International Journal of Plant & Soil Science

Volume 35, Issue 17, Page 54-61, 2023; Article no.IJPSS.102353
ISSN: 2320-7035

Effect of Chemical Herbicides on Diversified Weed Flora and Weed Control Efficiency in Maize (*Zea mays* L.)

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/IJPSS/2023/v35i173183

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/102353

Original Research Article

Received: 25/04/2023
Accepted: 28/06/2023
Published: 01/07/2023

ABSTRACT

The field experiment was carried out at Agriculture Research Farm, Integral University, Lucknow, Uttar Pradesh, India during *Kharif, 2021*. The experiment envisages study the effect of herbicides on the density, index and control efficiency of weed on maize crop. The experiment was laid down in the Randomized block design with twelve treatments replicated thrice. The highest weed control

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efficiency was observed in weed free treatment (T_{11}) due to weed free environment all over the maize growth period but among the herbicidal treatments the treatment (T_1) Atrazine 1.0 kg a.i ha^{-1} PE (Pre-emergence) showed highest weed control efficiency of 67.69 % up to 20 DAS. The treatment (T_8) Atrazine 0.5 kg a.i ha^{-1} PE followed by Tembotrione 0.120 kg a.i ha^{-1} PoE at 20 DAS resulted in the lowest weed count and lowest weed index of 5.59 sqm^{-1} and 7.62% respectively. The highest weed control efficiency of 79.78 % all over the crop growth period was observed in the treatment (T_8) Atrazine 0.5 kg a.i ha^{-1} PE followed by Tembotrione 0.120 kg a.i ha^{-1} PoE. The treatment Weedy check (T_{12}) recorded highest weed dry matter accumulation while among the herbicidal treatments the lowest weed dry matter accumulation was observed in T_8 treatment and was at par with the treatment T_7.

Keywords: Pendimethalin; tembotrione; weed index; weed control efficiency.

1. INTRODUCTION

"Maize (*Zea mays* L.) is believed to be originated from Mexico and Central America" [1]. "Maize is a multifunctional crop and an important cereal crop in the Poaceae family. It is widely used as a food for human beings and as well as for animal and poultry feed. It has number of Industrial uses including maize starch, dextrose, maize syrup, and maize flakes production" [2]. It also performs well in a variety of soil and climatic conditions.

"After rice and wheat, maize is the major cereal crop contributing to India's food security and farm income. Major area of maize is cultivated during kharif season in which weed's infestation is one of the most important yield-limiting factors. However, the first six weeks after planting of crop are the most critical period for crop weed competition, because initial slow growth in wider spacing of maize, coupled with congenial weather conditions allow luxuriant weed growth which might be reduced yield by 28-100%" [3,4]. "The critical period of crop-weed competition in maize during the rainy season was reported from 15-45 days after sowing" [5]. "Weeds compete with crop plants for light, space, water, and nutrients, particularly in the early stages of growth, since they are more adapted to agro-ecosystems than crop plants. Wide spacing in maize permits luxuriant development of several weed species, which affects photosynthetic efficiency, dry matter production, and partitioning to economic portions, resulting in poor grain yield" [6].

The competitive effect of a given density of weeds on crop depends on how long they remain in the field. The correlation between competition time and crop production decline is approximately sigmoidal. "The key period of crop weed competition in maize crops occurs between 30 and 45 days after planting sowing" [7]. "Due to high labour costs in maize cultivation areas, chemical control methods are preferred because of their fast results, easy application, and low cost as reported" by [8]. "Weed control in maize during the critical time is important for achieving increased yield. Hand weeding is effective, but it is quite costly. Amongst various production factors, weed management plays major role in increasing productivity of maize. Unchecked weed growth in crop may results in grain yield losses to the extent of 100%" [9]. Furthermore, the high demand for labour during peak season, as well as its scarcity, demands the usage of herbicides as a means of weed management. Chemical weed management, which is less labour intensive, is advised to address this restriction [10].

