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Pre- and post-emergence application of atrazine in integration with hand weeding for weed management in pearl millet

H.M. Bhuva* and A.C. Detroja

Pearl Millet Research Station, Junagadh Agricultural University, Jamnagar, Gujarat 361 006

**Email: hasmukhbhuva@gmail.com*

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ABSTRACT

A field experiment was conducted during the *Kharif* season of 2013 to 2015 at pearl millet Research Station, Jamnagar, Gujarat to study the effect of pre- and post-emergence application of atrazine integrated with manual weeding on weeds, crop productivity, nutrient removal and economics of pearl millet (*Pennisetum glaucum* L.). The experiment was laid out in a randomized block design comprising of eight weed control treatments with three replications. Lesser weed density (8.22 no./m^2 at 30 DAS and 11.89 no./m^2 at harvest) and weed-biomass (20.2 g/m^2), higher weed control efficiency (84.3%) and lower weed index (7.8%) were observed with post-emergence application of atrazine 0.40 kg/ha followed by (*fb*) hand weeding (HW) at 35 days after sowing (DAS). The pre-emergence application of atrazine 0.50 kg/ha + HW at 35 DAS was at par with post-emergence application of atrazine 0.40 kg/ha + HW at 35 DAS and recorded maximum net returns (` 40,087/ha) and benefit: cost ratio (2.97).

INTRODUCTION

Pearlmillet [*Pennisetum glaucum* (L.) R. Br. Emend.Stuntz] is a staple food grain crop of the arid and semi-arid regions of India. It is one of the important cereal crops globally after rice, wheat and maize. In India, pearl millet occupies an area of 7.32 million hectares producing 9.18 million tones with productivity of 1255 kg/ha. In Gujarat, it is cultivated over an area of 0.46 million hectares with a production and productivity of 0.77 million tones and 1677 kg/ha, respectively (DES 2016). Infestation of weeds is one of the most limiting factors of pearl millet production. Weeds compete with the crop plants for the essentials of growth, interfere with the utilization of land and water resources, and thus, adversely affect crop production. Weeds deplete 30-40% of applied nutrients from soil and compete with the crop plants for soil, moisture and sunlight too (Ram *et al.* 2004). Wider spacing and slow growing nature of the crop during the first 3-4 weeks provide enough opportunity for weeds to invade and offer severe competition resulting in 40-55% yield reduction (Sharma and Jain 2003, Banga *et al.* 2000). Keeping a crop weed-free throughout the crop season is a labour and cost-intensive affair. Hand-weeding is labourious, difficult to execute under frequent intermittent rains, cumbersome and time consuming besides being costly and economically not feasible in today's intensive agriculture (Sharma and Jain 2003).

Under scarcity of human labour, use of herbicide is the best option to reduce the weed menace during early stages of crop growth. Atrazine– a selective herbicide is well known and being extensively used in pearl millet grown during rainy season in the country (Das *et al.* 2013). Atrazine as pre-emergence is the most widely used herbicide for weed control in pearl millet. However, in case of continuous rainfall after sowing, spraying of pre-emergence herbicide may not be feasible. Furthermore, the efficacy of pre-emergence herbicides is moisture dependent. Too little or excessive moisture after herbicide application can result in poor weed control. Hence, there is a need to standardize the post-emergence dose of atrazine in pearl millet crop for safe and efficient weed control. The use of chemical along with manual weeding is best option for effective weed management (Girase *et al*. 2017) as neither herbicides nor mechanical cultivation are adequate for consistent and acceptable weed control. Keeping this in view, an attempt was made to find out the effect of integration of pre- and post-emergence application of atrazine with hand

weeding on weeds, crop productivity, nutrient removal and economics of rainy season pearlmillet.

