herbicides, crop grew vigorously and did not allow the later flushes of weeds to grow which in turn resulted in better yield

Table 3. Grain yield and economics under various herbicides combination

Pre-Emergence herbicides	Post-emergence herbicides	Grain yield (t/ha)	Cost of cultivation (x103 `/ha)	Net returns ($x10^3$ `/ha)	B : C Ratio
No Pre-emergence	No application	4.14	38.47	4.99	1.13
	Atrazine	6.07	39.12	20.61	1.63
	Tembotrione	7.43	43.17	32.24	1.81
	Halosulfuron	4.75	45.82	6.05	1.09
	Tembotrione + atrazine	7.75	43.82	34.95	1.86
	Halosulfuron + atrazine	5.40	46.47	16.92	1.22
Pendimethalin	No application	4.89	39.77	10.97	1.29
	Atrazine	7.91	40.42	38.63	2.06
	Tembotrione	9.06	44.47	48.06	2.14
	Halosulfuron	5.14	47.12	9.20	1.15
	Tembotrione + atrazine	10.65	44.82	64.05	2.50
	Halosulfuron + atrazine	6.13	47.77	25.14	1.35
Atrazine	No application	5.47	39.27	17.56	1.47
	Atrazine	9.59	39.92	56.77	2.53
	Tembotrione	10.63	43.97	64.99	2.54
	Halosulfuron	5.90	46.62	17.38	1.33
	Tembotrione + atrazine	11.57	44.62	74.21	2.73
	Halosulfuron + atrazine	6.48	47.27	68.04	1.44
LSD(p=0.05)	Pre-emergence	0.19	-	-	-
	Post-emergence	0.27	-	-	-
	Pre X post-emergence	0.45	-	-	-

For dose please see Table 1

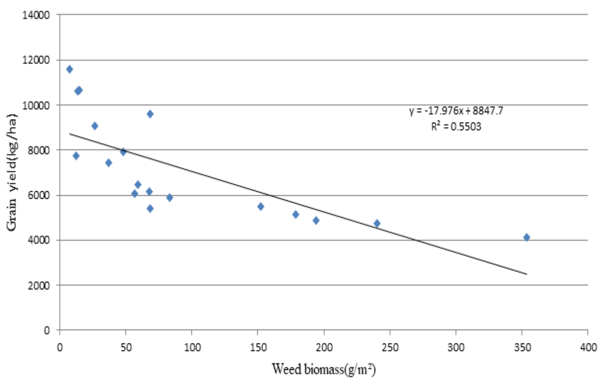

Figure 1. Relationship between weed biomass (g/m²) and grain yield (kg/ha)

performances. A strong negative correlation between weed biomass at 60 DAS and maize grain yield clearly suggested that weed biomass accounted for 55% variation in grain yield (**Figure 1**).

The net returns and B: C ratio increased sharply when herbicides were used in combination with both pre-emergence and post-emergence. When atrazine as pre-emergence was combined with tembotrione + atrazine as post-emergence, the net returns (` 74210/ha) and B: C ratio (2.73) were recorded maximum. This was in conformity with the findings of Triveni *et al.* (2017) who reported higher returns with the use of this herbicides combination in conventionally planted maize. Even tembotrione alone as post-emergence with either pre-emergence atrazine or pendimethalin resulted in increased yield performances. Tembotrione+atrazine as post-emergence with pre-emergence pendimethalin also recorded a superior returns and benefits signifying the impact of this herbicide combination irrespective of the pre-emergence herbicides used in this experiment. Barla *et al.* (2016) reported that pre-emergence atrazine or pendimethalin were equally effective in achieving higher productivity, profitability through better weed control in maize. Based on relative net profit, tembotrione alone as post-emergence could also be advocated with pre-emergence atrazine. On the basis of field study, it can be concluded that atrazine as pre-emergence combined with tembotrione + atrazine as post-emergence would be the most effective herbicides combination for controlling various weed flora in maize under zero till condition.

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