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Management of hardy weeds in maize under mid-hill conditions of Himachal Pradesh

Suresh Kumar*, S.S. Rana, Navell Chander and N.N. Angiras

Department of Agronomy, Forages and Grassland Management, CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur, Himachal Pradesh 176 062

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ABSTRACT

Twelve treatments involving tank-mix combinations of atrazine and pendimethalin as pre-emergence followed by (*fb*) post emergence application of 2,4-D and metsulfuron methyl along with hand weeding twice (20 and 40 DAS) and untreated check were tested in maize during 2009 and 2010 at Palampur. *Echinochloa colona, Panicum dichotomiflorum, Cyperus iria, Commelina benghalensis, Ageratum conyzoides, Digitaria sanguinalis* and *Polygonum alatum* were the dominant weeds. Pendimethalin 1.50 kg/ha, atrazine *fb* atrazine 0.75 kg/ha, atrazine 0.75/1.0 + pendimethalin 0.75/0.50 *fb* metsulfuron methyl 4 g/ha effectively controlled *Echinochloa colona*. Atrazine *fb* atrazine brought about significant reduction in the count of *Panicum dichotomiflorum* up to 60 DAS. Pendimethalin *fb* atrazine, atrazine 1.0 + pendimethalin 0.50 *fb* 2, 4-D 0.75 kg/ha and hand weeding twice effectively reduced the population of *Commelina* up to 60 DAS. Pendimethalin/atrazine *fb* atrazine and atrazine + pendimethalin *fb* 2,4-D/ metsulfuron-methyl controlled *Ageratum conyzoides* up to 60 DAS. Pendimethalin/atrazine *fb* atrazine, atrazine + pendimethalin *fb* metsulfuron-methyl/2, 4-D and pendimethalin significantly reduced total weed dry weight. Atrazine 1.0 + pendimethalin 0.50 kg/ha (post) and atrazine 0.75 + pendimethalin 0.75 kg/ha *fb* 2, 4-D gave significantly higher grain yield and net returns. Weeds reduced maize grain yield by 50.3%.

Key words: Atrazine, Herbicide combinations, Maize, Pendimethalin, Weeds

Maize (*Zea mays* L.) is an important cereal crop and plays a pivotal role in agricultural economy of Himachal Pradesh. Among the factors responsible for low yields, severe infestation by weeds due to wider row spacing coupled with frequent rains in rainy season inflict huge yield losses upto 68.9% (Walia *et al.* 2007). In order to obtain economical yield of maize, weeds must be kept under check. For controlling weeds in this crop, pre-emergence or early post-emergence application of atrazine depending upon the soil type has been recommended. Application of pendimethalin also has been recommended under maize + legume intercropping situations. These herbicides do not control hardy weed species like *Commelina benghalensis, Ageratum conyzoides* and *Brachiaria ramosa* as they appear late in the season. The infestation of these weeds is increasing day by day in the maize-growing areas of the state especially where the farmers are using atrazine year after year. So in order to widen the weed control spectrum, it is imperative to use combination of herbicides having different mode of action (Walia *et al.* 2007, Rana *et al.* 1998, Kumar *et al.* 2011). Therefore, tank-mix combinations of atrazine and pendimethalin alone as pre-emergence followed by post-emergence application of 2,4-D and metsulfuron-methyl were tried in the present investigation.

***Corresponding author:** skg_63@yahoo.com

MATERIALS AND METHODS

A field experiment was conducted during *kharif* seasons of 2009 and 2010 at Palampur in silty clay loam soil having pH 5.6 and medium in available N (289.4 kg/ ha), P (15.4 kg/ha) and K (272 kg/ha). Twelve treatments *viz*., pre-emergence atrazine and pendimethalin each at 1.50 kg/ha, atrazine and pendimethalin each followed by atrazine 0.75 kg/ha, atrazine and pendimethalin each at half rate in combination at sowing alone and followed by post-emergence 2,4-D at 0.75 kg/ha and metsulfuron-methyl at 4 g/ha, atrazine 2/3rd and pendimethalin 1/3rd in combination at sowing alone and followed by post-emergence 2, 4-D at 0.75 kg/ha and metsulfuron-methyl at 4 g/ha, hand weeding twice (20 and 40 DAS) and unweeded check were tested in randomized block design with three replications. Maize hybrid 'KH-101' was sown during first week of June 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 harvested in the first week of October. The crop was fertilized with 120 kg N, 60 kg P_2O_5 and 40 kg K_2O/ha through urea, single super phosphate and muriate of potash, respectively. The required quantity of half N and whole P_2O_5 and 40 kg K_2O was drilled at sowing. The remaining half N was band placed in two equal splits at knee high and tasseling stages. Hand weeding and hoeing as per treatment was done at 20 and

40 days after sowing. Herbicides as per treatment were applied with backpack power sprayer using 600 litre water/ha. Pre-emergence application of herbicides (pendimethalin and atrazine) was made within 48 hours of sowing. Post-emergence application of 2,4-D and metsulfuron-methyl was made on the emergence of broadleaf weeds. Weed count and dry weight (60 DAS and at harvest) were recorded at two spots using a quadrate of 50 x 50 cm. Yields were harvested from net plot. Impact assessment was carried out as per Walia (2003). Economics of the treatments was computed based upon prevalent prices.

