Indian Journal of Agronomy **64** (3): 373–377 (September 2019)

Research Paper

Effect of integrated weed management on weed growth and yield of winter maize (*Zea mays*)

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Received : November 2018; Revised accepted : June 2019

ABSTRACT

A field experiment was conducted during the winter (*rabi*) season of 2016 and 2017 at the Central Tobacco Research Institute, West Bengal. Treatments comprised 6 weed-management practices, viz. atrazine (1.5 kg/ha) + 2, 4-D (1 kg/ha) pendimethalin (1 kg/ha) + 2, 4-D (1 kg/ha), atrazine (1 kg/ha) + pendimethalin (kg a.i/ha) + 2, 4-D (1 kg/ha); atrazine (1.5 kg/ha) + 1 hand-weeding (HW), pendimethalin (1 kg/ha) + HW, atrazine (1 kg/ha) + pendimethalin (kg a.i/ha) + HW with weed-free check, and weedy checks with 4 replications in a randomized block design. The atrazine and pendimethalin were applied pre-emergence with tank mixed; 2, 4-D post-emergence at 30 days after sowing (30 DAS) and 1 hand-weeding at 30 DAS. The tank-mixed application of atrazine and pendimethalin followed by either post-emergence application of 2, 4-D at 30 DAS or 1 hand-weeding at 30 DAS significantly reduced the weed density by > 92% and weed dry weight by > 68% compared to weedy check. Maize yield attributes, grain yield and stover yield were significantly high in the weed-free check, at par with treatment of atrazine + pendimethalin + HW. The maximum yield loss was recorded in the weedy check by 66.55% and the minimum in atrazine + pendimethalin + HW, atrazine + pendimethalin + 2, 4-D. Treatment with atrazine + pendimethalin + 2, 4-D resulted in highest net returns (₹25,820) and benefit: cost (B:C ratio) of 0.54. The results clearly indicated that, the pre-emergence tank-mixed application of atrazine + pendimethalin followed by 1 hand-weeding at 30 DAS or the post-emergence application of 2, 4-D provided weed-free environment, and proved an effective integrated approach for weed management in winter (*rabi*) maize.

Key words : Herbicide, Integrated weed management, Maize, Yield

In India, maize is cultivated throughout the year owing to its photo-thermo-insensitive nature. The winter (*rabi*) maize is grown on an area of 1.8 million ha with the grain production of 7.0 million tonnes, with an average productivity of 3.9 t/ha (DACNET, 2018). Among the predominant *rabi* maize-growing states in India, West Bengal, particularly in *tarai* (foothills) region, represent considerable area. In this area, *rabi* maize cultivation is gaining popularity in place of tobacco, as farmers chose alternative crop to *motihari* tobacco. Since, *rabi* maize is a new crop for farmers in this region, they are facing many problems in its cultivation. Maize, being a widely spaced crop, gets infested with varieties of weeds and is subjected to heavy weed competition, which often inflicts considerable yield losses. Yield losses due to weed infestation in *rabi* maize was recorded 27–90% (Dalley *et al*., 2006; Kumar *et al*., 2015). Herbicide has been the primary tool worldwide (Ghersa *et al*., 2000; Liphadzi and Dille, 2006) in controlling weeds and considerably reducing yield losses of crops (Chikowo *et al*., 2009). Traditional weed control such as hand weeding are labour intensive. It has increased the cost of cultivation and availability of labour which is a big problem during the crop-growing season. Effective herbicidal control of weeds may save yield of crops, time, money and labour etc. Several studies have been conducted for control of weeds in rainy season (Sinha *et al*., 2000; Pandey *et al*., 2001; Singh and Sheoran, 2008; Bahar *et al*., 2009). However, information on weed management in *rabi* maize is meagre. Pre-emergence application of atrazine or pendimethalin followed by 1 hand-weeding at 30 days after sowing (DAS) was effective and recorded higher grain yield (Barad *et al*. 2016). Sequential application of atrazine or pendamethalin followed by application of post-emergence herbicide at 30 DAS resulted

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in the highest gross returns, net returns and B:C ratio (Yakadri *et al*., 2015). The methods for weed management suitable for *kharif* maize may not suitable for *rabi* maize, as weed dynamics may differ and also affected by climatic factors (Verma *et al*. 2009; Singh *et al*. 2015). Kumar *et al*. (2015) reported 30–45 DAS as critical period of crop-weed competition for *rabi* maize. This period differs from the most critical crop-weed competition at initial period of crop growth, i.e. 20–30 DAS in *kharif* maize (Barad *et al*., 2016). In the view of these problems, a study was conducted to find out an integrated and most effective method of weed management which will be suitable for *tarai* region of West Bengal during the *rabi* season.