2. MATERIALS AND METHODS

Experimental site: The experiment was carried out at Agriculture Research Farm, Integral University, Lucknow, Uttar Pradesh, India during Kharif, 2021. The city of Nawabs, Lucknow lies in the coordinates 26°51′N 80°57′E. Lucknow has a humid subtropical climate with hot, sunny summers from March to May. From June to October, the city receives an average of 827.2 millimetres of rainfall from the southwest monsoon winds. Summers are very hot with temperatures rising into the 40 to 45 °C (104 to 113 °F) range.

Edaphic condition: Soil samples were collected from different locations of the field at a depth 0–20 cm before sowing and analysed some physio-chemical characteristics in the Agriculture Laboratory, Faculty of Agriculture, Integral University. The soil of the experimental field was clayey in texture and slightly alkaline in pH (7.4). Organic carbon in the soil was 0.39% which was estimated by rapid titration method given by Walkley and Black, 1934. The available Nitrogen in soil was 143 kg ha^{-1}, which was estimated by the Alkaline permanganate method given by Subbiah and Asija, 1956. The available

Phosphorus was 15.3 kg ha^{-1} estimated by Olsen's method given by Jackson, 1967. The available K was 261.3 kg ha^{-1} which was estimated by the Flame photometer method given by Jackson, 1967.

Experimental design and treatment details: The experiment was designed as Randomized block design (RBD) with 12 Treatments replicated thrice. The treatment was allocated randomly in each block. The details of the treatment are as follows: - (T_1) Atrazine @ 1.0 kg a.i ha^{-1} PE (Pre-emergence); (T_2) Pendimethalin @ 1.0 kg a.i ha^{-1} PE; (T_3) Metribuzin 0.35 kg a.i ha^{-1} PE; (T_4) Atrazine 0.5 kg a.i ha^{-1} + Pendimethalin 0.5 kg a.i ha^{-1} PE; (T_5) 2,4-D sodium salt 0.8 kg a.i ha^{-1} PoE (Post-emergence) at 30 DAS (Days after sowing); (T_6) Tembotrione 0.120 kg a.i ha^{-1} PoE at 20 DAS; (T_7) Atrazine 0.5 kg a.i ha^{-1} PE followed by 2,4-D sodium salt 0.8 kg a.i ha^{-1} PoE at 30 DAS; (T_8) Atrazine 0.5 kg a.i ha^{-1} PE followed by Tembotrione 0.120 kg a.i ha^{-1} PoE at 20 DAS; (T_9) Topramezone 0.0252 kg a.i ha^{-1} PoE at 20 DAS; (T_{10}) Halosulfuron methyl 0.05 kg a.i ha^{-1} PoE at 20 DAS; (T_{11}) Weed free; and the treatment (T_{12}) was Weedy check.

Preparation of the experimental field and application of fertilizers: The first ploughing was done with a tractor drawn Disc harrow and the field was levelled with tractor drawn leveller. The seed bed was prepared by ploughing with a rotavator. Thereafter the field was laid out manually as per plan. Pioneer 3396 Hybrid was sown @ 25 kg ha^{-1} at 60 cm × 20 cm spacing. Plants were thinned to one plant per hill before the first irrigation. The initial irrigation was provided within a week after seeding, with further irrigations applied every 2 weeks throughout the growth season. The urea (46% N) was applied in split doses while DAP (46% P_2O_5) and MOP (60% K_2O) were applied as basal application among all the treatments uniformly.

Application of chemical herbicides: The chemical herbicides were sprayed as per plan with the help of Knapsack sprayer with the regular flat-fan nozzle. Some herbicides were applied as pre-emergence and some as post-emergence. Pre-emergence (PE) herbicides were applied just day after sowing while post-emergence as per plan.

3. RESULTS AND DISCUSSION

Weed flora in the experimental field: The general weed flora of the experimental field of kharif maize was recorded at 30 DAS from the weedy check plot. The weed flora in the experimental field were Echinochloa colonum, Brachiaria ramosa, Digitaria sanguinalis, Dactyloctenium aegyptium, Eleusine indica, Setaria glauca, Sorghum halepense, Panicum spp. Cynodon dactylon, Digitaria setigera, Digitaria ciliaris, and Leptochloa chinensis among grasses; Ageratum conyzoides, Galinsoga parviflora, Commelina benghalensis, Undernia cilata, Euphorbia geniculata, Oxalis latifolia, Celosia argentea, Aschynomene indica, Portulaca oleracea, Phyllanthus niruri, Amaranthus viridis, Acalypha indica, Tridax procumbens, Parthenium hysterophorus and Euphorbia hirta among non-grassy weeds and Cyperus rotundus and Cyperus iria among sedges. These weeds were also reported by [5].