MATERIALS AND METHODS

A field experiment was conducted during the *Kharif* seasons of 2013 to 2015, at Pearl millet Research Station, Junagadh Agricultural University, Jamnagar (22º47' N, 70º07' E, 18.00 m above the mean sea level), Gujarat, to assess the effect of pre- and post-emergence atrazine integrated with manual weeding on weeds. The site is situated in the North Saurashtra agro-climatic region of Gujarat under Gujarat plains and hills zone of India. The climate of this region is semi-arid and sub-tropical with fairly dry and hot summer. The rainy season commences in the second fortnight of June and ends in September, with an average annual rainfall of 500 mm. July and August are the peak months of rainfall. December and January are the coldest months of winter with the mean minimum temperature ranging from 15 ºC to 17 ºC. The mean maximum and minimum temperature recorded 30.3 ºC and 21.2 ºC, respectively. The experimental soil was clayey (14.81% sand, 17.74% silt and 67.45% clay) in texture and slightly alkaline in reaction with pH 7.9 and EC 0.42 dS/m. It was moderately fertile being low in organic carbon (4.2 g/kg), medium in available nitrogen (202.3 kg/ha) and phosphorus (10.6 kg/ha) and high in available potassium (282.5 kg/ha). The initial DTPA extractable Fe and Zn were 7.0 and 0.68 mg/kg, respectively. The soil moisture content at field capacity and permanent wilting point in the upper 30 cm soil depth were 28.5 and 16.7%, respectively. Besides, initial bulk density and porosity of the 30 cm soil depth were 1.42 Mg/m^3 and 44.9%, respectively. Rainfall received during crop period of 2013-14, 2014-15 and 2015-16 were 1209, 261.5 and 294 mm with 40, 17 and 19 rainy days, respectively.

The experiment was laid out in a randomized block design with 8 treatments replicated 3 times. The treatments were: weedy check; weed free; atrazine 0.5 kg/ha as pre-emergence application (PE) + hand weeding (HW) at 35 days after seeding (DAS); atrazine 0.10 kg/ha as post-emergence application (PoE) + HW at 35 DAS; atrazine 0.20 kg/ha as PoE + HW at 35 DAS; atrazine 0.30 kg/ha as PoE + HW at 35 DAS; atrazine 0.40 kg/ha as PoE + HW at 35 DAS; and HW twice at 20 and 40 DAS. In weed free plot, hand weeding was done at 15, 30 and 45 DAS. The PE atrazine was sprayed after sowing on wet soil and PoE was applied at 20 DAS (3rd leaf stage of weed) with the help of knapsack sprayer fitted with flood jet nozzle with discharge rate of 600 L water/ha. Pearl millet hybrid *'GHB 744'* was sown with 4.0 kg/ha seed by keeping 60 cm row spacing on 21 June 2013, 21 July 2014 and 21 June 2015 with onset of monsoon. The excess plants were thinned out at 20 DAS keeping within row distance at 10 cm to maintain uniform plant stand. The gross and net plot size was 5.0 × 3.6 m and 4.0 × 2.4 m, respectively. Pearl millet crop was fertilized with 80 kg N and 40 kg P/ha through urea and single super phosphate. At sowing 50% N along with full dose of P were applied and remaining 50% N was applied 30 DAS.

For measuring weed density, an area of 0.25 m^2 was selected randomly by throwing a metallic quadrate of size 0.5 × 0.5 m at 2 places at 30 DAS and at harvest and expressed on square meter basis (no./m^2). The weeds were dried in oven till a constant weight and then transformed into g/m^2 by using the appropriate formula. Weed density data showed variation and projected to square root transformation $\sqrt{x+0.5}$ to normalize their distribution. For nutrients removal study the weed samples collected were ground into fine powder and passed through a 40 mm mesh sieve and used for analysis of N, P and K concentration in weeds and the uptake of these nutrients. Nitrogen was estimated by Kjeldahl's method, P by Vanado-molybdo-phosphoric yellow colour method and K content was determined using flame photometry method. Growth, yield attributes and yield of pearl millet were recorded for 3 consecutive years. Due to yearly variation in price of pearl millet, the cost of cultivation and gross return were calculated by taking mean price of 3 years. Net returns were calculated by subtracting cost of cultivation from gross returns. All the data obtained were statistically analyzed using the F-test procedure given by Gomez and Gomez (1984). Least significant difference (LSD) values at p=0.05 were used for determine the significant of differences between means.

RESULTS AND DISCUSSION

Weed flora

The experimental field was infested with grassy weeds like, *Cynondon dactylon, Echinochloa colona, E. crus-galli*; broad-leaf weeds like, *Convolvulus arvensis, Digera arvensis, Commelina benghalensis, Amaranthus viridis, Trianthema portulacastrum, Eclipta alba* and sedges like, *Cyperus rotundus, C. esculentus* during all the years of experimentation.

