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Efficacy of Herbicides on Weed Dynamics and Weed Control Efficiency and its Effect on Productivity and Economics of Kharif Maize

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ABSTRACT

A range of herbicides was tested in the kharif season for three consecutive years (2015-2017) to find out the best broad spectrum pre and post-emergence herbicide for maize cultivation in Peninsular India. The result revealed that application of Atrazine (0.75 kg a.i./ha) + 2,4-D Amine (0.4 kg a.i./ha) at 25 DAS as post-emergence (T9); Atrazine @ 1.5 kg a.i./ha as preemergence followed by Tembotrione @ 120g a.i./ha as post-emergence at 25 DAS (T10); and Atrazine (0.75 kg a.i./ha) + Pendimethalin (0.75 kg a.i./ha) as preemergence (T4) effectively controlled the narrow and broad-leaved weeds throughout the cropping cycle. Post-emergence application of Halosulfuron @ 90 g/ha at 25 DAS was found highly effective in reducing sedge infestation in the maize crop. Unweeded plots registered 31.3 % yield penalty over weed-free plots. While chemical weed management employing various herbicides registered a 10-40% yield improvement over the weedy check. Among the various herbicides, T9, T10, and T4 recorded at par maize grain and straw yields, growth, and yield parameters with weed-free plots and showed the lowest yield penalty (weed index) caused by weeds over weed-free plots. Based on the findings, it may be concluded that application of Atrazine (0.75 kg a.i/ha) + Pendimethalin (0.75 kg a.i/ha) (T4); Atrazine (0.75 kg a.i./ha) + 2,4-D Amine (0.4 kg a.i./ha) at 25days after sowing(DAS) as post-emergence (T5); Pendimethalin (1 kg a.i/ha) as pre-emergence followed by Atrazine (0.75 kg a.i/ha) + 2,4-D Amine (0.4 kg a.i/ha) at 25 DAS as post-emergence (T9) ; and Atrazine (1.5 kg a.i/ha1) as pre-emergence followed by Tembotrione (120 g a.i/ha) at 25 DAS (T10) can be used to effectively reduce weed infestation and to get higher grain yield and net returns of maize in Peninsular India.

Keywords: *Maize, preemergence herbicide, post-emergence herbicide, weed dynamics, weed control efficiency, weed index.*

INTRODUCTION

Maize (*Zeamays* L.) is one of the most important cereal crops globally producing > one billion tonnes grain [1]. It is emerging as a remunerative crop for crop diversification and replacing traditional crops (winter wheat and rabi paddy) due to its strong market demand, year-round cultivation, high yields, and resilience to changing climate. In India, it has emerged as an important crop for feed, food, fodder, and biofuel occupying 9.86 million hectares of area with a production of 31.5 million tonnes and productivity of about 3.20 t/ha during 2020-21 [2]. Nearly 75% of maize is produced during the kharif season having very little productivity predominantly due to biotic and abiotic stress like weeds, moisture stress, nutrients, pests, and diseases. Amongst all, intense weed competition is one of the potential problems to realize higher yields of maize around the globe as well as in India. Wide spacing, and slow initial growth coupled with congenial weather conditions allow luxuriant growth of varied weed species in kharif maize.

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Weeds competes for water, nutrient, space, and light, resulting in significant yield losses. Weeds also harbor insects, pests, and diseases and they serve as an alternate host for other pests [3] . Yield losses in maize varied depending on the type of weeds, their intensity, and time of crop-weed competition [4]. In the absence of suitable and appropriate weed control practices, weeds can cause up to 70% yield losses in maize [5]. The first 3rd to 6th week of the maize growth period is very sensitive to weed infestation due to the narrow canopy which couldn't suppress excessive weed growth [6], [7], and [8]. During the critical period, the practice of repeated hand weeding are widely adopted, but it is more expensive, time-consuming, and less feasible due to incessant rains [9]. Hence, farmers need effective and economical alternatives for weed management. The pre and post-emergence herbicides with a broad spectrum of weed control are highly essential for the effective control of grasses, sedges, and broad-leaved weeds [3] . In this context, the present study was carried out to find out the effective weed control strategies to manage weed flora and its influence on growth, yield and economy of maize.