MATERIALS AND METHODS

A field experiment was conducted during the winter (*rabi*) season of 2016 and 2017 at the ICAR-Central Tobacco Research Institute, Research Station, Dinhata (26^o 20' N, 89^o 27' E, with 43 m above mean sea-level), West Bengal. The climate of the area was humid with mean annual air temperature as low as 5^{o}C during December–January (winter) to as high as 35^{o}C during April–May (summer). The relative humidity was 65 to 95% and total annual rainfall of more than 3,000 mm. During growing season, the maximum temperature of 17.4–34.4^{o}C, minimum temperature of 10.0–23.9^{o}C and total rainfall of 57.7 mm were recorded in 2016. However, the maximum temperature of 22.7–32.7 ^{o}C, minimum temperature of 3.5–19.4^{o}C and total rainfall of 785.2 mm were recorded during 2017. The experimental site was acidic (*p*H 6.5), low in organic carbon (0.06%), low in available P (9.8 kg/ha) and medium in available K (165.6 kg/ha). The experiment was conducted with 6 weed-management practices, viz. atrazine (1.5 kg/ha) + 2, 4-D (1 kg/ha), pendimethalin (1 kg/ha) + 2, 4-D (1 kg/ha), atrazine (1 kg/ha) + pendimethalin (kg/ha) + 2, 4-D (1 kg/ha), atrazine (1.5 kg/ha) + hand-weeding (HW), pendimethalin (1 kg/ha) + HW, atrazine (1 kg/ha) + pendimethalin (kg/ha) + HW with weed-free check, and weedy checks replicated 4 times in a randomized block design (RBD). The atrazine and pendimethalin were applied at pre-emergence (PE) with tank-mixed and 2, 4-D at post-emergence (PoE) at 30 DAS. One hand-weeding was performed 30 days after sowing in various treatments. For spraying of herbicide, knapsack sprayer (16 litres capacity) with flat-fan nozzle was used. In weed-free check plots, hand-weeding was done at 15, 30, 45 and 60 DAS to keep the plots as weed-free. Maize seed was sown in the first week of January with spacing of 60 cm × 20 cm, using seed rate of 18 kg/ha during both the years. Observations on weed density and weed dry matter were taken at 60 DAS, randomly, from plot area at 4 spots in each treatment with 0.25 m × 0.25 m quadrat and data were transformed to square-root transformation before statistical analysis. Weed-control efficiency (WCE), weed-control index (WCI) and relative yield loss (RYL) of maize were calculated as per the formula suggested by Mani *et al*. (1973), Mishra and Tosh (1979) and Tesfay *et al*. (2014) respectively. The costs of cultivation of various treatments were calculated based on the prevailing market price of the local market. Gross returns were calculated by multiplying maize grain yield with minimum support price (MSP) offered by Commission for Agricultural Costs and Prices (CACP), Government of India in respective years. The net returns were calculated by subtracting the total cost of cultivation from gross returns of respective treatments. The benefit: cost ratios (B:C) were calculated by the cost of cultivation divided by net returns. Two years weed data and crop data were pooled, and statistical analysis was performed by a window-based SAS 9.3 programme.

RESULTS AND DISCUSSION

Weed growth

Major 5 weed species comprising of 2 kinds of grasses [*Paspalum conjugatum* Berg and *Cynodon dactylon* (L.) Persoon] and 3 broad-leaf weeds [*Persicaria hydropiper* L., *Chenopodium album* L. and *Sonchus wightianus* DC.] were recorded in the maize field. The weed-management practices affected the weeds distribution across various treatments. The pre-emergence application of atrazine more effectively controlled the broad-leaf weeds than a pre-emergence application of pendimethalin, whereas pendimethalin proved more effective against grasses than atrazine (Singh *et al*., 2007; Das, 2008). However, tank-mixed application of both atrazine and pendimethalin at pre-emergence performs as broad-spectrum herbicide in controlling weeds. Therefore, tank-mixed application of atrazine + pendimethalin (0.75 + 0.75 kg/ha) has been recommended to control weeds in maize field (Susha *et al*., 2014). The weed-management practices significantly affected the weed density and its dry weight among various treatments (Table 1). The tank-mixed application of atrazine and pendimethalin followed by either post-emergence application of 2, 4-D at 30 DAS or 1 hand-weeding at 30 DAS significantly reduced the weed density by > 90% compared to the weedy check. Application of atrazine + pendimethalin + HW significantly reduced weed dry weight than the other treatments and was found at par with atrazine + pendimethalin + 2, 4-D. It was recorded that these 2 treatments reduced weed dry weight by 68.42% compared to weedy check. Significantly higher WCE and WCI were achieved under atrazine + pendimethalin + HW (77.07 and 63.91% respectively) treatment, being at par with atrazine + pendimethalin + 2, 4-D (Table 1). The pre-emergence tank-mixed application of atrazine and pendimethalin resulted in total weed control during the initial period of crop-growing period and followed by 1 hand-weeding, provided weed-free field, exhibited the highest WCE and WCI as compared to the other treatments. Patel *et al*. (2006) reported the maximum weed-control efficiency under pre-emergence application of atrazine + pendimethalin. However, spraying of 2, 4-D at 30 DAS could not control grasses, which remained in the field, contributed lower WCE and WCI in atrazine + pendimethalin + 2, 4-D than atrazine + pendimethalin + HW. These results confirm the findings of Shantveerayya and Agasimani (2012), Mathukia *et al.* (2014), Yakadri *et al*. (2015) and Barad *et al*. (2016).