Effect on weeds

All the weed management treatments were able to significantly reduced total weed density compared to weedy check at 30 DAS and harvesting stage (**Table 1**). The lowest density of total weeds was observed in weed-free plots and it was statistically significant over rest of the treatments during both the stages. The PoE application 0.40 kg/ha + HW at 35 DAS recorded significantly the lowest total weed density at 30 DAS (8.22 no./m^2) and at harvest (11.89 no./m^2) of the crop. Persistence of atrazine for longer period might have resulted in less weed population over weedy check treatment (Banga *et al.* 2000, Ram *et al.* 2005). The PoE application of atrazine 0.40 kg/ ha + HW at 35 DAS, significantly reduced the broad-leaf weeds over hand weeding twice at 20 and 40 DAS, while grassy weeds and sedges remained statistically at par with it. The PE application of atrazine 0.50 kg/ha + HW at 35 DAS, significantly reduced the broad-leaf weeds over weedy check during 30 DAS and at harvest, while grassy weeds and sedges remained statistically at par with weedy check except grassy weeds at harvest. These are in conformity with the findings of Munde *et al.* (2012) and Mishra *et al.* (2017), who reported that broad-leaf weed controlled more efficiently than grassy weeds and sedges withthe application of atrazine.

Weed biomass at harvest significantly influenced by different weed management practices (**Table 2**). The highest weed biomass was recorded with weedy check, while the lowest with weed free condition. The PoE application of atrazine 0.40 kg/ha + HW at 35 DAS noted lowest weed biomass, which was at par with PE application of atrazine 0.50 kg/ha + HW

Table 1. Effect of weed management treatments on weeds density at two growth stages of pearl millet (pooled data of 3 years)

Treatment	Weed density (no./m^2)							
	30 DAS				At harvest			
	Grassy	Broad-leaf	Sedges	Total	Grassy	Broad-leaf	Sedges	Total
Atrazine 0.50 kg/ha as PE + HW	3.15 (9.4)	3.27 (10.2)	2.84 (7.5)	5.26 (27.2)	3.28 (10.2)	4.31(18.0)	3.60 (12.5)	6.42 (40.8)
Atrazine 0.10 kg/ha as PoE + HW	2.94 (8.1)	2.44 (5.5)	3.15 (9.4)	4.85 (23.0)	3.82 (14.1)	2.79 (7.3)	3.42 (11.2)	5.75 (32.6)
Atrazine 0.20 kg/ha as PoE + HW	2.74 (7.0)	1.65 (2.2)	2.93 (8.1)	4.22 (17.3)	3.39 (11.0)	2.09 (3.8)	3.09 (9.0)	4.94 (23.9)
Atrazine 0.30 kg/ha as PoE + HW	2.36 (5.0)	1.50 (1.7)	2.22 (4.4)	3.42 (11.2)	3.36 (10.8)	1.60 (2.1)	3.08 (9.0)	4.73 (21.9)
Atrazine 0.40 kg/ha as PoE + HW	2.29 (4.7)	1.12 (0.7)	1.79 (2.7)	2.95 (8.2)	2.37 (5.1)	1.39 (1.4)	2.42 (5.3)	3.52 (11.9)
Hand weeding twice at 20 and 40 DAS	2.12 (4.0)	2.71 (6.8)	1.92 (3.2)	3.81 (14.0)	2.66 (6.6)	2.75 (7.0)	2.43 (5.4)	4.42 (19.0)
Weedy check	3.73 (13.4)	6.15 (37.4)	3.22 (9.9)	7.82 (60.7)	4.47 (19.4)	7.21(51.5)	3.76 (13.6)	9.22 (84.6)
Weed free*	0.71 (0)	0.71 (0)	0.71 (0)	0.71 (0)	1.45 (1.6)	1.61 (2.1)	1.21 (1.0)	2.27 (4.7)
LSD (p=0.05)	0..67	0.96	0.64	1.01	0.75	0.98	0.68	1.05

Values are subjected to square root $\sqrt{x+0.5}$ transformation; figures in parentheses are original weed density/m^2**;** DAS: Days after sowing; HW: One hand weeding at 35 days after sowing; PE: Pre-emergence; PoE: Post-emergence; *Hand weeding at 15, 30 and 45 days after sowing (DAS)