RESULTS AND DISCUSSION

Effect on weeds

Weed flora was composed of *Commelina benghalensis* (25.6 and 12.3% at 60 DAS and at harvest, respectively), *Ageratum conyzoides* (45.1 and 56.1%), *Echinochloa colona* (L.) Link (17.6% and 8.7%), *Panicum dichotomiflorum* (8.4 and 7.7%), *Cyperus iria* (2.8 and 7.2%), *Digitaria sanguinalis* (0.0 and 8.2%) and *Polygonum alatum* (0.5 and 8.0%). *Aeschynomene indica* also showed its sporadic occurrence especially in the treated plots.

Treatments under evaluation brought about significant variation in the count and dry weight of *Echinochloa colona* at 60 DAS. All treatments except pendimethalin 1.50 kg/ha (pre), atrazine 1.0 kg/ha + pendimethalin 0.5 kg/ha (pre) *fb* 2,4-D 0.75 kg/ha (post) and atrazine 1.0 kg/ha + pendimethalin 0.5 kg/ha (pre) *fb* metsulfuron-methyl 4 g/ha (post) in 2009 were superior to weedy check in suppressing the growth of *Echinochloa colona* during both the years. However, pendimethalin 1.50 kg/ha and atrazine 0.75 kg/ha + pendimethalin 0.75 kg/ha (pre) *fb* metsulfuron-methyl 4 g/ha in 2009 and atrazine 1.5 kg/ha (pre) *fb* atrazine 0.75 kg/ha (post) and atrazine 1.0 kg/ha + pendimethalin 0.5 kg/ha (pre) *fb* metsulfuron-methyl 4 g/ha (post) in 2010 could bring about significant reduction in its count. Saini and Angiras (1998) reported significant superiority of atrazine or pendimethalin as well as atrazine followed by atrazine against *Echinochloa* sp (*E. colona* and *E. crusgalli*) in maize.

There was significant variation in the count and dry weight of *Panicum dichotomiflorum* during 2010. Only atrazine 1.5 kg/ha (pre) *fb* atrazine 0.75 kg/ha (post) could bring about significantly reduction in the count of *Panicum* at 60 DAS. However, all treatments were significantly superior to weedy check in reducing its count and dry weight at harvest. Superiority of herbicide combinations in controlling *Panicum* has been reported by Saini and Angiras (1998).

Pendimethalin 0.75 kg/ha (pre) *fb* atrazine 0.75 kg/ha (post), atrazine 1.0 kg/ha + pendimethalin 0.5 kg/ha (pre) *fb* 2,4-D 0.75 kg/ha (post) and hand weeding twice (20 and 40 DAS) remaining at par with atrazine 1.5 kg/ha (pre), atrazine 1.0 kg/ha + pendimethalin 0.5 kg/ha (pre) *fb* metsulfuron-methyl 4 g/ha (post) and atrazine 1.0 kg/ha + pendimethalin 0.5 kg/ha (pre) *fb* metsulfuron-methyl 4 g/ha (post) in lowering dry weight of *Commelina benghalensis* were superior to rest of the treatments up to 60 DAS during 2009. All treatments were superior to weedy check in reducing count of *Commelina benghalensis* up to 60 DAS but atrazine 0.75 kg/ha + pendimethalin 0.75 kg/ha *fb* 2,4-D and atrazine 0.75 kg/ha + pendimethalin 0.75 kg/ha (pre) *fb* metsulfuron-methyl could not suppress its growth over unweeded check during 2010. Atrazine 1.0 kg/ha + pendimethalin 0.5 kg/ha (pre) remained at par with atrazine 1.5 kg/ha (pre) *fb* atrazine 0.75 kg/ha (post) pendimethalin 1.5 kg/ha (pre), atrazine 0.75 kg/ha + pendimethalin 0.75 kg/ha (pre), pendimethalin 1.5 kg/ha (pre) *fb* atrazine 0.75 kg/ha (post), atrazine 1.0 kg/ha + pendimethalin 0.5 kg/ha (pre) *fb* 2,4-D 0.75 kg/ha (post), atrazine 1.0 kg/ha + pendimethalin 0.5 kg/ha (pre) *fb* metsulfuron-methyl 4 g/ha (post) and hand weeding twice (20 and 40 DAS) gave significantly lower dry weight of *Commelina benghalensis* over other treatments up to 60 DAS during 2010. Atrazine 1.5 kg/ha (pre) *fb* atrazine 0.75 kg/ha (post) being at par with atrazine 1.5 kg/ha (pre), pendimethalin 1.5 kg/ha (pre), pendimethalin 1.50 kg/ha *fb* atrazine 0.75 kg/ha (post) atrazine 0.75 kg/ha + pendimethalin 0.75 kg/ha (pre) *fb* 2,4-D 0.75 kg/ha (post), atrazine 1.0 kg/ha + pendimethalin 0.5 kg/ha (pre) *fb* 2,4-D 0.75 kg/ha (post), atrazine 1.0 kg/ha + pendimethalin 0.5 kg/ha (pre) *fb* metsulfuron-methyl 4 g/ha (post) and hand weeding (20 and 40 DAS) gave lower count of *Commelina* up to 60 DAS in 2010. Similar results have also been shown by Saini and Angiras (1998).