MATERIALS AND METHODS

A field experiment was conducted in the kharif season for three consecutive years (2015-2017) at Agricultural Research Station, Karimnagar($18^0$26'N, 79^0 5'E, and 229 msl) in Telangana state. The experimental site falls under a semi-arid tropical climate with dry, hot summers and cool winters. The average annual rainfall of the area is 890 mm, most of which is from June to October. The total rainfall received during the experimental period (June to October) was 633.4, 795.3, and 568 mm during 2015, 2016, and 2017, respectively. The soil of the experimental field was red sandy loam in texture having 7.09 pH and 0.26 dS/m EC. The 0-15 cm soil profile had 0.71% organic carbon [10], 176 kg/ha available N [11], 27 kg/ha available P [12], and 392 kg/ha available K [13] before the initiation of the experiment. The experiment was carried out in randomized blocks design (RBD) with three replications and ten treatments. The treatments comprising of T1- Control (Weedy check), T2 – Weed free, T3 – Atrazine @ 1.5 kg a.i./ha as pre-emergence (PRE), T4 – Atrazine (0.75 kg a.i./ha) + Pendimethalin (0.75 kg a.i./ha) as PRE, T5 – Atrazine (0.75 kg a.i./ha) + 2,4-D Amine (0.4 kg a.i./ha) at 25days after sowing(DAS) as post emergence (POE), T6-Halosulfuron@ 90 g/ha at 25 DAS as POE, T7- Atrazine (0.75 kg a.i./ha) as PRE followed by Halosulfuuron@ 90 g/ha at 25 DAS as POE, T8 – Tembotrione @ 120g a.i./ha as POE at 25 DAS, T9 – Pendimethalin (1 kg a.i./ha) as PRE followed by Atrazine (0.75 kg a.i./ha) and 2,4-D Amine (0.4 kg a.i./ha) at 25DAS as POE and T10- Atrazine @ 1.5 kg a.i./ha as PRE followed by Tembotrione @ 120g a.i./ha as POE at 25 DAS. All herbicides were applied using @500 l water/ha with the help of a knapsack sprayer fitted with a flat fan nozzle. Single cross maize hybrid, DHM-117 was dibbled manually at 60 cmrow to row spacing and 20 cm plant to plant distance. Sowing was done using 20 kg seed per hectare on 26^{th}, 28^{th} and 26^{th}June during 2015, 2016, and 2017, respectively. All recommended management practices were followed to raise the crop. Data about weed density and dry weight were recorded at 30 and 50 DAS. A 50 × 50 cm^2 quadrate was placed randomly at two places in each plot and species-wise weed population was counted and removed. The harvested weed samples were washed in clean water, sun-dried, and finally oven-dried at 70^0C for 48 hr and weighed. The efficiency of weed management by various treatments was assessed by weed control efficiency (WCE) and weed index (WI).

$$\text{WCE (\%)} = \frac{\text{Weeds dry weight in weedy check - Weeds dry weight in the treated plot}}{\text{Weeds dry weight in weedy check}} \times 100$$

$$\text{WI} = \frac{\text{Grain yield in weed-free plot - Grain yield in the treated plot}}{\text{Grain yield in weed-free plot}} \times 100$$

The observations on days taken to 50% tasselling and silking, cob girth, kernel row/cob, the kernel no./row, and 100-grain weight were recorded. Cost of maize cultivation under various treatments was estimated based on prevailing market rates of inputs. Gross returns were calculated by multiplying maize yield with the market price for the respective experimental years. The net returns were calculated by subtracting the total cost of cultivation from gross returns. The benefit-cost ratio was calculated as the ratio of gross returns to the cost of cultivation. Due to high variance, actual weed density was transformed by square root transformation {$\sqrt{(x+0.05)}$} for statistical analysis. Data were analyzed using the analysis of variance technique suggested by [14]. The results were presented at 5% level of significance (P=0.05) and critical difference (CD) values were calculated to compare the various treatment means. The effect of years was not significant and all the experimental data is subjected to pooled analysis.