Table 2. Effect of weed management treatments on weed biomass, weed control efficiency, weed index and pearl millet growth and yield attributes (pooled data of 3 years)

Treatment	Weed biomass (g/m^2)	Weed control efficiency (%)	Weed index (%)	Growth attributes		Yield attributes			
				Plant height (cm)	Total tillers/ plant	Effective tillers/ plant	Ear head length (cm)	Ear head thickness (cm)	1,000 grain weight (g)
Atrazine 0.50 kg/ha as PE +HW	23.2	81.95	05.42	176.6	2.98	2.53	25.72	2.51	9.58
Atrazine 0.10 kg/ha as PoE + HW	67.2	47.71	23.48	169.5	2.69	2.24	24.11	2.35	9.39
Atrazine 0.20 kg/ha as PoE + HW	55.0	57.20	21.08	171.4	2.76	2.33	24.81	2.37	9.45
Atrazine 0.30 kg/ha as PoE + HW	36.3	71.75	17.28	172.7	2.84	2.40	25.03	2.42	9.53
Atrazine 0.40 kg/ha as PoE + HW	20.2	84.28	07.79	173.6	2.93	2.49	25.42	2.47	9.67
Hand weeding twice at 20 and 40 DAS	27.5	78.60	15.81	173.8	2.89	2.46	25.65	2.54	9.55
Weedy check	128.5	00.00	43.90	158.8	2.31	1.76	22.87	2.25	8.58
Weed free*	7.7	94.01	00.00	179.0	3.04	2.62	26.16	2.67	9.72
LSD (p=0.05)	14.8	10.54	6.97	5.7	0.17	0.16	1.32	0.23	0.30

DAS: Days after sowing; HW: One hand weeding at 35 days after sowing; PE: Pre-emergence; PoE: Post-emergence; *Hand weeding at 15, 30 and 45 days after sowing (DAS)

at 35 DAS and hand weeding twice at 20 and 40 DAS. All the weed management treatments were able to significantly increase weed control efficiency (WCE) over weedy check and decrease weed index (WI) over weed free condition. Significantly the highest WCE noted with weed free (94.0%), which was at par with PoE application of atrazine 0.4 kg/ha + HW at 35 DAS (84.3%). Post-emergence application of atrazine 0.4 kg/ha + HW at 35 DAS, PE application of atrazine 0.5 kg/ha + HW at 35 DAS and hand weeding twice at 20 and 40 DAS recorded at par WCE with each other. Among all the weed control treatments, the lower WI was recorded with PE application of atrazine 0.5 kg/ha + HW at 35 DAS (5.4%), which was at par with PoE application of atrazine 0.4 kg/ha + HW at 35 DAS (7.8%). Weedy check recorded the maximum weed index (43.9%) due to maximum weed growth during entire crop growth period. The maximum WCE and minimum WI with PoE atrazine application was reported by Girase *et al.* (2017) in *Kharif* and Das *et al.* (2013) in summer season.

Effect on crop

All the weed control treatments significantly increased the growth and yield attributes and grain and stover yields of pearl millet compared with weedy check (**Table 2** and **3**). Different growth attributes, *viz*. plant height and total tillers/plant and yield attributes, *viz.* effective tillers/plant, ear head length, ear head thickness and 1,000 grain weight were recorded significantly the highest with weed free, which were at par with PE application of atrazine 0.50 kg/ha + HW at 35 DAS and post-emergence application of atrazine 0.40 kg/ha + HW at 35 DAS over weedy check. This might be owing to low weed density and biomass, which helped reduction in crop-weed competition and better crop growth and production of more effective tillers (Girase *et al*. 2017). The grain and stover yields (3.47 and 5.31 t/ha respectively) were significantly higher in weed free treatment and were at par with PE application of atrazine 0.50 kg/ha + HW at 35 DAS (3.28 and 5.10 t/ ha, respectively) and PoE application of atrazine 0.40 kg/ha + HW at 35 DAS (3.20 and 4.93 t/ha, respectively). The efficient weed control measures reduced weed density and biomass resulting in improvement of yield related traits and ultimately crop yield (Mathukia *et al.* 2015, Ram *et al.* 2004). The lowest grain and stover yields were recorded with weedy check. This might be due to the fact that the luxuriant growth of many weed species with greater nutrient removal from the soil thus, reduced the crop yield considerably. These findings are in close conformity with those reported by Singh *et al.* (2017) and Kiroriwal *et al.* (2012).