Application of pendimethalin 1.5 kg/ha (pre) *fb* atrazine 0.75 kg/ha (post), atrazine 1.50 kg/ha *fb* atrazine 0.75 kg/ha, atrazine 0.75 kg/ha + pendimethalin 0.75 kg/ha (pre) *fb* 2,4-D 0.75 kg/ha (Post), atrazine 1.0 kg/ha + pendimethalin 0.5 kg/ha (pre) *fb* metsulfuron-methyl 4 g/ha (post), hand weeding twice (20 and 40 DAS) and atrazine 1.0 kg/ha + pendimethalin 0.5 kg/ha (pre) *fb*. 2,4-D 0.75 kg/ha (post) significantly suppressed the growth of *Ageratum conyzoides* at one or the other stage. The effectiveness of atrazine or pendimethalin (pre-emergence) followed by atrazine (post) against *Ageratum conyzoides* has been well documented (Saini and Angiras 1998). Under the remaining treatments, the count and dry weight of *Ageratum conyzoides* were either higher or not significantly different from the untreated check. This could be attributed

Table 1. Effect of treatments on count (no./m^2) and dry weight (g/m^2) of *Echinochloa* and *Panicum* in maize

Treatment	Dose (kg/ha)	Time	*Echinochloa*								*Panicum*							
			Count				Dry weight				Count				Dry weight			
			60 DAS		At harvest		60 DAS		At harvest		60 DAS		At harvest		60 DAS		At harvest	
			2009	2010	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010
Atrazine	1.50	Pre	2.3 (5.3)	3.4 (10.7)	2.5 (6.7)	2.3 (5.3)	1.2 (0.5)	1.6 (1.5)	1.4 (1.15)	1.3 (0.7)	1.7 (2.7)	2.5 (5.3)	3.1 (10.67)	1.0 (0.0)	1.0 (0.0)	1.2 (0.5)	2.2 (5.15)	1.0 (0.0)
Pendimethalin	1.50	Pre	1.0 (0.0)	2.7 (8.0)	1.9 (4.0)	1.4 (0.3)	1.9 (3.1)	1.3 (0.7)	1.2 (0.46)	1.1 (0.1)	1.7 (4.0)	3.8 (13.3)	1.0 (0.00)	1.4 (1.3)	1.0 (0.0)	1.5 (1.4)	1.0 (0.00)	1.1 (0.2)
Atrazine *fb* atrazine	1.50 *fb* 0.75	Pre *fb* post	1.7 (2.7)	1.0 (0.0)	1.4 (1.3)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.1 (0.15)	1.0 (0.0)	1.3 (1.3)	1.0 (0.0)	2.7 (8.00)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.6 (1.84)	1.0 (0.0)
Pendimethalin *fb* atrazine	1.50 *fb* 0.75	Pre *fb* post	3.8 (18.0)	2.1 (4.0)	1.7 (2.7)	2.1 (4.0)	1.1 (0.1)	1.1 (0.3)	1.1 (0.28)	1.2 (0.5)	2.1 (6.00)	2.9 (9.3)	2.7 (8.00)	1.8 (2.7)	1.0 (0.0)	1.5 (1.6)	1.5 (1.48)	1.1 (0.3)
Atrazine + pendimethalin	0.75 + 0.75	Pre	2.7 (12.0)	5.0 (24.0)	1.7 (2.7)	2.5 (5.3)	1.0 (0.0)	1.5 (1.4)	1.2 (0.41)	1.3 (0.7)	2.8 (10.0)	4.3 (17.3)	2.9 (8.00)	1.4 (1.3)	1.1 (0.1)	2.1 (3.7)	1.5 (1.22)	1.1 (0.2)
Atrazine + pendimethalin *fb* 2,4-D	0.75 + 0.75 *fb* 0.75	Pre *fb* post	2.1 (6.0)	3.1 (10.7)	1.7 (2.7)	1.8 (2.7)	1.5 (1.5)	1.6 (1.9)	1.1 (0.24)	1.1 (0.3)	2.3 (8.0)	2.9 (9.3)	1.0 (0.00)	1.0 (0.0)	1.0 (0.0)	1.5 (1.5)	1.0 (0.00)	1.0 (0.0)
Atrazine + pendimethalin *fb* metsulfuron-methyl	0.75 + 0.75 *fb* 0.004	Pre *fb* post	1.2 (0.7)	2.1 (4.0)	2.0 (5.3)	2.3 (5.3)	1.7 (2.3)	1.2 (0.4)	1.4 (1.12)	1.2 (0.6)	2.3 (8.0)	5.0 (24.0)	2.9 (8.00)	2.1 (4.0)	1.0 (0.0)	3.1 (8.7)	1.5 (1.28)	1.2 (0.4)
Atrazine + pendimethalin	1.0 + 0.50	Pre	2.1 (4.7)	2.3 (5.3)	1.4 (1.3)	1.8 (2.7)	1.4 (0.9)	1.2 (0.5)	1.1 (0.16)	1.1 (0.3)	2.0 (5.33)	2.9 (8.0)	1.0 (0.00)	1.4 (1.3)	1.0 (0.0)	1.3 (0.8)	1.0 (0.00)	1.1 (0.1)
Atrazine + pendimethalin *fb* 2,4-D	1.0 + 0.50 *fb* 0.75	Pre *fb* post	2.7 (8.0)	3.0 (8.0)	3.4 (10.7)	1.8 (2.7)	2.1 (4.1)	1.3 (0.6)	1.6 (1.50)	1.1 (0.3)	3.5 (14.7)	2.9 (8.0)	3.7 (13.33)	1.4 (1.3)	1.0 (0.0)	1.3 (0.7)	1.9 (2.77)	1.1 (0.1)
Atrazine + pendimethalin *fb* metsulfuron-methyl	1.0 + 0.50 *fb* 0.004	Pre *fb* post	2.6 (7.3)	1.8 (2.7)	3.6 (12.0)	1.4 (1.3)	2.5 (5.2)	1.1 (0.2)	2.0 (3.49)	1.1 (0.1)	2.5 (9.3)	2.5 (6.7)	2.7 (8.00)	1.0 (0.0)	1.0 (0.0)	1.2 (0.6)	1.7 (1.99)	1.0 (0.0)
Hand weeding	-	20 and 40 DAS	2.8 (8.7)	2.7 (8.0)	2.9 (9.3)	1.7 (2.7)	1.0 (0.0)	1.4 (0.9)	2.0 (3.67)	1.1 (0.4)	1.0 (0.0)	2.3 (5.3)	2.7 (8.00)	1.0 (0.0)	1.0 (0.0)	1.2 (0.4)	1.6 (1.75)	1.0 (0.0)
Untreated check	-		3.6 (13.3)	3.6 (12.0)	2.8 (13.3)	3.2 (9.3)	2.9 (9.9)	2.9 (7.8)	2.1 (5.61)	1.5 (1.2)	1.3 (1.3)	3.1 (10.7)	3.1 (10.67)	3.2 (9.3)	1.1 (0.2)	1.5 (1.4)	2.3 (5.21)	1.4 (0.9)
LSD (P=0.05)			2.0	1.8	NS	NS	1.1	0.5	NS	NS	NS	1.9	NS	1.0	NS	0.7	NS	0.2