RESULTS AND DISCUSSION

Weed density and biomass

The major weed flora belonging to different species were identified. In maize crop, the dominant narrow leaved weeds (NLW's) observed are *Elusine indica spp., Panicum repense, Dactelocteniumaegyptium, and Denibraretroflexa* were the most prominent grassy weeds. Among broad-leaved weeds (BLW's) *Digeriaarevensis, Commelina bengalensis, Boerhaviaerrecta, Ipomea pes-trigidis, Trichodesma indicum, Euphorbia hirta, Phyllanthus niruri, Tribulus Terrestris, Celosia argentea* and *Physalis minima* were more dominant. *Cyperus rotundus* L. and *Cyperus retroflexa* were observed as prominent sedges in the experiment.

The weed density and drymatter varied due to different herbicides treatments at 30 and 50 DAS (Table 1).Significantly maximum weed density of narrow-leaved, broad-leaved and total weed flora at 30 DAS and 50 DAS was recorded in the weedy check and treatments without preemergence herbicides (T5, T6 and T8). Experimental plot that received pre-emergence herbicide application (T4< T9<T3=T10<T7) recorded the least total weed density and dry matter at 30 DAS. Among the pre-emergence herbicides, application of Pendimethalin alone (T9)or in combination with Atrazine (T4) recorded significantly lesser grassy weeds density(0.9 & 1.9 m^{-2}, respectively) while preemergence application of Atrazine (T10 & T3) observed least broad-leaved weed density (1.8 & 3.1 m^{-2}). Sedges density at 30 DAS was non significantly affected by all these herbicide treatments which indicates the in-efficacy of the pre-emergence herbicides on sedge management. It was found that T4 controlled the wide range of weed flora including NLW and BLW, and therefore reduction in total weed density and biomass was recorded in maize. [15] reported that the application of Atrazine (50%) @ 1.25 kg + Pendimethalin (50%) @ 2.5 l/ha was found effective compared to other herbicides. At 50 DAS, among the herbicide treatments, T7 recorded the least total weed density (16.1 m^{-2}) and dry matter (7.6 g m^{-2}). While, T9 and T10 recorded the least grassy as well as broad-leaved weed population due to post-emergence application of herbicides which has lowered the weed density [16]. Post-emergence application of Halosulfuron (T6 and T7) effectively controlled the sedges, which is evident by the reduction of weed density of sedges by 83 % at 50 DAS when compared to 30 DAS. Application of Tembotrione@ 120 g a.i./ha as POE in T8 and T10 also reduced the sedges density at 50 DAS.

Weed control efficiency and weed index

Weed control efficiency represents the magnitude of weed reduction by herbicides over un-weeded treatment. Weed free plot recorded the highest weed control efficiency (100 %) at 30 and 50 DAS (Table 1). T4 recorded the highest weed control efficiency (70.8%) at 30 DAS due to effective control of diverse weed flora.T7 (67.9%) envisaged higher weed control efficiency at 50 DAS by managing the sedges infestation. It was observed that the sole application of pre-emergence herbicides (T3 and T4) well-managed weeds up to 30 DAS (WCE 65-70%) but they failed to control the weeds flushes beyond 30 DAS as their WCE was reduced to 40-47%. Application of both pre and post-emergence herbicides maintained the WCE > 60% throughout the cropping cycle (Fig1).

Weed index represents per cent yield loss caused by weeds in a treatment as compared to weed weed-free check therefore treatments with lower lower weed index are considered good [17], [18]. Significantly highest weed index was recorded with the weedy check (31.3) (Table 1). While T9 (3.9), T10 (4.6), and T4 (6.5) recorded the least value of weed index. The better weed management and lower weed competition in these treatments enhanced the yield and therefore lowered down the weed index (Fig 2).