Nutrient removal by weeds

Mean data of 3 years showed that all weed control treatments brought significant variation in nutrient removal by weeds in pearl millet (**Table 3**). The nutrient removal by weeds under unweeded situation was the maximum. The nutrient removal by weeds in all the weed control treatments was significantly lower compared with weedy check. The lowest NPK removal by weeds was recorded with weed free situation, which was statistically at par with PoE application of atrazine 0.4 kg/ha + HW at 35 DAS and PE application of atrazine 0.50 kg/ha + HW at 35 DAS. Similar reduction in nutrient removal by weeds under different weed management practices had also reported by Swapnil *et al.* (2017) in sorghum and Goswami *et al.* (2002) in pearl millet.

Economics

The choice of any weed control method ultimately depends on economics and efficiency in controlling weeds. The highest gross returns (` 56,508/ha) and net returns (` 41,733/ha) were observed in weed free treatment, which remained at par with PE application of atrazine 0.50 kg/ha + HW at 35 DAS and PoE application of atrazine 0.40 kg/ha + HW at 35 DAS. The maximum cost of cultivation was registered with weed free treatment due to higher cost of labour charges. Similar results were also reported by Mathukia *et al.* (2015) and Mishra *et al.* (2017). Significantly the highest benefit: cost ratio (BCR) was reported with PE application of atrazine 0.50 kg/ha + HW at 35 DAS (2.97) and remained at par with PoE application of atrazine 0.40 kg/ha + HW at 35 DAS (2.90) and weed free situation (2.82). Girase *et al.* (2017) also recorded the higher benefit: cost ratio with application of atrazine over weed free conditions. All the weed control treatments resulted in higher gross and net returns and BCR over weedy check.

Conclusion

Based on above results, it may be concluded that in case of labour scarcity, PE application of atrazine 0.50 kg/ha followed by hand weeding at 35 DAS or PoE application of atrazine 0.40 kg/ha at 3 leaf stage of weed followed by hand weeding at 35 DAS could be a best option for achieving higher yield, net returns, benefit: cost ratio as well as significant weed suppression in pearl millet.

Table 3. Effect of weed management treatments on pearl millet yield,nutrient removal by weeds and economics (pooled data of 3 years)

Treatment	Yield (t/ha)		Nutrient removal by weeds (kg/ha)			Economics			
	Grain	Stover	N	P	K	Gross returns (x10^3 `/ha)	Cost of cultivation (x10^3 `/ha)	Net returns (x10^3 `/ha)	Benefit: cost ratio
Atrazine 0.5 kg/ha as PE +HW	3.28	5.10	2.99	0.46	2.76	53.56	13.47	40.09	2.97
Atrazine 0.1 kg/ha as PoE + HW	2.65	4.42	8.80	1.38	8.20	43.77	13.07	30.70	2.35
Atrazine 0.2 kg/ha as PoE + HW	2.74	4.55	7.15	1.11	6.60	45.13	13.18	31.95	2.43
Atrazine 0.3 kg/ha as PoE + HW	2.86	4.69	4.72	0.73	4.36	47.18	13.27	33.91	2.55
Atrazine 0.4 kg/ha as PoE + HW	3.20	4.93	2.61	0.40	2.40	52.16	13.38	38.78	2.90
Hand weeding twice at 20 and 40 DAS	2.92	4.81	3.55	0.54	3.27	48.09	13.73	34.36	2.50
Weedy check	1.94	3.70	16.96	2.66	15.81	32.79	11.63	21.16	1.82
Weed free*	3.47	5.31	0.99	0.15	0.90	56.51	14.78	41.73	2.82
LSD (P=0.05)	0.28	0.38	2.27	0.32	2.08	4.89	-	3.41	0.27

DAS: Days after sowing;HW: One hand weeding at 35 days after sowing; PE: Pre-emergence; PoE: Post-emergence; *Hand weeding at 15,30 and 45 days after sowing (DAS)

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