Weed count as influenced by weed control treatments in maize: The total number of weeds differed significantly due to different weed control methods are given in Table 1. Initially at 20 DAS significantly lowest total weeds population recorded in treatment Weed free (T_{11}) than rest of the weed management treatments. Among the herbicidal treatments Atrazine 1 kg a.i. ha^{-1} (T_1) and Metribuzin 0.35 kg a.i. ha^{-1} (T_3), produced lower weed count but were statistically at par with each other and which further followed by Atrazine 0.50 kg a.i. ha^{-1} + Pendimethalin 0.50 kg a.i. ha^{-1} (T_4), Atrazine 0.50 kg a.i. ha^{-1} fb 2,4-D sodium salt 0.5kg a.i. ha^{-1} (T_7), Atrazine 0.50 kg a.i. ha^{-1} fb tembotrione 0.120 kg a.i. ha^{-1} (T_8), Pendimethalin 1kg a.i. ha^{-1} (T_2), 2,4-D sodium salt 0.80 kg a.i. ha^{-1} T_5), Tembotrione 0.120 kg a.i. ha^{-1} (T_6), Topramezone 0.0252 kg a.i. ha^{-1} (T_9), Halosulfuron methyl 0.05 kg a.i. ha^{-1} (T_{10}) but these treatments were comparable with each other. The Weedy check (T_{12}) recorded significantly higher weed population. At 40, 60 and at 80 DAS, significantly reduction in total weeds count was in treatment weed free (T_{11}). Among the different herbicidal treatments Atrazine 0.5 kg/ha fb tembotrione 0.120 kg a.i. ha^{-1} (T_8) and Atrazine 0.5 kg a.i. ha^{-1} fb 2,4-D sodium salt 0.5kg a.i. ha^{-1} (T_7) showed effective control on weed than rest of the herbicidal treatments and at par with each other.

At the harvest stage, treatment Weed free (T11) was found to be significantly superior to the other weed management treatments in terms of reducing overall weed population. The combination of Atrazine 0.50kg/ha fb tembotrione 0.120 kg a.i. ha^{-1} (T_8) showed its superiority in lowering down the weed population over Atrazine

0.50 kg a.i. ha^{-1} fb 2,4-D sodium salt 0.5 kg a.i. ha^{-1} (T_7), Atrazine @ 1 kg a.i. ha^{-1} (T_1), Atrazine 0.50 kg a.i. ha^{-1} 0.50 kg a.i. ha^{-1} + Pendimethalin 0.50 kg a.i. ha^{-1} (T_4), Topramezone 0.0252 kg a.i. ha^{-1} (T_9), Tembotrione 0.120 kg a.i. ha^{-1} (T_6), Metribuzin 0.35 kg a.i. ha^{-1} (T_3), Halosulfuron methyl 0.05 kg a.i. ha^{-1} (T_{10}), 2,4-D sodium salt 0.80 kg a.i. ha^{-1} (T_5), Pendimethalin 1kg a.i. ha^{-1} (T_2). Among these treatments Atrazine 0.50 kg a.i. ha^{-1} fb tembotrione 0.120 kg a.i. ha^{-1} (T_8), Atrazine 0.50 kg a.i. ha^{-1} fb 2,4- D sodium salt 0.5kg a.i. ha^{-1} (T_7) and Atrazine 1 kg a.i. ha^{-1} (T_1) were found statistically at par with each other. The treatment weedy check (T_{12}) recorded highest total weed population at all the stages of crop growth.