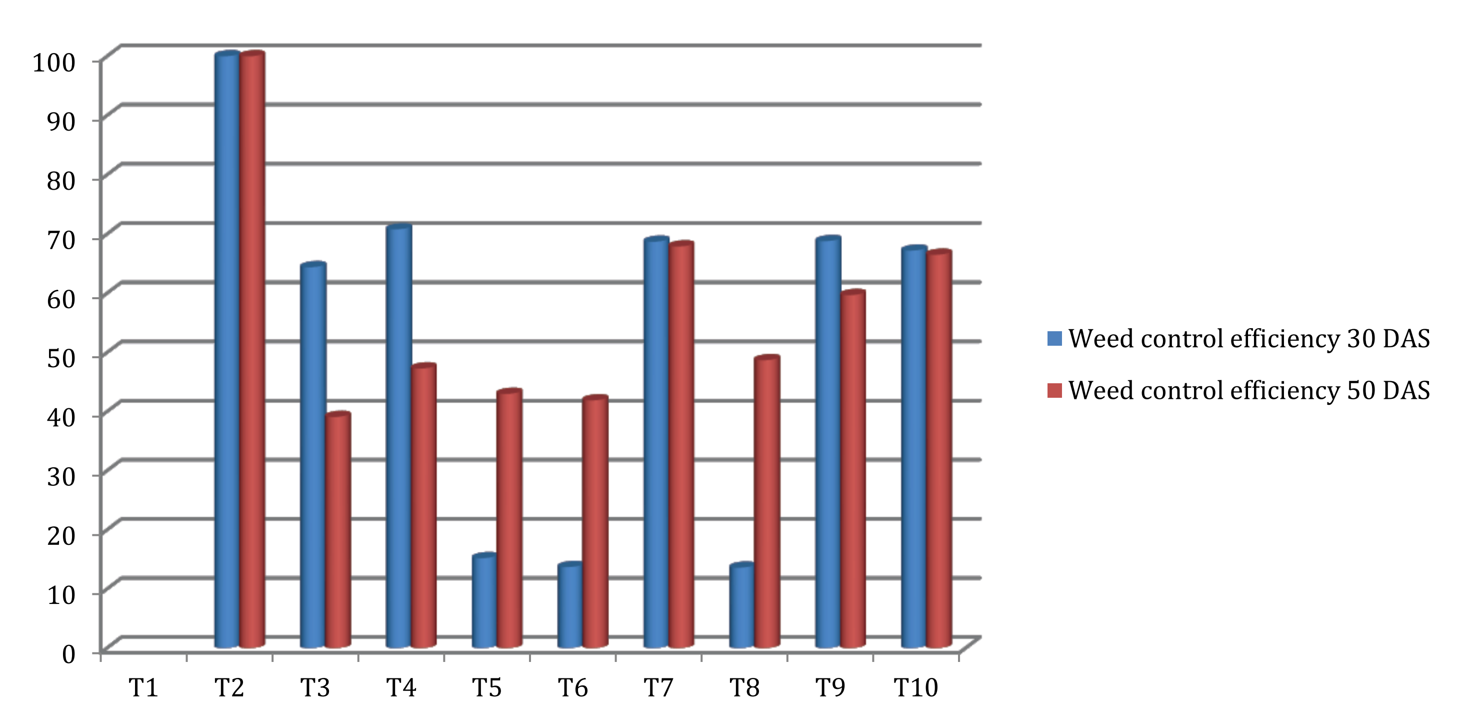

Fig 1 : Weed control efficiency at 30 and 50 DAS in different weed control treatments

