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Investigation on efficacy of pre and post emergence herbicides of pearl millet (*Pennisetum glaucum* L.): Productivity, weed dynamics and economics

SG Mehetre, PP Pawar, MD Gurav, RA Pawar and VC Are

Abstract
An experiment entitled “Weed management in hybrid pearl millet (Adishakti) under rainfed condition” was conducted during *kharif* season of 2020 at Post Graduate Research Farm, Agronomy Section, College of Agriculture, Dhule. The experiment consisted of nine treatments *viz.*, weedy check (T_1), weed free (T_2), atrazine @ 0.50 kg ha^{-1} PoE (T_3), 2,4-D (Dimethyl amine) @ 0.5 kg ha^{-1} at 25-30 DAS PoE (T_4), 2,4-D (Na Salt) @ 0.5 kg ha^{-1} at 25-30 DAS PoE (T_5), atrazine @ 0.5 kg ha^{-1} PE *fb* 2,4-D (Dimethyl amine) @ 0.5 kg ha^{-1} at 25-30 DAS PoE (T_6), atrazine @ 0.5 kg ha^{-1} PE *fb* 2,4-D (Na Salt) @ 0.5 kg ha^{-1} at 25-30 DAS PoE (T_7), pendimethalin 750 g ha^{-1} PE *fb* 2,4-D (Dimethyl amine) @ 0.5 kg ha^{-1} at 25-30 DAS PoE (T_8), pendimethalin 750 g ha^{-1} PE *fb* 2,4-D (Na Salt) @ 0.5 kg ha^{-1} at 25-30 DAS PoE (T_9) and followed a randomized block design with three replications. Out of the nine treatments, weed free (T_2) recorded highest yield be it grain or straw which was statistically at par to treatment T_9 *i.e.* pendimethalin 750 g ha^{-1} PE *fb* 2,4-D (Na Salt) @ 0.5 kg ha^{-1} at 25-30 DAS PoE. Weed intensity and weed dry weight were found significantly lower in weed free (T_2) treatment which was statistically at par to pendimethalin 750 g ha^{-1} PE *fb* 2,4-D (Na Salt) @ 0.5 kg ha^{-1} at 25-30 DAS PoE (T_9). The highest benefit: cost ratio was recorded under pendimethalin 750 g ha^{-1} PE *fb* 2,4-D (Na Salt) @ 0.5 kg ha^{-1} at 25-30 DAS PoE (T_9) followed by pendimethalin 750 g ha^{-1} PE *fb* 2,4-D (Dimethyl amine) @ 0.5 kg ha^{-1} at 25-30 DAS PoE (T_8) and weed free (T_2) (2.54, 2.32 and 2.27, respectively). Hence, it can be concluded that sequential application of pre-emergence herbicide *i.e.* Pendimethalin followed by post-emergence herbicide *i.e.* 2,4-D (Na Salt and Dimethyl amine) are effective with higher benefit: cost ratio than hand weeding due to higher cost for labor weeding. Sequential application of pre- followed by post-emergence herbicides was also found effective than application of pre-emergence herbicides only.

Keywords: Pearl millet, herbicide, pre-emergence, post-emergence and weed management

Introduction
Pearl millet (*Pennisetum glaucum* L.) is one of the major coarse grain crops and is considered to be a poor man’s food. Heavy weed infestation is one of the major constraints that limit the productivity of pearl millet crop. Weeds emerge fast and grow rapidly competing with the crop severally for growth resources *viz.*, nutrients, moisture, sunlight and space during entire vegetative and early reproductive stages of pearl millet. The critical period for weed competition in pearl millet is up to 30-45 days after sowing (Bhan *et al.* 1998) [2]. Weeds cause lower grain and straw yield of pearl millet. On an average, 55% yield reduction due to heavy weed infestation in pearl millet crop was observed by Banga *et al.* (2000) [1] while, Kumar and Shaik (1993) [6] reported 43.4%. Weeds emerge along with the crop causing serious competition during the initial growth period resulting in seed yield loss up to 40% or more (Sharma and Jain, 2003) [8]. Hence, managing weeds during this period is most critical for obtaining higher yields.