Values given in parentheses are original means

Table 2. Effect of treatments on count (no./m^2) and dry weight (g/m^2) of *Commelina* and *Ageratum* in maize

Treatment	Dose (kg/ha)	Time	*Commelina*								*Ageratum*							
			Count				Dry weight				Count				Dry weight			
			60 DAS		At harvest		60 DAS		At harvest		60 DAS		At harvest		60 DAS		At harvest	
			2009	2010	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010
Atrazine	1.50	Pre	2.7 (8.0)	2.7 (6.7)	4.6 (20.00)	4.1 (16.0)	1.2 (0.5)	1.6 (1.8)	2.9 (7.83)	1.9 (2.7)	3.4 (22.7)	7.8 (60.0)	16.0 (256.0)	7.3 (52.0)	1.9 (2.7)	4.0 (15.1)	8.1 (65.2)	3.6 (12.2)
Pendimethalin	1.50	Pre	1.5 (2.0)	1.9 (4.0)	1.9 (4.00)	5.1 (25.3)	1.9 (2.9)	1.2 (0.4)	1.3 (0.95)	2.8 (7.0)	3.0 (12.0)	1.7 (2.7)	12.2 (148.0)	2.2 (6.7)	1.6 (1.8)	1.1 (0.1)	2.2 (4.6)	1.3 (0.9)
Atrazine *fb* atrazine	1.50 *fb* 0.75	Pre *fb* post	1.9 (4.0)	1.0 (0.0)	3.2 (9.33)	1.0 (0.0)	1.8 (2.7)	1.4 (1.3)	1.5 (1.37)	1.0 (0.0)	2.2 (11.3)	1.0 (0.0)	3.8 (17.3)	4.1 (16.0)	1.0 (0.0)	1.0 (0.0)	6.3 (39.3)	1.6 (1.6)
Pendimethalin *fb* atrazine	1.50 *fb* 0.75	Pre *fb* post	3.0 (10.0)	2.5 (6.7)	1.0 (0.00)	3.4 (10.7)	1.0 (0.0)	1.3 (0.7)	1.0 (0.00)	1.5 (1.2)	2.3 (7.3)	1.7 (2.7)	4.1 (21.3)	2.5 (6.7)	1.0 (0.0)	1.1 (0.2)	2.4 (5.6)	1.3 (0.8)
Atrazine + pendimethalin	0.75 + 0.75	Pre	2.6 (7.3)	2.7 (8.0)	2.0 (5.33)	2.5 (6.7)	1.6 (1.9)	1.2 (0.6)	1.6 (2.15)	1.3 (0.9)	3.0 (12.0)	4.9 (22.7)	11.7 (193.3)	5.0 (24.0)	2.0 (3.7)	1.9 (2.6)	5.6 (41.5)	2.0 (3.0)
Atrazine + pendimethalin *fb* 2,4-D	0.75 + 0.75 *fb* 0.75	Pre *fb* post	1.8 (2.7)	1.7 (2.7)	5.0 (24.00)	3.2 (9.3)	1.7 (2.95)	2.3 (4.6)	3.2 (9.36)	1.6 (1.6)	4.0 (20.0)	4.3 (17.3)	14.9 (221.3)	7.6 (57.3)	1.7 (1.9)	1.8 (2.1)	6.3 (39.1)	3.5 (11.7)
Atrazine + pendimethalin *fb* metsulfuron-methyl	0.75 + 0.75 *fb* 0.004	Pre *fb* post	2.2 (5.3)	2.9 (9.3)	4.3 (17.33)	4.0 (14.7)	1.4 (1.1)	2.0 (4.0)	2.4 (4.90)	1.9 (2.5)	2.7 (12.7)	4.1 (16.0)	16.4 (266.7)	2.1 (4.0)	2.1 (5.5)	1.5 (1.2)	7.1 (49.9)	1.2 (0.4)
Atrazine + pendimethalin	1.0 + 0.50	Pre	1.6 (3.3)	3.4 (10.7)	2.2 (6.67)	2.1 (4.0)	1.6 (1.9)	1.0 (0.0)	1.7 (2.93)	1.2 (0.4)	3.2 (14.0)	4.7 (49.3)	16.0 (254.7)	5.7 (32.0)	1.9 (4.2)	2.4 (8.3)	6.7 (44.4)	2.8 (6.7)
Atrazine + pendimethalin *fb* 2,4-D	1.0 + 0.50 *fb* 0.75	Pre *fb* post	2.5 (7.3)	1.7 (2.7)	1.0 (0.00)	1.9 (4.0)	1.0 (0.0)	1.2 (0.5)	1.0 (0.00)	2.5 (5.8)	4.3 (24.0)	1.0 (0.0)	12.2 (148.0)	1.7 (2.7)	1.7 (1.8)	1.0 (0.0)	5.7 (32.2)	1.1 (0.2)