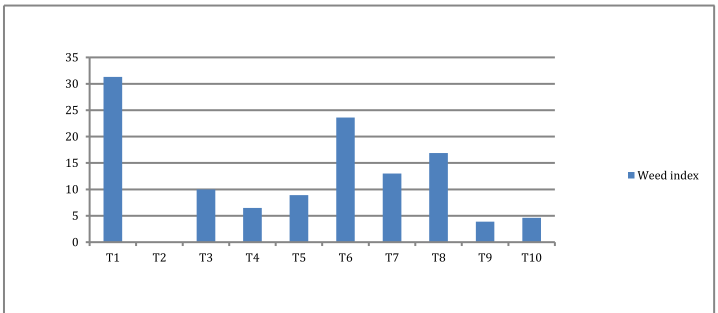

Fig 2 : Weed index as affected by different weed control treatments

Growth, development and yield parameters

Significantly the minimum and maximum plant height, and yield parameters were observed at T1 and T4, respectively (Table 2). Various herbicide treatments did not significantly differ in plant height. Stress caused by early weed competition delayed the rate of maize development. Days to 50% tasselling and silking were maximum in weedy check and the plot escaped with pre-emergence weed application (T5, T6, T8). Among the herbicide treatments, T9. T10 and T4 recorded the significant maximum cob length, kernel number, kernel rows/cob, kernel no./row, and 100-grain weight. Better weed management by the herbicide during a critical period may be led to more availability of nutrients and less crop-weed competition which gives a better physiological environment for the nutrition of maize crop, thereby better plant growth [19] as reflected by plant height & yield attributes. The POE application of Halosulfuron (T6 and T7) showed the lowest value of growth and yield parameters. The phytotoxic effect (leaf yellowing) of Halosulfuron herbicide may cause the retardation of maize growth for a short period which led to a reduction in yield parameters in Halosulfuron applied treatments (Table 2).

Grain and straw yields

The maize grain and straw yields differed significantly due to weed management treatments (Table 3). Weeds caused per cent 31.4%grain yield penalty in an un-weeded plot as compared to weed weed-free plot. Earlier, [20] also found 33-50% yield loss by weeds in maize. The grain and straw yields were significantly higher in weed-free plot (8.30 and 9.07 t/ ha) and found at par with the T9, T10, T4, T5 and T3.These herbicide treatments effectively diminished the weed growth and dry matter and eventually accelerated the growth of maize plant, enhanced the yield attributes of the crop and ultimately led to increased maize grain yield(Table 1-3). Significantly lowest grain and stover yields were recorded with weedy check (5.70and 5.92 t/ha) due to greater weed density and dry matter and associated competition for available resources [21] led to hampered crop growth, and development and thereby decreased grain yield. As compared to un-weeded plot, 10-40% higher grain yield was obtained when the chemical weed management approach was followed.

Economics

Weed management employing herbicides was found more economical as compared to weed free treatment.Among the different weed management practices, maximum net returns of 56,024₹/ha and B:C ratio (1:96) was obtained in T4 and was statistically at par with T5,T9 and T10 treatments which also recorded on par B:C ratio respectively. However, significantly minimum net returns and B:C ratio were obtained in weedy check along with T6 and T7.

Conclusions

Based on the findings, it may be concluded that pre-emergence application of Atrazine (0.75 kg a.i/ha) + Pendimethalin (0.75 kg a.i/ha) (T4); Atrazine (0.75 kg a.i./ha) + 2,4-D Amine (0.4 kg a.i./ha) at 25days after sowing(DAS) as post-emergence (T5); Pendimethalin (1 kg a.i/ha) as pre-emergence followed by

Atrazine (0.75 kg a.i/ha) + 2,4-D Amine (0.4 kg a.i/ha) at 25 DAS as post-emergence (T9) ; and Atrazine (1.5 kg a.i/ha1) as pre-emergence followed by Tembotrione (120 g a.i/ha) at 25 DAS (T10) are the most economical method for weed management in maize on red sandy loam soils of Peninsular India. Halosulfuron (90 g/ha) at 25 DAS as post-emergence can be used in the field heavily infested by sedges.

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Conflicts of Interest: The author declares no conflict of interest.

Table 1 Effect of herbicide application on weed density, weed dry matter, weed control efficiency and weed index at 30 and 50 DASin maize.