Almost all types of weeds *viz.*, grassy, broad leaved weeds and sedges infested the pearl millet field. Some predominant weed species are *Cynodon dactylon, Dinebra retroflexa, Echinochloa colona, Brachiaria eruciformis, Cyperus rotundus, Parthenium hysterophorus, Commelina benghalensis, Amaranthus viridis* and *Trianthema portulacastrum* which cause heavy losses in pearl millet production. Mainly manual weeding has been employed to control weeds in pearl millet, but on the other hand, it is proving difficult due to labor shortages at crucial weeding times and rising labor costs. Atrazine and pendimethalin recommended as a pre-emergence herbicide is also not effective against some of the weeds both grassy and non-grassy as well the sedges *Cyperus rotundus.* Hence there is a need for some alternate post-emergence herbicides which can be provide broad spectrum weed control in *kharif* pearl millet without affecting the crop growth and yield of crop. Use of herbicides would make weed control more acceptable to the farmers and control of weeds by using herbicides was a cheaper proposition than with manual methods. Considering the importance of efficient weed management methods, this study sought to identify the best weed control treatment for increasing pearl millet yield by employing nine herbicidal combinations to minimize crop-weed competition for resources and to identify treatments with higher weed control efficiency.

Methodology

The field experiment was conducted at the Post Graduate Research Farm, Department of Agronomy, College of Agriculture, Dhule during the *kharif* season of year 2020. Climatologically, this area falls in the sub-tropical region at the North. Generally monsoon commences by third week of June and retreats at the end of September with the average annual rainfall of 607 mm. Experiment consisted of nine treatments laid out in randomized block design with three replications. The treatments consist with weedy check (T_1), weed free (T_2), atrazine @ 0.50 kg ha^{-1} PoE (T_3), 2,4-D (Dimethyl amine) @ 0.5 kg ha^{-1} at 25-30 DAS PoE (T_4), 2,4-D (Na Salt) @ 0.5 kg ha^{-1} at 25-30 DAS PoE (T_5), atrazine @ 0.5 kg ha^{-1} PE *fb* 2,4-D (Dimethyl amine) @ 0.5 kg ha^{-1} at 25-30 DAS PoE (T_6), atrazine @ 0.5 kg ha^{-1} PE *fb* 2,4-D (Na Salt) @ 0.5 kg ha^{-1} at 25-30 DAS PoE (T_7), pendimethalin 750 g ha^{-1} PE *fb* 2,4-D (Dimethyl amine) @ 0.5 kg ha^{-1} at 25-30 DAS PoE (T_8), pendimethalin 750 g ha^{-1} PE *fb* 2,4-D (Na Salt) @ 0.5 kg ha^{-1} at 25-30 DAS PoE (T_9). The seed of pearl millet variety DHBH 9071 (Adishakti) was sown on 1st July 2020 at spacing of 45 x 15 cm^2 using seed rate 3-4 kg ha^{-1}. The fertilizer was applied as per the recommended dose to pearl millet crop as 60:30:30 kg NPK ha^{-1}.

A 1 × 1 m^2 size quadrate was used to collect data on weed density and weed control efficiency at 30, 45, and 60 days after sowing. Weed control efficiency was calculated based on weed dry matter. The normality of distribution was not observed in the context of weed observations. As a result, before statistical analysis, the data were subjected to square root transformation to normalize the distribution. Data on grain yield and straw yield were recorded. Economic analysis of data was also done using the cost of inputs and selling price of produce obtained after processing of harvested material. The F-test approach was used to statistically examine all of the data. To establish the significance of differences between treatment means, critical difference values of P=0.05 were frequently utilized.

The crop was grown with recommended package of practices and was harvested at maturity on 5th October 2020.

Table 1: Effect of different weed management treatments on weed intensity, dry weight of weeds, weed index and weed control efficiency