Atrazine + pendimethalin *fb* metsulfuron-methyl	1.0 + 0.50 *fb* 0.004	Pre *fb* post	3.3 (13.3)	2.7 (6.7)	3.2 (12.00)	2.7 (8.0)	1.2 (0.6)	1.1 (0.2)	2.2 (3.84)	1.4 (1.0)	5.1 (33.3)	2.9 (9.3)	12.4 (152.0)	8.1 (65.3)	1.0 (0.0)	1.3 (0.9)	5.9 (34.0	3.4 (10.9)
Hand weeding	-	20 & 40 DAS	2.5 (9.3)	2.1 (4.0)	3.5 (14.67)	2.3 (5.3)	1.0 (0.0)	1.3 (0.6)	2.4 (5.88)	1.3 (0.7)	6.3 (38.7)	10.0 (100.0)	11.0 (170.7)	7.4 (53.3)	1.0 (0.0)	3.9 (14.1)	5.9 (45.9)	3.3 (10.3)
Untreated check	-		3.1 (10.0)	5.2 (26.7)	3.1 (10.67)	4.7 (21.3)	2.7 (7.6)	2.2 (4.2)	1.9 (2.88)	1.2 (0.5)	3.3 (15.3)	1.0 (0.0)	8.6 (101.3)	4.6 (45.3)	2.1 (3.5)	1.0 (0.0)	4.5 (25.9)	2.8 (12.9)
LSD (P=0.05)			NS	1.8	1.4	1.3	0.6	0.5	1.3	0.6	3.6	3.4	5.1	3.4	1.1	1.2	3.3	1.6

Values given in the parentheses are the original means

Table 3. Effect of treatments on weed dry weight weed control efficiency and plant height of maize

Treatment	Dose (kg/ha)	Time	Weed dry weight (g/m^2)				WCE (%)	Plant height	
			2009		2010				
			60 DAS	At harvest	60 DAS	At harvest		2009	2010
Atrazine	1.50	Pre	3.6 (12.6)	9.7 (93.3)	4.4 (18.3)	3.7 (12.5)	-5.1	276	271
Pendimethalin	1.50	Pre	2.7 (8.1)	6.9 (46.9)	2.1 (3.5)	3.2 (9.4)	60.5	293	287
Atrazine *fb* atrazine	1.50 *fb* 0.75	Pre *fb* post	2.6 (5.8)	2.8 (8.9)	1.0 (0.0)	2.6 (5.8)	80.3	278	285
Pendimethalin *fb* atrazine	1.50 *fb* 0.75	Pre *fb* post	1.9 (2.9)	3.1 (11.1)	2.3 (4.4)	2.0 (2.9)	75.2	286	277
Atrazine + pendimethalin	0.75 + 0.75	Pre	3.6 (12.8)	6.9 (54.2)	4.1 (15.7)	2.6 (5.6)	3.1	279	275
Atrazine + pendimethalin *fb* 2,4-D	0.75 + 0.75 *fb* 0.75	Pre *fb* post	3.4 (10.8)	7.2 (50.6)	3.3 (10.5)	3.9 (14.3)	27.6	280	279
Atrazine + pendimethalin *fb* metsulfuron-methyl	0.75 + 0.75 *fb* 0.004	Pre *fb* post	2.7 (6.5)	7.8 (60.0)	1.8 (2.4)	2.3 (4.4)	69.7	284	178
Atrazine + pendimethalin	1.0 + 0.50	Pre	3.6 (12.8)	7.0 (48.1)	3.8 (14.5)	3.0 (8.1)	7.1	293	286
Atrazine + pendimethalin *fb* 2,4-D	1.0 + 0.50 *fb* 0.75	Pre *fb* post	2.6 (6.1)	6.8 (45.3)	2.1 (3.6)	3.0 (8.2)	67.0	297	288
Atrazine + pendimethalin *fb* metsulfuron-methyl	1.0 + 0.50 *fb* 0.004	Pre *fb* post	2.6 (6.0)	7.0 (48.9)	2.1 (3.5)	3.7 (12.7)	67.7	274	273
Hand weeding	-	20 & 40*	1.0 (0.0)	7.1 (67.9)	4.3 (17.7)	3.6 (12.0)	39.8	287	281
Untreated check	-		3.9 (14.8)	7.0 (60.8)	3.8 (14.6)	4.0 (18.2)	0.0	188	186
LSD (P=0.05)			1.7	NS	1.2	1.2	-	36	39