Treatments	Weed density at 30 DAS (g/m^2)				Weed density at 50 DAS (g/m^2)				Weed dry matter (g/m^2)		Weed control efficiency (%)		Weed index
	Grasses	Sedges	BLW's	Total	Grasses	Sedges	BLW's	Total	30 DAS	50 DAS	30 DAS	50 DAS	
T1	4.3 (18.4)	4.8 (23.0)	4.4 (19.1)	7.8 (60.5)	4.9 (23.7)	5.4 (29.0)	4.5 (20.0)	8.5 (72.7)	27.8	33.6	-	-	31.3
T2	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0	0.0	100	100	0.0
T3	2.5 (6.3)	3.9 (15.0)	1.8 (3.1)	4.9 (24.3)	2.9 (8.2)	4.1 (16.9)	2.5 (6.0)	5.6 (31.1)	10.0	14.4	64.4	39.1	10.0
T4	1.4 (1.9)	4.1 (17.0)	2.0 (4.0)	4.8 (22.9)	2.6 (6.8)	4.4 (19.5)	2.4 (5.9)	5.7 (32.2)	8.1	12.5	70.8	47.3	6.5
T5	3.7 (13.4)	4.3 (18.7)	3.8 (14.6)	6.8 (46.7)	3.8 (14.1)	4.4 (19.5)	2.5 (6.3)	6.3 (40.0)	23.5	13.5	15.2	43.0	8.9
T6	3.3 (11.0)	4.7 (21.6)	4.1 (16.7)	7.0 (49.3)	3.3 (10.7)	1.9 (3.5)	4.4 (19.7)	5.8 (33.9)	24.0	13.7	13.7	41.9	23.6
T7	2.0 (4.0)	4.6 (20.7)	1.8 (3.1)	5.3 (27.7)	2.1 (4.4)	1.8 (3.3)	2.9 (8.3)	4.0 (16.1)	8.8	7.6	68.7	67.9	13.0
T8	3.6 (12.7)	4.4 (19.2)	3.7 (13.5)	6.7 (45.4)	2.3 (5.1)	4.0 (14.2)	2.8 (7.6)	5.3 (27.9)	24.0	12.1	13.6	48.7	16.9
T9	1.0 (0.9)	4.3 (19.2)	2.0 (3.8)	4.9 (23.9)	1.6 (2.4)	4.6 (20.8)	1.5 (2.1)	5.0 (25.4)	8.7	9.5	68.8	59.7	3.9
T10	2.2 (4.9)	4.3 (18.3)	1.4 (1.8)	5.0 (25.1)	1.8 (3.3)	3.7 (13.4)	2.3 (5.2)	4.7 (22.0)	9.1	7.9	67.2	66.5	4.6
C.D (p=0.05)	1.4	0.9	1.1	4.5	0.9	1.5	1.1	1.4	3.30	2.60	6.9	7.8	4.3
Treatments details are given in materials and methods section.													

Table 2 Effect of herbicide application on growth, phenology and yield parameters of maize.

Treatments	Plant height at harvest (cm)	Days to 50% tasseling	Days to 50% silking	Cob length (cm)	Cob girth (mm)	Kernel rows/cob	Kernel no./row	100- grain weight (g)
T1	200.6	53.2	57.5	15.9	15.3	13.9	28.4	30.7
T2	222.8	52.2	54.9	18.6	16.9	14.8	33.8	36.4
T3	219.7	50.2	53.4	17.3	15.6	14.1	31.6	33.0
T4	220.8	51.4	53.7	18.3	16.3	14.5	33.0	35.2
T5	222.9	52.5	55.3	18.0	16.0	14.2	32.3	34.5
T6	207.7	53.2	56.4	16.7	15.7	14.2	30.4	31.9
T7	214.7	52.3	54.5	17.1	15.9	14.2	30.3	31.6
T8	210.9	53.5	55.9	17.4	16.2	14.4	32.3	34.4
T9	220.4	51.8	53.0	18.4	16.6	14.6	33.7	36.3
T10	219.0	51.4	53.2	18.4	16.5	14.7	33.6	36.8
C.D (p=0.05)	18.5	1.5	2.7	1.5	NS	1.2	4.4	2.6

Treatments details are given in materials and methods section.

Table 3 Effect of herbicide application on grain and straw yield and maize production economics.

Treatments	Grain yield (t/ha)	Stalk yield (t/ha)	Net returns (×10³₹/ha)	B:C ratio
T1	5.70	5.92	28.0	1.51
T2	8.30	9.07	43.6	1.62
T3	7.47	7.42	43.4	1.69
T4	7.76	8.43	**55.0**	**1.96**
T5	7.56	8.33	47.8	1.84
T6	6.34	7.01	32.4	1.55
T7	7.22	8.44	39.6	1.66
T8	6.90	7.84	42.0	1.70
T9	7.98	8.98	48.8	1.80
T10	7.92	8.83	47.3	1.77
C.D (p=0.05)	0.99	1.43	11.2	0.23

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