Treatments	Weed intensity (no./m^2)			Dry weight of weeds (g/m^2)	Weed index (%)	Weed control efficiency (%)		
	30 DAS	45 DAS	60 DAS			30 DAS	45 DAS	60 DAS
T_1 - Weedy check	8.63 (74.00)	9.77 (95.00)	10.75 (115.00)	112.51	59.26	0	0	0
T_2 - Weed free	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	00	-	100	100	100
T_3 - Atrazine @ 0.50 kg ha^{-1} PoE	6.75 (45.00)	7.52 (56.00)	8.57 (73.00)	71.69	37.67	39.19	36.84	40.00
T_4 - 2,4-D (Dimethyl amine) @ 0.5 kg ha^{-1} at 25-30 DAS PoE	5.52 (30.00)	6.52 (42.00)	7.97 (63.00)	64.90	36.68	62.16	60.00	55.65
T_5 - 2,4-D (Na Salt) @ 0.5 kg ha^{-1} at 25-30 DAS PoE	5.15 (26.00)	6.20 (38.00)	7.58 (57.00)	57.30	31.56	63.51	55.79	59.13
T_6 - Atrazine @ 0.5 kg ha^{-1} PE *fb* 2,4-D (Dimethyl amine) @ 0.5 kg ha^{-1} at 25-30 DAS PoE	4.74 (22.00)	5.61 (31.00)	6.82 (46.00)	44.51	23.88	70.27	63.16	63.48
T_7 - Atrazine @ 0.5 kg ha^{-1} PE *fb* 2,4-D (Na Salt) @ 0.5 kg ha^{-1} at 25-30 DAS PoE	4.18 (17.00)	5.15 (26.00)	6.12 (37.00)	41.03	18.67	77.03	72.63	68.70
T_8 - Pendimethalin 750 g ha^{-1} PE *fb* 2,4-D (Dimethyl amine) @ 0.5 kg ha^{-1} at 25-30 DAS PoE	3.54 (12.00)	4.18 (17.00)	4.95 (24.00)	32.37	12.02	82.43	78.95	72.17
T_9 - Pendimethalin 750 g ha^{-1} PE *fb* 2,4-D (Na Salt) @ 0.5 kg ha^{-1} at 25-30 DAS PoE	3.08 (9.00)	3.81 (14.00)	4.42 (19.00)	24.76	6.15	90.54	85.26	82.61
S.E.(m) +	0.20	0.16	0.24	2.65	-	-	-	-
C.D. at 5%	0.59	0.47	0.73	7.94	-	-	-	-
General mean	4.70	5.50	6.43	49.90	-	-	-	-

***** Figures in parantheses are original values. All figures subjected to transformed values to square root $\sqrt{(X + 0.5)}$. DAS – Days after sowing, *fb* – Followed by, PE – Pre-emeregence,
PoE – Post-emergence

Table 2: Effect of different weed management treatments on grain yield, straw yield and economics of pearl millet

Treatments	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})	Total cost of cultivation (₹ ha^{-1})	Gross returns (₹ ha^{-1})	Net returns (₹ ha^{-1})	B:C ratio
T_1 - Weedy check	1180.35	2709.34	33754	45938	12184	1.36
T_2 - Weed free	2896.92	5316.87	41754	136449	94695	2.27
T_3 - Atrazine @ 0.50 kg ha^{-1} PoE	1805.65	3911.23	35079	85407	50328	1.43
T_4 - 2,4-D (Dimethyl amine) @ 0.5 kg ha^{-1} at 25-30 DAS PoE	1834.29	3968.53	34929	86759	51830	1.48
T_5 - 2,4-D (Na Salt) @ 0.5 kg ha^{-1} at 25-30 DAS PoE	1982.61	4165.23	34894	93700	58806	1.69
T_6 - Atrazine @ 0.5 kg ha^{-1} PE *fb* 2,4-D (Dimethyl amine) @ 0.5 kg ha^{-1} at 25-30 DAS PoE	2205.05	4610.53	36254	104199	67945	1.87
T_7 - Atrazine @ 0.5 kg ha^{-1} PE *fb* 2,4-D (Na Salt)	2356.02	4630.78	36219	111156	74937	2.07

@ 0.5 kg ha-1 at 25-30 DAS PoE						
T_8 - Pendimethalin 750 g ha-1 PE *fb* 2,4-D (Dimethyl amine) @ 0.5 kg ha-1 at 25-30 DAS PoE	2548.76	4974.99	36248	120228	83980	2.32
T_9 - Pendimethalin 750 g ha-1 PE *fb* 2,4-D (Na Salt) @ 0.5 kg ha-1 at 25-30 DAS PoE	2718.73	5099.12	36213	128122	91909	2.54
S.E.(m) +	63.64	114.35	-	-	-	-
C.D. at 5%	190.80	342.84	-	-	-	-
General mean	2169.82	4376.29	-	-	-	-

Result and Discussion

Weed control efficiency

WCE indicates that how well weed controlled by the herbicide by reducing weed population or dry weight over weedy plot in treated plot. At 60 DAS, the weed control efficiency (%) (Table 1) was recorded maximum in weed free treatment (100%) and it was significantly higher compared to all other treatments. Among herbicidal treatments pendimethalin @ 750 g ha-1 PE *fb* 2,4-D (Na Salt) @ 0.5 kg ha-1 at 25-30 DAS PoE showed maximum weed control efficiency (82.61%) followed by pendimethalin @ 750 g ha-1 PE *fb* 2,4-D (Dimethyl amine) @ 0.5 kg ha-1 at 25-30 DAS PoE (72.17%). These findings corroborate the findings of the previous study reported by Channabasavanna *et al.* (2015) [3], Sivamurugan *et al*. (2017) [9] and Kumar and Chawla (2019) [7].