Among the various treatments, weed free (T_{11}) recorded significantly lowest weed count at 20, 40, 60, 80 and at harvest, that might be due to keeping weed free environment. But in pre-emergence herbicidal treatments, the lowest dicot weed count m^{-2} was observed with Atrazine 1 kg a.i/ha (T_1) up to 20 DAS, this might be due to the pre-emergence application of atrazine, which results in better weed control at initial stage. The treatment Atrazine 0.50kg/ha fb tembotrione 0.120 kg/ha (T_8) and Atrazine 0.50 kg/ha fb 2,4-D sodium salt 0.5kg/ha (T_7) showed its superiority by recording least dicot weed count at 40, 60, 80 and at harvest. This might be due to combination of both herbicides that have longer affect on controlling weed population. The post emergence herbicide tembotrione showed better effect on many broadleaf weeds. Due to numerous weed management measures applied at all stages of crop growth, the overall weed population was dramatically decreased. This may be because both individual and combined applications of herbicides were successful in rapidly decreasing the overall weed population. Gantoli et al. [11], Madhavi et al. [12], Singh et al. [13], and Tarundeep et al. [14] all reported similar findings.

Table 1. Total weed count (sqm^{-1}) as influenced by weed control treatments in maize

Treatments	Total weed count (sqm^{-1})				
	20 DAS	**40 DAS**	**60 DAS**	**80 DAS**	**At harvest**
T_1	3.99 (15.43)	5.70 (29.65)	6.91 (44.20)	7.07 (43.9)	6.57 (42.00)
T_2	5.44 (27.46)	7.95 (63.03)	8.70 (75.13)	8.79 (76.67)	8.39 (69.93)
T_3	4.27 (17.80)	5.64 (47.00)	7.66 (60.78)	7.79 (61.06)	7.34 (52.24)
T_4	5.02 (24.67)	7.00 (35.17)	7.14 (46.48)	7.24 (51.97)	6.78 (47.16)
T_5	7.55 (56.67)	7.22 (52.78)	8.15 (72.91)	8.25 (61.63)	7.85 (62.6)
T_6	7.67 (58.33)	6.54 (44.85)	7.39 (56.18)	7.50 (67.64)	7.03 (48.90)
T_7	5.73 (35.37)	5.13 (26.83)	6.34 (39.73)	6.50 (39.8)	5.79 (34.73)
T_8	6.33 (38.20)	4.93 (22.77)	6.07 (36.40)	6.27 (39.00)	5.59 (27.47)
T_9	7.61 (57.50)	6.99 (41.25)	7.23 (49.00)	7.35 (53.57)	6.93 (48.10)
T_{10}	7.47 (55.07)	6.56 (51.62)	7.93 (64.16)	8.01 (64.32)	7.55 (56.64)
T_{11}	2.41 (5.39)	2.76 (7.13)	3.29 (10.33)	3.35 (10.90)	2.77 (7.24)
T_{12}	7.85 (61.07)	10.94 (133.90)	12.96 (167.41)	13.06 (170.13)	12.89 (165.77)
SE (M) ±	**0.29**	**0.26**	**0.35**	**0.32**	**0.30**
C. D. at 5 %	**0.87**	**0.78**	**1.03**	**0.94**	**0.88**
GM	5.94	6.45	7.48	7.60	7.12