Values given in parentheses are original means; *Days after sowing

to the fact that *A. conyzoides* appeared at the later stage and by that time all other weed species covered the ground fully and let a very few plants of this weed to come up in the weedy check, whereas in treated plots it escaped application of herbicides and its population was increased. *Ageratum* usually appears in large numbers in later stages and its distribution appeares to be contiguous rather than uniform as there is large variation in the population of this weed. Weed control treatments could not bring about significant variation in the count and dry weight of *Digitaria sanguinalis, Cyperus* sp., *Polygonum alatum* and *Aeschynomene indica* at any stage during both the years.

Weed control treatments brought about significant variation in the total weed dry weight at 60 DAS during both the years, and at harvest during 2010. At 60 DAS during 2009, hand weeding twice and pendimethalin *fb* atrazine could bring about significant reduction in total weed dry weight over untreated check. The other treatments could not curtail the growth of the survivors or the late comers rather they assumed alarming growth in the absence of competition. However, in 2010, pendimethalin 1.5 kg/ha (pre) *fb* atrazine 0.75 kg/ha (post), atrazine 1.5 kg/ha (pre) *fb* atrazine 0.75 kg/ha (post) atrazine 0.75 kg/ha + pendimethalin 0.75 kg/ha (pre) *fb* 2,4-D 0.75 kg/ha (post), atrazine 1.0 kg/ha + pendimethalin 0.5 kg/ha (pre), atrazine 1.0 kg/ha + pendimethalin 0.5 kg/ha (pre) *fb* 2,4-D 0.75 kg/ha (post) and atrazine 1.0 kg/ha + pendimethalin 0.5 kg/ha (pre) *fb* metsulfuron-methyl 4 g/ha (post) were all effective in reducing total weed dry weight as compared to untreated check upto harvest. Atrazine *fb* atrazine resulted in highest weed control efficiency of 80.3%. This was followed by pendimethalin *fb* atrazine, atrazine 0.75 kg/ha + pendimethalin 0.75 kg/ha *fb* metsulfuron-methyl, atrazine 1.0 kg/ha + pendimetnalin 0.50 kg/ha *fb* metsulfuron-methyl and atrazine 1.0 kg/ha + pendimethalin 0.50 kg/ha *fb* 2,4-D. Mundra *et al.* (2003), Patel *et al.* (2006) and Walia *et al.* (2007) also reported significant reduction in count and dry weight of weeds with tank-mix application of herbicides in maize.

Effect on crop

All weed control treatments were significantly superior to untreated check in influencing plant height during 2009. However, under atrazine 1.0 kg/ha + pendimethalin 0.5 kg/ha (pre) and atrazine 1.0 kg/ha + pendimethalin 0.5 kg/ha (pre) *fb* metsulfuron-methyl 4 g/ha (post) plant height did not differ significantly from that under untreated check in 2010. Controlling weeds is important in obtaining desired plant stand as evident from higher plant population under all treatments over the untreated check. However, atrazine 1.0 kg/ha + pendimethalin 0.5 kg/ha (pre) *fb* metsulfuron-methyl 4 g/ha (post) had lower effective plant population than all the other treatments.

All treatments were significantly superior to untreated check in increasing grain and straw yield of maize in 2009. However, possibly owing to toxic effect of metsulfuron-methyl, atrazine 1.0 kg/ha + pendimethalin 0.5 kg/ha (pre) *fb* metsulfuron-methyl 4 g/ha (post) did not differ significantly from weedy check in influencing the yield of maize in 2010. Atrazine 1.0 kg/ha + pendimethalin 0.5 kg/ha (pre) *fb* 2,4-D 0.75 kg/ha (post) during both the years and atrazine 1.0 kg/ha + pendimethalin 0.5 kg/ha (pre) *fb* metsulfuron-methyl 4 g/ha (post) and atrazine 0.75 kg/ha + pendimethalin 0.75 kg/ha (pre) *fb*. metsulfuron-methyl 4 g/ha (post) in 2009, all being at par to handweeding and atrazine 1.5 kg/ha (pre) *fb* atrazine 0.75 kg/ha (post) resulted in significantly higher grain as well as straw yield of maize over rest of the treatments. Grain and straw yield of maize was negatively associated with weed biomass (r = -0.584 and -0.336, respectively) and count (r = -0.447 and -0.509), though, the degree of association was low. Weeds in untreated check reduced maize grain yield by 50.3% over the best treatment atrazine 1.0 kg/ha + pendimethalin 0.5 kg/ha (pre) *fb* 2,4-D 0.75 kg/ha (post).