Maize yield and yield loss

Different weed-management practices significantly affected maize grains/cob, 1,000-grain weight (test weight), shelling %, grain yield, stover yield, harvest index (HI) and relative yield loss (Table 1; Fig. 1). The grains/cob

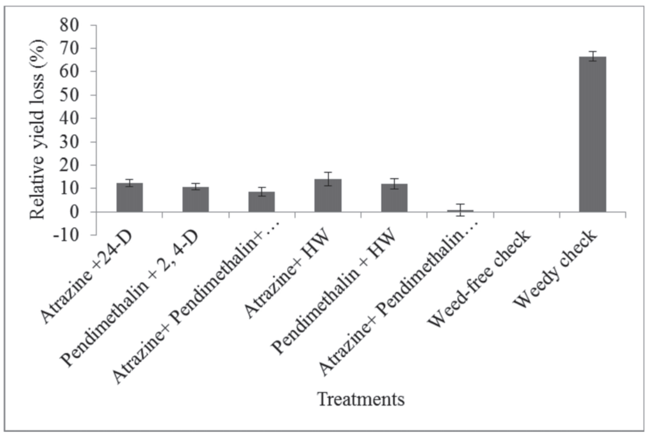

Fig. 1. Relative yield loss as affected by weed-management practices (2 years pooled data); Bar indicate standard error (±)

were significantly high in weed-free check (399.9), at par with atrazine + pendimethalin + 2, 4-D and atrazine + pendimethalin + HW. The test weight of maize grains ranged from 139.8–183.7 g in different treatments. The highest test weight was recorded in weed-free check (183.7), at par with atrazine + pendimethalin + 2, 4-D and atrazine + pendimethalin + HW, which might be due to weed-free plots that provided sufficient quantities of nutrients, moisture and sunlight, resulting in bold grains in weed free-check, atrazine + pendimethalin + 2, 4-D and atrazine + pendimethalin + HW treatments. The shelling (%) of maize grain was 58.4–63.6 which did not differ significantly among the treatments (Table 1).

Maize grain yield and stover yield data were significantly high in weed-free check at par with atrazine + pendimethalin + HW and atrazine + pendimethalin + 2, 4-D treatments. The 2 year average of grain yield was 66.40% higher under atrazine + pendimethalin + HW and 63.46% higher under atrazine + pendimethalin + 2, 4-D treatments than weedy check. The maize stover yield was the highest in weed-free check, followed by atrazine + pendimethalin + 2, 4-D and atrazine + pendimethalin + HW (Table 1), which might be due to the tank-mixed application of atrazine and pendimethalin at pre-emergence that led to weed free condition in the initial period of crop growth. Barla *et al*. (2016) concluded that pre-emergence application of atrazine + pendimethalin (0.5 + 0.5 kg/ha) results in higher productivity, profitability and effective weed control in maize. However, one hand-weeding 30 days after sowing or application of 2, 4-D at post-emergence at 30 DAS resulted in weed-free environment throughout the growing period of maize and provided highest grains/cob and bold grain leading to more grain and stover yield. With respect to harvest index, weed-free

Table 1. Effect of weed management on weed growth, weed-control efficiency (WCE), weed-control index (WCI), maize yield attributes, shelling (%), grain yield, stover yield and harvest index (HI) (pooled data of 2 years)