Total Weed Dry matter accumulation (g/m^2): Prior to the application of weed management techniques, the dry weight of the weeds was measured. In general, the dry matter of the weed was at its lowest point at 20 DAS, rose, reached its highest point at 80 DAS, and then slightly decreased at harvest. Total dry weight of weeds differed significantly with different weed control treatments at various crop growth stages are given in Table 2. At 20 DAS, the treatment Weed free (T_{11}) registered significantly less weed dry weight over rest of the treatments. The pre-emergence herbicides treatments i.e., Atrazine 1 kg a.i/ha (T_1) was found at par with Metribuzin 0.35 kg/ha (T_3) and Atrazine 0.50 kg/ha + Pendimethalin 0.50kg/ha (T_4) recorded less dry matter of weed as compare to post emergence application of herbicides. The treatment Weedy check (T_{12}) recorded highest weed dry matter accumulation. The weed dry matter from 40 DAS up to harvest had significantly influenced by different weed control treatments in which treatment Weed free (T_{11}) recorded significantly lowest weed dry matter. The different herbicidal treatment applied, in which Atrazine 0.50kg/ha fb tembotrione 0.120 kg/ha (T_8) recorded significantly minimum weed dry weight, treatment Atrazine 0.50 kg/ha fb 2,4-D sodium salt 0.5kg/ha (T_7) and Atrazine 1 kg a.i/ha (T_1) are statistically at par with each other. The pre-emergence treatment Pendimethalin 1kg/ha (T_2) was not effective in later stage of crop growth, however Weedy check (T_{12}) plot recorded significantly higher weed dry weight. Treatment Weed free (T_{11}) recorded significantly lowest weed dry matter at 20, 40, 60, 80 and at harvest, might be due to keeping weed free environment, while among the various herbicidal weed control treatments, minimum weed dry matter m^{-2} observed with Atrazine 1 kg a.i/ha (T_1) up to 20 DAS, and later stages Atrazine 0.50kg/ha fb tembotrione 0.120 kg/ha (T_8) and treatment Atrazine 0.50 kg/ha fb 2,4- D sodium salt 0.5kg/ha (T_7) recorded significantly minimum weed dry weight, might be due to combination of both herbicides that have longer effect on controlling weed population. Similar type of result was also observed by Singh et al. [15], Mukherjee & Rai [16] and Kumar & Chawla [17].

Weed control efficiency (%) as influenced by weed control treatments: The data pertaining to weed control efficiency is given in Table-3. The highest weed control efficiency was observed in treatment weed free (T_{11}) from 20 DAS up to at harvest, because of keeping weed free environment and found superior over rest of all herbicidal treatments. At 20 DAS among the herbicidal treatments Atrazine 1 kg a.i/ha (T_1) recorded highest weed control efficiency which was at par with treatment Metribuzin @ 0.35 kg/ha (T_3) and followed by Atrazine 0.50kg/ha + Pendimethalin 0.50 kg/ha (T_4). The weed control efficiency from 40 DAS up to harvest had significantly influenced by different weed control treatments in which treatment weed free (T_{11}) recorded highest weed control efficiency. The different herbicidal treatment applied, in which Atrazine 0.50 kg/ha fb tembotrione 0.120 kg/ha (T_8) recorded maximum weed control efficiency and treatment Atrazine 0.50 kg/ha fb 2,4-D sodium salt 0.5kg/ha (T_7) and Atrazine 1 kg a.i/ha (T_1) are comparable with each other.

Treatment weed free (T_{11}) recorded significantly highest weed control efficiency at 20, 40, 60, 80 and at harvest, might be due to keeping weed free environment due to good control of weeds, while among the various herbicidal weed control treatments, maximum weed control efficiency at all stages of crop growth was observed with Atrazine 0.50 kg/ha fb tembotrione 0.120 kg/ha (T_8). This result corroborates with finding of Singh & Angiras [18]; Patel et al.[19]; Shantveerayya & Agasimani [20], Gantoli et al. [11] and Yadav et al. [21].

Weed Index (%) as influenced by weed control treatments: Data pertaining to weed index (%) are presented in Table-3. Weed index was computed as the yield reduction comparative to highest yielding treatment i.e., Weed free (T_{11}). Among the weed management practices treatment Atrazine 0.50 kg/ha fb tembotrione 0.120 kg/ha (T_8) recorded minimum weed index (7.62%). It was followed by the treatments Atrazine 0.50 kg/ha fb 2,4-D sodium salt @ 0.5kg/ha (9.16%), Atrazine 1 kg a.i/ha (11.6%), Atrazine @ 0.50kg/ha + Pendimethalin 0.50kg/ha (18.77%), Metribuzin 0.35 kg/ha (20.84%), Topramezone 0.0252 kg/ha (21.04%), Tembotrione 0.120 kg/ha (23.37%), 2,4-D sodium salt 0.80 kg/ha (25.52%), Halosulfuron methyl 0.05 kg/ha (27.95%), Pendimethalin 1kg/ha (31.26%). The Highest weed index was observed in Weedy check (54.88%). Lower is the weed index in chemical treatments, better the efficiency of that herbicide in controlling weeds, which provided favourable conditions for crop growth which ultimately increased the grain yield of maize crop as compared to weedy check treatment. The similar result observed by Thakur and Singh [22]; Patel et al. [19], Gantoli et al. [11] and Sharma et al.[23].