Impact assessment and economics

Treatment efficiency index (TEI), which indicates weed killing potential and phytotoxicity on the crop (Walia 2003), was highest under atrazine *fb* atrazine. This was followed by pendimethalin *fb* atrazine and atrazine 0.75 kg/ha + pendimethalin 0.75 kg/ha *fb* 2,4-D. The treatments under study followed the similar trend for crop resistance index (CRI) as TEI. Atrazine 0.75 kg/ha + pendimethalin 0.75 kg/ha *fb* metsulfuron-methyl and atrazine 1.0 kg/ha + pendimethalin 0.50 kg/ha had lower weed persistence index (WPI) as compared to other treatments. However, owing to phytotoxicity of metsulfuron-methyl especially during the second year of study, these treatments were next only to atrazine *fb* atrazine, pendimethalin *fb* atrazine and atrazine 0.75 kg/ha + pendimethalin 0.75 kg/ha *fb* 2,4-D for TEI and CRI. Atrazine/pendimethalin *fb* atrazine, atrazine + pendimethalin *fb* 2,4-D or metsulfuron-methyl, pendimethalin and hand weeding twice were superior to atrazine + pendimethalin (pre) alone for weed management index (WMI), agronomic management index (AMI) and integrated weed management index (IWMI). This suggested that surviving weeds or those appearing in late flushes need to be taken care with some post-emergence herbicide application or manually. Dry matter accumulation under atrazine 1.50 kg/ha treated plots was higher than

Table 4. Effect of different treatments on yield attributes and yield of maize

Treatment	Dose (kg/ha)	Time	Plant population /ha		Cob length (cm)		Cob girth (cm)		No. of rows /cob		Grain yield (t/ha)		Stover yield (t/ha)	
			2009	2010	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010
Atrazine	1.50	Pre	60,101	58,331	15.0	14.27	14.6	13.6	14.3	13.60	4.69	4.34	16.2	16.0
Pendimethalin	1.50	Pre	65,604	60,275	15.1	14.53	14.5	13.8	14.5	14.33	4.81	4.87	16.4	16.5
Atrazine *fb* atrazine	1.50 *fb* 0.75	Pre *fb* post	64,895	62,220	15.2	15.47	14.6	14.0	14.9	14.33	5.87	5.47	17.2	17.2
Pendimethalin *fb* atrazine	1.50 *fb* 0.75	Pre *fb* post	65,694	64,720	15.1	15.87	14.3	14.0	15.1	13.20	5.19	5.19	17.1	16.9
Atrazine + pendimethalin	0.75 + 0.75	*Pre*	63,488	63,053	14.9	14.80	14.9	13.9	14.8	14.13	5.04	4.75	16.5	16.5
Atrazine + pendimethalin *fb* 2,4-D	0.75 + 0.75 *fb* 0.75	Pre fb post	68,101	64,164	16.1	15.47	14.6	13.2	14.1	12.90	5.31	5.16	17.3	17.1
Atrazine + pendimethalin *fb* metsulfuron-methyl	0.75 + 0.75 *fb* 0.004	Pre *fb* post	64,895	62,498	16.3	14.33	15.6	14.5	14.9	14.60	6.52	3.50	17.8	13.5
Atrazine + pendimethalin	1.0 + 0.50	Pre	63,779	61,386	15.0	15.60	15.3	14.1	14.7	13.97	4.61	4.37	16.2	16.0
Atrazine + pendimethalin *fb* 2,4-D	1.0 + 0.50 *fb* 0.75	Pre *fb* post	67,985	65,220	16.7	16.13	14.0	14.2	16.7	15.07	6.17	5.63	17.1	16.8
Atrazine + pendimethalin *fb* metsulfuron-methyl	1.0 + 0.50 *fb* 0.004	Pre *fb* post	60,843	48,331	14.8	14.60	14.1	13.6	14.4	13.73	6.12	2.93	17.1	12.1
Hand weeding	-	20 and 40 DAS	63,985	61,664	14.4	14.27	14.8	13.9	14.2	13.80	5.90	5.46	16.8	16.4
Untreated check	-		40,843	34,443	12.0	11.80	12.4	12.3	12.6	11.3	3.19	2.68	13.5	12.1
LSD (P=0.05)			10,830	9,482	2.3	2.8	1.5	1.3	1.1	1.2	0.82	0.55	0.9	0.8

Table 5. Impact assessment indices and economics of weed control treatments in maize