Weed index

WI indicates how efficiently weeds were controlled which reflect in term of yield. Among all the weed control treatments, weed free treatment produced zero weed index (WI) and the treatments pendimethalin @ 750 g ha-1 PE *fb* 2,4-D (Na Salt) @ 0.5 kg ha-1 at 25-30 DAS PoE and pendimethalin @ 750 g ha-1 PE *fb* 2,4-D (Dimethyl amine) @ 0.5 kg ha-1 at 25-30 DAS PoE produced significantly lower WI (6.15% and 12.02%). Maximum weed index (59.26%) was found under weedy check. Weedy check registered the highest weed index due to the highest weed growth over the entire crop growth cycle, resulting in extreme weed competition by unregulated growth of weeds and the highest reduction in yield. These findings corroborate those of the previous study reported by Channabasavanna *et al.* (2015) [3], Sivamurugan *et al.* (2017) [9] and Kumar and Chawla (2019) [7].

Weed intensity

Weed intensity consists of grasses, sedges and broad leaves collected per meter square area which shows overall view of abundance of weeds in the crop field. At 60 DAS, among weed control treatments, weed free treatment recorded significantly minimum weed intensity per m^2 (0.71) whereas weedy check exhibited maximum weed intensity per m^2 (10.75) (Table 1). Among herbicidal treatments, minimum weed intensity per m^2 (4.42) was recorded under pendimethalin @ 750 g ha-1 PE *fb* 2,4-D (Na Salt) @ 0.5 kg ha-1 at 25-30 DAS PoE followed by pendimethalin @ 750 g ha-1 PE *fb* 2,4-D (Dimethyl amine) @ 0.5 kg ha-1 at 25-30 DAS PoE (4.95 no/m^2). These findings are consistent with those of Sivamurugan *et al.* (2017) [9] and Kumar and Chawla (2019) [7].

Dry weight of weeds (At harvest)

The different weed management treatments resulted in considerable differences in weed dry weight. Weed free noted remarkably the lowest dry weight of weeds. Among different chemical weed management treatments, the treatment with application of pendimethalin 750 g ha-1 PE *fb* 2,4-D (Na Salt) @ 0.5 kg ha-1 at 25-30 DAS PoE recorded significantly minimum dry weight of weeds (24.76 g/m^2) at harvest stage of pearl millet than other chemical weed management treatments which is found to be comparable to pendimethalin 750 g ha-1 PE *fb* 2,4-D (Dimethyl amine) @ 0.5 kg ha-1 at 25-30 DAS PoE (32.37 g/m^2). Significantly the highest dry weight of weeds (112.51 g/m^2) was registered in a weedy check. At the harvest stage of pearl millet, all weed control treatments considerably reduced the dry weight of weeds when compared to the weedy check. This could be as a result of effective control of weeds by spraying of pre-emergence and post-emergence herbicides in respective treatments. In comparison to weedy check, this lowered crop-weed competition, resulting in less dry matter. Sequential application of pre-emergence and post-emergence herbicides found better over application of post-emergence herbicide alone. These findings corroborate the findings of Kumar and Chawla (2019) [7].

Yield

Data revealed that the grain yield of pearl millet was significantly influenced by several weed management treatments. Among several weed management treatments highest grain yield (2896.92 kg ha-1) was found in weed free treatment which was statistically at par to treatment T_9 *i.e.* pendimethalin 750 g ha-1 PE *fb* 2,4-D (Na Salt) @ 0.5 kg ha-1 at 25-30 DAS PoE (2718.73 kg ha-1) and superior over rest of the treatments. Pendimethalin 750 g ha-1 PE *fb* 2, 4-D (Dimethyl amine) @ 0.5 kg ha-1 at 25-30 DAS PoE recorded the grain yield 2548.76 kg ha-1. Lowest grain yield was obtained under weedy check (1180.35 kg ha-1) (Table 2). Highest straw yield was obtained under weed free treatment (5316.87 kg ha-1) which was statistically at par to treatment T_9 *i.e.* pendimethalin 750 g ha-1 PE *fb* 2,4-D (Na Salt) @ 0.5 kg ha-1 at 25-30 DAS PoE (5099.12 kg ha-1) followed by pendimethalin 750 g ha-1 PE *fb* 2,4-D (Dimethyl amine) @ 0.5 kg ha-1 at 25-30 DAS PoE (4974.99 kg ha-1). Lowest straw yield (2709.34 kg ha-1) was produced under weedy check. The improved grain yield and straw yield in these treatments attributed by better interception of sunlight, soil nutrients and space by the crop due to lower weed intensity and higher WCE, as well as better yield attributes. The yield advantage of various weed management treatments over weedy control was largely attributed to improved yield attributes and cooperatively decreased weed intensity and weed dry weight with higher WCE. This data is consistent with Channabasavanna *et al.* (2015) [3], Dobariya *et al.* (2014) [4], Kamble *et al.* (2015) [5], Kumar and Chawla (2019) [7] and Sivamurugan (2017) [9].