Table 2. Total Weed Dry matter accumulation (g/m^2) as influenced by weed control treatments in maize

Treatments	Total Weed dry matter accumulation (g/m2)				
	20 DAS	**40 DAS**	**60 DAS**	**80 DAS**	**At harvest**
T_1	3.71 (13.27)	5.80 (33.28)	7.37 (55.47)	7.53 (56.20)	6.94 (47.70)
T_2	5.07 (25.32)	7.52 (56.06)	7.47 (71.20)	8.34 (72.47)	8.09 (64.87)
T_3	4.49 (19.77)	6.51 (41.92)	7.73 (58.43)	7.89 (61.83)	8.44 (60.06)
T_4	4.75 (22.13)	6.85 (46.47)	8.02 (63.83)	7.82 (66.09)	7.29 (52.77)
T_5	6.12 (37.03)	6.9 (48.40)	8.24 (67.37)	8.43 (70.67)	7.94 (62.71)
T_6	6.31 (39.33)	6.30 (39.22)	7.64 (57.93)	7.71 (58.97)	7.51 (55.97)
T_7	5.32 (27.89)	4.91 (23.83)	6.69 (44.37)	6.77 (45.43)	5.96 (35.13)
T_8	5.83 (33.56)	4.71 (21.88)	6.44 (41.01)	6.48 (41.57)	5.70 (32.21)
T_9	6.15 (37.39)	6.04 (36.17)	7.58 (57.07)	7.61 (57.50)	7.65 (53.10)
T_{10}	6.19 (37.92)	6.52 (42.14)	7.96 (62.97)	8.04 (64.23)	7.94 (62.59)
T_{11}	1.53 (1.83)	2.02 (3.63)	2.66 (6.60)	2.68 (6.73)	2.33 (4.93)
T_{12}	6.45 (41.07)	12.09 (145.80)	12.62 (158.90)	12.61 (160.60)	12.64 (159.30)
SE (M) ±	0.27	0.25	0.33	0.32	0.38
C. D. at 5 %	0.79	0.76	0.97	0.94	1.11
GM	3.71 (13.27)	5.80 (33.28)	7.37 (55.47)	7.53 (56.20)	6.94 (47.70)

Table 3. Weed control efficiency (%) and weed index (%) as influenced by weed control treatments in maize

Treatments	Weed control efficiency (%)					Weed index (%)
	20DAS	**40DAS**	**60DAS**	**80DAS**	**At harvest**	
T_1	67.69	77.17	65.09	65.01	70.06	11.6
T_2	38.35	61.55	55.19	54.88	56.77	31.26
T_3	51.86	71.25	63.23	61.50	62.30	20.84
T_4	46.12	68.13	59.83	58.85	66.87	18.77
T_5	9.84	66.80	57.54	56.00	60.63	25.52
T_6	4.24	73.10	63.54	63.28	64.87	23.37
T_7	32.09	83.66	72.08	71.71	77.95	9.16
T_8	18.29	84.99	74.19	74.12	79.78	7.62
T_9	8.96	75.19	64.08	64.20	66.67	21.04
T_{10}	7.67	71.10	60.37	60.01	60.71	27.95
T_{11}	95.54	97.51	95.85	95.81	96.91	--
T_{12}	--	--	--	--	--	54.88

4. CONCLUSION

Therefore, farmers of Central plain zone of Uttar Pradesh should be suggested that they should apply Atrazine 0.50 kg ha^{-1} as pre-emergence herbicide followed by Tembotrione 0.120 kg ha^{-1} as post-emergence herbicide. The application of Atrazine and Tembotrione herbicides are most effective in controlling weeds in maize field and are helpful in increasing the crop yields by reducing the crop weed competition.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Peer-review history:
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