Treatment	Dose (kg/ha)	Time	TEI	WPI	CRI	WMI	AMI	IWMI	CWC	GR	GRWC	NRWC	MBCR
Atrazine	1.50	Pre	0.51	1.68	1.25	-30.2	-31.2	-30.7	1350	54640	15860	14510	10.75
Pendimethalin	1.50	Pre	1.64	1.23	3.43	2.7	1.7	2.2	2780	57318	18538	15758	5.67
Atrazine *fb*. atrazine	1.50 *fb* 0.75	Pre *fb* post	4.73	0.38	7.37	2.4	1.4	1.9	2265	64079	25299	23034	10.17
Pendimethalin *fb*. atrazine	1.50 *fb* 0.75	Pre *fb* post	3.10	0.33	5.68	2.4	1.4	1.9	3695	60553	21773	18078	4.89
Atrazine + pendimethalin	0.75 + 0.75	Pre	0.69	1.04	1.40	54.5	53.5	54.0	2065	57791	19011	16946	8.21
Atrazine + pendimethalin *fb*. 2,4-D	0.75 + 0.75 *fb* 0.75	Pre *fb* post	1.08	1.01	1.97	6.5	5.5	6.0	2808	61103	22323	19515	6.95
Atrazine + pendimethalin *fb*. metsulfuron-methyl	0.75 + 0.75 *fb* 0.004	Pre *fb* post	2.33	0.27	4.34	2.4	1.4	1.9	2945	57272	18492	15547	5.28
Atrazine + pendimethalin	1.0 + 0.50	Pre	0.57	0.72	1.41	21.4	20.4	20.9	1827	54478	15698	13871	7.59
Atrazine + pendimethalin *fb*. 2,4-D	1.0 + 0.50 *fb* 0.75	Pre *fb* post	3.07	0.45	4.40	3.0	2.0	2.5	2570	66290	27510	24940	9.70
Atrazine + pendimethalin fb. metsulfuron-methyl	1.0 + 0.50 *fb* 0.004	Pre *fb* post	1.68	0.28	3.76	2.3	1.3	1.8	2707	52471	13691	10984	4.06
Hand weeding	-	20 & 40 DAS	1.55	1.12	2.35	4.9	3.9	4.4	12000	60388	21608	9608	0.80
Untreated check	-		0.00	1.00	1.00	-	-	-	-	38780	-	-	-
LSD (P=0.05)													

Grain ₹=6750 per tonne, Straw= ₹1000/tonne; TEI, treatment efficiency index; WPI, weed persistence index; CRI, crop resistance index; WMI, weed management index; AMI, agronomic management index; IMWI, integrated weed management index; CWC, cost of weed control (₹/ha); GR, gross returns (₹/ha); GRWC, gross returns due to weed control (₹/ha); NRWC, net returns due to weed control (₹/ha); MBCR, Marginal benefit: cost ratio; Pendimethalin, ₹490/kg ; Atrazine, 290/kg ; ₹2,4-D, 250/kg, Metsulfuron methyl, ₹140/8 gram

under untreated check, and therefore, unusual values of WMI, AMI and IWMI were noticed under this treatment.

Control of weeds using herbicides was a cheaper proposition than with manual methods. Cost of weed control using herbicides was only 11.3-30.8% of the total cost under manual weeding. Atrazine 1.50 kg/ha was the cheapest treatment, whereas pendimethalin 1.50 kg/ha *fb* atrazine 0.75 kg/ha, was the costliest. Only atrazine 1.0 kg/ha + pendimethalin 0.50 kg/ha *fb* 2, 4-D, atrazine 1.50 kg/ha *fb* atrazine 0.75 kg/ha (post) and atrazine 0.75 kg/ha + pendimethalin 0.75 kg/ha *fb* 2,4-D gave higher gross returns due to weed control over traditional practice. However, all herbicidal treatments were superior to hand weeding twice in terms of net returns due to weed control and MBCR. Atrazine 1.0 kg/ha + pendimethalin 0.5 kg/ha (pre) *fb* 2,4-D 0.75 kg/ha (post) resulted in the highest net returns due to weed control. This was followed by atrazine 1.5 kg/ha (pre) *fb* atrazine 0.75 kg/ha (post) and atrazine 0.75 kg/ha + pendimethalin 0.75 kg/ha (pre) *fb* 2,4-D 0.75 g/ha (post). Highest MBCR was fetched under atrazine 1.5 kg/ha (pre), and was closely followed by atrazine 1.5 kg/ha (pre) *fb* atrazine 0.75 kg/ha (post) and atrazine 1.0 kg/ha + pendimethalin 0.5 kg/ha (pre) *fb* 2,4-D 0.75 kg/ha (post) Higher MBCR with herbicides has also been reported by Kumar *et al.* (2011).

It was concluded that atrazine 1.0 kg/ha + pendimethalin 0.5 kg/ha (pre) *fb* 2,4-D 0.75 kg/ha (post), followed by atrazine 1.5 kg/ha (pre) *fb* atrazine 0.75 kg/ha (post), atrazine 0.75 kg/ha + pendimethalin 0.75 kg/ha (pre) *fb* 2,4-D 0.75 kg/ha (post), pendimethalin 1.5 kg/ha (pre) *fb*. atrazine 0.75 kg/ha (post) and atrazine 0.75 kg/ha + pendimethalin 0.75 kg/ha (pre) *fb*. metsulfuron-methyl 4 g/ha (post) could be the better alternatives to hand weeding in managing different flushes of weeds in maize.

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