Economics

Reflection of management of weed can be seen in yield but finely how cost effectively weed managed, this can be observed only in economics of production system of the crop. The highest gross return of ₹ 136449 ha-1 was recorded under weed free treatment followed by pendimethalin 750 g ha^{-1} PE *fb* 2,4-D (Na Salt) @ 0.5 kg ha^{-1} at 25-30 DAS PoE (₹ 128122 ha^{-1}), pendimethalin 750 g ha^{-1} PE *fb* 2,4-D (Dimethyl amine) @ 0.5 kg ha^{-1} at 25-30 DAS PoE (₹ 120228 ha^{-1}), atrazine @ 0.5 kg ha^{-1} PE *fb* 2,4-D (Na Salt) @ 0.5 kg ha^{-1} at 25-30 DAS PoE (₹ 111156 ha^{-1}) and atrazine @ 0.5 kg ha^{-1} PE *fb* 2,4-D (Dimethyl amine) @ 0.5 kg ha^{-1} at 25-30 DAS PoE (₹ 104199 ha^{-1}). Lowest gross return was obtained under weedy check (₹ 45938 ha^{-1}). The highest net return of ₹ 94695 ha^{-1} was recorded under weed free treatment followed by pendimethalin 750 g ha^{-1} PE *fb* 2,4-D (Na Salt) @ 0.5 kg ha^{-1} at 25-30 DAS PoE (₹ 91909 ha^{-1}), pendimethalin 750 g ha^{-1} PE *fb* 2,4-D (Dimethyl amine) @ 0.5 kg ha^{-1} at 25-30 DAS PoE (₹ 83980 ha^{-1}), atrazine @ 0.5 kg ha^{-1} PE *fb* 2,4-D (Na Salt) @ 0.5 kg ha^{-1} at 25-30 DAS PoE (₹ 74937 ha^{-1}) and atrazine @ 0.5 kg ha^{-1} PE *fb* 2,4-D (Dimethyl amine) @ 0.5 kg ha^{-1} at 25-30 DAS PoE (₹ 67945 ha^{-1}). Lowest net return was obtained under weedy check (₹ 12184 ha^{-1}). Data revealed that effect of different weed control treatments was found significant on benefit: cost ratio. Highest benefit: cost ratio (2.54) was found under pendimethalin 750 g ha^{-1} PE *fb* 2,4-D (Na Salt) @ 0.5 kg ha^{-1} at 25-30 DAS PoE followed by pendimethalin 750 g ha^{-1} PE *fb* 2,4-D (Dimethyl amine) @ 0.5 kg ha^{-1} at 25-30 DAS PoE (2.32) and weed free (2.27). However, the gross and net monetary returns were maximum under weed free practice but lowest B:C ratio as compared to sequential application of pendimethalin 750 g ha^{-1} PE *fb* 2,4-D (Na Salt) @ 0.5 kg ha^{-1} at 25-30 DAS PoE and pendimethalin 750 g ha^{-1} PE *fb* 2,4-D (Dimethyl amine) @ 0.5 kg ha^{-1} at 25-30 DAS PoE due to higher cost for labor weeding. Lowest benefit: cost ratio (1.36) was found under weedy check. These findings are consistent with Kamble *et al.* (2015) [5], Dobariya *et al.* (2014) [4] and Sivamurugan (2017) [9].

Conclusion

Based on the field trial findings, it is rational to assume that potential output and effective weed control in pearl millet may be reached by maintaining weed free conditions throughout crop growing phase, where labor is readily accessible but economically this treatment is not feasible to the farmers because of having less benefit: cost ratio. Whereas, another alternative like application of pendimethalin @ 750 g ha^{-1} PE *fb* 2,4-D (Na Salt) @ 0.5 kg ha^{-1} at 25-30 DAS PoE (T_9) and pendimethalin @ 750 g ha^{-1} PE *fb* 2,4-D (Dimethyl amine) @ 0.5 kg ha^{-1} at 25-30 DAS PoE (T_8) effective with higher benefit: cost ratio as well as higher yield attributes.

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