Treatment	Weed density (Numbers/m^2)	Weed dry weight (g)	WCE (%)	WCI (%)	Grains/ cob	1,000-grain weight (g)	Shelling (%)	Grain yield (t/ha)	Stover yield (t/ha)	HI
Atrazine + 2, 4-D	12.0 (144.2)	1.88 (0.21)	53.58	35.84	372.2	172.5	58.4	4.49	7.51	0.333
Pendimethalin + 2, 4-D	7.9 (62.6)	1.73 (0.16)	69.40	40.69	378.0	175.0	59.8	4.57	7.48	0.334
Atrazine + pendimethalin + 2, 4-D	7.0 (49.8)	1.35 (0.06)	72.56	53.78	385.9	181.9	62.2	4.67	7.96	0.329
Atrazine + hand-weeding (HW)	9.2 (84.7)	1.33 (0.21)	64.60	54.35	350.0	178.6	61.2	4.41	7.09	0.332
Pendimethalin + HW	8.2 (68.8)	1.31 (0.16)	67.90	55.16	379.7	181.1	60.2	4.51	7.79	0.323
Atrazine + pendimethalin + HW	5.9 (35.3)	1.05 (0.06)	77.07	63.91	393.9	182.9	62.7	5.09	7.83	0.346
Weed-free check	0.7 (0.0)	0.71 (0.00)	97.27	75.81	399.9	183.7	63.6	5.12	8.82	0.328
Weedy check	26.1 (684.3)	2.92 (0.19)	0.00	0.00	288.7	139.8	59.6	1.70	4.47	0.235
SEm±	0.64	0.05	1.88	1.56	10.3	4.8	2.4	0.12	0.23	0.013
CD (P=0.05)	1.87	0.14	5.53	4.59	30.2	14.0	NS	0.35	0.68	0.039

Figures in parentheses indicate original value; NS, non-significant

Table 2. Economics of weed-control treatments in winter maize (pooled data of 2 years)

Treatment	Cost of cultivation (×₹10³)	Gross returns (×₹10³)	Net returns (×₹10³)	Benefit: cost ratio
Atrazine + 2, 4-D	46.79	70.42	23.63	0.50
Pendimethalin + 2, 4-D	46.97	71.65	24.68	0.53
Atrazine + pendimethalin + 2, 4-D	47.60	73.42	25.82	0.54
Atrazine + hand-weeding (HW)	53.64	69.10	15.46	0.29
Pendimethalin + HW	53.82	71.13	17.31	0.32
Atrazine + pendimethalin + HW	54.45	79.14	13.00	0.45
Weed-free check	67.51	80.51	13.00	0.19
Weedy check	45.01	28.98	–16.02	–0.36
SEm±	–	1.50	1.41	0.03
CD (P=0.05)	–	4.40	4.14	0.09

check and all other which treatments showed more or less similar result and significantly higher than weedy check, which might be due to thin maize plant which produced less grain yield in proportion to biomass in weedy check.

Among the treatments, the highest yield loss was recorded in weedy check and the lowest in atrazine + pendimethalin + HW, less than 1%, followed by atrazine + pendimethalin + 2, 4-D (8.63%) (Fig. 1). This might be due to weed free environment throughout the active growing period in treatment atrazine + pendimethalin + HW, but in atrazine + pendimethalin + 2,4-D some grasses remained in the field; which was not controlled by use of herbicide and competed for resources. Olorunmaiye and Olorunmaiye (2009) reported that, pre-emergence application of herbicide followed by mechanical or manual weeding exhibited the best weed control and better crop yield in maize.

Economics

Economics of the weed-management practices differed due to the variation of herbicide price, dose, labour requirements and crop yield (Table 2). The treatments involving pre-emergence followed by post-emergence application of herbicide recorded less cost of cultivation than pre-emergence herbicide application followed by one hand-weeding at 30 DAS in various treatments. This variation may be due to less labour requirement for application of herbicide than one hand-weeding at 30 DAS. Weed-free check recorded significantly higher gross returns, being at par with atrazine + pendimethalin + HW. High net returns were recorded under atrazine + pendimethalin + 2, 4-D treatment, being at par with atrazine + 2,4-D and pendimethalin + 2, 4-D. Treatment of atrazine + pendimethalin + 2, 4-D resulted in 1.99 times more net returns than weed-free check. This might be due to the fact that more labour required for manual hand-weeding resulted in the maximum cost of cultivation in weed-free check. With respect to benefit: cost ratio (B:C), in treatments where labourers were not required for hand-weeding showed higher B:C than treatments where labourers were required for hand-weeding. The highest B:C was recorded in atrazine + pendimethalin + 2, 4-D (0.54). Singh *et al*. (2015) reported similar result. However, weedy check plots exhibited negative net returns and B:C, which might be due to heavy weed infestation that resulted in less yield.

It may be concluded that treatment atrazine + pendimethalin + HW was most effective for weed suppression, better yield attributes, and more crop yield. Atrazine + pendimethalin + 2, 4-D was more beneficial than atrazine + pendimethalin + HW from economic point of view. Thus, it may be recommended that, pre-emergence tank-mixed application of atrazine + pendimethalin, followed by 1 hand-weeding 30 days after sowing provided weed-free environment. However, during labour shortage for hand weeding during crop growing period, the post-emergence application of 2, 4-D at 30 DAS may harness maximum yield and avoid considerable yield loss due to weed infestation in the *tarai* region of West Bengal during the *rabi* season.

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